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Prediction Of Flexural Strength Of Nano-Silica Blended (NSB) Concrete

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Abstract
This study carried out experimental investigations on the flexural strength of nano-silica blended (NSB) concrete. Fifteen (15) mix ratios were generated as trial mix ratios using Scheffe's (5,2) factor space. The laboratory results on flexural strength produced using the first fifteen trial mix ratios were used to develop mathematical model for the prediction and optimization of the flexural strength of nano-silica concrete. For the mathematical model validation, additional fifteen mix ratios were generated to serve as control mix ratios. The mathematical models developed were tested for adequacy using the results of the control mix ratios at 95% level of confidence using F-statistics. The calculated F-value was found to be 0.2807, below the critical F-value of 0.4026, showing that the models developed is adequate to predict and optimize the flexural strength of NSB concrete. The R-squared value for the flexural strength at 28 days is 0.95 which is a good fit of the line to the data. The maximum value of the flexural strength is 8.92N/mm^2, at mix ratio 0.29: 0.95 : 0.05 : 1.51 : 2.04. In conclusion, nano-silica improves the flexural strength of concrete. This is high strength concrete and therefore can be used to construct reinforced concrete structures such as water-retaining structures, bridges and dams.
Keywords: *Concrete, Nano-silica, Flexural Strength, Scheffe's Model, NSB, Optimization, Prediction.*

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I. Introduction

In civil engineering works, concrete is the material of choice works and it is one of the most useful materials in the construction industry. Concrete is one of the oldest and most common construction materials in the world, mainly due to its low cost, availability, its long durability, and ability to sustain extreme weather environments. According to Lippiatt and Ahman (2004), each person on the planet produces, on average, one ton of concrete annually. One of the materials utilized in large quantities for constructions is cement, however when the production of cement rises, pollution increases (Ji, 2005). During the production of Portland Cement large amounts of carbon dioxide (CO_2) is released into the atmosphere resulting increasing the greenhouse effect (Bondar, 2013). According to Allwood *et al*. (2010), it is observed that the cement industry alone produces 5-7% of global CO_2 emissions which is about 1.35 billion tons annually. In order to limit environmental pollution, the construction industries are presenting numerous new and propelled materials for the development of structures the key tactic is to use less cement in concrete and substitute it with other pozzolanic elements as nano-silica (Byung-Wan *et al*., 2007; Nilli *et al*., 2009; Nazari *et al*., 2010).

Nanotechnology has gained widespread scientific interest due to the incredibly small substances containing nanometer-sized particles. Their extremely small size makes them exceptionally effective at altering the ultrafine characteristics of concrete. A larger area is implied by the particles' small size (Alireza *et al*., 2010). Pozzolans are a class of siliceous and aluminous materials which ordinary, have little or no cementitious nature but which will, in finely divided form and in the presence of water, react chemically with calcium hydroxide $Ca(OH)_2$, at ordinary temperature to form compounds possessing cementitious properties. The quantification of the capacity of a pozzolan to react with calcium hydroxide and water is given by measuring its pozzolanic activity (Snellings *et al*., 2012). NS applications in cement concrete make concrete suitable (Nazari *et al*., 2010). Construction companies can employ nano-silica blended (NSB) concrete in high-rise buildings because of its improved workability, increased strength, and stability in volume, all of which come at a similar cost (Kong & Hou, 2015). The addition of mineral additive to the cement matrix and using a water reduction agent are essential steps in creating NSB concrete, this is because admixtures can alter or enhance the qualities of concrete, both while it is fresh and when it has hardened (Mihai, 2008; Akogu, 2011; Rixom and Mailvaganam, 2007; Naqash et al, 2014). A low water/cement ratio, and sufficient superplasticizer are all necessary for NSB concrete, this is because they can boost strength at a suitable percentage of cement replacement with additives or supplementary cementitious materials such fly ash (FA), metakaolin (MK), and silica fume (SF) were used (Rashad, 2013; Sobolev, 2004; Güneyisi *et al*., 2012; Hassan *et al*., 2012; Matte & Moranville, 1999; Mazloom, 2004; Kumar *et al*., 2012).. Using water-reducing admixtures with high efficiency will result in concrete mixes with good density and high workability. ASTM C494 () slump loss will be lessened as a result.

El-Baky et al. (2013) found that when 7% of cement was substituted with nano-silica in cement mortar, the compressive strength increased by 55.7%. Additionally, as the amount of nano-silica in the cement mortar increased, so did its flexural strength. According to Hussain and Sastry (2014), concrete's compressive strength, split tensile strength, and flexural strength increase by 25.807%, 25.766%, and 18.9%, respectively, when cement is replaced by silica fume up to 7.5% of the time and by nano-silica up to 2%.

These investigations all demonstrated how effectively nano-silica increases the flexural, splitting, and compressive strengths of various concrete kinds. Rashid et al. (2011) experimentally investigated how nano SiO_2 particles affected the concrete's mechanical (compressive, split tensile and flexural strength) and physical (water permeability, workability, and setting time) characteristics. The experimental results showed that binary blended concrete containing up to 2% nano SiO_2 particles had noticeably higher compressive, split tensile and flexural strengths than normal concrete. In the study, it was concluded that, for samples cured in lime solution, the workability and setting time of fresh concrete are reduced when nano SiO_2 particles are partially substituted. Dhinakaranet al. (2014) experimentally investigated concrete's microstructure and strength characteristics using Nano SiO_2. Concrete containing 5%, 10%, and 15% silica by weight was mixed with silica that had been reduced to nano-size in a planetary ball mill. The experimental findings demonstrated a 10% replacement, revealed that the compressive strength increased. Porro et al. (2005) experimentally conducted a comparative study between nano-silica and micro-silica and it was found that when added to cement paste, nano-silica is more effective than micro-silica at improving mechanical properties and increasing compressive strength because it consumes more portlandite (a mineral that contains calcium hydroxide, or $Ca(OH)_2$) than silica fume. Additionally, they concluded that colloidal nano-silica outperforms agglomerated silica in terms of increasing compressive strength because the nano-silica in the colloidal solution is purely nano and not agglomerated, and that the reactivity and production of C-S-H gel increase as the nano-silica particle size decreases. Said et al. (2012) experimentally investigated the impact of colloidal nano-silica on concrete by mixing it with class F fly ash. It was found that adding varying amounts of nano-silica greatly enhanced the performance of concrete, whether fly ash was added or not. A significant improvement in strength is provided by the combination that contains 30% fly ash (FA) and 6% CNS. The mixture containing nano-silica had much decreased porosity and threshold pore diameter. Physical penetration depth and passing charges both markedly improved, according to the RCPT test.

II. Methodology

Materials

The materials that were used in the production of concrete are listed below:

Cement: The cement used is the 3X 42.5N Grade Portland Limestone cement manufactured by Dangote Nigeria Limited with properties conforming to BS 12:1996 as displayed in Fig. 1(A). It is marketed at most cement shops in Port Harcourt. The cements were properly stacked to avoid contact with moisture.

River Sand: The river sand used in this study was sourced from Choba River in Rivers State. It was clean, well graded and has a specific gravity of 2.65. It was washed and sundried for two weeks to remove the moisture content which could lead to increase in the water content of the mix. The grading and properties was carried out to the requirements of BS 812 (1975). The particle size distribution of the fine aggregate shows that the sand used is classified as zone 2 based on the grading limits for fine aggregates. The maximum size of fine aggregate was 5mm.

Granite: The granite aggregates were obtained from crushed rock in Rivers State. The aggregate was thoroughly washed and sun-dried for one week to remove dirts. The granite aggregates were of high quality with maximum size of 20mm.

Water: The water used in this study was clean, fresh, colourless, odourless, tasteless and free from organic matters that may affect the desired quality of concrete. It conformed to the requirements of BS EN 1008 (2002).

Nano-silica (NS): Nano-silica powder, a white fluffy powder composed of high purity silica (SiO_2) content of 98.1%, and particle size of 10.04nm, ordered from Nanjing Yaojie Energy-Saving Technology Co., Ltd was used in this investigation. Nano-silica content in concrete from 0% to 17% by total weight of cement. The nano-silica is displayed in Fig. 1(B) and Table 4 shows the metal oxide analysis.

Superplasticizer (Conplast SP430): Conplast SP430 is a sulphonated naphthalene polymer based chemical admixtures, a product of Fosroc. It was purchased from Purechem Manufacturing Limited, Lagos Nigeria. Conplast SP430 was purchased and supplied as a brown solution which instantly disperses in water, with specific gravity of 1.18 at 22ºC + 2ºC. In this study, Conplast SP430 was added to concrete at a 1.0% by weight of binder. This admixture is in accordance with ASTM C494 [44].

Fig. 1: (A) Portland Limestone Cement (B) NS) (C) NSB Concrete in Beam Moulds (D) Demoulded NSB Concrete Beam Specimens (E) NS Beam Specimens in Curing Tank (F) NSB Concrete Beam Specimens to be Marked for Testing (G) Marking of NSB Concrete Beam Specimens for Flexural Test (H) Support Mechanism for Third Point Load Test (I) Third Point Load Test on NSB Concrete Beam Specimen

Methods

This study is to determine the properties of nano-silica, fine aggregate, coarse aggregate which are used for concrete. The Scheffe's analytical models used in this study. The number of components is 5 (water, cement, river sand, granite and nano-silica) and a second degree polynomial was used, which implies that q=5 and m=2. The diagrammatical representation of the factor space for a 5-component component concrete mixture used in this study is as shown in Fig. 2. The response is a function of the component factors X_1, X_2, X_3, X_4 and X_5 respectively. The first fifteen mix ratios were used to develop the mathematical models for the prediction and optimisation of the flexural strength. Additional fifteen (15) mix ratios were used as check points to validate the models for each response. The mix ratios shown in Tables 1 and 2 are based on Scheffe's (5, 2) factor space.

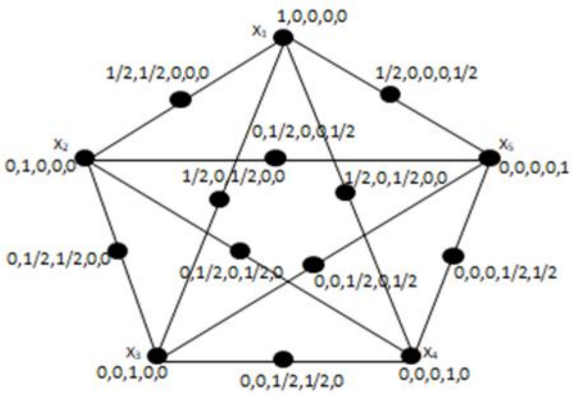


Fig.2: A Factor Space for a 5-Component Concrete Mixture used in this Study

Table 1. Design Matrix for Trial Mix Ratios Based on Scheffe's (5, 2) Factor Space

X_1	X_2	X_3	X_4	X_5	Response	S_1	S_2	S_3	S_4	S_5
1	0	0	0	0	Y_1	0.29	0.95	0.05	1.51	2.04
0	1	0	0	0	Y_2	0.3	0.92	0.08	1.2	2.2
0	0	1	0	0	Y_3	0.34	0.89	0.11	1.32	2.14
0	0	0	1	0	Y_4	0.35	0.86	0.14	1.28	2.56
0	0	0	0	1	Y_5	0.28	0.83	0.17	1.33	2.36
0.50	0.50	0	0	0	Y_{12}	0.295	0.935	0.065	1.355	2.12
0.50	0	0.50	0	0	Y_{13}	0.315	0.92	0.08	1.415	2.09
0.50	0	0	0.50	0	Y_{14}	0.32	0.905	0.095	1.395	2.3
0.50	0	0	0	0.50	Y_{15}	0.285	0.89	0.11	1.42	2.2
0	0.50	0.50	0	0	Y_{23}	0.32	0.905	0.095	1.26	2.17
0	0.50	0	0.50	0	Y_{24}	0.325	0.89	0.11	1.24	2.38
0	0.50	0	0	0.50	Y_{25}	0.29	0.875	0.125	1.265	2.28
0	0	0.50	0.50	0	Y_{34}	0.345	0.875	0.125	1.3	2.35
0	0	0.50	0	0.50	Y_{35}	0.31	0.86	0.14	1.325	2.25
0	0	0	0.50	0.50	Y_{45}	0.315	0.845	0.155	1.305	2.46

Table 2. Design Matrix for Control Mix Ratios Based on Scheffe's (5, 2) Factor

X_1	X_2	X_3	X_4	X_5	Response	S_1	S_2	S_3	S_4	S_5
0.2	0.2	0.2	0.2	0.2	Y_1	0.312	0.89	0.11	1.328	2.26
0	0.25	0.5	0	0.25	Y_2	0.315	0.8825	0.1175	1.2925	2.21
0.25	0.25	0	0.25	0.25	Y_3	0.305	0.89	0.11	1.33	2.29
0.25	0.25	0.25	0.25	0	Y_4	0.32	0.905	0.095	1.3275	2.235
0.25	0.25	0.25	0.25	0.25	Y_5	0.3175	0.875	0.125	1.2825	2.315
0	0.5	0.25	0.25	0	Y_{12}	0.3225	0.8975	0.1025	1.25	2.275
0	0.25	0.25	0.5	0	Y_{13}	0.335	0.8825	0.1175	1.27	2.365
0.5	0.25	0.25	0	0	Y_{14}	0.305	0.9275	0.0725	1.385	2.105
0	0	0.25	0.25	0.5	Y_{15}	0.3125	0.8525	0.1475	1.315	2.355
0.5	0	0	0.5	0.25	Y_{23}	0.3175	0.875	0.125	1.35	2.38
0	0.25	0.5	0.25	0	Y_{24}	0.3325	0.89	0.11	1.28	2.26
0	0	0.5	0.25	0.25	Y_{25}	0.3275	0.8675	0.1325	1.3125	2.3
0.2	0.2	0.2	0	0.4	Y_{34}	0.298	0.884	0.116	1.338	2.22
0	0.4	0.2	0.2	0.2	Y_{35}	0.314	0.884	0.116	1.266	2.292
0.2	0.2	0	0.2	0.4	Y_{45}	0.3	0.878	0.122	1.33	2.304

Scheffe Regression Technique Design Method

Scheffé (1958) assumed a polynomial function of degree m in the q variables $X_1, X_2 \ldots X_q$ subject to the constraint of Equation (1) is of the form:

$$\hat{y}_i = b_o + \sum_{1\le i\le q} b_i X_i + \sum_{1\le i\le j\le q} b_{ij} X_i X_j + \sum_{1\le i\le j\le k\le q} b_{ijk} X_i X_j X_k + \sum b i_1 i_2 --- i_n X_{i1} X_{i2} X_{in} \quad (1)$$

Where $(1 \le i \le q, 1 \le i \le j \le q, 1 \le i \le j \le k \le q, 1 \le i_1 \le i_2 \le \cdots \le i_n \le q$ respectively, b= constant coefficients and i and j are points on the factor space. Equation (1) is an m-order Taylor series, which approximates the response surface. Substituting the values of i and j into Equation (1) for a 5-component concrete mixture transforms to Equation (2)

$$Y = \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + \alpha_5 X_5 + \alpha_{12} X_1 X_2 + \alpha_{13} X_1 X_3 + \alpha_{14} X_1 X_4 + \alpha_{15} X_1 X_5 + \alpha_{23} X_2 X_3 + \alpha_{24} X_2 X_4 + \alpha_{25} X_2 X_5 + \alpha_{34} X_3 X_4 + \alpha_{35} X_3 X_5 + \alpha_{45} X_4 X_5 \quad (2)$$

Equation (2) is the response to the pure component, i and the binary mixture, ij. If the response at ith point on the factor space is yi, then at point 1, component X1= 1 and the other components X2=X3=X4=X4=0 and so on then the Equation (2) now becomes (3)

$$Y = X_1(2X_1 - 1)y_1 + X_2(2X_2 - 1)y_2 + X_3(2X_3 - 1)y_3 + X_4(2X_4 - 1)y_4 + X_5(2X_5 - 1)y_5 + 4y_{12}X_1X_2 + 4y_{13}X_1X_3 + 4y_{14}X_1X_4 + 4y_{15}X_1X_5 + 4y_{23}X_2X_3 + 4y_{24}X_2X_4 + 4y_{25}X_2X_5 + 4y_{34}X_3X_4 + 4y_{35}X_3X_5 + 4y_{45}X_4X_5 \quad (3)$$

Equation (3) is the regression model that predicts the flexural strength of a 5-component concrete mixture.

Production and Testing of Nano-silica Blended Concrete Beam Specimens

Water, cement, nano-silica, sharp sand, granite and superplasticizer were the varied masses of the NSB concrete components that were weighed and stored in their respective containers. Granite was added to the cement/nano-silica-sand mixture after the cement/nano-silica and sand had been dry mixed until a homogeneous consistency was reached. In order to create homogenous fresh concrete, water was added to the dry combination of cement/nano-silica, sand, and granite using a consistent dose of 1.0% superplasticizer to weight of binder. To ascertain the workability of the fresh concrete, slump test was performed. To ensure that there was no concrete debris left in the moulds before casting, the moulds were watertight, cleaned, and positioned. They were also properly lubricated with oil to prevent the concrete from adhering to the moulds and to facilitate the easy removal of the test specimens of nano-silica blended concrete. In order to ensure appropriate distribution of the concrete within the moulds and proper compaction, the freshly made NSB concrete was poured into the prismatic beam moulds (150 x 150 x 500 mm) in three layers of 35 blows using a tamping rod. A steel ruler was used to write the batch label on the concrete after its surface had been leveled and smoothed with a hand trowel. Following the casting process, the concrete specimens that had been combined with nanosilica were allowed to set at room temperature for 24 hours before being demolded and completely submerged in water for a total of 28 days to cure. Following a 28-day water curing period, the beam specimens were tested for flexure.

In accordance with ASTM C78, the flexural test was performed on the cured beam specimens. The third point load test system was used. The position of the load and reaction points were marked on the beam specimens before positioning the beams for flexure. As seen in Fig. 3, the beam specimen was positioned on the loading point with a span, L, of 450mm and put through the third point load test, ASTM C78. The beam specimen was subjected to an increasing load until failure. Eq. (4) was used to determine the flexural strength after the maximum load at failure was reached.

$$f_f = \frac{P_f L}{bd^2} \quad (4)$$

Where, $f_f = Flexural\ strength,\ (\mathrm{N}/mm^2)$;
$P_f\ = Load\ at\ failure,\ (N)$;
$L\ = Span\ of\ beam, (mm)$;
$b\ = Width\ of\ beam, (mm)$;
$d\ = Depth\ of\ beam, (mm)$.

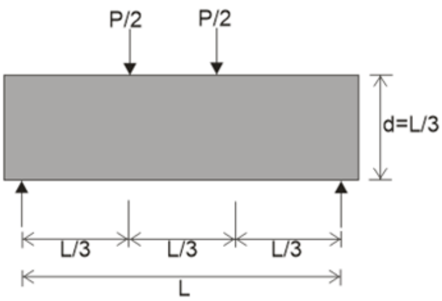
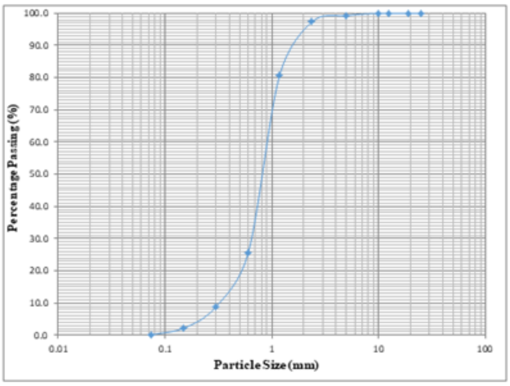


Fig. 3. Third-Point Load Test Setup.

III. Results And Discussion

The results of the sieve analysis tests for the aggregates are presented in Fig. 4 and Fig. 5 respectively. The sand had coefficient of uniformity (Cu) of 2.81 and coefficient of curvature (Cc) of 1.47. The granite chippings recorded a Cu value of 1.90 and a Cc value of 1.16. These show that the sand and granite are well graded.



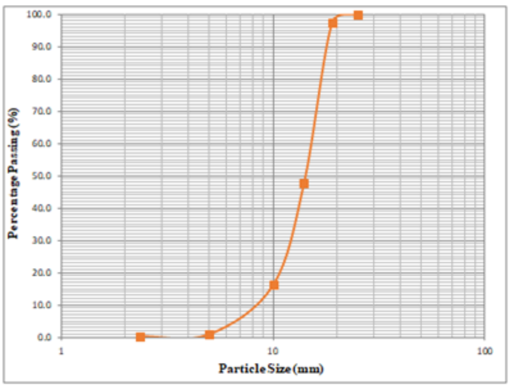


Fig. 4. Chart of Particle Size Distribution for Sand
Fig. 5. Chart of Particle Size Distribution Curve for Granite

Results of Slump Test on NSB Concrete

The results of the slump test on NSB concrete clearly show that the slump decreases with increasing NS content in the mix ratios (both for the trial and control mixes) as depicted in Fig. 6 and Fig. 7 accordingly. The relationship between slump and NS content is relatively linear. For the trial mixes, the slump decreased from 168mm to 80mm as the NS content increased from 0% (TB0) to 17% (TB5) when compared with the unreinforced concrete specimen (TB0). Similarly, for the control mixes, the slump decreased from 168mm to 83mm, as the NS content increased from 0% (CB0) to 14.75% (CB9). These findings are in line with previous studies by Askar et al. [33] and Garces et al. [48], who reported that the addition of NS to concrete leads to an increase in air content and porosity, resulting in a lower slump and reduced workability.

The relationship between slump and the percentage of NS content (V_f) in the mixes can be mathematically expressed as linear regression models, as shown in Eqs. (3) and (4) for the trial mixes and control mixes respectively. The goodness-of-fit for these regression models, as indicated by the R-squared values, were 0.70 and 0.88 accordingly. The values demonstrated the strong correlation between NS content and slump behaviour. The results of the slump test on NSB clearly highlight the significant impact of NS content on the workability and dispensability of the fresh concrete mixture. The inverse relationship between NS content and slump value, as well as the linear regression models developed, provide valuable insights into the influence of NS on the rheological properties of the concrete, which is an important consideration in the mix design and implementation of this composite material.

Slump (Trial Mixes) = - 4.03599 NS (%) + 136.1211 (3)

Slump (Control Mixes) = - 5.71268 NS (%) + 154.7506 (4)

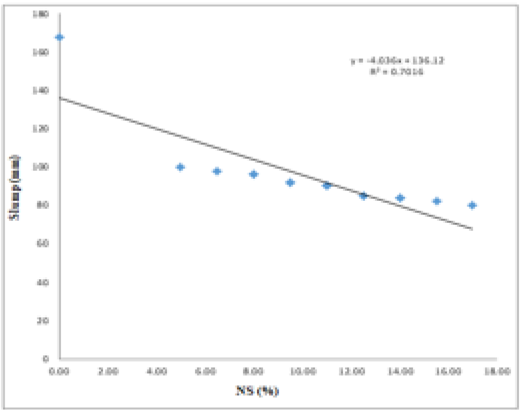


Fig. 6. Trial Mixes Result of Slump Test on Fresh Nano-silica Blended Concrete

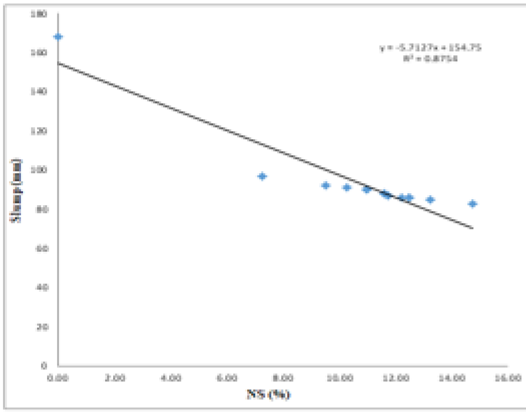


Fig. 7. Control Mixes Result of Slump Test on Nano-silica Blended Concrete

Results of Flexural Strength Test

Flexural strength test results for the trial and control mixes are presented in Fig. 8 and Fig. 9 correspondingly. For the trial mixes a clear trend was observed. The flexural strength ranged from (5.67N/mm2 to 8.92N/mm2) for nano-silica content ranging from (0 – 17%). At 0% NS content (TB0), the flexural strength was 5.67 N/mm^2. The 5% nano-silica content (TB1) had a flexural strength value of 8.92N/mm^2, and a strength improvement of 36.44% when compared with concrete without nano-silica.

However, 5% NS content was found to be the optimum NS content, further addition in NS content showed that, the flexural strength steadily decreased, reaching a minimum value of 6.40N/mm^2 at 15.50% NS content (TB15). This represents an increase of about 11.46% in flexural strength when compared to the unreinforced concrete mix (TB0). The result is in agreement with the finding of Heidari and Tavakoli (2012); Alireza et al. (2012); Alirza et al. (2010); Rashid et al. (2011); Ji (2005); Javni et al., 2002; Senff et al., 2009; Shih et al., 2006; Abyaneh et al., 2013; El-Baky et al., 2013; Hussain and Sastry, 2014 which found in their study that nano SiO_2 particles improve the flexural strength and physical qualities of concrete.

Interestingly, the graph also suggests that after reaching the optimal 5% NS content, further increases in NS contents do not yield any significant improvements in flexural strength. This indicates that there is an upper limit to the beneficial effects of NS on flexural performance, likely due to factors such as reduced workability and increased porosity at higher NS contents. The results presented in Fig. 9, for the control mixes show a very similar trend. The flexural strength increases steadily with NS content, reaching a maximum of 8.20 N/mm^2 at 7.25% NS (CB8). Beyond this point, the flexural strength slightly decreases with further increases in NS. This supports the findings from the trial mixes and suggests that 5-7.5% is the optimal NS content range for maximizing the flexural performance of this type of Portland cement concrete.

The consistency in the results between the trial and control mixes provides confidence in the reliability and reproducibility of the experimental findings. The strong correlation between NS content and flexural strength demonstrated in both figures highlights the effectiveness of NS as cement replacement material by significantly enhancing the flexural properties of concrete by its large surface area and pozzolanic reactivity, allowing for a reduction in the amount of cement needed while still achieving desired strength and durability.

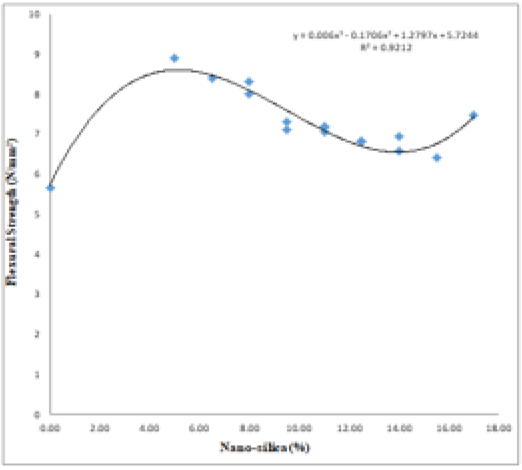


Fig. 8. Result of Flexural Strength of Hardened Nano-silica Blended Concrete Beam Specimens of Trial Mixes at 28 Days

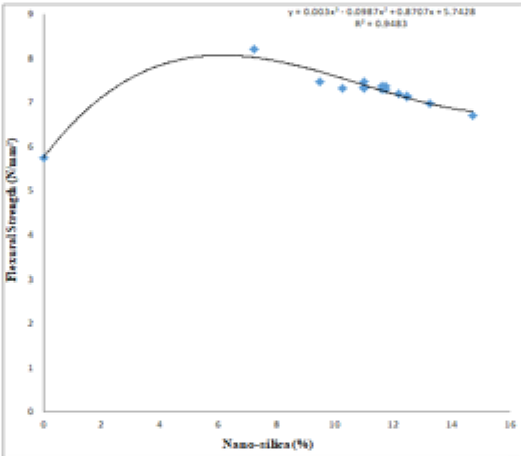


Fig. 9. Result of Flexural Strength of Hardened Nano-silica Blended Concrete Beam Specimens of Control Mixes at 28 Days

Mathematical Model for the Prediction of Flexural Strength

Equation (5) is the regression model for the prediction of flexural strength of nano silica blended concrete.

$$F_{cu} = 8.92X_1 + 8.30X_2 + 7.07X_3 + 6.93X_4 + 7.47X_5 - 0.84X_1X_2 + 0.002X_1X_3 - 3.26X_1X_4 - 3.98X_1X_5 - 1.46X_2X_3 - 1.82X_2X_4 - 4.26X_2X_5 - 0.80X_3X_4 - 2.76X_3X_5 - 3.20X_4X_5 \quad (5)$$

The experimental and predicted values of the flexural strength F-statistic test are presented in Table 3.

Results of Experimental and Predicted Values and Model Validation

The Scheffe's mathematical model was used to predict the flexural strength. The predicted values were compared with their control experimental values and the variations were tested for validity. The predicted and the experimental values were tested for adequacy using F-statistic at 95% confidence level. The charts for the flexural strength showing experimental values vs. predicted values are presented in Fig. 10. The results of flexural strength F-statistic values, for F-computed and F-critical show that the calculated F-value is 0.28 and this was less than the critical value of 0.4026 as shown in Table 3. This proves that the experimental and predicted values coincide at all the experimental points for the control readings, and the model is adequate to predict the flexural strength of NS concrete. Therefore, the null hypothesis was accepted for the flexural strength model developed showing that the model is adequate for predicting the flexural strength.

Table 3. Result of Experimental and Predicted Values F- Statistic Values

	Experimental Value	Predicted Values
Mean	7.299333	7.09282
Variance	0.098282	0.350158
Observations	15	15
df	14	14
F	0.280679	
P(F<=f) one-tail	0.011782	
F Critical one-tail	0.402621	

Table 4. Result of Metal Oxide Analysis of Nano-silica

S/N	Sample	Unit	Nano-silica
1.	CaO	%	0.21
2.	Al_2O_3	%	0.83
3.	Fe_2O_3	%	0.54
4.	PbO	%	0.18
5.	MgO	%	0.20
6.	K_2O	%	0.08
7.	SiO_2	%	97.81
8.	Na_2O	%	0.05
9.	ZnO	%	0.04
10.	TiO_2	%	0.06
11.	Particle size	nm	10.4

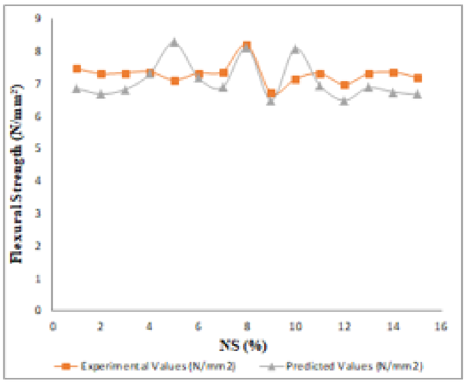


Fig. 10. Result of Flexural Strength of Experimental Values and Predicted Values

IV. Conclusions

Based on the results obtained from this study the following conclusions are made:

(i) Nano-silica acts as a cement replacement material by significantly enhancing the flexural strength of concrete through its large surface area and pozzolanic reactivity, allowing for a reduction in the amount of cement needed while still achieving desired strength and durability.

(ii) All mix ratios containing NS have lower slump values when compared with the mixes without NS.

(iii) The addition of NS to the concrete mix decreased the workability of fresh NS concrete, because the water demand to wet the constituent materials increased due to increased surface area by the NS.

(iv) All mix ratios containing NS have higher flexural strength values when compared with the mixes without NS.

(v) Flexural strength increased and then reached a maximum strength value of 8.92N/mm^2 at 5% NS content at 28 days.

(vi) Optimum NS content is 5%, and the percentage effective flexural strength values at 28 days is 36.44%.

(vii) Mathematical model was developed to predict the flexural strength of NSB concrete using the Scheffe's regression technique.

(viii) The predicted values of flexural strength of NSB concrete were tested for adequacy at 95% confidence level using F-statistic test, the results showed that the calculated F-value was 0.28, which is less than the critical value (0.4026), showing that the experimental and predicted values are found to coincide at all the experimental points and the model is adequate to predict the flexural strength of NSB concrete.

(ix) The experimental and predicted values of the flexural strength of NSB concrete were found to be correlated.

(x) The addition of NS in concrete production is very adequate in advancing the flexural strength of Portland cement concrete.

V. Recommendations

Based on the results obtained from this study, the following recommendations are hereby made.

The addition of nano-silica (NS) was found to have improved the flexural strength properties of concrete significantly. However, there were issues of reduced slump values as nano-silica content increased. It is recommended that further study on suitable water reducing admixture for improved workability.

VI. Contributions To Knowledge

This study has:

1. Developed mathematical models to predict and optimize the structural characteristics of nano-silica blended concrete.
2. Eliminated the use of arbitrary mix ratios in the production of nano-silica blended concrete.
3. Served as a reference material for the advancement of NSB concrete.

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