Journal of Asian Scientific Research
ISSN(e): 2223-1331
ISSN(p): 2226-5724
DOI: 10.55493/5003.v13i1.4771
Vol. 13, No. 1, 54-67.

URL: www.aessweb.com

Utilization of response surface methodology in optimization of locally sourced aggregates

Emmanuel Ifeanyi Ogunjiofor[1+]
Femi Ogundeji Ayodele[2]

[1]*Department of Civil Engineering, Chukwuemeka Odumegwu Ojukwu University, Anambra State, Nigeria.*
Email: ogunjioforemmanuel@gmail.com
[2]*Department of Surveying and Geoinformatics, Federal Polytechnic Oko, Nigeria.*
Email: femayoy2k2@yahoo.com


(+ Corresponding author)

Article History
Received: 9 January 2023
Revised: 7 March 2023
Accepted: 20 March 2023
Published: 5 April 2023

Keywords
Cement
Compressive strength
Concrete
Construction
Local aggregate
Optimization
Response surface methodology.

ABSTRACT

This research investigated the optimization of locally sourced aggregate, mixed with variable cement ratios to determine its optimum compressive strength. Samples of standard sizes of local fine and coarse aggregate were obtained at the popular excavation sites. The concrete materials were weighed, batched, mixed, cast and cured using four different mix proportions of 1:2:4, 1.2:2:4, 1.4:2:4 and 1.6:2:4 of cement, fine and coarse aggregate at constant water/cement ratio of 0.5. A total of 48 concrete cubes of 150mmx150mmx150mm were produced, cured for 7, 14, 21 and 28 days and tested. Mathematical model equation relating the compressive strength of the local stone with variability of cement was developed using Response Surface Methodology (RSM). The significance and suitability of the equation was confirmed using the analysis of variance (ANOVA). The ANOVA for the quadratic and Surface Cubic model shows that the adjusted R2 of 0.9808 and F-value of 227.76 in compressive strength of the concrete is confidently accounted for by the independent variable. This demonstrates that the equation's predictions of compressive strength for various concrete structures are accurate. Therefore, utilization of local aggregate is advised for the construction of most of the dominant low-rise residential buildings in Anambra and other neighbouring States.

Contribution/ Originality: The study investigated the strength of concrete produced with locally sourced aggregates in Anambra State at different cement proportions. And a Mathematical model equation relating the compressive strength was developed using RSM. The model was able to determine the optimum cement content requirement of the local aggregates for structural purposes.

1. INTRODUCTION

Aggregates, cement, water, and occasionally additives are the components of the man-made engineering substance known as concrete. One of the most popular building components that is known for its wide range of usage due to its strength and durability is concrete [1, 2]. Over 90% of all residential and commercial buildings in Nigeria are made of reinforced concrete, which is a result of its properties making it a particularly essential material in the country's construction industry [3, 4]. Almost one-third of the volume of concrete, or between 60 and 75 percent of the overall volume of concrete, is made up of coarse aggregate [5-7]. As a result, aggregate is crucial in determining how strong, long-lasting, workable, porous, and other properties of concrete are. The characteristic strength and fracture concrete can alter as a result of changes in the characteristics of fine and coarse aggregate. Understanding the kind and characteristics of the aggregate used to create concrete is essential in order to forecast how the concrete's characteristic will be in practice. Numerous studies on subjects related to concrete, including self-compacting concrete [8] the incorporation of various natural and synthetic fibers [9, 10] nanomaterials [11] and waste materials [12-14] have been conducted in the past.

Naturally, aggregate variation is a result of variation in the parent rock formation that forms the aggregates. That's why aggregate from different location tends to differ slightly from each other in characteristics. That notwithstanding there is a generally accepted characteristic that an aggregate needs to possess before it can be accepted such as its weight, size, shape, aggregate type, index of angularity, surface roughness, elastic modulus, bulk density, and specific gravity, grading of aggregate, thermal properties, cleanliness, bulking of aggregate, crushing type, absorption, moisture content etc [15]. To ensure an increase in the contact surface between aggregates and cement paste, which is essential for the strength and durability of concrete, there is a need for thorough and adequate design as well as well-supervised construction [16].

Conventionally, most construction works on concrete make use of granite as coarse aggregate. This was based on the assumption that granite produces the strongest and most durable concrete, that local aggregate does not produce strengthful and durable concrete. This assumption has made so many building developers spend heavily on purchasing and hauling granite from their quarry location to their site. Uncertainties have been found in a study by Ede, et al. [17] on the use of gravel for making concrete. This reservation is made because granite is stronger and has a more uniform chemical composition, while gravel has a more varied size distribution, a higher degree of sorting, and a composition that is more harmful. Aginam, et al. [7] Investigated how different coarse particles affected concrete's compressive strength in Southeastern Nigeria and discovered that the least compressive strength of 16.9kN/m^2 was produced with unwashed gravel while 20.0kN/m^2 was produced with washed gravel. They deduced that impurities on the local aggregate impact the compressive strengths of concrete which was confirmed by the study done by David, et al. [18] and Apebo, et al. [19] on locally sourced coarse aggregate. Concrete strength may be correlated with aggregate form, type, surface area, and internal structure. But if its engineering qualities are well recognized, using locally obtained material is not prohibitively out of place. In a state like Anambra where there is no granite query currently, building developers go as far as travelling thousands of miles to procure granite. The recent increase in the price of diesel has caused the price of haulage of granite to skyrocket thereby causing a massive increase in the cost of building, housing and other infrastructural developments. This phenomenon is becoming worrisome, especially in this post-COVID-19 era overwhelmed with the socio-economic crisis.

On the other hand, some other researchers have worked on recycled aggregates concrete (RAC). It is a type of environmentally friendly concrete produced by partly or completely replacing natural aggregates with recycled aggregates made from leftover concrete blocks from construction projects after mechanically squashing, grading and cleaning the aggregates. Notably, the use of RAC allows for the recycling of construction waste, which has significant ecological, economic, and social consequences [20, 21] in addition to addressing the environmental issues brought on by building waste dumps. Despite having a lower apparent density than natural aggregate, a higher water absorption rate, and a lower crushing value, recycled aggregates can be combined with natural aggregates to satisfy the criteria for the workability and strength of RAC. Real-world applications of RAC include the building of the US-41 in the United States and the Diepmannsbach Bridge in Germany [22].

Adding some supplementary cementitious materials (SCMs) to RAC can improve its freezing-thawing (F-T) resistance properties, as has been demonstrated in previous research [23, 24]. Additionally, dense calcium silicate hydrate (C-S-H) gels can be produced by SCMs due to their pozzolanic properties, which is expected to increase the durability of RAC. Typically, SCMs can improve RAC's compactness by filling the cement matrix's tiny pores.

Yu, et al. [25] Looked into how different replacement rates of ceramic waste powder (CWP) affected the freeze-thaw durability of RAC. Six sets of CWP doping ratios of 0%, 10%, 20%, 30%, 40, and 50% were planned for this experiment. Basic mechanical and physical performance statistics for each set of specimens were assessed throughout the normal curing age prior to the F-T cycling test. After each F-T cycle, the impact-echo technique and compressive strength test were used to evaluate the durability performance of the RAC. The lifespan of RAC mixtures was predicted using a Grey-Markov model. The impact-echo technique was found to be more suitable for determining the resilience of RAC under freeze-thaw conditions.

Patowary and Mahmood [26] researched on the Mechanical Properties of concrete produced with Local Coarse Aggregate sourced from Bangladesh. They examined the compressive strength, splitting tensile strength, and elastic modulus at 7, 14, and 28 days of curing of the concrete. Their findings demonstrated that Dinajpur Hili (Indian Black Stone), is most appropriate for concreting.

The need to reawaken the consciousness of building developers on the fact that local aggregates in Anambra state can be effectively used to produce a standard, durable and devised concrete calls for this research. This fact can only be proved through extensive testing and observation. It was reported by Mackechnie [27] that sandstone is increasingly being used in concrete construction in most places of the world and concrete produced with it can compete favourably with granite chippings in terms of strength and other mechanical properties if properly graded and constructed.

Bamigboye, et al. [28] Evaluated the economics of substituting local aggregate for granite in the production of concrete. The findings, which were in line with a study by Jae, et al. [29] showed that adding more granite to concrete significantly improves its consistency attributes. Additionally, according to Sulymon, et al. [30] the concrete's compressive, flexural, and split tensile strengths are significantly influenced by the local aggregate source.

Khadka and Mishra [31] investigated how small aggregate sources affected the compressive strength of cement concrete. All 48 samples underwent compression testing to determine their compressive strength, which varies from 20.64 N/mm^2 to 32.47 N/mm^2 and exceeds the minimum strength offered by M20 grade. For each of the sixteen combinations of aggregates, a different mean compressive strength number was found. When combined with four distinct samples of coarse aggregate, the fine aggregate from the Chisang source outperformed the other three sources in terms of average compressive strength. Other researches on quality of cement, aggregates source, variability of fine aggregate were conducted by Mishra and Sharestha [32]; Mishra and Jha [33]; Megha and Gauhar [34]; Mishra and Chaudhary [35].

The fine aggregates gradation curve from a study by Nayaju and Tamrakar [36] evaluating the fine aggregates from the Budhi Gandaki-Narayani River, which is rich in carrying natural fine aggregates from the Higher and Lesser Himalayas region, showed that aggregates were varied from uniform to well graded, the detrimental materials excepting organic matter ranged from 0.3%-1.5%, and the presence of organic matter ranged from 0.57%-1.11%. They noted that the pattern indicated that organic matter and harmful inorganic material were both accumulating in the river's southern reaches. A study revealed that the aggregate's bulk density is less than 2 grams per cubic centimeter, and its water absorption value varies from 0.48 to 2.87%.

Practically, regardless of the source, the primary goal of using aggregate in concrete remains the same. According to Ezeokonkwo, et al. [37] the fundamental purpose of coarse aggregate is to give concrete volume and act as a less expensive filler than cement. According to Chindaprasirt, et al. [38]; Chen, et al. [39] aggregate give the finished concrete volume stability and durability. Wight [40] Demonstrated that regardless of the source, aggregates that meet certain requirements, such as cleanliness, hardness, strong, tough, durable particles, freedom from chemicals, freedom from coat and other fine materials that may affect the bond and hydration of cement paste, are suitable for concrete work. This study experimented and found that local aggregates in Anambra State can be used to produce concrete of adequate strength and durability at different mix ratios.

Aggregates were sourced from the two main sources of local aggregates in the state which are Onitsha and Awka. The aggregates were batched on mix ratios of 1:2:4, 1.2:2:4, 1.4:2:4 and 1.6:2:4 (cement: fine aggregate: coarse aggregate). The study helped to optimize the actual mix ratio and strength characteristics for different structural elements using Response Surface Methodology.

2. MATERIALS AND METHOD

2.1. Materials

The study adopts sampling methods while selecting the materials. The coarse aggregate was obtained from Awka, the capital city of Anambra state. Natural river sand from the banks of the River Niger in Onitsha, Anambra State, served as the fine aggregate. Aggregates were properly washed and dried and were free from deleterious materials, the aggregates were prepared following BS standards [41].

A local seller of cement provided Dangote Ordinary Portland Cement used for the experiment. The cement was marked and was free from contamination, homogeneously fine, it has a specific gravity and unit weight of 3.15 and 1445kg/m^3 respectively and confirms the BS specifications [42].

The Concrete was mixed and cured using potable lab water from the Civil Engineering Departmental laboratory. The water met BS requirements and was free of suspended particles and chemical contaminants [43].

2.2. Preparation of the Samples and Laboratory Tests

The aggregate materials were sieved with a standard sieve, the shaking was properly done using the vibrating sieve shaker and it confirms with BS Standards [44]. Different weight batching of 1:2:4, 1.2:2:4, 1.4:2:4 and 1.6:2:4 were used to ascertain the actual mix that will give a standard target mean strength at different days of curing [45]. It was done using a 0.5 water-to-cement ratio. The elements of the concrete were properly mixed and a total number of 48 cubes of 150mmx150mmx150mm were cast using standard steel mounds. Identifications were marked on the concrete after a few hours of casting for easy identification during curing. The cubes were demoulded after 24 hours and were submerged in a curing tank. They were cured for 7, 14, 21 and 28 days. On the mature days, the cubes were weighed and crushed in the departmental laboratory using Universal Testing Machine.

2.3. Optimization of Compressive Strength Using Response Surface Method (RSM)

A Response Surface Methodology is one of the recently common optimization techniques used in the analysis of experimented studies [46]. By assessing the impact of several factors and their interactions on one or more response variables, the approach can be used to quickly identify the best response for the subject of interest [47]. Here, the approach was used to produce a standard concrete mix utilizing local aggregates while optimizing the link between variability and the ideal proportion of cement. The RSM specifies the relationship between the response and essential controllable parameter inputs of the concrete when all independent variables are measurable, controllable and continuous in the experiment [48]. In this study, the major variable is cement '$x_1 \ldots x_k$' which combines with local stone to produce the compressive strength of the concrete 'y'. the relationship is expressed linearly in Equation 1 as follows;

$$y = f(x_1) + f(x_2) + f(x_3) + f(x_4) + \cdots \ldots \ldots f(x_k) \qquad (1)$$

Where y denotes the response (dependent variable).

$x_1, x_2, x_3, x_4, \ldots\ldots\ldots x_k$ are independent variables.

Finding an adequate interaction value for the link between the experimental parameters in the independent variables or factors and the response surface is important to maximize the response of the concrete compressive strength variable y [49-51]. To actualize this, a second-order polynomial of RSM is adopted and expressed in Equation 2 as follows;

$$y_i = b_o + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n} b_{ii} x^2{}_i + \sum_{ii>j}^{n} \sum_{j}^{n} b_{ij} x_i x_j + e \qquad (2)$$

Where y_i is the predicted compressive strength response.

b_o, b_i, b_{ii} and b_{ij} are coefficients.

x_i and x_j are actual factors.

e = Error term.

F-test was used to evaluate the significance of the model while the adequacy of the model was equally checked using the coefficient of determination R^2 and adjusted R^2.

3. RESULTS AND DISCUSSIONS

3.1. Optimization Model for the Compressive Strength Experimental Design and Analysis

The experimental design matrix for the compressive strength of variable Ordinary Portland Cement (OPC) mix ratios with locally sourced aggregates at different curing days was presented in Table 1. It was discovered that the compressive strength increases with an increase in cement proportion. The difference in strength variability at 1.4 and 1.6 of cement content in the mix have a closer compressive strength compared to others. The mix ratio of 1:2:4 had the lowest strength while that of 1.4:2:4 and 1.6:2:4 were averagely high and comparable to that of conventional strength grade of granite.

Table 1. Experimental design matrix table for different mix ratios.

Run	Factor 1	Factor 2	Response 1
Serial number	A: Mix ratio Variable cement (OPC)	B: Time (Curing days) Days	Compressive strength N/mm²
1	1:2:4	7	14.20
2	1.2:2:4	7	16.20
3	1.4:2:4	7	17.75
4	1.6:2:4	7	18.45
5	1:2:4	14	20.15
6	1.2:2:4	14	20.10
7	1.4:2:4	14	21.85
8	1.6:2:4	14	22.90
9	1:2:4	21	23.10
10	1.2:2:4	21	23.75
11	1.4:2:4	21	24.10
12	1.6:2:4	21	24.95
13	1:2:4	28	27.60
14	1.2:2:4	28	28.10
15	1.4:2:4	28	28.85
16	1.6:2:4	28	29.50

This indicates that there is a serious influence of cement on the compressive strength of the concrete produced. The difference in increase in strength became minimal upto the mix ratio of 1.2:2:4 at 28days of curing. That of 1.4:2:4 was only 2.6% higher than that of 1.2:2:4 which implies that the quality of the mortar at the cement content was optimum for a good concrete work.

Table 2. Model summary statistics of the concrete strength.

Model summary statistics						
Equation source	Std. dev.	Main R-squared	Adjusted R-squared	Predicted R-squared	Obtained press	Possible outcome
Linear	0.68	0.9808	0.9778	0.9692	9.74	Suggested
2FI	0.59	0.9868	0.9835	0.9751	7.88	Suggested
Quadratic	0.65	0.9869	0.9803	0.9622	11.96	Suggested
Cubic	0.39	0.9971	0.9927	0.9697	9.57	Suggested
Quartic	0.40	0.9985	0.9926	0.9146	27.03	Aliased

The ANOVA for the quadratic model in Table 2 shows that the adjusted R^2 of 0.9808 indicated 98.08% of the systematic variation in compressive strength of the concrete is confidently accounted for by the independent variable (fine aggregate, coarse aggregate, water-cement ratio, and curing days). The percentage value shows that there is appropriate proportioning of the concrete components. This tandems with the theoretical attributes of concrete that states that concrete strength, characteristics, properties, density etc is proportional with the size, shape, and ratios of the cement, fine and coarse aggregates. This becomes so important in the use of local aggregates that predominant in some local areas and for low housing buildings.

The F-value of 227.76 in the ANOVA for the Response Surface Cubic model suggests that the model is significant. "Prob > F" values less than 0.0001 denote the significance of the model terms A, B, AB, A^2, B^2,A^2B, AB^2, A^3, and B^3 are important model terms and Degree of freedom (Df) values as seen in the Table 3.

Table 3. Compressive Strength Response of the variable mix.

Source	Sum of squares	Df	Mean square	F value	P-value prob > F	Significances
Model	315.51	9	35.06	227.76	< 0.0001	Significant
A-Mix ratio	1.33	1	1.33	8.66	0.0259	Significant
B-Curing days	8.53	1	8.53	55.39	0.0003	Significant
AB	1.91	1	1.91	12.42	0.0125	Significant
A^2	1.406E-003	1	1.406E-003	9.136E-003	0.9270	Significant
B^2	3.906E-003	1	3.906E-003	0.025	0.8787	Significant
A^2B	0.15	1	0.15	0.97	0.3635	Significant
AB^2	0.29	1	0.29	1.91	0.2162	Significant
A^3	0.075	1	0.075	0.49	0.5112	Significant
B^3	2.72	1	2.72	17.67	0.0057	Significant
Residual	0.92	6	0.15	0.85	0.6222	Significant
Cor total	316.44	15	21.66	98.39	3.5632	Significant

The coded factors presented in Table 4 and Equation 3 can be used to predict the response for each variable mix of 1, 1.2, 1.4 and 1.6 of cement and their respective compressive strengths. The values of confidence of intervals (CI) and variance inspection factor (VIF) were optimum. This becomes necessary where only local materials are comparatively available for concrete works. In such a case, it is cheaper to make use of available materials at different proportionate of cement to get the desired strength of any of the concrete elements such as foundation, columns, beams and slab. Equation 3 offered the mathematical model for the compressive strength in terms of the coded factors, and Equation 4 presented the mathematical model for the compressive strength in terms of the actual mix factors. These equations parameters are variables that can be adjusted to obtain a new result for different material components. This is highly necessary for a situation where the characteristics of the natural aggregates continues to deviate and differ from the study locations. In such a case all that is needed is to input the parameters of the local aggregates, the required mix ratio and prospective compressive strength will be obtained. This serves as a model for some other local aggregates that have not been subjected to test in different localities and the tentative compressive strength of the materials.

Table 4. Compressive strength factor of the variable mix.

Factor	Coefficient estimate	Df	Standard error	95% CI low	95% CI high	VIF
Intercept	22.60	1	0.20	22.12	23.09	14.24
A-Mix ratio	1.46	1	0.50	0.25	2.68	14.24
B-Time	3.70	1	0.50	2.48	4.91	14.24
AB	-0.62	1	0.18	-1.05	-0.19	1.00
A^2	0.021	1	0.22	-0.52	0.56	1.00
B^2	-0.035	1	0.22	-0.58	0.50	1.00
A^2B	0.29	1	0.30	-0.43	1.02	2.56
AB^2	0.41	1	0.30	-0.32	1.13	2.56
A^3	-0.34	1	0.49	-1.55	0.86	12.67
B^3	2.07	1	0.49	0.87	3.28	12.67

Formula for the final equation with coded factors:

$$Compressive\ strength = +22.60 + 1.64 * A + 3.70 * B - 0.62 * AB + 0.021 * A^2 * B^2 + 0.29 * A^2B + 0.41 * AB^2 - 0.34 * A^3 + 2.07 * B^3 \quad (3)$$

Formula for the final equation with Actual factors:

$$Compressive\ strength = +0.99375 + 1.54021 * X + 2.40158 * T - 0.18771 * X * T + 0.55938 * X^2 - 0.10057 * T^2 + 0.012321 * X^2 * T + 2.47449^{003} * X * T^2 - 0.10208 * X^3 + 1.79179^{003} * T^3 \quad (4)$$

Where X is the mix ratio and T is the time (curing days)

3.2. Illustration of the Effect of the Variable Mix Ratios

Figure 1 shows that close and strong correlation between the Normal and Residual experimental details. Also, Figure 2 shows the outcome of the Residual and Predicted compressive strength values.

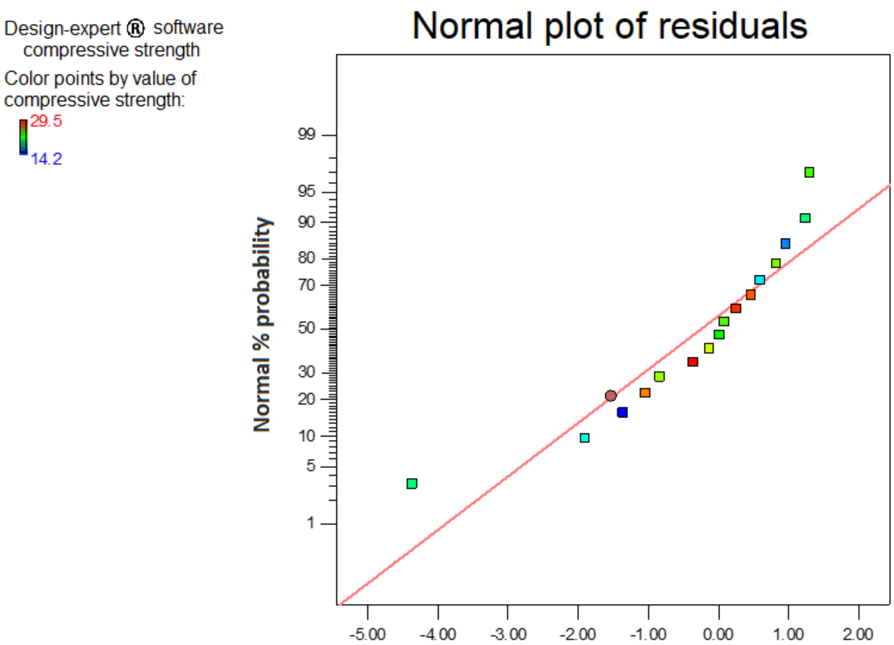

Figure 1. Graph of compressive strength residuals.

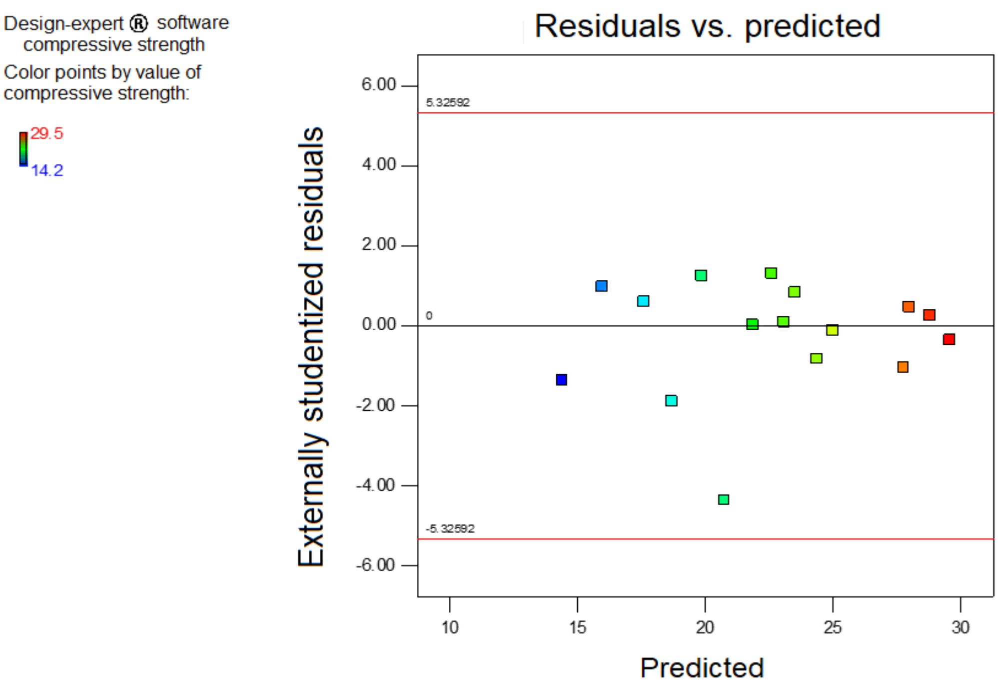

Figure 2. Graph of compressive strength residuals verse predicted.

Figure 3 depicts the compressive strength of predicted verse actual of the variable mix, the strength which was dependent on time and mix ratio was graphically illustrated on the value to affirm that the model can effectively predict the compressive strength of other mix ratios of local aggregates with cement. The design points coding of the model and its compressive strength was presented in Figure 4, the figure used colour codes to categories the strength which were based on time and mix ratio variables.

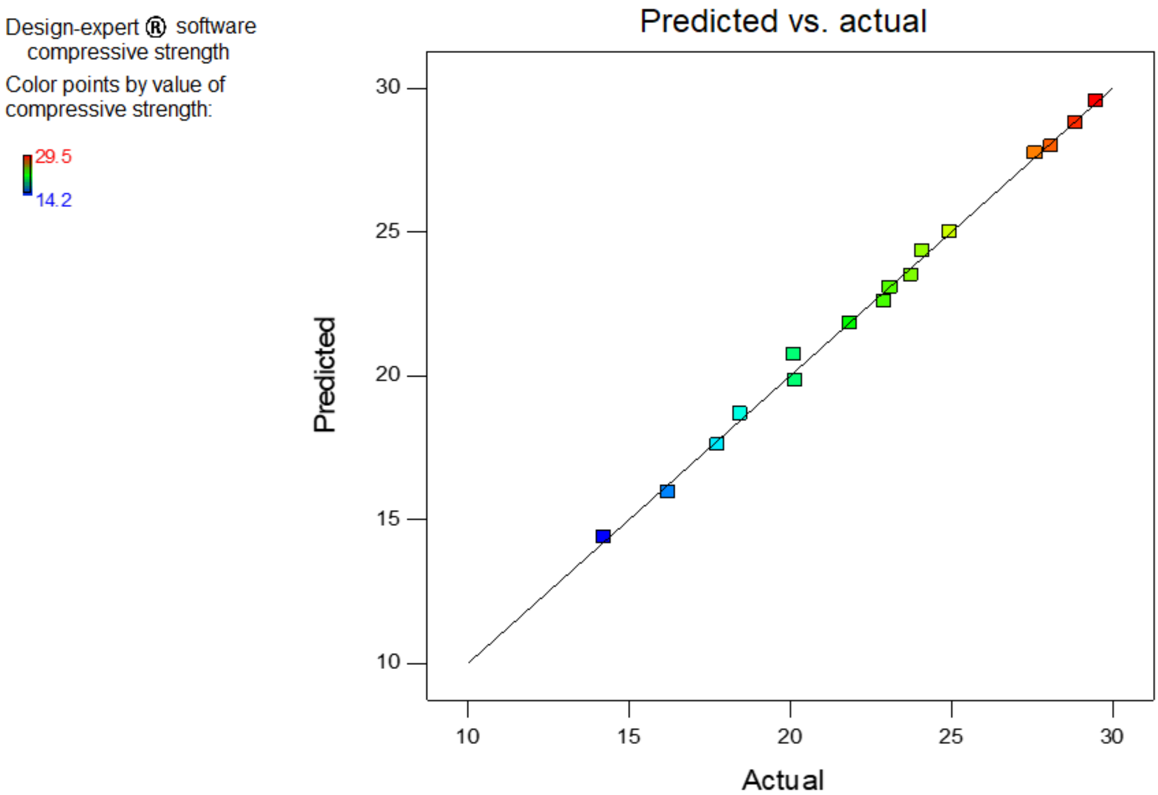

Figure 3. Graph of compressive strength predicted verse actual.

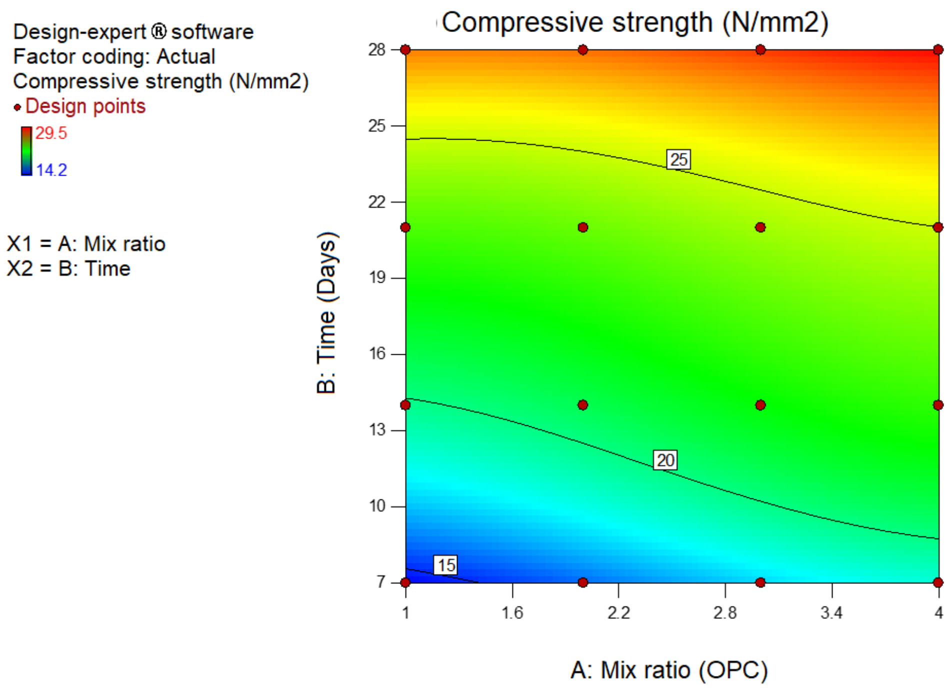

Figure 4. Graph of compressive strength verse mix ratio.

The residual verse run behaviour of the model was presented in Figure 5, where the externally studentized residual was plotted against the run. It determines the strength distribution of the selected concrete samples that is independent of the parameters of other samples around it, which are not directly relevant to the strength test of the concrete concerned.

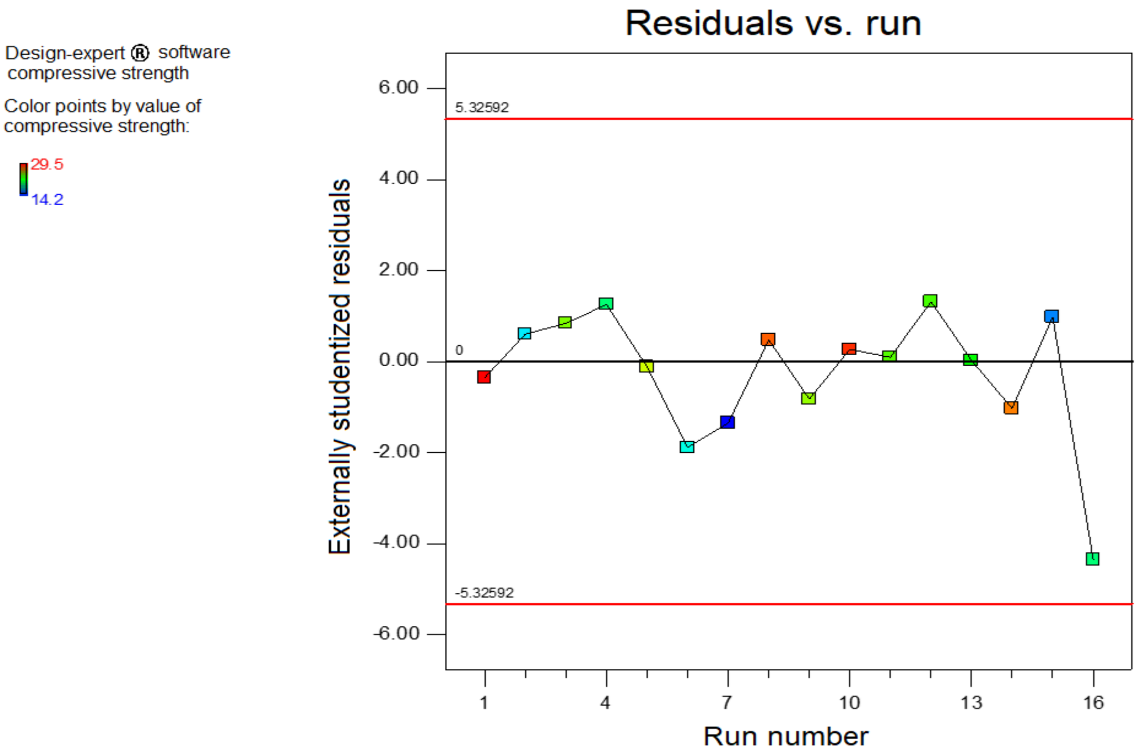

Figure 5. Graph of compressive strength of residuals verse run.

The perturbation behaviour of the model was presented in Figure 6, where variables 'A' and 'B' were used to obtain the optimum point of the mix ratio's compressive strength with respect to time.

Figure 7 shows the interaction value between the compressive strength and the mix ratios. The design points shows that the strength increases as the time (Days) of curing and cement contents increases.

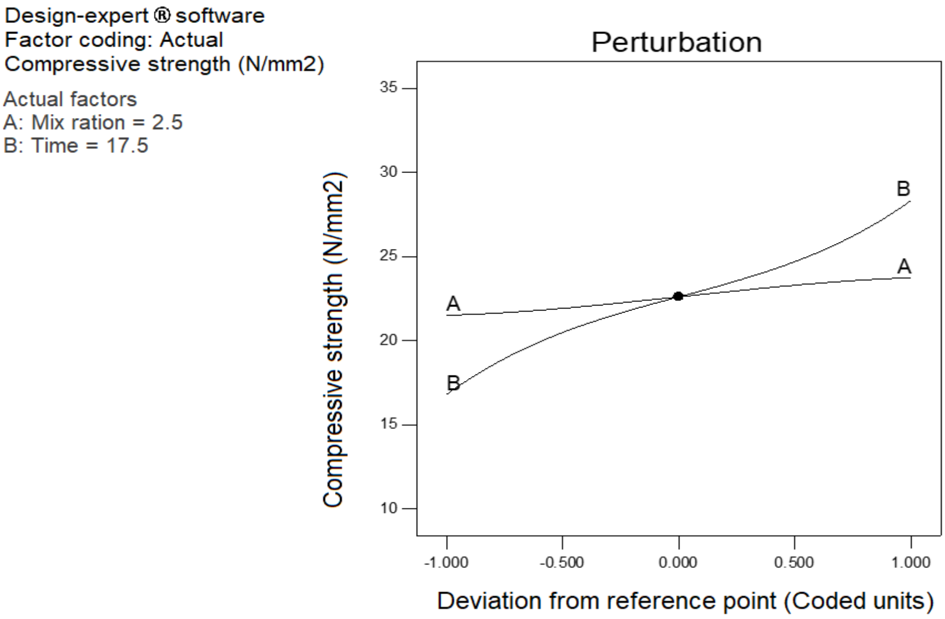

Figure 6. Graph of compressive strength perturbation.

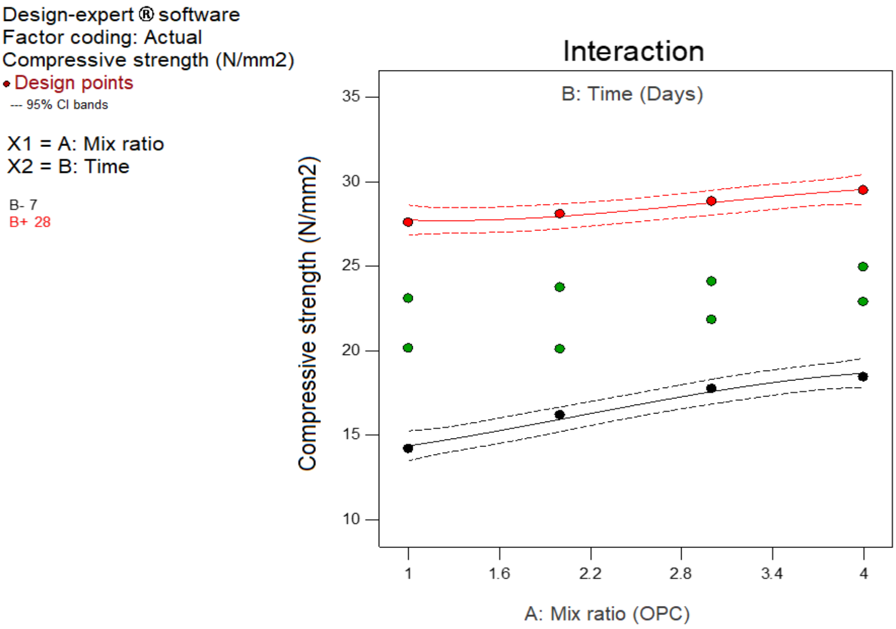

Figure 7. Graph of compressive interaction with the mix ratio.

The three-dimensional plots of the combined impact of mix ratio and curing days on concrete's compressive strength were shown in Figure 8. The compressive strength is increased by the weight gain of the cement and the number of curing days. The grade 30 goal mean strength was very nearly met by the optimal compressive strength of 29.5N/mm2 at 28 days of curing employing a 0.5 water-cement ratio. This suggests that if a modest increase in cement is added to the local mix, there is a negligible difference between concrete formed with standard coarse aggregate and that created using local stone.

The model therefore proved that different local aggregates can be utilized in production of good grades of concrete at different proportions of the concrete material content and curing days. The local aggregates should be adequately cleaned to ensure that it's free from dirt and any other impurities that may affect the concrete strength.

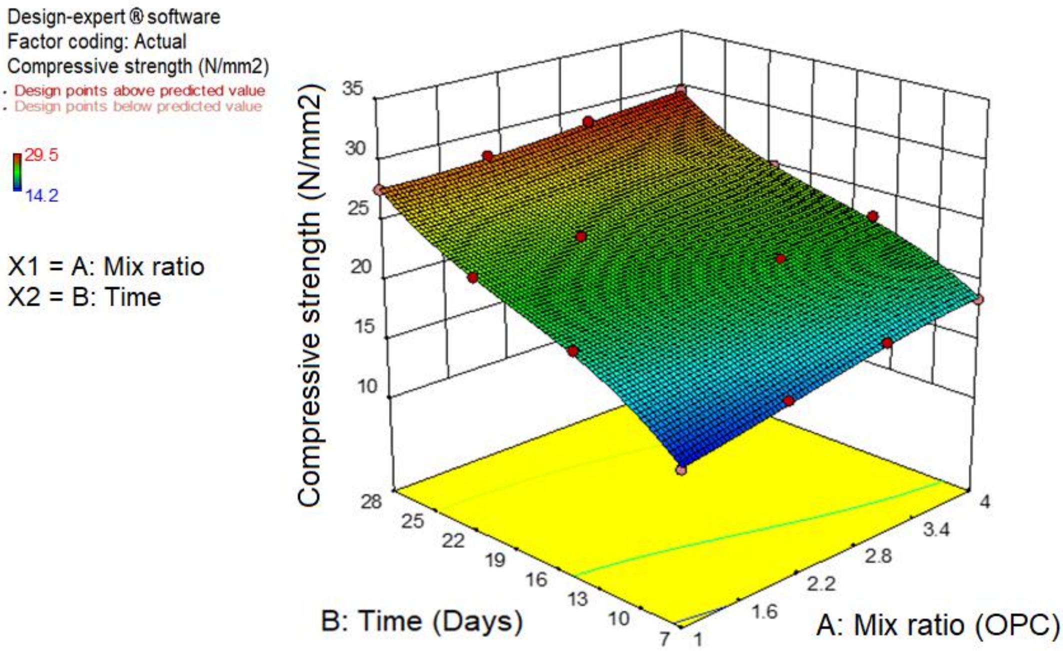

Figure 8. 3-dimensional plot of the Concrete's compressive strength.

4. CONCLUSION

The study's major goal was to figure out how much cement may safely be used for concrete projects made from locally produced Anambra State aggregate. This was necessary because of the steep rise in building material prices in Nigeria from the Covid-19 era, which contributed to the high cost of houses and rents. At a constant water-cement ratio of 0.5, the compressive strength of concrete made with locally sourced aggregates was examined at varying amounts of 1:2:4, 1.2:2:4, 1.4:2:4, and 1.6:2:4. Response Surface Methodology was used to create the mathematical model equation connecting the compressive strength of the local aggregate with the variability of cement (RSM). The optimum result of the different mixes at 28days which are 27.60 N/mm^2, 28.10 N/mm^2, 28.85 N/mm^2 and 29.50 N/mm^2 respectively were increased with an increase in cement content. The significance and appropriateness of the equation were examined using the analysis of variance (ANOVA). The ANOVA for the quadratic and Surface Cubic model shows that the adjusted R^2 of 0.9808 and F-value of 227.76 in compressive strength of the concrete are confidently accounted for by the independent variable. It can be inferred from the study that local aggregates can be used to produce a standard concrete for any structural material if the right proportion of cement and some other constituents are used in the right proportion. Therefore, utilization of local aggregate is strongly advised for the construction of most of the dominant low-rise residential buildings in Anambra and other neighbouring States.

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: Both authors contributed equally to the conception and design of the study.

REFERENCES

[1] E. I. Ogunjiofor, "Possibility of usage of seawater for mixing and curing of concrete in salty water localities," *Journal of Engineering Research and Reports*, vol. 19, no. 3, pp. 19-27, 2020. https://doi.org/10.9734/jerr/2020/v19i317234

[2] S. Kim, Y. Kim, M. Usman, C. Park, and A. Hanif, "Durability of slag waste incorporated steel fiber-reinforced concrete in marine environment," *Journal of Building Engineering*, vol. 33, p. 101641, 2021. https://doi.org/10.1016/j.jobe.2020.101641

[3] O. Joshua, K. O. Olusola, C. Ayegba, and A. I. Yusuf, "Assessment of the quality steel reinforcement bars available in Nigerian market," presented at the AEI 2013: Building Solutions for Architectural Engineering, 2013.

[4] S. A. Memon, M. Zain, D. Zhang, S. K. U. Rehman, M. Usman, and D. Lee, "Emerging trends in the growth of structural systems for tall buildings," *Journal of Structural Integrity and Maintenance*, vol. 5, no. 3, pp. 155-170, 2020. https://doi.org/10.1080/24705314.2020.1765270

[5] G. Bamigboye, A. N. Ede, and U. E. Umana, "Assessment of strength characteristics of concrete made from locally sourced gravel aggregate from South-South Nigeria," *British Journal of Applied Science & Technology*, vol. 12, no. 5, pp. 1-10, 2016. https://doi.org/10.9734/bjast/2016/20365

[6] M. Usman *et al.*, "Eco-friendly self-compacting cement pastes incorporating wood waste as cement replacement: A feasibility study," *Journal of Cleaner Production*, vol. 190, pp. 679-688, 2018. https://doi.org/10.1016/j.jclepro.2018.04.186

[7] C. Aginam, C. Chidolue, and C. Nwakire, "Investigating the effects of coarse aggregate types on the compressive strength of concrete," *International Journal of Engineering Research and Applications*, vol. 3, no. 4, pp. 1140-1144, 2013.

[8] H. Baloch, M. Usman, S. A. Rizwan, and A. Hanif, "Properties enhancement of super absorbent polymer (SAP) incorporated self-compacting cement pastes modified by nano silica (NS) addition," *Construction and Building Materials*, vol. 203, pp. 18-26, 2019. https://doi.org/10.1016/j.conbuildmat.2019.01.096

[9] W. Ahmad *et al.*, "Effect of coconut fiber length and content on properties of high strength concrete," *Materials*, vol. 13, no. 5, p. 1075, 2020. https://doi.org/10.3390/ma13051075

[10] M. Usman, S. H. Farooq, M. Umair, and A. Hanif, "Axial compressive behavior of confined steel fiber reinforced high strength concrete," *Construction and Building Materials*, vol. 230, p. 117043, 2020. https://doi.org/10.1016/j.conbuildmat.2019.117043

[11] A. Shamim, S. Ahmad, A. Khitab, W. Anwar, R. A. Khushnood, and M. Usman, "Applications of nano technology in civil engineering: A review," *International Journal of Strategic Engineering*, vol. 1, no. 1, pp. 48-64, 2018. https://doi.org/10.4018/ijose.2018010104

[12] M. U. Shah, M. Usman, M. U. Hanif, I. Naseem, and S. Farooq, "Utilization of solid waste from brick industry and hydrated lime in self-compacting cement pastes," *Materials*, vol. 14, no. 5, p. 1109, 2021. https://doi.org/10.3390/ma14051109

[13] H. Lee, A. Hanif, M. Usman, K. Yonghwan, H. Oh, and K. SeongKyum, "Interfacial characteristics of cement mortars containing aggregate derived from industrial slag waste," *Journal of Structural Integrity and Maintenance*, vol. 5, no. 4, pp. 236–243, 2020. https://doi.org/10.1080/24705314.2020.1783124

[14] H. J. Yang, M. Usman, and A. Hanif, "Suitability of liquid crystal display (LCD) glass waste as supplementary cementing material (SCM): Assessment based on strength, porosity, and durability," *Journal of Building Engineering*, vol. 42, p. 102793, 2021. https://doi.org/10.1016/j.jobe.2021.102793

[15] S. Mindess, J. F. Young, and D. Darwin, *Concrete*, 2nd ed. New Jersey: Pearson Education, Inc, 2003.

[16] S. O. Nwokoye and C. A. Ezeagu, "Optimization of the strength of concrete made from Nigerian processed aggregate," *International Refereed Journal of Engineering and Science*, vol. 5, no. 4, pp. 45-61, 2016.

[17] A. N. Ede, S. O. Adebayo, G. O. Bamigboye, and J. Ogundeji, "Structural, economic and environmental study of concrete and timber as structural members for residential buildings in Nigeria," *The International Journal of Engineering and Sciences*, vol. 37, no. 1, pp. 43-52, 2015.

[18] O. N. David, I. F. Olabosipo, J. Opeyemi, O. Ayodeji, and O. Ignatius, "Comparative analysis of concrete strength utilizing quarry-crushed and locally sourced coarse aggregate," *International Journal of Mechanical Engineering and Technology*, vol. 9, no. 1, pp. 607 – 617, 2018.

[19] N. Apebo, M. Iorwua, and J. Agunwamba, "Comparative analysis of the compressive strength of concrete with gravel and crushed over burnt bricks as coarse aggregates," *Nigerian Journal of Technology*, vol. 32, no. 1, pp. 7-12, 2013.

[20] P. Li, Y. Zhao, X. Long, Y. Zhou, and Z. Chen, "Ductility evaluation of damaged recycled aggregate concrete columns repaired with carbon fiber-reinforced polymer and large rupture strain FRP," *Frontiers in Materials*, vol. 7, p. 568036, 2020. https://doi.org/10.3389/fmats.2020.568036

[21] I. Amadi, H. Beushausen, and M. Alexander, "Multi-technique approach to enhance the properties of fine recycled aggregate concrete," *Frontiers in Materials*, vol. 9, p. 893852, 2022. https://doi.org/10.3389/fmats.2022.893852

[22] C. M. Nwakaire, S. P. Yap, C. C. Onn, C. W. Yuen, and H. A. Ibrahim, "Utilization of recycled concrete aggregates for sustainable highway pavement applications: A review," *Construction and Building Materials*, vol. 235, p. 117444, 2020. https://doi.org/10.1016/j.conbuildmat.2019.117444

[23] B. Bennett, P. Visintin, and T. Xie, "Global warming potential of recycled aggregate concrete with supplementary cementitious materials," *Journal of Building Engineering*, vol. 52, p. 104394, 2022. https://doi.org/10.1016/j.jobe.2022.104394

[24] Y. Wang, Z. Liu, Y. Wang, D. Wang, C. Yuan, and R. Liu, "Effect of recycled aggregate and supplementary cementitious material on the chloride threshold for steel bar corrosion in concrete," *Construction and Building Materials*, vol. 346, p. 128418, 2022. https://doi.org/10.1016/j.conbuildmat.2022.128418

[25] J. Yu, D. Liu, and Z. Zhang, "Durability and life prediction analysis of recycled aggregate concrete with ceramic waste powder under freeze-thaw conditions based on impact-echo method and Grey-Markov model," *Frontiers in Materials*, vol. 9, p. 1060294, 2022. https://doi.org/10.3389/fmats.2022.1060294

[26] F. Patowary and R. A. Mahmood, "Effect of local coarse aggregate type on concrete mechanical properties in Bangladesh," *International Journal of Engineering and Advanced Technology*, vol. 11, no. 4, pp. 104 – 107, 2022. http://dx.doi.org/10.35940/ijeat.D3490.0411422

[27] J. R. Mackechnie, "Shrinkage of concrete containing Greywacke sandstone aggregate," *ACI Materials Journal*, vol. 103, no. 5, p. 390, 2006. https://doi.org/10.14359/18162

[28] G. O. Bamigboye, A. N. Ede, A. A. Raheem, O. M. Olafinnade, and U. Okorie, "Economic exploitation of gravel in concrete production," *Material Science Forum*, vol. 866, pp. 73–77, 2016b. https://doi.org/10.4028/www.scientific.net/msf.866.73

[29] S. Jae, H. Y. Keun, and K. J. Joong, "Influence of aggregate size on the compressive strength effect according to different concrete types," *Journal of Construction and Building Materials*, vol. 44, no. 15, pp. 716 – 725, 2013. https://doi.org/10.1016/j.conbuildmat.2013.03.066

[30] N. Sulymon *et al.*, "Engineering properties of concrete made from gravel obtained in South-West Nigeria," *Cogent Engineering*, vol. 4, no. 1, p. 1295793, 2017. https://doi.org/10.1080/23311916.2017.1295793

[31] S. Khadka and A. K. Mishra, "Effect of fine aggregate sources on compressive strength of cement concrete," *Journal of Advanced Research in Construction and Urban Architecture*, vol. 7, no. 1, pp. 9-17, 2022. https://doi.org/10.24321/2456.9925.202201

[32] A. K. Mishra and B. Sharestha, "Assessment of consumer influencing factor in decision making for selecting cement brands," *South Asian Research Journal of Business and Management*, vol. 1, no. 3, pp. 91-105, 2019. https://doi.org/10.36346/sarjbm.2019.v01i03.002

[33] A. K. Mishra and A. Jha, "Quality assessment of Sarbottam cement of Nepal," *International Journal of Operations Management and Services*, vol. 9, no. 1, pp. 1-22, 2019.

[34] K. Megha and M. Gauhar, "A review paper on the effect of different types of coarse aggregate on concrete," *Materials Science and Engineering*, vol. 14, no. 431, pp. 1-7, 2018.

[35] A. K. Mishra and U. Chaudhary, "Cost effectiveness assessment of different nepalese cement brands for selected sites of supermarket," *Journal of Advanced Research in Construction & Urban Architecture*, vol. 3, no. 3, pp. 12-33, 2018.

[36] A. B. Nayaju and N. K. Tamrakar, "Evaluation of fine aggregates from the Budhi Gandaki-Narayani River, central Nepal for mortar and concrete," *Journal of Nepal Geological Society*, vol. 58, pp. 69-81, 2019. https://doi.org/10.3126/jngs.v58i0.24575

[37] J. Ezeokonkwo, K. Okolie, and P. Ogunoh, "Assessment of quality of coarse aggregate used in concrete production in Anambra State, Nigeria," *Journal of Scientific and Engineering Research*, vol. 2, no. 2, pp. 40-51, 2015.

[38] P. Chindaprasirt, S. Hantanaka, N. Mishima, T. Yuasa, and T. Chareerat, "Effect of binder strength and aggregate size on the compressive strength and void ratio of porous concrete," *International Journal of Minerals, Metallurgy and Materials*, vol. 16, no. 6, pp. 714 – 719, 2009.

[39] H. S. Chen, W. X. Xu, and Z. Lv, "Effect of particle size distribution, shape and volume fraction of aggregate on the wall effect of concrete via random sequential packing of polydispersed ellipsoidal particles," *Physica A: Statistical Mechanics and its Applications*, vol. 392, no. 3, pp. 416 – 426, 2013. https://doi.org/10.1016/j.physa.2012.09.014

[40] J. Wight, *Reinforced concrete mechanics and design*. New York: Pearson Education, 2012.

[41] BS 12620, *Aggregate for concrete*. London: British Standard Institute, 2002.

[42] BS EN 197–1, *Cement part 1: Composition, specifications and conformity criteria for common cements*. London: British Standard Institute, 2011.

[43] BS EN 1008: 2002, *Mixing water for concrete: Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry as mixing water for concrete*. London: British Standard Institute, 1980.

[44] BS EN 933-1, *Test for geometrical properties of aggregates. Determination of particle distribution. Sieve method*. London: British Standard Institute, 2012.

[45] BS 8500-1 and BS 8500-2, *Method of specifying and guidance for the specifier*. London: British Standard Institute, 2002.

[46] N. P. Refinery and M. N. Braimah, "Utilization of response surface methodology (RS) in the optimization of crude oil refinery," *Journal of Multidisciplinary Engineering Science and Technology*, vol. 3, no. 3, pp. 4361 – 4369, 2016.

[47] D. C. Montgomery, *Design and analysis of experiments: Response surface and designs*. New Jersey: John Wiley and Sons, Inc, 2005.

[48] N. Bradley, "The response surface methodology," M.A. Thesis. Indiana University South Bend, 2007.

[49] M. M. Mohan and M. Rajendran, "Optimization of mix proportions of mineral aggregate using box Jenken design of experiments," *Cement and Concrete Composites*, vol. 25, no. 7, pp. 751 – 758, 2002. https://doi.org/10.1016/s0958-9465(02)00116-6

[50] S. Genedij and B. Juris, "Concrete design and optimization," presented at the 2nd International Symposium in Civil Engineering, Budapest, 1998.

[51] P. Goltermann and V. Johansen, "Packaging of aggregates: An alternative tool to determine the optimal aggregate mix," *ACI Materials Journal*, vol. 94, no. 5, pp. 435 – 443, 2001. https://doi.org/10.14359/328