

## Optimisation of Concrete Mix Design Using River Sand as Fine Aggregate

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### Abstract

*The construction industry has been plagued by the long-standing threat of building collapse. In an attempt to stop the trend, numerous studies have been conducted, but to no avail. A contributing factor to this threat has been identified as low-quality concrete. In this study, a model to optimise the design of concrete mixes was developed. Twenty-seven trial mixes were made and a total of 81 cubes were cast, with three cubes cast for each mix. Each factor's relevance and relative contribution to the variation in concrete's compressive strength were evaluated using ANOVA. The statistical study was done using R software and SPSS, and the optimisation values were determined using Excel Solver and Python. The cubes used in the trial mixes have compressive strengths ranging from 18.17 to 40.71N/mm<sup>2</sup>. A water-to-cement ratio of 0.35, a cement content of 375 kg/m<sup>3</sup>, and a coarse aggregate/total aggregate ratio of 0.65 yielded the best compressive strength. The optimum compressive strength obtained is at water - cement ratio of 0.35, cement content of 375kg/m<sup>3</sup>, and coarse aggregate/total aggregate ratio of 0.65.*

**Key Words:** Optimisation Concrete, Mix Design, River Sand, Fine Aggregate

### 1.0 Background to the Study

Concrete is one of the most significant man-made building materials that has been used for many centuries, dating back to the ancient Egyptian and Roman Empire. Kairali (2023) defined concrete as the mixing of fine and coarse aggregate with cement acting as a binding material that reacts with water to produce a solid mass when set. It was further stated that when the components are mixed together in the right proportion, it hardens and becomes like stone. The use of subpar concrete has been implicated as one of the reasons why buildings collapse, so it is important to note that high-quality and long-lasting concrete is required for high-quality civil engineering projects. (Yuan et al., 2021, Qasrawi 2016, Neville (2011), and Alexander and Mindess, 2010 all stated that proper mix proportioning entails combining the constituent materials of concrete in the appropriate ratio; however, increasing costs of constituent materials of concrete have resulted in compromise of the appropriate proportion.) In addition, Patil and Rajakumara (2018) hinted that the increase in the rate of infrastructural development has resulted in an increase in demand for concrete, so it is necessary to think about how the complexity of concrete cost can be controlled. Kairali (2023) believed that the mix proportion of concrete constituent materials must be well balanced in order to obtain quality and durable concrete.

Four types of concrete mix proportion are described in BS 5328:1:1997: prescribed mix, standard mix, and designated mix. Deroressaeu et al. (2018) divided concrete mix design into two categories: the Performance Based method (PBM) and the Prescriptive method (PM). According to them, the PBM is an iterative process while the prescriptive method is linear, and it evolved from the cement-sand and coarse aggregate volumetric ratio in the 1990s to the absolute volume method (AVM) established by the Portland Cement Association (PCA) and the American Concrete Institute (ACI).

Nominal or prescribed mix proportioning is a common practice on construction sites in many different locations in Nigeria. The method specifies a specific mix proportion by assigning a specific ratio to the various ingredients of concrete, such as 1:1½:3, 1:2:4, 1:3:6, and 1:4:8. According to this method, one part is attributed to cement, a specific part to fine aggregates, and twice the proportion of fine aggregate to coarse aggregate. The method does not take into account the variation in the properties of the various component materials, particularly aggregates, which, according to Ramamurthy (2010), varies from place to place. As a result, it is recommended that the design mix method be used to determine the proportion of the various ingredients of concrete. In order to determine the best way to combine these ingredients to achieve an optimal mix that will

meet all desired performance criteria, it is necessary to investigate how the various parameters affect the properties of concrete through these interrelationships. The parameters that jointly affect the structural performance of concrete are (WCR), total aggregate – cement (TAC) ratio, and coarse aggregate – total aggregate (CA/TA) ratio. These parameters are interdependent (Sharid et al., 2012; Patil and Rajakumara, 2018).

According to Zhang *et. al.* (2020)[not in the reference], optimisation is the process of concurrently achieving multiple competing goals. Concrete's mechanical properties, cost, workability, environmental requirements, and durability are some of the competing goals that impact its quality. Certain characteristics of wet and hardened concrete are either minimized or maximized in the process of optimizing the design of the concrete mix. This means that the amount of ingredients used must be determined in a way that will produce concrete at the lowest possible cost while yet meeting the necessary specifications for the different desired qualities. Deroressaeu et al. (2018) claim that the primary motivation for optimizing concrete mix design is the requirement to create concrete that meets a number of conflicting performance criteria. The benefits include time savings, human energy and effort conservation, and a reduction in the likelihood of errors. Additionally, it eliminates the necessity for data interpolation and extrapolation and guarantees the accuracy of the variables' determined values. Patil and Rajakumara (2018). According to Ahmad and Alghamid (2014), changing important mixture factors such as the W/C ratio, CA/TA ratio, and TA/C ratio helps optimize the concrete mix.

## 2.0 Concrete Mix Design Optimisation Methods

- I. Previous attempts to maximize the qualities of concrete have resulted in the development of several techniques, according to Ahmad & Alghamid (2014). The techniques are: Full Experimental Method: De Rousseau et al. (2018) and Ji et al. (2017) state that the method necessitates a number of trials that are carried out through trial and error. The approach is accurate and dependable. Its drawback is that it requires a lot of experimental labor to apply the results to a small number of local materials.
- II. Full Analytical Method: This approach decreased the number of trial mixes needed to get an ideal value. The amount of the concrete mix was rationalized rationally and methodically in order to accomplish this goal (ASTM C 33, 2016). When using this approach, the designer needs to be aware of the precise weight of the components and rely on prior work experience to acquire pertinent formulas. This will reduce the amount of time and money needed for the experimental work in the earlier way (ASTM C 33, 2016). It suggests that the approach is cost-effective and time-efficient. The main drawback, though, is that the result is imprecise due to the differences in the properties of the many components.
- III. Semi-Experimental Method: This approach solves the optimisation problem by combining the procedures of the two earlier approaches with a variety of analytical tools. Artificial neural networks, genetic algorithms, and mathematical programming are a few examples of these techniques. Rosa et al. (2023), Kobaka (2021) Although it is a very accurate and dependable procedure, it has the drawback of requiring a lot of time-consuming experimental work.
- IV. Statistical Method: This approach enhances and changes the complete experimental method's process. Trial batches must be set up and thereafter statistically analyzed. For every trial batch, the approach entails carefully choosing a certain ratio or proportion for the various components. Following this, test specimens are created, the pertinent test is conducted, and the test results are statistically analyzed using a standard statistical instrument. A model is then derived from the experiment and fitted to the data collected for every performance criterion. The model equation is then created using each response as an algebraic expression or equation. There are established levels of variance notwithstanding the presence of some experimental activity. This approach has the advantage of having more accurate, dependable, and cost-effective blend proportions.

The best ratio of the several mix components was found in this investigation using the statistical method. This is due to its three benefits: accuracy, dependability, and cost effectiveness. Each of the parameters (W/C ratio, CA/TA ratio, and cementitious material content) was set up at three different levels, and the data obtained from

the setup was examined using the proper statistical software. Following the formulation of the mathematical polynomial regression using the results, the ideal values of cost and compressive strength were determined.

## 2.1 Previous Works on Concrete Mix Design Models

Several studies have been carried out to evolve ways by which the attendant problems of using nominal mixes can be solved. Some of such studies are:

- I. Bolomeya Model for Designing a Normal Concrete Mix: Abdelgader *et. al.* (2012) constructed the model and came to the following conclusions:
  - i.) The component material mix ratio adheres to the ACI and BS procedures.
  - ii.) The slump value has decreased.
  - iii.) The technique produces compressive and tensile strength that satisfies pertinent specifications. But the approach merely takes the impact of water consumption into account. The impact of different component materials was not taken into account.
- II. The spreadsheet model for concrete mix design was created by Sheok and Singh (2016) in order to determine the concrete mix's lowest potential cost. Their research shows that the generated spreadsheet may be used to produce a cost-effective concrete mix, which lowers the cost of producing concrete. The study ignores the variations and characteristics of the concrete's component materials in favor of focusing solely on the financial implications.
- III. Concrete mix chart usage Design: Based on a range of cement contents, Okoloekwe and Okafor (2007) created a model for reproducing expected concrete strength. A chart for the design of concrete mix for various concrete grades ranging from 10N/mm<sup>2</sup> to 50N/mm<sup>2</sup> was created as a consequence of the work. There was no explanation of how the data for the models were created.  
Concrete Mix Gradation and Fineness Modulus Model Design: In order to improve the performance of fine aggregate in concrete, Sabih *et al.* (2016) conducted research to optimize the gradation and fineness modulus of natural fine aggregate. Without giving other materials, such coarse aggregate, any thought, this study primarily looked at the gradation and fineness modulus of fine aggregate.
- IV. Simplex Based Model of Concrete Mix Design: Okere *et al.* (2013) used a simplex based concrete mix design in their own investigation. In their study, they created a modified equation that was utilized to measure the quantities of the different components of concrete using the arbitrary defined mix proportion. The results showed that in only two of the mixes, the predicted result using the converted equation was somewhat higher than the experiment's result, while in the other three, it gave lower values. Without taking into account the characteristics of the concrete's constituent elements, the procedure only employed the nominally required approach.
- V. **Optimum Mix Design Model for Minimum Concrete Strength Requirement:** Alabi *et al.* conducted the study (2012). Akure pit sand was utilized as fine aggregate in the study at a 1:2:4 mix ratio. Their study's findings show an extremely low 28-day strength of 10.13N/mm<sup>2</sup>, which is lower than the minimum value of 20N/mm<sup>2</sup> required by BS 8110 part 1 (1997). The study only took pit sand into account, failing to adequately account for the potential impact of other component components. Additionally, the study used a nominal mix ratio of 1:2:4, meaning that variations in the mix proportion of the different concrete component ingredients were not taken into account.
- VI. A study on "optimization of concrete mixture design using locally available ingredient" was conducted by Shamsad and Ahmad (2007). Crushed stone fragments were utilized as coarse aggregate, and medium coarse sand was utilized as fine aggregate. The study's methodology involved varying the CA/TA and TA/CA ratios while maintaining a fixed W/C ratio and ignoring moisture content and water absorption capacity.

## 3.0 Materials and methods

### General Information on Material Acquisition for Optimization of Concrete Mix Proportion

The standard constituent materials frequently utilized in concrete construction served as the source of materials for this study. These included water, cement, coarse aggregate (granite), and fine aggregate (river sand), all of which are important factors. Grade 42.5 Dangote Portland Cement, which satisfies the standards outlined in BS 12:1992, the British Standard for Ordinary Portland Cement, was the cement utilized in this study. River sand,

which is a preferred option for concrete production because of its granular structure and grading, was utilized as the fine aggregate. It was collected from riverbeds or banks. Granite was chosen as the coarse aggregate for this investigation because it is suitable for creating strong, long-lasting concrete. Its maximum nominal size is 20 mm, and its angular shape improves the mechanical qualities of the concrete by enhancing particle interlocking. In this investigation, potable water was used for both mixing and curing, guaranteeing that it was devoid of impurities, pollutants, and dirt. The water complied with BS EN 1008:2002, which establishes specifications for water used in the mixing of concrete. It was obtained from a dependable and hygienic source, ensuring quality and consistency throughout the investigation. Table 1 shows the percentage of component materials utilized in the creation of the test specimen used to generate data for the statistical optimization model.

Table 1 Proportion of Components Used in the Study

Component	1	2	3	Level
Water/Cement Ratio	0.35	0.4	0.45	3
Cement Content(kg/m <sup>3</sup> )	325	350	375	3
Coarse Aggregate/Total Aggregate ratio	0.6	0.65	0.7	3

### 3.1 Procedure of data generation for the Statistical Optimization Model

Designing the proportion of the concrete mix for different combination ratios of the various elements mentioned above in accordance with complete factorial design is the process for creating an optimization model for the study. A 28-day curing period was followed by the preparation and testing of trial mixtures of the different combinations. The statistical model for optimization was developed by recording and analyzing the obtained data without the addition of any kind of mixing.

### 3.2 Development of Optimisation Models

River sand was used as the fine aggregate in this study's optimization model for compressive strength. To find the ideal mix proportions, the same crucial parameters—such as the W/C ratio, CC, and CA/TA ratio—were changed. The goal was to increase the concrete's compressive strength while preserving its workability and making sure it complied with the required durability and exposure conditions. To determine the ideal mix proportions, the model combined optimization methods with experimental data. The model's output offers insights into the trade-offs between material strength and performance in addition to recommendations for optimizing concrete's compressive strength. The model is essential for producing concrete that meets both economic and engineering requirements in practical applications.

### 3.3 Determination of the Objective Function and the Constraint Function:

The goal of concrete mix proportion optimization is to maximize concrete's compressive strength while meeting important restrictions. The limitations guarantee that the mixture satisfies the necessary performance requirements for durability and strength. The Water/Cement (W/C) ratio, Cement Content (CC), and Coarse Aggregate/Fine Aggregate (CA/TA) ratio are the three primary parameters that influence the compressive strength of concrete and act as constraints in the optimization model, according to Sharid et al. (2012). To guarantee that the concrete reaches the necessary performance qualities, certain limitations must be fulfilled. In order to maximize the Compressive Strength, the following objective functions were developed. This objective seeks to determine the optimal mix that results in the highest compressive strength by adjusting the values of the W/C ratio, CC, and CA/TA ratio. By varying these parameters, the model aims to achieve a balance that maximizes the concrete's compressive strength without violating other constraints.

### 3.4 Statistical Analysis and Modeling

The data obtained from the experimental design were analyzed using a combination of statistical methods to evaluate the impact of various factors on the compressive strength and cost of concrete. The analysis followed three primary phases:

1. Factorial Analysis: This phase involved analyzing the influence of different elements (W/C ratio, CC, CA/TA ratio) on the performance of concrete. It gave insights into how variances in these factors affected the outcomes.
2. Analysis of Variance (ANOVA): ANOVA was utilized to assess each factor's significance and ascertain its

relative contribution to the variation in concrete's compressive strength. This statistical test assisted in determining whether or not the factors significantly affected the performance of the concrete.

Regression Analysis: In this stage, a mathematical model that explained the connection between the mix proportions and the cost or compressive strength was fitted using regression techniques. An empirical model that included the important factors found in the earlier stages was fitted using polynomial regression. Based on the input factors, this model was essential for forecasting the concrete mix's performance. R software and SPSS were utilized for the statistical analysis, while Python and Excel Solver were used to calculate the optimization value. These tools made it possible to accurately predict the concrete mix and conduct in-depth research.

The optimisation procedure was automated and simplified with Python, enabling effective solution space search and the determination of the ideal concrete mix proportions. By ensuring that the concrete mix proportions developed in this study were both economical and met performance standards, these statistical and optimization procedures offered the construction sector important insights. The non-negative integer variables a, b, and c were designated as the independent variables. When “b” is CC, “c” is the CA/TA ratio, and “a” is the W/C ratio.

The constraints are:

$$a = 0.35 \leq x \leq 0.4 \tag{1}$$

$$b = 325 \leq x \leq 375 \tag{2}$$

$$c = 0.6 \leq x \leq 0.7 \tag{3}$$

The objective functions for compressive strength of river sand is:

$$-21.811 + 0.152b - 59.878c \tag{4}$$

After imputing all necessary data the solver was instructed accordingly and the result obtained. The final code was written and the output was obtained.

#### 4.0 Results and Discussion

**4.1 Physical Properties of Aggregates used in the Study:** The sieve analysis curves for each of the materials utilized in the study—granite and river sand, respectively—are shown in Figures 1 and 2. The curve was used to determine the Cc and Cu. The results of the two parameters were used to determine the gradation of the fine and coarse aggregates used in the study. RS has a Cu of 4.88 and a Cc of 1.44 based on the values of the two parameters shown in Table 2. Granite has Cu and Cc values of 1.64 and 1.11, respectively. The findings indicate that although granite is equally graded, RS is well graded. Additionally, the table displays the aggregates' specific gravity and water absorption data. Granite has a specific gravity of 2.67, whereas river sand has a specific gravity of 2.64. These values fall within the 2.2 and 2.9 ranges described in BS 882:1992. Granite absorbs 0.85% of water, while river sand absorbs 1.69%. Both figures fall short of the 2% threshold for key buildings set forth in BS 8007: 1997.

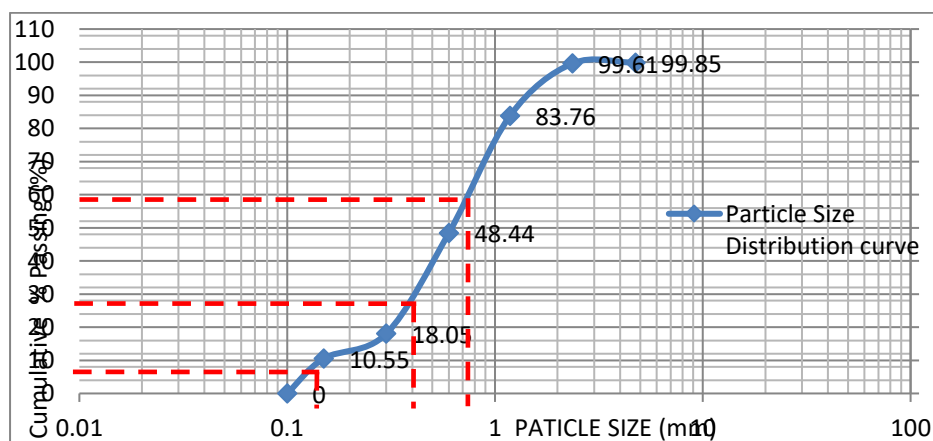


Figure 1 Particle Size distribution curve for River Sand

Table 2 Physical Properties of Aggregates used in the Study.

Material	River Sand	Granite
Fineness Modulus	3.4	5.17

Specific Gravity	2.64	2.67
Water Absorption	1.9	0.85
Coefficient of Uniformity	4.88	1.64
Coefficient of Curvature	1.44	1.11

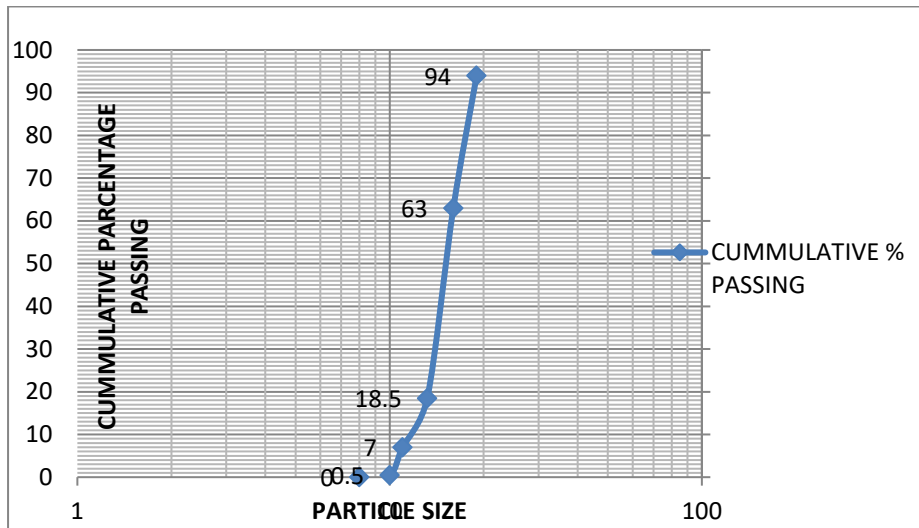


Figure 2 Particle Size Distribution Curve for Granite

#### 4.2 Result of the Factorial Analysis of the effect of Variation of Component Materials of Concrete on Compressive Strength of River Sand Concrete

The impact of the W/C, CC, and CA/TA ratios on the compressive strength of river sand concrete is shown in Table 3, along with the outcome for the compressive strength of river sand in relation to the individual components and their interactions. Given that the table's confidence level is below 95%, it can be confirmed that A2 and A3 have no discernible impact. On the other hand, the confidence levels for B2 and D2 are 99.9%, and those for B3 and D3 are 99%. Therefore, as their confidence levels exceed the 95% threshold set by Frost (2019), it may be concluded that they are all significant. Because the values are more than the 95% confidence level, the results of the interactions between the different elements show that the interactions between A2 and B3 and B3 and D3 are significant. The other interactions are not significant because their confidence levels are below 95%.

Table 3 Factorial Analysis of the effect of W/C ratio, CC and CA/TA Ratio on Compressive Strength of River Sand Concrete

	Estimate	Std. Error	t-value	p-value
(Intercept)	10.0337	3.5602	2.818	0.02255
A2	9.0356	4.4736	2.020	0.07809
A3	2.3733	4.4736	0.531	0.61016
B2	13.8244	4.4736	3.090	0.01489
B3	20.0644	4.4736	4.485	0.00204
D2	14.8478	4.4736	3.319	0.01056
D3	19.4711	4.4736	4.352	0.00244
A2:B2	-1.7533	4.9006	-0.358	0.72977
A3:B2	-4.0600	4.9006	-0.828	0.43143
A2:B3	-14.9933	4.9006	-3.059	0.01560
A3:B3	0.9700	4.9006	0.198	0.84803
B2:D2	-6.9300	4.9006	-1.414	0.19505
B3:D2	-6.2733	4.9006	-1.280	0.23638
B2:D3	-11.0533	4.9006	-2.255	0.05410
B3:D3	-13.7600	4.9006	-2.808	0.02292

A2:D2	-3.0600	4.9006	-0.624	0.54975
A3:D2	-0.8833	4.9006	-0.180	0.86144
A2:D3	-5.9467	4.9006	-1.213	0.25957
A3:D3	-6.3567	4.9006	-1.297	0.23075

#### 4.4 Result of the Analysis Variance of the effect of Variation of Component Materials of Concrete on Compressive Strength of River Sand Concrete

The ANOVA results for all of the components combined with their interactions are displayed in Table 4. Since the confidence level is less than 95%, it is evident from the table that factor A's effect is not significant. On the other hand, the confidence levels for variables B and C are higher than 95%. The values are therefore important. Additionally, because the confidence level is higher than 95%, the interaction between A and B is significant. However, due to their lower than 95% confidence levels, the interactions between A with D; and B with D are not significant. Even though the data show that the water-to-cement ratio, or A, has a negligible impact in this case, it is considered when developing the regression model for determining the compressive strength. This is due to the fact that water cannot be removed during the concrete-making process and is required for the hydration of cement, which maintains the loose state of the other constituents.

Table 4 Analysis of Variance of the effect of W/C ratio, CC and CA/TA Ratio on Compressive Strength of River Sand Concrete

	Df	Sum Sq	Mean Sq	F value	Pr (>F)
A	2	11.0	5.49	0.305	0.74534
B	2	355.7	177.86	9.874	0.00691
D	2	413.8	206.89	11.486	0.00445
A:B	4	346.6	86.65	4.811	0.02844
B:D	4	163.7	40.92	2.272	0.15027
A:D	4	45.3	11.32	0.628	0.65590
Residuals	8	144.1	18.01		

#### 4.5 Result of the Regression Analysis of the effect of Variation of Component Materials of Concrete on Compressive Strength of River Sand Concrete

Table 5 Regression Analysis of the effect of W/C ratio, CC and CA/TA Ratio on Compressive Strength of River Sand Concrete

Coefficients:

	Estimate	Std. Error	t-value	p-value
(Intercept)	17.77648	30.67498	0.580	0.56788
A	-10.70000	29.59705	-0.362	0.72101
B	0.17424	0.05919	2.944	0.00729
D	-70.98889	29.59705	-2.399	0.02497

Consequently, the formulated regression model for the compressive strength of river sand concrete using the values of the regression analysis in Table 5 is:

$$f_c = 17.7765 - 10.70A + 0.17424B - 70.98889D \dots \dots \dots (1)$$

Where A is the W/C ratio, B is the CC and D is the CA/TA ratio. All the values used were by their masses.

The water-to-cement ratio, or Factor A, is kept in the regression model for compressive strength prediction even though it seems negligible in this analysis. This is due to the fact that water is a necessary ingredient for hydrating cement and preserving workability during the concrete-making process. In reality, it is not possible to omit water. When creating the regression model, the important factors (B and C) and interaction (A x B) will be given priority. This guarantees that the model appropriately depicts how important variables affect compressive strength. Table 5 displays the regression analysis results for the impacts of cement content (CC), water-to-cement (W/C) ratio, and coarse aggregate-to-total aggregate (CA/TA) ratio on river sand concrete's compressive strength.

#### 4.6 Optimisation Result of Compressive Strength of Both River Sand Concrete

As stated earlier, the concrete mix design was obtained from the formulated compressive strength model developed from the regression analysis. Two constraints were used to obtain the objective function. The optimization result for river sand concrete is presented in Table 6.

Table 6 Optimized Values of Concrete Mix Design for Compressive Strength of River Sand

Optimization option	F's	Qc	X1 (w/cm)	X2 (CA/TA	Significant level
(i)	24.5	325	0.35	0.65	Low
	28.9	350	0.35	0.65	Medium
	33.2	375	0.35	0.65	High
(ii)	20	325	0.28	0.72	Low
	30		0.44	0.56	Medium
	40		0.61	0.39	High
	20	350	0.20	0.80	Low
	30		0.37	0.63	Medium
	40		0.53	0.49	High
	20	375	0.13	0.87	Low
	30		0.30	0.70	Medium
	40		0.46	0.54	High

Table 6 shows that the compressive strength of river sand rose from 24.5N/mm<sup>2</sup> to 28.9N/mm<sup>2</sup> when the CC increased from 325 kg/m<sup>3</sup> to 350 kg/m<sup>3</sup>. In a similar vein, raising the CC from 350 kg/m<sup>3</sup> to 375 kg/m<sup>3</sup> causes the river's compressive strength to rise from 28.9 N/mm<sup>2</sup> to 33.2 N/mm<sup>2</sup>. Thus, it can be claimed that a rise in CC results in an increase in the compressive strength of concrete. This suggests that the ideal W/C ratio of 0.35 and CA/TA ratio of 0.65 result in an ideal compressive strength of 33.2 N/mm<sup>2</sup> for river sand. It is therefore possible to conclude that the ideal compressive strength is achieved at a CC of 375 kg/m<sup>3</sup>, a W/C ratio of 0.35, and a CA/TA ratio of 0.65.

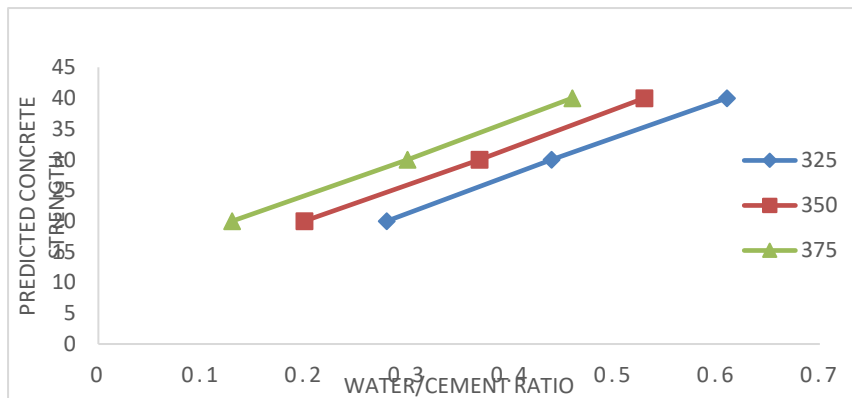


Figure 3 Chart of Predicted Concrete Strength at Different W/C ratio and Different CC.

Target strengths of 20N/mm<sup>2</sup>, 30N/mm<sup>2</sup>, and 40N/mm<sup>2</sup> as listed in Tables 5 and 6 are used to plot the data from the second optimization option in Figures 3 and 4. Based on the data, compressive strength increases when the W/C ratio increases for the same amount of CC, but decreases when the CA/TA ratio decreases.

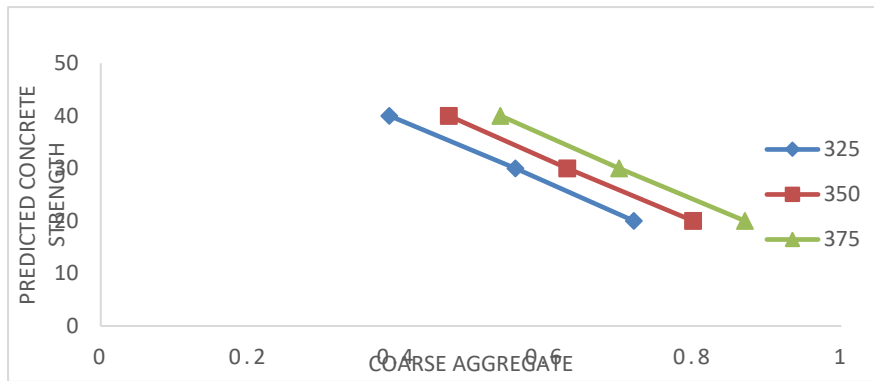


Figure 4 Chart of Predicted Concrete Strength at Different CA/TA Ratio and Different CC

The following are the possible factors that can influence the optimized compressive strength obtained from the model:

- i. The type, size and gradation as well as the shape and texture of the aggregate
- ii. The characteristics of the cement type fineness and setting times
- iii. The use of admixtures
- iv. The condition and duration of which the concrete is cured and
- v. The environmental conditions.

Consequently, the application of the model can be influenced to a great extent by the followings:

- i. **Aggregate Properties:** Variations in the gradation and type of the aggregate require that the model's coefficient needs modification.
- ii. **Cement Characteristics:** Similarly, the type and fineness of cement can result in variation of the model's response to the W/C ratio (A) or cement content (B).
- iii. **Admixtures:** Addition of chemicals or other mineral as admixtures can alter the model's coefficients or introduce new interactions.
- iv. **Curing Conditions:** Changes in temperature, humidity, or curing time may affect projections of the model.
- v. **Environmental Factors:** The effect of the environment such as weathering, humidity, temperature or chemical exposure can also affect the model's applicability resulting in concrete deterioration.

Therefore, it may be necessary to give due considerations to modifications to the coefficients based on the above factors. It will also be necessary to update coefficients in accordance with specific circumstances highlighted above.

## 5.0 Conclusion

The study's findings led to the following conclusions:

Every item utilized in the research complies with the guidelines set forth in the British Standard Code of Practice.

Factorial analysis reveals that while variables B2, B3, D2, and D3 have a considerable impact, factors A2 and A3 have no discernible influence. Factor A is not significant, according to the ANOVA result, while components B and D are. While variables B and D do not interact much, factors A and B do interact significantly. The results of regression analysis show that B and D have significant values but A does not. Thus,  $f_c = 17.7765 - 10.7A + 0.1742B - 70.9889D$  is the optimum model. The optimization model yielded an optimal compressive strength of 33.2N/mm<sup>2</sup>, which is achieved at W/C of 0.35, CA/TA of 0.65, and CC of 375 kg/m<sup>3</sup>.

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