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Characterization of Bambara Nut Shell Ash (BNSA) in Concrete Production

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ABSTRACT

The goal of achieving concrete with adequate durability properties in terms of reduced susceptibility to alkali-silica and mechanical-strength behaviour has led to several high-performance materials development. While the use of Bambara nut shell ash in concrete is gaining acceptance in various applications, the mineralogical composition of such by-product materials cannot be easily controlled as a manufactured pozzolan. In this research work, the characterization and use of BNSA in concrete production was investigated. A mix proportion of 1:3:6 with water cement ratio of 0.55 were used. The percentage replacement of cement with BNSA from 0-40%. Concrete cubes of 150mm × 150mm × 150mm of OPC/BNSA were cast and cured at 3, 7, 28, 60 and 90 days respectively. At the end of each period of hydration, three replicate concrete samples for each period of hydration were crushed and their average comprehensive strength recorded. The result for the compressive strength test indicated rise in percentage difference as the BNSA replacement ratio increases from 5% to 40% with a value of 20.69% to 46.53% respectively. The concrete density response showed slight increment in percentage difference with a value of 0.85% to 3.47% for BNSA replacement ratio of 5% to 40% respectively. The Poisson ratio test results obtained indicates percentage difference increase as the BNSA ratio increases from 5% to 40% with a value of 5.17% to 11.14% respectively. Furthermore, the young's modulus of elasticity results obtained showed percentage difference rise from 9.4% to 14.17% as BNSA ratio increases from 10.81% to 29.412% as BNSA replacement ratio increases from 5% to 40% respectively. The results indicate satisfactory performance at 5% replacement.

Keywords: Compressive strength; density; poisson ratio; Young's modulus of Elasticity and Modulus of Rigidity; Bambara nut shell ash

INTRODUCTION

The production of concrete utilizes cement as its major ingredient. This cementitious portion of the concrete mixture is responsible for effective binding of the aggregates together when hydrated. The volume of cement utilized for concrete production has an effect on the cost-effectiveness of the project and in ensuring eco-friendly environment; so it is very important to minimize the cement quantity to be consumed in the concrete production process by partially substituting cement with waste ash which possesses pozzolanic behavior (Onyelowe et al. 2020; Lothenbach et al. 2011). The increasing volume of generated wastes from industrial, domestic or agricultural processes presents a great concern and threat to actualization of sustainable eco-efficient environment primarily caused by rapid population increase and urbanization. Also, there is higher waste generation rate within the developing countries among the poor urban regions due to poor and inefficient waste management system compared to developed countries. Wastes are indiscriminately disposed and openly burnt in an unregulated manner, the practices results to severe safety, health, and environmental degradation challenges (Coutinho 2002). Inadequate management of these waste provide a clear breeding atmosphere for pests and disease vectors, contributes to global warming, and promotes unhealthy environment.

Therefore, it is essential to recycle and properly incorporate these waste as a supplementary cementitious materials (SCM) in concrete so as to control the growing rate of indiscriminate dispose of waste and achieve eco-friendly, sustainable, and cost-effective infrastructure (Alaneme & Mbadike 2021). The substitution of cement with SCM in concrete also helps to decrease the CO2 volume emitted during utilization and production when calcium-carbonate is heated. Due to technological, cost and environmental advantages, blended cements are more often preferred to OPC in concrete production. CO2 is referred to as one of the major greenhouse gas which causes climate change and global warming in the world (Onyelowe et al. 2019, 2020).

The research work's overall ideal is to incorporate BNSA which is a solid waste derivative in the concrete by replacement of cement ingredient partially and carrying out statistical analysis to comparatively assess the cement-BNSA blended concrete with the control. The incorporation of BNSA in concrete manufacture may provide satisfactory solution to the problem posed by concrete production. The use of waste derivatives such as SCM have been investigated by several researchers so as to obtain the best proportion of the admixture in concrete (Prasad et al. 2009; Naderpour et al. 2018). Alabadan et al. (2005) studied the effect of BNSA in concrete where the cement content were partially replaced at varying ratio from 0% to 50%. The maximum compressive strength response of 20.68 N/mm2 and 31.24 N/mm2 for 10% and 0% replacement respectively were obtained and from the results. The concrete's compressive strength decreased with higher percentage replacement by BNSA but there is increase in strength with prolonged hydration period. Also, Paul et al. (2019) reviewed the agricultural solid waste derivatives utilization as a SCM so as to curtail the environmental effects of concrete production and enhance sustainability. Rice husk ash, palm-oil fuel ash, bamboo leaf ash and sugarcane bangase ash effect in concrete's engineering properties were investigated and from the study, appropriately designed concrete mixes incorporating these agricultural waste possess better or similar durability and mechanical properties when compared to the unblended cement concrete performance.

This research study aims to examine the use of SCM derived from solid agricultural waste material to replace cement partially in the concrete mixture which will encourage the re-cycling and re-use of waste materials for construction purposes. The objective of this research is to evaluate the effect of varying ratios of cement-BNSA in the concrete mixture in order to obtain the optimum ratio of combining cement-BNSA with respect to mechanical strength behaviour of the concrete (Elinwa et al. 2005; Alaneme et al. 2021). This research will provide special guide added to existing knowledge on the utilization of BNSA in concrete production as SCM. This study contributes to the development of a methodology for assessing concrete manufacture from Bambara nut shell ash. The concrete's durability and environmental impact are closely connected to its transport properties which control the kinetics of the penetration of water and aggressive agent into concrete (Redmond et al. 2002; Alaneme & Mbadike 2019; Punienta et al. 1999).

CEMENT HYDRATION

Concrete is produced by proper mixing of aggregates, water and cement in order to obtain a workable paste; it is then placed and compacted thoroughly in the mold and left to harden. The cement hydration reaction is very essential to actualization of the required mechanical strength performance of the concrete produced (Alaneme & Mbadike 2021). Di-calcium silicate (C2S), tri-calcium silicate (C3S), tetra-calcium alumino ferrate and tri-calcium aluminate are the major clinker phases present in cement. In cement hydration reaction, each of these compounds undergo hydration and contributes to the concrete's overall engineering properties but only the calcium silicates have significant effect on the strength characteristics while the aluminate and alumino ferrate affects its rheological properties. The hydration reaction of these phases are presented in Eqns. 1 – 4 (Joshua 2018; Neville 2011).

$$C_2S + 2H \rightarrow CSH + CH \quad (1)$$

$$C_3S + H \rightarrow CSH + 2CH \quad (2)$$

$$C_4AF + 4CH + 22H \rightarrow C_4AH_{13} + C_4FH_{13} \quad (3)$$

$$C_3A + H \rightarrow CAH \quad (4)$$

As water is added to the cement mix, C3S reacts rapidly to produce hydroxide ions, calcium ions, and heat (exothermic); it is accompanied by rise in pH to highly alkaline at 12 because of the availability of the hydroxide ions. The production of these ions continues until saturation of the system is attained and once these occurs, the crystallization of CH commences and the formation of CSH simultaneously. The C3S hydration is accelerated by the precipitation of ions out of the solution to produce hydroxide and calcium ions (Korpa et al. 2008; Jain 2012). The CSH crystals develops and gets thicker, preventing water molecules from getting into the unhydrated C3S region. The reaction pace is controlled by the diffusion rate of the water molecules through the CSH coating which thickens with time resulting in production of CSH to decrease and get slower. Di-calcium silicates (C_2S) also has effects on the strength properties of the concrete by the hydration process. It reacts with water in a manner similar to the hydration of tri-calcium silicates (C_3S) but in a slower rate with lesser heat evolved due to the less reactive nature of C_2S (Edmeades et al. 2006).

C_3A hydration reaction initially is vigorous in the absence of gypsum which mostly results to flash-set due to rapid production of hexagonal crystal phases of CAH and sufficient strength is developed in the process to restrict continuous mixing. The reaction involves the conversion to cubic hydro-garnet (C_3H_6) which is the stable phase thermodynamically at ambient temperature (Mehta et al. 2006). Gypsum normally retards this reaction and the hydration reaction products of C3A in the presence of gypsum depends majorly on the sulfate ions available due to gypsum dissolution. Ettringite ($C_6AS_3H_{32}$) is the primary phase produced here and it is a stable phase provided that there is adequate soluble sulfate supply. Another reaction would take place due to the consumption of all the available soluble sulfate before the complete hydration of C_3A; in that reaction, the remaining C_3A would react with the ettringite initially formed to produce tetra calcium aluminate monosulfate-12-hydrate (C_4ASH_{12}) (Clark et al. 1999).

Furthermore, C4AF hydration generate products similar to C3A hydration in comparable conditions. It possesses aluminate (Al3+) and ferrite (Fe3+) ions while calcium ferrite and iron iii hydroxide gel are the products of C4AF hydration as its reactivity is much slower compared to C3A (Morandeau et al. 2014).

A schematic illustration of the pore spaces of the mixture for calcium silicates through different hydration stages is presented in Figure 1. Initially, at stage (1), hydration reaction has not occurred yet and the pores which are the empty spaces between the grains are filled with water. For stage (2), hydration commences where CH and CSH starts to form; at stage (3), the hydration reaction continues with the empty pore spaces observed to be occupied with water and hydration products. Finally, at stage (4), forms a nearly hardened paste as the majority of the pore spaces are filled with CH and CSH (Aitcin 2008).

CSH and CH is formed due to hydration of C2S and C_3S; CSH imparts mechanical strength to the cement mixture. CH is very important especially at the early curing stages to provide required level of alkalinity to the hardening cement mixture (Long et al. 2018). However, the control of excess CH is very essential to prevent alkali silicate reaction and this could be achieved by the use of pozzolanic materials which possesses alumina-silicate

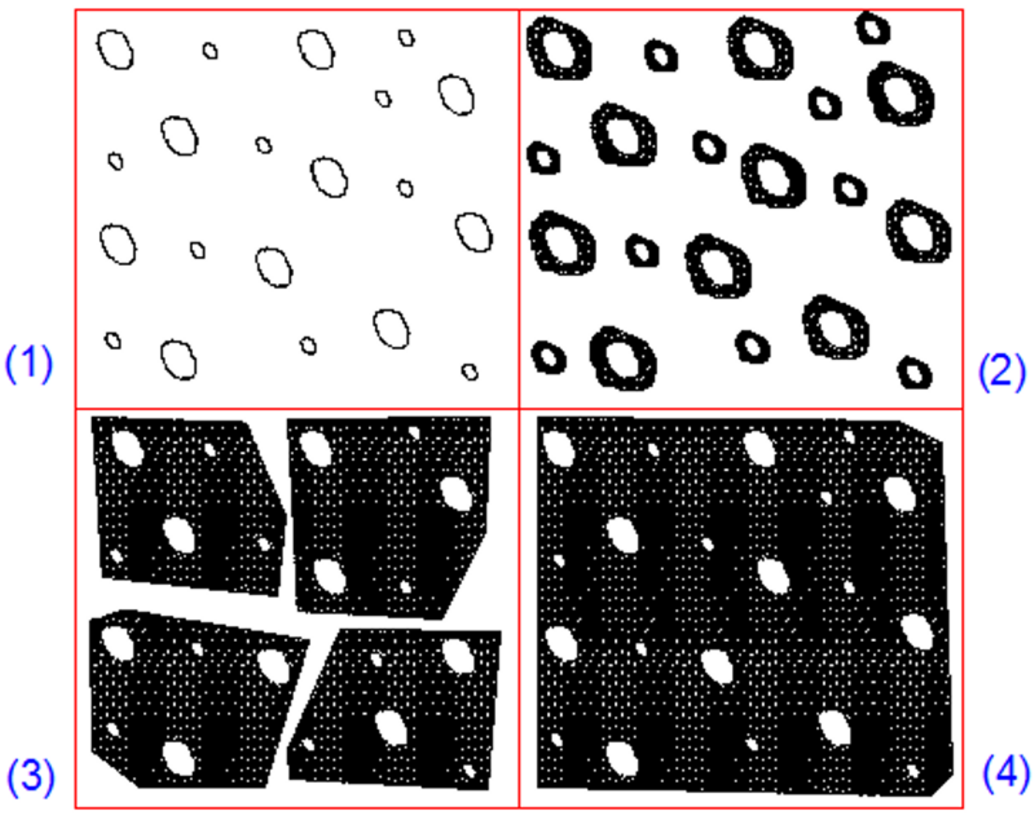

FIGURE 1. Calcium Silicates Hydration

content as a SCM. For cement blended with pozzolanic material, the CH produced during cement hydration reaction in the present of water reacts with alumina and silica present in the pozzolanic material to form more CAH and CSH which indicates more gain in strength which occurs during pozzolanic reaction shown in Eqns. 5 – 6 (Neville 2011).

$$CH + S + H \rightarrow CSH \tag{5}$$

$$CH + A + H \rightarrow CAH \tag{6}$$

The pozzolanic reaction results to more consumption of CH in the blended cement leading to increase of CSH and decrease in CH produced during hydration reactions. It is a long term irreversible reaction involving water, silicic acid, and calcium hydroxide to produce a firm and stronger cementation matrix with better durability characteristics (Martirena et al. 1998).

MATERIALS AND METHODS

TEST MATERIALS

The Dangote cement which is a brand of Portland cement was used in this work. It conforms to BS 12 (1978).

AGGREGATES

The fine aggregates for this work are clean river sand which is free from deleterious materials. The fine aggregate used passes through 2.36mm sieve size.

The coarse aggregate used is also very clean and free from dirt. The coarse aggregates passes through 19mm sieve size. Both aggregates conform to BS 3797(1967) and ASTM C125-16 for fine and coarse aggregates respectively well graded and conforming to BS EN12620.

WATER

The water used is potable water and it satisfies ASTM C1602-12 requirement of water for use in concrete mixtures.

BAMBARA NUT SHELL ASH (BNSA)

Bambara nut shell was obtained from the people that are preparing and cooking it in a very large quantity for commercial purposes. The shells that were removed from the nuts were dried under the sun and burnt at a temperature of about 120°C in a kiln. After burning, the ash was collected and sieved in the laboratory with 150/µm sieve size to obtain a finely divided material which were taken for the practical (Alaneme & Mbadike 2021b).

METHODS

COMPRESSIVE STRENGTH

A standard mix ratio of 1:3:6 with water cement ratio of 0.55 was used to cast concrete cubes for the determination of compressive strength, young's modulus of Elasticity and modulus of Rigidity, Poisson's ratio, and density. For the compressive strength test, BNSA was used to replace cement at 0%, 5%, 1%, 30%, and 40% respectively in the concrete mixture. The concrete was placed in 150mm × 150mm × 150mm mould volume which are concrete cubes and cured in water at room temperature for 3 days, 7 days, 28 days, 60 days and 90 days respectively. Three sample replicates were cast for each hydration period to get a total of 90 concretes and the concrete cubes were crushed to obtain average compressive strength. The compressive strength (CS) was calculated as presented in Eqn. 7 (Attah et al. 2020).

$$CS = \frac{crushing\ load\ (N)}{cross\text{-}sectional\ area\ of\ concrete\ cube\ (mm2)} \tag{7}$$

CHEMICAL ANALYSIS TEST

The chemical properties of test cement and BNSA were determined through X-Ray Fluorescence (XRF) analysis. The spectra were collected on a PANalitycal PW3020 Bragg-Brentano θ - 2θ geometry diffractometer equipped with a secondary monochromator over an angular range 2θ = 3°−80°. The Cu-Kα Diffraction was generated at 45 kV and 40 mA (lambda = 0.15418 nm). Peaks present in these diagrams were identified using Powder Diffraction embedded database. The mineral composition quantification as derived from the peak diffraction area was made using the EVA software BRUKER-AXS® (Smith et al. 2001).

DENSITY

The mass of each concrete cubes was recorded by weighing them in a weighing balance in the laboratory before crushing them in a compressive testing machine. The density of the three concrete cubes for each curing period was determined and the average recorded using the mathematical relationship in Eqn. 8.

$$Density = \frac{mass\ (Kg)}{volume\ (m3)} \tag{8}$$

POISSON'S RATIO

Poisson's ratio, P, is the lateral strain to the longitudinal strain. This was determined in the mechanical Engineering laboratory of Federal University of Technology, Owerri, Imo State. The Poisson's ratio for three concrete cubes in each hydration period was determined and the average recorded (Alaneme & Mbadike 2021b).

MODULUS OF ELASTICITY (MOE)

Modulus of Elasticity (Ec) is the ratio of the stress to strain in concrete. The strain in concrete is not only due to stress but also shrinkage. Strain in concrete increases with time (creep) under sustained loading. Modulus of Elasticity on concrete depends on the strength of the concrete. The higher the strength, the higher the modulus of elasticity Ec given by Neville & Brooks (2002) as presented in Eqn. 9.

$$E_c = 1.7\rho^2 fc\mu^{0.33} \times 10^{-6} \quad (9)$$

Where ρ = density of concrete

fcμ = concrete's compressive strength

MODULUS OF RIGIDITY

The modulus of rigidity or shear modulus, Gc of concrete is computed as shown in Eqn. 10.

$$G_c = \frac{j}{Y_c} \quad (10)$$

where j = shear stress on concrete; Y_c = shear (lateral) strain in concrete

The modulus of rigidity is not usually determined by direct measurement (Neville 1993) [32]. Lateral strain, Y_c is given by Berugo (950) [33] as presented in Eqn. 11.

$$Y_c = \frac{\mu\sigma}{Ec} \quad (11)$$

where μ is the static, Poisson's ratio; σ is the compression stress at cracking; and Ec is the concrete's modulus of elasticity over the linear range of deformation.

The modulus of rigidity can be determined as given by Neville (2011) as presented in Eqn. 12

$$G_c = \frac{Ec}{2(\mu+1)} \quad (12)$$

STATISTICAL TECHNIQUES AND TOOLS

The mechanical strength characteristics results generated from the laboratory were analyzed statistically using analysis of variance (ANOVA) to validate if there is statistical difference among the k-groups to be compared. After the ANOVA, Dunnett's test were further utilized in this study to find out if the differences obtained as the group means consisting of varying degrees of cement replacement by BNSA compared to the control group is significant; in order to evaluate objectively the effects of varying mixture proportion and to obtain the best combination ratio of BNSA in response to the concrete's mechanical property (Alaneme & Mbadike 2019). Dunnett's statistical method is a post-hoc test that is performed after we run a significant one-way ANOVA so as to obtain which differences is significant. It differs from other post-hoc tests like Duncan Multiple Range test (DMRT), Newman-Kuels test, Tukey's, and Scheffe's test because its methodology restricts the computation to comparing a number of test groups with a single control group and does not test these experimental groups against another. In Dunnett's method, K-groups were assessed where one of them is the fixed control population and the rest in the form (k-1) is compared to it. Every group with sample size ni is to be compared with the fixed control group possessing size of sample nc and is computed as shown in Eqn. 13 (Dunnett C.W. 1985).

$$T = t_\alpha(k-1, n-k)\sqrt{MSE\left(\frac{1}{n_i}+\frac{1}{n_c}\right)}$$

t_a is generated from the Dunnett's t-table and then we take the pairwise differences $\left|\bar{x}_i - \bar{x}_c\right|$.

RESULTS AND DISCUSSION

CHEMICAL CHARACTERIZATION OF THE TEST PORTLAND CEMENT AND BNSA

The chemical analysis results of BNSA and cement used in this study is shown in Table 1. The result obtained indicates that BNSA contains mainly SiO2 (54.58%), Al2O3 (16.8%) and Fe2O3 (8.46%). The sum of SiO2, Al2O3, and Fe2O3 is more than 70% minimum prescribed by ASTM C618, 98 (2008) for a good pozzolan. The chemical composition is an important factor that affects the activity of pozzolanic materials. Potential pozzolanic materials contain substantial amount of SiO2, Al2O3, and Fe2O3. Al-rawas et al. (1998) reported that the total of SiO2, Al2O3, and Fe2O3 is a good indicator of the pozzolanic activity. The presence of calcium 10.16% in BNSA enhances the complete hydration of cement and consequently the strength development of concrete. The presence of calcium oxide constitutes about 11.30% of Portland limestone cement. The setting and constituent hardening of paste water and cement was directly responsible for strength of concrete. This was enhanced by the presence of calcium in BNSA. The mechanism is that the aluminates and silicates in the presence of water from the cement form products of hydrates which in time produces a hard mass (Alaneme et al. 2020).

TABLE 1. Chemical Analysis of Test cement and BNSA

Chemical Analysis Results		
Elemental Oxide	BNSA (%)	Cement (%)
CaO	10.16	11.3
MgO	0.5	0.093
Fe_2O_3	8.46	6.405
Na2O	0.36	2.1
Al2O3	16.8	20.6
SiO_2	54.58	52.4
ZnO	0.72	Trace
MnO	2.56	Trace
LOI	3.45	3.9
SO4	1.41	Trace
CUO	1	Trace
TiO_2	Trace	0.52
CdO	Trace	Trace
K2O	Trace	2.6

COMPRESSIVE STRENGTH TEST RESULTS

The average compressive strength test results were obtained when Bambara nut shell ash (BNSA) was used to replace cement at 0% - 40% replacement level and cured at 3 days, 7 days, 28 days, 60 days and 90 days respectively is presented in Figure 2. The compressive strength result for 5% - 40% replacement of cement with BNSA ranges 13.00 N/mm2 – 32.88 N/mm2 as against 25.48 N/mm2 – 42.04 N/mm2 for 0% replacement. The result shows that the average compressive strength increases for prolonged curing period. The result also indicates that the average compressive strength decreases as the cement replacement with BNSA increases. The concrete density results with respect to cement replacement is presented in Figure 3. Result of the density ranges from 2207 Kg/m3- 2499 Kg/m3 for 5% - 40% as against 2207 Kg/m3 – 2550 Kg/m3 for the control test. From the results, density of the concrete decreased as the cement replacement with BNSA increases and also increases with prolonged curing period (Shafigh et al. 2014; Gambhir 2004; Alaneme& Mbadike 2019b).

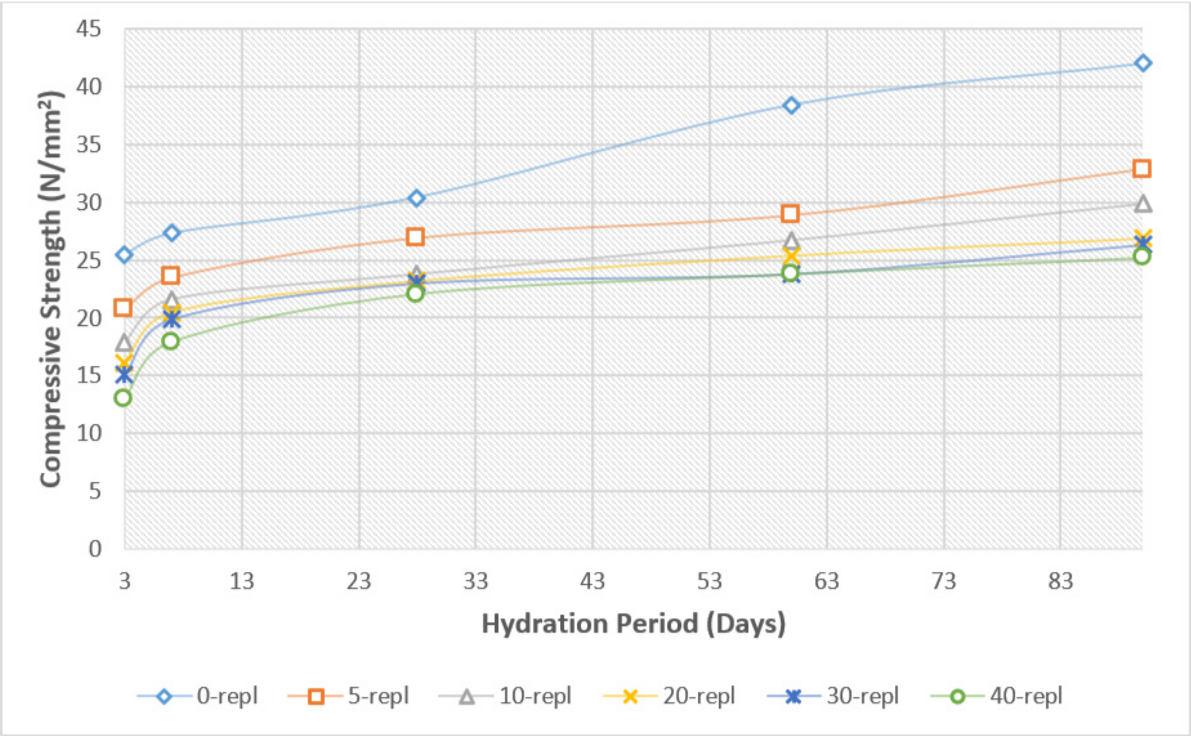

FIGURE 2. Graph of compressive strength test results against curing age of concrete

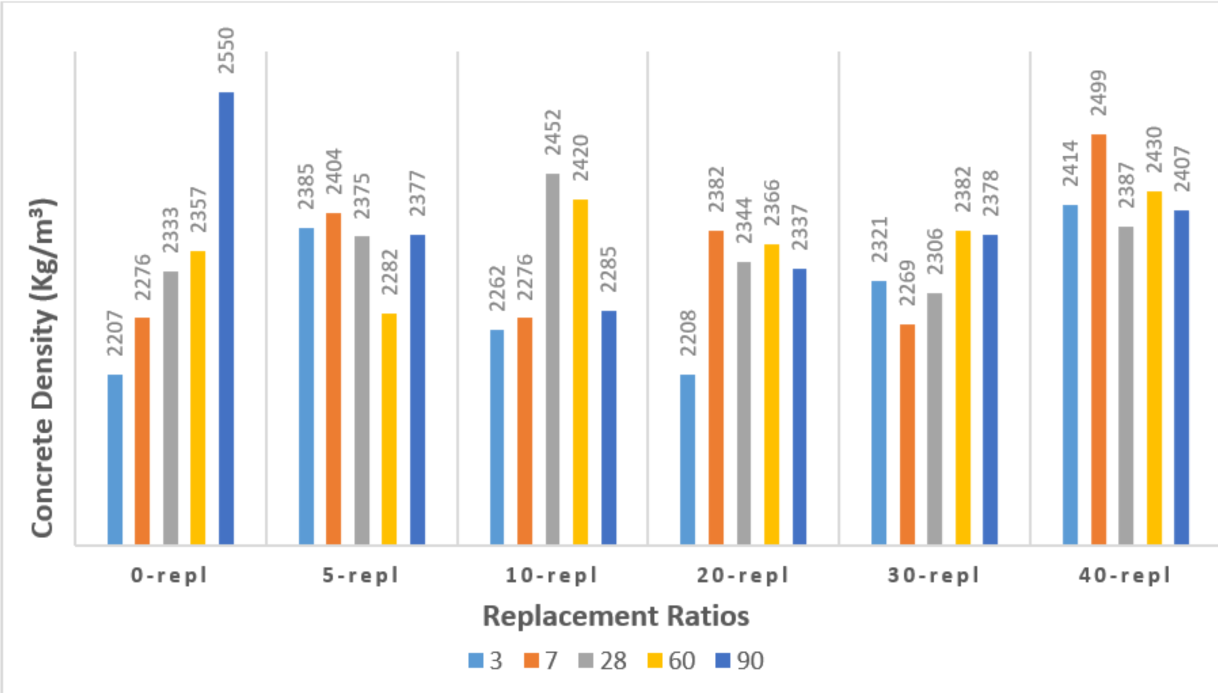

FIGURE 3. Concrete density results

DETERMINATION OF POZZOLANIC ACTIVITY INDEX OF CEMENT- BAMBARA NUT SHELL ASH CONCRETE

For the pozzolanic activity assessment with cement ASTM Standard C618 [36] prescribed the pozzolanic activity index measurement. This is established by the determination of strength of mixtures with the specified replacement index of cement by pozzolana. The pozzolanic activity index of BNSA concrete was also determined as 70.3%. This result shows that BNSA has a very high remarkable pozzolanic properties as stipulated in ASTM C 618 (2008).

Pozzolanic activity index is obtained by the formulae in Eqn. 14.

$$\frac{\text{Crushing strength of 35\% replacement of cement with the BNSA at 28 days hydration period}}{\text{Crushing strength at 28days for control test}} \times \frac{100}{1} \qquad (14)$$

$$= \frac{21.40}{30.43} \times \frac{100}{1} = 70.3\%$$

MODULUS OF ELASTICITY, RIGIDITY AND POISSON'S RATIO VS. CURING AGE OF CONCRETE

The result of Poisson's ratio obtained when BNSA was used to replace cement at the same replacement level is presented in Figure 4. The Poisson's ratio results obtained ranges from 0.42 - 1.29 for 5 % - 40% as against 0.26 - 1.53 for the control test. The Poisson's ratio decreases with the increase in the percentage replacement level of cement with BNSA and increases with the increase in hydration period. Young's modulus of elasticity obtained with BNSA used to replace cement at the same replacement level is shown in a graph in Figure 5. The result ranges from 2.08 × 10-5 - 2.25 × 10-5 for 5% - 40%, while the control test ranges 2.40 × 10-5 -3.80 × 10-5. The result shows that young's modulus of elasticity decreases with increase in the replacement level of cement with BNSA; the modulus of elasticity increases with prolonged hydration period. Also, Figure 6 shows the result of young's modulus of rigidity obtained when BNSA was used to replace cement at 0% - 40%. The result shows modulus of rigidity ranges from 0.5 × 10-5 – 0.99 × 10-5 for 5% - 40% as against 0.75 × 10-5 - 1.06 × 10-5 for the control test. The result shows that modulus of rigidity decreases with increase in the percentage replacement level of cement with BNSA. The modulus of rigidity also increases with increase in the hydration period (Takafumi et al. 2009; Kolawole et al. 2014).

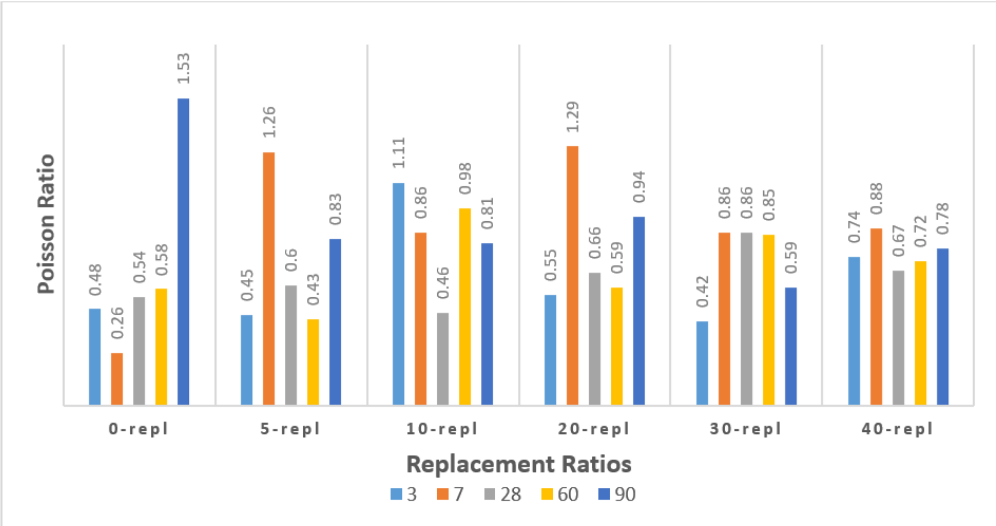

FIGURE 4. Poisson's Ratio Results

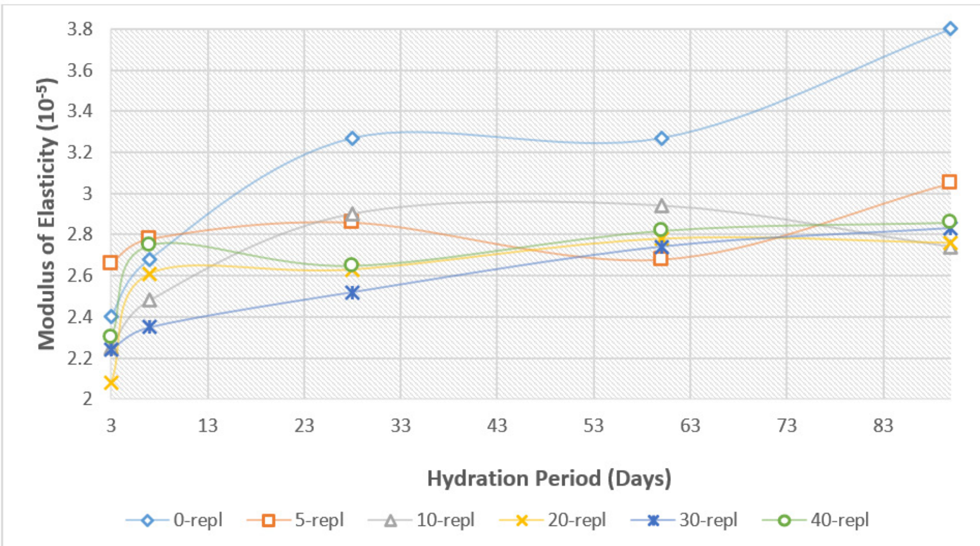

FIGURE 5. Graph of modulus of elasticity results

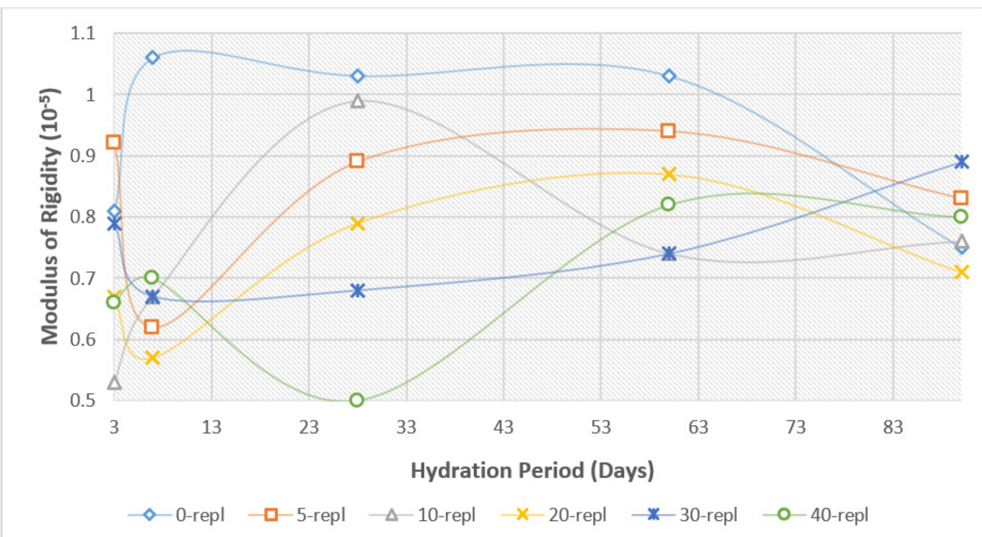

FIGURE 6. Graph of modulus of rigidity results

STATISTICAL ANALYSIS AND RESULTS VALIDATION

The experimental data validation is essential to statistically assess the behavior of various concentration ratios of the BNSA in concrete compared with the control mix which has 0% replacement. The means of the data were analyzed using ANOVA and Dunnett test to determine the statistical significance level between the data sets. Dunnett's method is a statistical tool essentially used in ANOVA computation in order to create confidence intervals (CI) for mean differences between the factor levels against the control group. If CI is 0, there is no significant difference between means under comparison and a family error rate for all comparisons is expected to be specified where Dunnett's method finds the CI for each set of comparison. Multiple comparisons enable us to assess which means are significantly different and also predict how much different. Using a set of hypothesis tests and confidence interval we can then assess the statistical significance of differences between the compared means. The CI helps us to evaluate the significance of differences practically among the compared means (Rencher & Christensen 2012; Kim et al. 2004).

RESEARCH HYPOTHESIS

This prescribes the criteria which enables the rejection or acceptance of statistical hypothesis and is presented in Table 2; showing the null and alternative hypothesis.

TABLE 2. Statistical hypothesis

Null hypothesis	All means are equal
Alternative hypothesis	Not all means are equal
Significance level	α = 0.05

Equal variances were assumed for the analysis.

FACTOR LEVELS INFORMATION

The factor levels information consists of the k-groups under investigation which includes the varying ratios of replacement by BNSA and the control with 0% replacement totaling six factor levels as shown in Table 3. For the statistical assessment.

TABLE 3. Factor information

Factor	Levels	Values
Factor	6	0-repl, 5-repl, 10-repl, 20-repl, 30-repl, 40-repl

ONE-WAY ANOVA RESULTS

ANOVA One-way method is a statistical hypothesis test which assesses two mutually statements exclusively about two or more population means. These two statements are the null alternative hypotheses. Sample data is utilized by hypothesis test to determine whether to accept or reject the null/alternate hypothesis. The result of ANOVA is shown in Table 4 which is calculated using F-statistics to compute a P-value and F-value of 0.01 and 3.92 respectively. This result indicates that the means differ significant; that is some of the group means are different. So we conducted Dunnett statistical posy-hoc tests to determine how different the group means are when compared to the control group (Ogbonna et al. 2020; Amartey et al. 2017).

TABLE 4. Analysis of variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	5	511.3	102.25	3.92	0.010
Error	24	625.7	26.07		
Total	29	1137.0			

MODEL SUMMARY

The model summary result from the ANOVA computation is shown in Table 5 which shows a low predicted R2 of 14.01% and implies that the model produces imprecise estimations for new observations. The imprecision may be due to small number (count) of the test groups. Thus, making generalization with the model beyond the sample data would produce inaccurate predictions (Khademi et al. 2016; Alaneme et al. 2020b). The mean summary showing the standard deviation and confidence interval of 95% is also shown in Table 6.

TABLE 5. Model summary

S	R-sq	R-sq(adj)	R-sq(pred)
5.10616	44.97%	33.50%	14.01%

TABLE 6. Means

Factor	N	Mean	StDev	95% CI
0-repl	5	32.75	7.19	(28.03, 37.46)
5-repl	5	26.61	4.70	(21.89, 31.32)
10-repl	5	23.98	4.61	(19.26, 28.69)

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20-repl	5	22.43	4.27	(17.71, 27.14)
30-repl	5	21.60	4.32	(16.89, 26.31)
40-repl	5	20.39	4.95	(15.67, 25.10)

Pooled StDev = 5.10616

The summary of the mean comparison computation is shown in the interval plot graph for the compressive strength response with respect to varying mix proportions of the BNSA-cement blend is presented in Figure 7.

RESIDUAL PLOTS FOR THE INPUT-OUTPUT PARAMETERS

The output plots of the statistical analysis showing the normal probability plot, the fitted value vs. residual, and the residual vs. frequency histogram chart which shows the compliances of the regression assumption is shown in Figure 8. The results present diagnostic assessment which ensures the satisfaction of the regression modelling assumptions in terms of multicollinearity and normality properties. The histogram of residuals presents the residuals distribution for all observations and it is used to determine

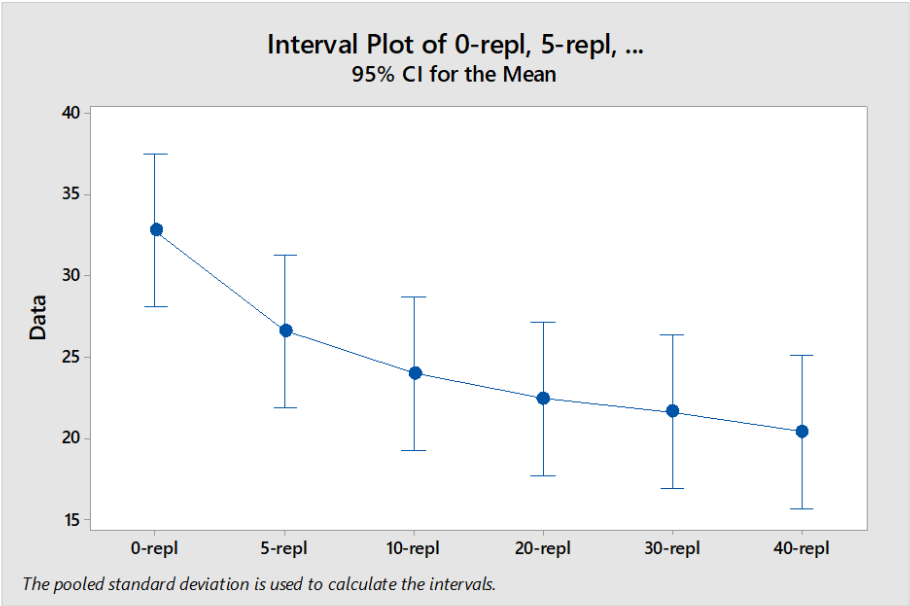

FIGURE 7. Interval plot

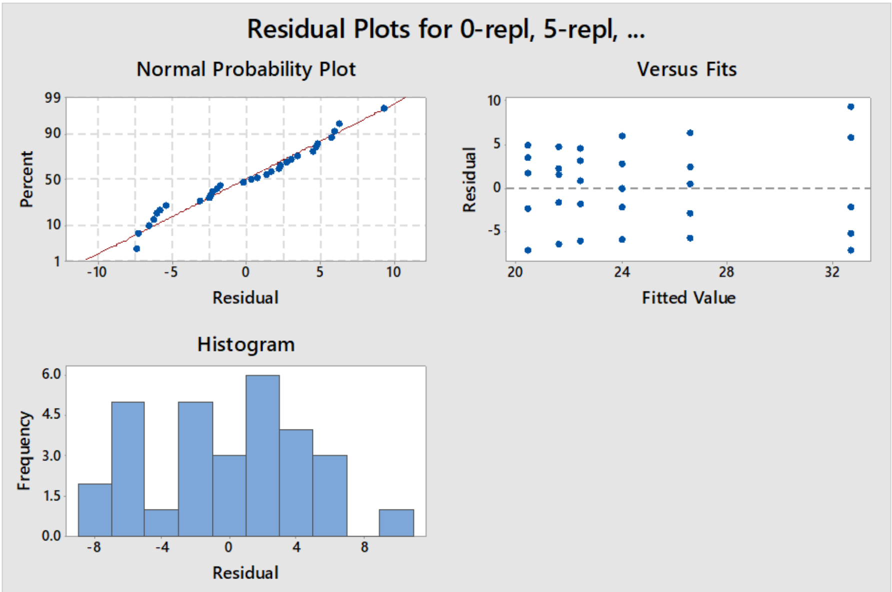

FIGURE 8. Residual plots

the skewness of the data under investigation. The plot for normal probability of residuals shows the residuals vs. expected residual values in a normal distribution. It is helps to verify the assumption of constant variance and that the residuals are distributed normally for the plot to follow approximately a straight line. Residual vs. fits plots verify the normal distribution assumption and has the fitted values on the x-axis and the residuals on the y-axis; they also possess constant variance. The plot shows that the variance of the residuals increases with fitted values and the scatter gap widens as the fit increases; this pattern implies that the residuals variances are non-constant and unequal (Mohammadhassani et al. 2013; Alaneme et al. 2021b).

DUNNETT TEST

To assess how the group means differences are from the control; grouping information using the Dunnett method at 95% confidence, where the varying replacement proportions of the BNSA-cement blend ranging from 5% - 40% were statistically compared with 0% replacement which is the control group. The result summary is presented in Table 7. From the grouping results we observe there is no significant difference between 5% replacement by BNSA and the control group.

TABLE 7. Grouping details using the Dunnett Method at 95% confidence

Factor	N	Mean	Grouping
0-repl (control)	5	32.75	A
5-repl	5	26.61	A
10-repl	5	23.98	
20-repl	5	22.43	
30-repl	5	21.60	
40-repl	5	20.39	

Means not labeled with the letter A are significantly different from the control level mean.

TABLE 8. Dunnett Simultaneous tests for level mean - Control mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
5-repl - 0-repl	-6.14	3.23	(-14.84, 2.56)	-1.90	0.235
10-repl - 0-repl	-8.77	3.23	(-17.47, -0.07)	-2.72	0.048
20-repl - 0-repl	-10.32	3.23	(-19.02, -1.62)	-3.20	0.016
30-repl - 0-repl	-11.15	3.23	(-19.85, -2.44)	-3.45	0.009
40-repl - 0-repl	-12.36	3.23	(-21.06, -3.66)	-3.83	0.004

Individual confidence level = 98.74%

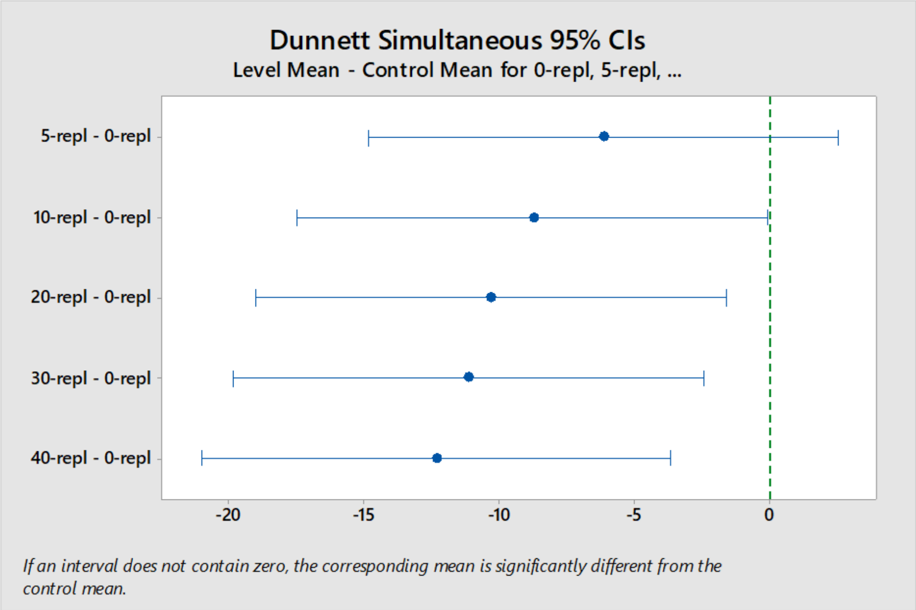

FIGURE 9. Dunnett Simultaneous Test Plot at 95% CIs

The Dunnett simultaneous test for the group means compared with the control group so as to calculate the difference of means, sum of error differences, T-value, and adjusted P-value for the k-1 groups compared with the control group. The result is presented in Table 8.

The results obtained from the Dunnett pairwise comparison test, we obtained the difference of means of -6.14, -8.77, -10.32, -11.15 and -12.36 for 5%, 10%, 20%, 30% and 40% respectively, with a sum of errors difference of 3.23 as shown in Figure 9. From the presented results, we can observe the statistical rating of the performance for the varying ratios of replacement with BNSA compared with the control in ascending order 40%, 30%, 20%, 10% and 5% produced the best performance. The optimum mixture combination level to obtain the maximum achievable compressive strength response was observed at 5% replacement ratio with T-value of -1.90 and adjusted P-value of 0.235 (Ogbonna et al. 2020; Goktepe et al. 2006).

CONCLUSION

Assessment of the effects of BNSA as SCM in concrete production were carried out in this research study and from the research findings, the following conclusions were drawn.

1. The incorporation of the Bambara nut shell ash in concrete matrix will reduce the strength of concrete produced and the strength development of concrete produced increases with increase in hydration period. The decrease in compressive strength as the percentage replacement of BNSA increases may be due to the fact that $Ca(OH)_2$ does not disappear and C-S-H decreases with the addition of the BNSA residues.

2. From chemical analysis of the BNSA, it possessed Fe_2O_3, Al_2O_3, and SiO_2 to a sum of 79.84% which indicates a good pozzolanic behaviour. BNSA can be used as admixture (Retarder) in concrete production; due to their high specific surface area and amorphous characteristics, they possess remarkable high pozzolanic activity and can be used as supplementary cementitious materials.

3. To validate the experimental observations regarding the mechanical strength behaviour of BNSA-cement concrete blend, statistical method were employed to analyze the data using ANOVA and Dunnett post-hoc test to determine the level of statistical significance when the groups consisting of varying ratios of replacement is compared with the control group (0%-replacement). A 95% confidence intervals of (-14.84, 2.56), (-17.47, -0.07), (-19.02, -1.62), (-19.85, -2.44), and (-21.06, -3.66) for 5%, 10%, 20%, 30% and 40%-replacement ratio results respectively was computed with errors sum difference of 3.23.

4. From the research study carried out to investigate the effect of BNSA utilization as supplementary cementitious materials, the optimal ratio of combination was derived at 5% replacement ratio. Incorporation of BNSA in concrete would encourage the recycling and re-use of solid waste thereby enhance eco-friendly and sustainable engineering.

DECLARATION OF COMPETING INTEREST

None.

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