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CONCRETE CHARACTERISTICS MODELLING FOR MINIMAL COST AND OPTIMUM PERFORMANCE OF ABUJA HOUSING INFRASTRUCTURES

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ABSTRACT

Abuja has experienced phenomenal infrastructural growth in the last two decades and concrete is at the heart of it. The cost of concrete has increased over the years due to the increased costs of its constituents like aggregates and cement. Many housing projects have slowed down due to the skyrocketing costs. A scientific approach in reducing concrete cost without compromising quality control is investigated. The compressive strength and workability characteristics of concrete mixes from different coarse aggregate sizes were determined in the laboratory. The cost of the mixes as determined from the market prices of the constituents were also determined. The intention was to use the Response Surface Methodology (RSM) to obtain a concrete cost predictive model that can be optimized to link the strength, workability and aggregate sizes to give a minimal cost of the concrete. Statistical packages like SPSS, WEKA and E-Views were used to verify the adequacy of the model. The results from the model show that for all concrete mixes of volume $0.041m^3$. The optimum cost which is the least and most reasonable cost is made from 25mm size coarse aggregate at NGN29,942.49. It also has the least slump and highest strength for each of the mix ratios of 1:3:6, 1:2:4 and 1:1½: 3 after 28 days of curing. This therefore provides the most economical option in terms of cost and quality. The integration of hardened concrete strength, wet concrete workability and aggregate sizes produced a predictive mathematical model for minimal cost, which is recommended for use in cost projection and quality control in Abuja Infrastructural development.

Keywords: *Coarse aggregate, Compressive strength, Concrete, Cost, Housing, Model*

INTRODUCTION

Abuja, the capital of Nigeria is one of the fastest-growing cities in Africa where massive housing and infrastructural development is ongoing (Abubakar, 2014, Mahmud *et al*., 2016, Ujoh, 2010). Most of the structures are concrete-based and so, require high quantities of constituents like aggregates. The cost of these materials tremendously increased in the last two decades leading to compromises in quality control. This is attested to by reported cases of building collapses (Ogbemudia *et al*., 2021). There is a need to scientifically formulate a more economical concrete without compromising quality.

Many works on the strength characteristics of concrete with different aggregate materials and brands of cement are available (Wu *et al*., 2001), (Waziri *et al*., 2011), (Abdullahi, 2012), (Ukpata & Ephraim, 2012) and (Meddah *et al*., 2010).

Aggregates are very important in concrete. They constitute 60% to 80% of concrete volume (Ghasemi, 2017), (Ajamu & Ige, 2015). Increasing the number of aggregates in concrete corresponds to less usage of cement which has several benefits, like. reduction in the cost of producing concrete, decrease in some of the durability problems of hardened concrete, like reducing shrinkage and cracking (And & Ezeagu, 2016). Previous works (Ahmed *et al*., 2016) show that the cost of concrete mix increases with workability, the maximum size of aggregate, the strength of concrete, and the reduced water-to-cement ratio. Estimating the cost of concrete requires many variables and will vary from location to location or from site to site (BS EN 1992-1-2:2004).

Away from the routine method, the adaptive approach here proposes that all elements of the building be modeled in their unit rate form. The various quantities are multiplied by their unit rate cost and subsequently summed up with prime cost items, giving the cost of the building. A major feature of this model is that it can be subjected to further mathematical treatment of change when variables are constrained (Samuel & Snapp, 2015). The cost model in this paper has been restricted to the concrete component used in the city of Abuja

RSM is a technique widely used to optimize various processes (Yolmeh & Jafari, 2017). Also, helpful for fitting the models and analyzing the problems in which quite a lot of independent parameters control the dependent parameter(s) (Khuri, Andre & Cornell, 1996). It has found application in the various areas of the chemical industry, physical and engineering sciences, biological, clinical, and social sciences (Khuri and Andre, 2001). It was used in optimizing the coagulation process (Trinh & Kang, 2010) and performance measures or quality characteristics of industrial products or processes (Dan *et al*., 2014) and (Myers *et al*., 2016). It is adopted in the modeling and optimization hereby reported.

This work presents an effort on the development of models for predicting the economical values of concrete mixes while considering the price regimes of the constituent materials in the Abuja environs.

MATERIALS AND METHODS

MATERIALS AND THEIR PREPARATIONS

Materials sourced and used for this research work included Ordinary Portland Cement (OPC) of 42.5R from the "Dangote" brand, water obtained from the distribution network of Abuja Water Board and coarse aggregate of

different sizes obtained from a crushing plant in Mpape, Abuja. In this research work, different sizes of coarse aggregate (10mm, 13mm, 19mm & 25mm) were used to prepare concrete of different mixes common in the study environment (1:1½:3, 1:2:4 and 1:3:6). Concrete cubes in four batches of these mixes were prepared using the four different aggregate sizes. The cost inherent in the preparation of the different concrete cubes was noted before the experimental procedures.

The fine aggregate was sourced from the Gurara River at Yaba, Abuja. Earlier work on the sand presented it as suitable for concreting (Sanusi *et al.*, 2021). The Fine aggregate was washed to remove impurities before use in the dry state. The laboratory equipment used includes a steel cube mold, digital scale, set of BS sieves, Universal Testing Machine (UTM), and poker vibrator. The materials and their properties were characterized using the European Standards (BS EN 1990-2-2007, 2010) and (BS EN 196-3:2005 +A1:2008, 2005)

TESTS
SIEVE ANALYSIS
The coarse and fine aggregates used were measured and passed through mechanically operated sieves to obtain the coarse aggregate sizes 10.0mm to 25mm respectively. The fine aggregate was graded between 4.75mm (No.4) sieve and 150μmm (No.100). Both activities were in accordance with BS EN 196-6 (2018)

PROPORTIONING AND MIX RATIOS

Table 1 shows the proportioning of OPC, fine aggregate and coarse aggregates that gave the various mix ratios. The volume and weight values show that the concrete density is approximately 2,370.73kg/m³.

Table 1: Proportioning of mixes for different coarse aggregate sizes

S/N	Aggregate Size (mm)	Mix-ratio			No. of cubes	Vol. (m³)	Equiv. Wt. (kg)	Cement Qty.	Fine-Agg. Qty. (kg)	Coarse-Agg. Qty. (kg)	Water Cont. (kg)
1	10	1	3	6	12	0.041	97.2	9.72	29.16	58.32	5.35
2	10	1	2	4	12	0.041	97.2	13.89	27.77	55.54	7.64
3	10	1	1.5	3	12	0.041	97.2	17.67	26.51	53.02	9.72
4	13	1	3	6	12	0.041	97.2	9.72	29.16	58.32	5.35
5	13	1	2	4	12	0.041	97.2	13.89	27.77	55.54	7.64
6	13	1	1.5	3	12	0.041	97.2	17.67	26.51	53.02	9.72
7	19	1	3	6	12	0.041	97.2	9.72	29.16	58.32	5.35
8	19	1	2	4	12	0.041	97.2	13.89	27.77	55.54	7.64
9	19	1	1.5	3	12	0.041	97.2	17.67	26.51	53.02	9.72
10	25	1	3	6	12	0.041	97.2	9.72	29.16	58.32	5.35
11	25	1	2	4	12	0.041	97.2	13.89	27.77	55.54	7.64
12	25	1	1.5	3	12	0.041	97.2	17.67	26.51	53.02	9.72

WORKABILITY

The slump test on fresh concrete was carried out by the standard test method for slump hydraulic-cement concrete as outlined in the relevant codes (BS EN 12350-2:2009-Testing Fresh Concrete, Part 2: Slump Test, 2009) for the different mixes used for this research work. Measurements of the corresponding reduction in height of the compacted volume of fresh concrete immediately after removing the slump cone were recorded as slump values for the mix.

COMPRESSIVE STRENGTH TESTS

A compressive strength test was conducted on each of the 150x150x150mm cube samples produced from the three mix ratios respectively. The water-cement (w/c) ratio adopted was 0.55 based on the concrete mix design manual of COREN (COREN, 2017). The UTM by BS EN (BS-EN 12390-3-2009, 2009) was used to crush the cubes after 28 days of curing by ponding.

COST OF CONCRETE

The cumulative unit cost of producing batches of 150x150x150mm concrete cubes was computed from the cost of laboratory inputs and recorded per cubic meter. The cost of production of concrete used in this research work is a function of the constituent materials (cement, fine aggregate, coarse aggregate, and water) as well as 15% provision (which generally represents the mark-up rate in the Abuja area but excludes tax) for handling which encompasses production cost and fees associated with preparing the surface. The observed cost values obtained for each concrete mix were required for modeling cost variabilities to aggregate sizes, compressive strength, and workability values. Tables of mix ratios to cost are presented in Tables 1, 2, and 3: These values represent the market rates of the time (2020) and can be applied to all the coarse aggregates.

Table 1: Determination of Cost of 1:3:6 Mix Design.

Material	Ratio	Weight (Kg)	Rate (NGN)	Amount (NGN)	Cube Volume (m³)	Rate/m³ (NGN)
Cement	1.0	0.806	51.00	41.12	0.003375	12,183.70
Fine-Aggregate	3.0	2.418	3.10	7.50	0.003375	2,222.22
Coarse-Aggregate	6.0	4.837	3.00	14.52	0.003375	4,302.22
Water	0.55	0.443	0.15	0.07	0.003375	20.74
Handling				9.48	0.003375	2,809.33
Total		8.505		72.69		21,538.22

Note: NGN denotes Nigerian Naira

Table 2: Determination of Cost of 1:2:4 Mix Design.

Material	Ratio	Weight (Kg)	Rate (NGN)	Amount (NGN)	Cube Volume (m³)	Rate/m³ (NGN)
Cement	1.0	1.124	51.00	57.46	0.003375	17,025.19
Fine-Aggregate	2.0	2.253	3.10	6.99	0.003375	2,071.11
Coarse-Aggregate	4.0	4.506	3.00	13.52	0.003375	4,005.93
Water	0.55	0.55	0.15	0.10	0.003375	29.63
Handling				11.71	0.003375	3,469.78
				89.78		26,601.63

Note: NGN denotes Nigerian Naira

Table 3: Determination of Cost of 1:1½:3 Mix Design.

Material	Ratio	Weight (Kg)	Rate (NGN)	Amount (NGN)	Cube Volume (m³)	Rate/m³ (NGN)
Cement	1.0	1.406	51.00	71.70	0.003375	21,224.44
Fine-Aggregate	1.5	2.109	3.10	6.54	0.003375	1,937.78
Coarse-Aggregate	3.0	4.217	3.00	12.66	0.003375	3,751.11
Water	0.55	0.773	0.15	0.12	0.003375	35.56
Handling				13.65	0.003375	4,045.33
		8.505		104.67		31,014.22

Note: NGN denotes Nigerian Naira

PREDICTIVE COST MODEL DEVELOPMENT

Results obtained from the laboratory were combined by procedures of multiple regression. Independent variables used in the cost-model formulation were compressive strength, aggregate size, and slump value. Multiple regression method based on the RSM was implemented by using software applications "E-views" and "Weka". The resulting model for 28th-day strength values was tested using recommended slump values in BS EN 12350-2:2009). Four models were developed for the 28-day concrete using E-Views, SPSS, Weka, and Microsoft Excel. The cost of production was taken as the dependent variable. The values of the coefficient of determination of the various models were recorded for each model.

RESULTS AND DISCUSSIONS

PRELIMINARY MATERIAL ANALYSIS

Particle size distribution plot of the fine aggregate indicates values of uniformity coefficient C_u and coefficient of curvature C_z of 8.10 and 3.07 respectively. With C_u above 8 and the absence of particles lower than 0.02mm (clay), it is considered well-graded and suitable for use by British standards (BS, 1990). Figure 1 shows the grading plot. The grading Tables are available on demand.
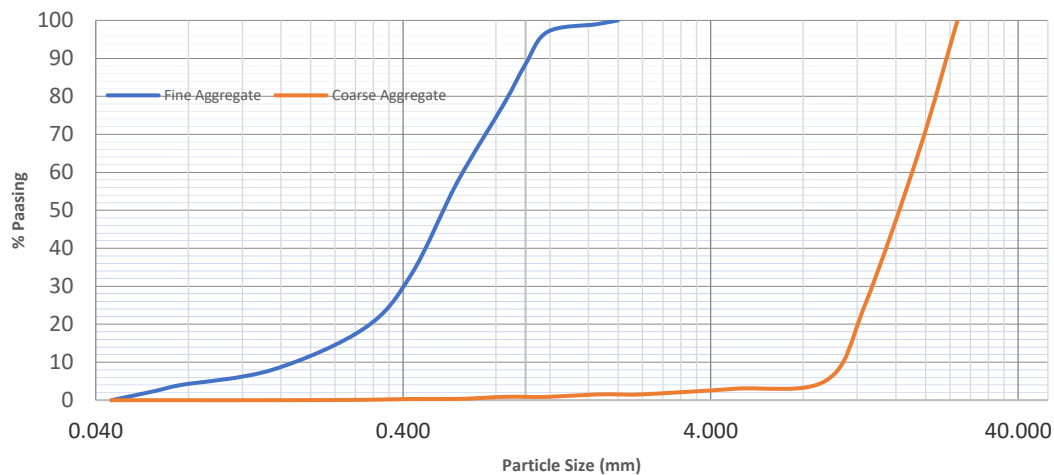

Figure 1: Particle Size Distribution Curves of Fine and Coarse Aggregate Samples.

RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND WORKABILITY OF SAMPLES

Table 4 shows the values of the slump, and compressive strength (σ) for each of the concrete mixes at 28 days and with the different aggregate sizes. It also presents the cost of concrete samples per volume.

Table 4: Slump, compressive strength, and cost values of concrete mixes with various coarse aggregate sizes

Mix ratio	1:3:6			1:2:4			1:1½:3		
Aggregate Size (mm)	Slump	σ	cost	Slump	σ	cost	Slump	σ	cost
10	31.5	14.1	21.54	23.5	22.1	26.61	18.6	24.0	31.02
13	28.4	15.6	21.54	20.8	22.8	26.61	16.2	27.6	31.02
19	26.0	16.6	21.54	18.5	23.8	26.61	14.6	29.4	31.02
25	23.3	17.4	21.54	16.7	25.5	26.61	13.1	30.6	31.02

Table 4 shows compressive strength decreased generally as the slump increased, in a linear relationship. There is also a general decline in a slump with a corresponding increase in coarse aggregate sizes. This is not unexpected because of the higher water content associated with less rich concrete mixes and smaller size coarse aggregates (Neville, 2003).

COMPRESSIVE STRENGTH AND COARSE AGGREGATE SIZE

From Table 4, a plot of the relationship between compressive strength and coarse aggregate size for the 1:1½:3 mix is a non-linear logarithmic one as shown in Figure 2. This is the trend in the three mixes. There is an increase in compressive strength with a corresponding increase in aggregate sizes. Regression analysis produced a logarithmic curve with a coefficient of determination (R^2) of 91.88%. These results are by the standards of the American Concrete Institute (ACI, 2002).
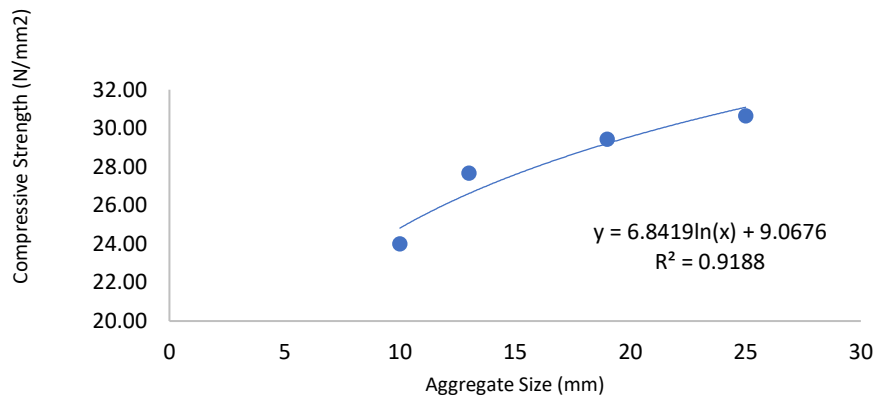

Figure 2: Relationship of compressive strength with aggregate size for 1:1½:3 mix

COST ANALYSIS OF MIXES WITH VARIATION IN AGGREGATE SIZE AND COMPRESSIVE STRENGTH

From Table 4, it is observed that the cost only varies with mixed proportions and not with aggregate sizes, as presented in Tables 1 – 3. Compressive strength also increased with richer mixes.

A plot of compressive strength against the cost of concrete production as shown in Figure 3 for 1:1½:3 mix indicate the higher financial implication of producing richer mixes and by implication, higher grades of concrete. The increase is in a non-linear manner with an R^2 of 99.89%. The trend is the same for the other two mixes.
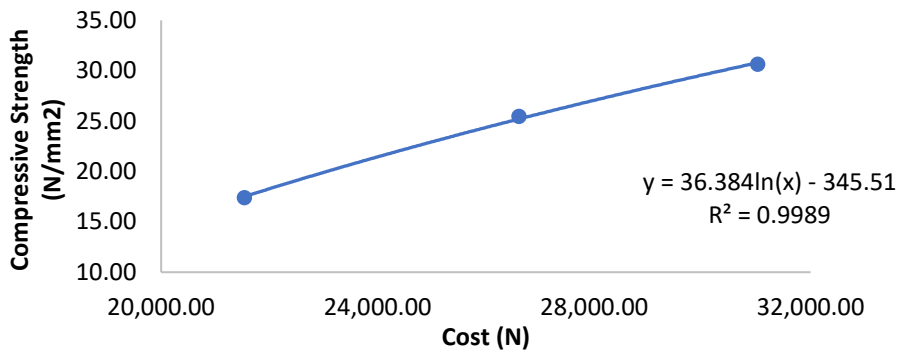

Figure 3: Relationship of compressive strength with the cost for 1:1½:3 mix

COMPARATIVE COST DISTRIBUTION OF AGGREGATE SIZES IN CONCRETE.

Analysis of the cost of representative aggregate quantities required for the production of sample cubes was obtained from the coarse aggregate size distribution of the whole all-in-aggregate from the open market. Table 5 shows the breakdown of size distribution and equivalent cost while Figure 4 shows the graphical representation. The cost of aggregate sizes below 10mm was redistributed among the four aggregate sizes. The regression curve follows a quadratic pattern with R^2 of 97.38%. Optimisation computations on the regression model showed that 16mm aggregate size presented the highest cost in all mixes as seen in Figure 4. The implication of this is to minimize the use of 16mm coarse aggregates in Abuja if cost is in consideration.

Table 5: Cost Distribution of Aggregate Sizes in Concrete

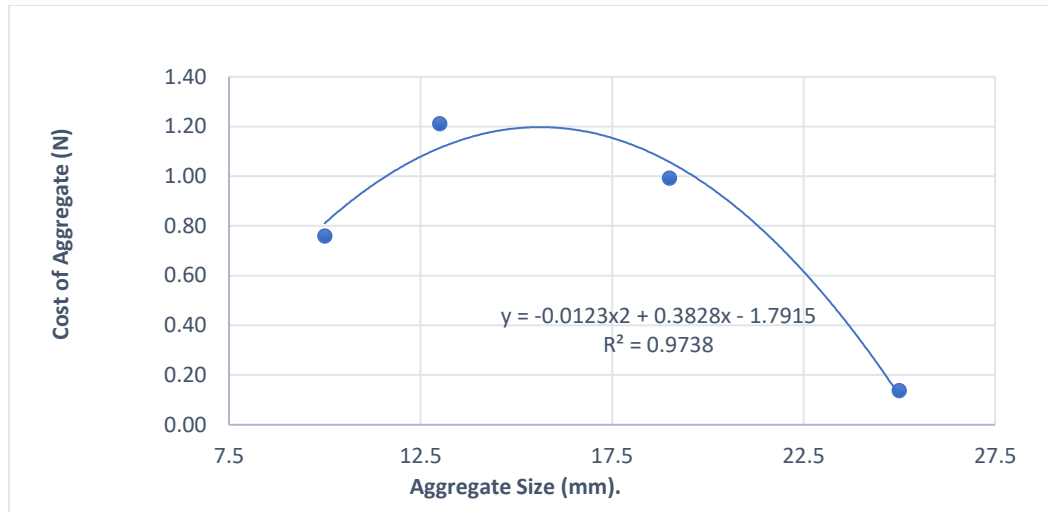| Aggregate Size (mm)	Wt. Retained (g)	% Completion	Rate (NGN/kg)	Rate (NGN/kg)	Actual Rate (NGN)
25	46.1	4.39%	0.14	0.0017	0.14
19	331.97	31.62%	0.98	0.0120	0.99
13	405.28	38.60%	1.20	0.0147	1.21
10	253.92	24.18%	0.75	0.0092	0.76
Below 10	12.73	1.21%	0.04	Cost of aggregate size below 10mm redistributed	
	1050		3.10		3.10

Figure 4: Cost Distribution of Aggregate Sizes in Concrete

MODELLING OF COST

EViews, SPSS, Weka, and Microsoft Excel applications were used in procuring an empirical model that incorporates cost per volume as the dependent variable and compressive strength, aggregate size, and workability as independent variables for use in determining the cost of concrete. In general, the surface response model analysis of selected concrete parameters takes the form shown in equation (1):

$$\text{cost per unit volume} = \gamma_0 + \gamma_1(\text{slump value}) + \gamma_2(\text{compressive value}) + \gamma_3(\text{aggregate size}) \quad (1)$$

Where; $\gamma_0, \gamma_1, \gamma_2, \gamma_3$ represent modification factors.

Table 6 shows the coefficients from the modeling applications.

Table 6: Summary of Coefficients obtained from Different Cost Predictive Models on 28-day Strength.

Modeling Application	Compressive Strength	Aggregate Size	Slump Value	Constant
E-Views	114.96	-315.91	-665.62	43,038.39
SPSS	115.10	-315.89	-665.48	43,032.29
WEKA	115.10	-315.89	-665.48	43,032.29
Microsoft-Excel	115.10	-315.89	-665.48	43,032.29

With equation (1) and the coefficients in Table 6, equation (2) is derived using SPSS, WEKA, and Microsoft Excel. They also have coefficients of determination, R^2 = 97.0, 96.99, and 96.7 respectively.

$$\frac{\textbf{Cost}}{\textbf{m}^3} = \textbf{115.1 Compressive Strenght} - \textbf{315.89 Aggregate Size} - \textbf{665.48 Slump Value} + \textbf{43,032.29}$$

(2)

With the use of the E-Views Software Application, a second equation (3) is derived with coefficients of determination, R^2 = 96.7

$$\frac{\text{Cost}}{\text{m}^3} = 114.96 \text{ Compressive Strenght} - 315.91 \text{ Aggregate Size} - 665.62 \text{ Slump Value} + 43,038.39$$

(3)

Model (2) may be adopted over (3) due to higher values of R^2. When sample laboratory results in values were inputted into equation (2), the predicted costs from the model are shown in Table 7. The values are very close to the manually determined costs that are shown in Tables 1, 2, and 3. This validates the predictive model as a useful tool for cost and quality control forecasting in concrete production.

Table 7: Summary of Model-Generated Costs for All Concrete Mixes

Mix ratio	1:3:6			1:2:4			1:1½:3		
Aggregate size	Slump (mm)	σ (N/mm²)	Predicted cost from model (NGN)	Slump (mm)	σ (N/mm²)	Predicted cost from model (NGN)	Slump (mm)	σ (N/mm²)	Predicted cost from model (NGN)
10	31.50	14.10	20,533.30	23.50	22.10	26,777.94	18.60	24.00	30,257.90
13	28.40	15.60	21,821.46	20.80	22.81	27,709.03	16.20	27.67	31,329.59
19	26.00	16.57	21,635.06	18.50	23.77	27,454.92	14.60	29.43	30,701.51
25	23.30	17.44	21,636.85	16.70	24.87	26,884.09	13.10	30.63	29,942.49

CONCLUSIONS

Many laboratories and computational efforts invested in this research produced a mathematical model that gives a scientific approach to predicting the minimized cost of concrete if certain variables are known. The conclusion can therefore be presented as follows:

1. A mathematical model developed from the Response Surface Methodology (RSM) was formulated and optimized to compute the minimized cost of concrete when the size of the coarse aggregate, the slump of the fresh concrete, and the compressive strength of the hardened concrete are known.

2. The size of coarse aggregates has an impact on the compressive strength and cost of concrete. Also, the optimum cost which is the least and most reasonable cost is made from 25mm size coarse aggregate at NGN29,942.49. It has the least slump and highest strength for each mixing ratio respectively. This, therefore, provides the most economical option in terms of cost and quality.

3. Promoters of infrastructural development with concrete as a major input in Abuja, Nigeria may use the predictive model so formulated to address quality of work and cost minimization.

RECOMMENDATIONS

1. More work could be done by incorporating more quality control parameters and reducing or varying the assumed 15% provision for handling which encompasses production cost and fees for more exact cost values.

2. Similar work could be done on other concrete mixes, mortar, and other construction composite materials.

CONFLICT OF INTEREST

There is no conflict of interest in the course of this research and the manuscript preparation

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REFERENCES

Abubakar, I. R. (2014). Abuja City Profile. *Cities,* **41**: 81–91. doi: 10.1016/j.cities.2014.05.008.

Abdullahi, M. (2012). Effect of aggregate type on Compressive strength of concrete. International Journal of Civil and Structural Engineering, **2**(3):791–800. https://doi.org/10.6088/ijcser.00202030008

ACI Committee 221 (2002). ACI PRC-221-96): Guide for Use of Normal Weight and Heavyweight Aggregates in Concrete. concrete.org

Ahmed, M., Islam, S., Nazar, S., & Khan, R. A. (2016). A Comparative Study of Popular Concrete Mix Design Methods from Qualitative and Cost-Effective Point of View for Extreme Environment. Arabian Journal for Science and Engineering, 41(4), 1403–1412. https://doi.org/10.1007/s13369-015-1946-9

Ajamu, S. O., & Ige, J. A. (2015). Effect of Coarse Aggregate Size on the Compressive Strength and the Flexural Strength of Concrete Beam. Journal of Engineering Research and Applications Www.Ijera.Com, 5(1), 67–75. www.ijera.com

And, N. S. O., & Ezeagu C A. (2016). Optimization of the Strength of Concrete Made From Nigerian Processed Aggregate. International Refereed Journal of Engineering and Science (IRJES) ISSN (Online), 5(4), 2319–183. www.irjes.com

British Standard Institute. (1990). BS 812-112: Methods for Determination of Aggregate Impact Value (AIV). British Standard Institute.

BS EN 196-6 (2018): Methods of Testing Cement Part 6: Determination of Fineness, British Standards (BS) Institution, London.

BS EN 12350-2:2009-Testing fresh concrete, Part 2: Slump Test, Bs En 12350-2:2009 1 (2009).

BS-EN 12390-3-2009. (2009). Compressive Strength of Test Specimens. In Testing Hardened Concrete (pp. 4–10). European Committee for Standardization.

BS, E. N.-. (2005). BS EN 196-1:1995 (Methods of Testing Cement). Part 1: Determination of Strength, BS EN 169-(1), 36.

BS EN 196-3:2005 +A1:2008. (2005). Methods of testing cement - Part 3: Determination of setting times and soundness. British Standard, 3, 18.

BS NA EN 1990-2-2007. (2010). UK National Annex to Eurocode 7: Geotechnical design - Part 2: Ground Investigation and Testing. BSI Standards Publication.

BS EN 1992-1-2:2004 – Design of concrete structures, 3 485 (2014). https://doi.org/10.1007/978-3-642-41714-6_51755

COREN. (2017). Concrete Mix Design Manual. Council for the Regulation of Engineering in Nigeria. Special Publication No. COREN/2017/016/RC. 11

Dan, S., Dan, N., & Pal, T. K. (2014). Application of response surface methodology (RSM) in statistical optimisation and pharmaceutical characterization of a matrix tablet formulation using metformin HCL as a model drug. Innoriginal International Journal of Sciences, 1(2), 1–6.

Ghasemi, Y. (2017). Aggregates in Concrete Mix Design (Issue January). http://www.diva-portal.org/smash/get/diva2:1068902/FULLTEXT01.pdf%0Awww.ltu.se

International Standard Organization. (2020). ISO 11277: Soil Quality-Determination of Particle Size Distribution in Mineral Soil Material-Method by Sieving and Sedimentation. 61010-1 © Iec:2001, 13. www.iso.org

Khuri, André I. (2001). An overview of the use of generalized linear models in response surface methodology. Nonlinear Analysis, Theory, Methods and Applications, 47(3), 2023–2034. https://doi.org/10.1016/S0362-546X(01)00330-3

Khuri, Andre I., & Cornell, J. A. (1996). Response Surfaces: Designs and Analyses: Second Edition. In Psychological Reports (Vol. 65, Issue 2, p. 536). https://books.google.com/books?hl=en&lr=&id=D7arMQLrTccC&pgis=1

Mahmoud, M. I., Duker, A., Conrad, C., Thiel, M., & Ahmad, H. S. (2016). Analysis of settlement expansion and urban growth modelling using geoinformation for assessing potential impacts of urbanization on climate in Abuja City, Nigeria. Remote Sensing, 8(3). https://doi.org/10.3390/rs8030220

Meddah, M. S., Zitouni, S., & Belaâbes, S. (2010). Effect of size and content of coarse aggregate on the compressive strength of concrete. Construction and Building Materials, 31(3), 220–225. http://dx.doi.org/10.1016/j.conbuildmat.2009.10.009

Myers, R. H., Montgomery, D. C., & Anderson-Cook, C. M. (2016). Response Surface Methodology: Process and Product Optimization Using Designed Experiments (Fourth). John Wiley & Sons, Inc., Hoboken, New Jersey. http://www.wiley.com/go/permission.

Neville, A. M., Properties of Concrete. (2003). Fourth Edition. Pearson Education Ltd. Singapore. p.187.

Ogbemudia, C. E., Ndububa, E. E., & Mbaezue, N. D. (2021). An Investigation into causes of Building Collapse in Abuja, Nigeria, Global Science Journal, 9, 435–446.

Samuel, E. I., & Snapp, O. J. (2015). Cost Model for Unit Rate Pricing of Concrete in Construction Projects. International Journal of Construction Engineering and Management, 4(4), 149–158. https://doi.org/10.5923/j.ijcem.20150404.05

Sanusi A., Ndububa E. E., Amuda A. G., Mambo A. D., Mohammed A and Mohammed I, H. (n.d.). Properties of Fine Aggregates in Abuja and Environs. Journal of Civil Engineering. Nigerian Institution of Civil Engineers, 12(1), 22–35. https://doi.org/10.4324/9781315387222-6

Statistics, D. (1977). Demographic Statistics. Alpacas, Sheep, and Men, May, 219–228. https://doi.org/10.1016/b978-0-12-527850-8.50022-5

Trinh, T. K., & Kang, L.-S. (2010). Application of Response Surface Method as an Experimental Design to Optimize Coagulation Tests. Environmental Engineering Research, 15(2), 63–70. https://doi.org/10.4491/eer.2010.15.2.063

Tsado, T. Y. (2010). Strength Variability of Some Common Portland Cement Used in Federal Capital Territory, Abuja , Nigeria. Global Jour. of Engg. & Tech., 4(1), 107–113. https://www.bing.com/search?q=strength+variability+of+some+common+portland+cement+used+in+federal+capital+territory%2C+abuja%2C+nigeria&form=EDGTCT&qs=PF&cvid=b5ff56fb3bdf48d795a0b76b3757aad6&refig=917f3be6dac14f58ae933eac358349fa&cc=NG&setlang=en-GB&plva

Ujoh, F., Kwabe, I., Ifatimehin, O. O., & D, I. (2010). Understanding urban sprawl in the Federal Capital City , Abuja: Towards sustainable urbanization in Nigeria. Journal of Geography and Regional Planning, 3(5), 106–113.

Ukpata, J. O., & Ephraim, M. (2012). Flexural and tensile strength properties of concrete using lateritic sand and quarry dust as fine aggregate. August 2014.

Waziri B.S, Bukar, A. ., & Gaji, Y. Z. A. (2011). Applicability of Quarry Sand as A Fine Aggregate in The Production of Medium Grade Concrete. Continental Journal of Engineering Sciences, 6(2), 1–6. http://www.wiloludjournal.com

Wu, K., Chen, B., Yao, W., & Zhang, D. (2001). Effect of coarse aggregate type on mechanical properties of high-performance concrete. 31, 1421–1425.

Yolmeh, M., & Jafari, S. M. (2017). Applications of Response Surface Methodology in the Food Industry Processes. Food and Bioprocess Technology, 10(3), 413–433. https://doi.org/10.1007/s11947-016-1855-2