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Prediction Of Compressive Strength And Static Modulus Of Elasticity Of Nano-Silica Blended Concrete

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Abstract
The compressive strength and modulus of elasticity of nano-silica blended (NSB) concrete were experimentally investigated in this work. The nano-silica blended concrete consist of water (W), cement (C), nano-silica (NS), sand (S) and granite (G) and the Scheffe's (5,2) factor space was used to create fifteen (15) trial mix ratios. The mathematical model for the prediction and optimization of the compressive strength and the static modulus of elasticity of NSB concrete were developed by utilizing the laboratory results gotten from the first fifteen trial mix ratios. Fifteen more mix ratios were generated as control mix ratios for the mathematical model validations. The results of the control mix ratios were used to test the adequacy of the established mathematical models at a 95% confidence level using F-statistics. Below the critical F-value of 0.4026, the computed F-values for compressive strength and static modulus of elasticity were 0.0301 and 0.0092, respectively. This indicated that the models created are sufficient to predict the compressive strength and static modulus of elasticity of NSB concrete. The trendlines is a good fit of the data, as indicated by the 28-day compressive strength R-squared value of 0.95. The optimum compressive strength at mix ratio 0.29: 0.95: 0.05: 1.51: 2.04 (W:C:NS:S:G) is 68.09N/mm^2 at 5% NS content. The optimum static modulus of elasticity is 40.569GPa. In conclusion, nano-silica acts as a cement replacement material by significantly enhancing the mechanical properties 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. This high strength concrete can be used for advanced construction such as bridges, dams, and water-retaining structures.

Keywords: *Concrete, Nano-silica, Compressive Strength, Static Modulus of Elasticity, Scheffe's Model, Prediction.*

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I. Introduction

Concrete is the preferred material for civil engineering projects and is among the most practical materials used in the construction industry. According to Osadebe (2003), concrete is a composite consisting of four components: cement, water, fine aggregate (sand), and coarse aggregate. 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. The cement industry is the primary source of concrete production, with an annual global produce of almost 2.6 billion tons (USGS, 2010). As a result of the calcination and grinding processes, CO_2 emissions during cement manufacture are responsible for the majority of cement's environmental effect (Proske et al., 2013). The decarbonization of limestone and the energy (fuel and electricity) used in the clinker production process are the primary causes of CO_2 emissions (Van den Heede & De Belie, 2012). According to estimates from various authors, the global production of cement accounts for between 4.5 and 8% of anthropogenic CO_2 emissions each year (Naik and Kumar, 2010; Van den Heede and De Belie, 2012; Olivier et al, 2013). Consequently, cement's environmental features may benefit from lower cement clinker content. Additionally, it should be noted that the cement industry is regarded as one of the sectors with the biggest energy consumption and sources of carbon dioxide (CO_2) emissions. The majority of the global climate change is ascribed to carbon dioxide, which is regarded as the primary greenhouse gas (GHG) (Crippa et al., 2021). About 5% of the world's annual man-made CO_2 emissions are attributable to the cement manufacturing sector (WBCSD, 2002), with 50% of these emissions coming from chemical reactions during production and the remaining 50% from fuel use. Numerous studies have been conducted to try to lessen the impact of the cement industry on greenhouse gas emissions, either by increasing the efficiency of the manufacturing process (Deja et al., 2010 and Crippa et al., 2021) or by using supplementary cementitious materials (SCMs), which can either completely or partially replace regular cement (Gartner, 2004). Supplementary cementitious material (SEM) is a substance that contributes to the properties of the hardened concrete through hydraulic or pozzolanic activity, or both, when used in conjunction with Portland cement (CSA A3001, 2003).

The application of nanotechnology provided already breakthroughs in many areas such as medicine and healthcare, energy, biotechnology, information technology, electronics, materials and manufacturing, and many others (Sobolev et al., 2006; Sanchez and Sobolev, 2010). The nanotechnology concept was introduced for the first time by Feynmam (1960) with his famous work entitled ''There's plenty of room at the bottom". This latter term was without a real meaning until Taguchi (1974) related the nanotechnology to the processing of materials, atom by atom or molecule by molecule. Later, a more accurate definition of nanotechnology was presented by Drexler (1981), such as the production with dimensions and precision between 0, 1 and 100 nm. Another accepted terms is that nanotechnology involves the study at nano-range (1 nm = 1x10-9 m).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). The use of NS as partial replacement for cement can lead to a rise in the compressive strength, split tensile test, flexural strength, shear strength, static modulus of elasticity and water absorption of nano-silica blended concrete as well as a reduction in the pollution caused by cement (Bai, 2014). 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 environmental impact and sustainability of concrete can be improved using different approaches and the combined use of silica fines with a concrete mix design tool (Hüsken & Brouwers, 2008). 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.

Additionally, a number of studies demonstrated that the use of nano-silica results in significant increases in the performance of concrete and cement mortars (Li et al., 2024). 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 compressive 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. According to Belkowitz and Armentrout (2009), the reaction's surface area was increased by the nano-silica's tiny particle size. Heidari and Tavakoli (2012) experimentally studied the combined effects of using nano SiO_2 from 0.5 to 1% and ground ceramic powder from 10% to 40% by weight content as partial replacement of cement. At 0.5 to 1% was the ideal dose of nano SiO2 particles, resulted in a significant reduction in water absorption capacity and an improvement in compressive strength when 20% of the material was replaced with pulverized ceramic powder.

Givi and Rashid (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 SiO2 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 SiO2 particles are partially substituted. Nill et al. (2009) experimentally studied the combined effects of micro silica and colloidal nano-silica on concrete qualities. The study revealed that a concrete mixture containing 1.5% nano-silica and 6% micro silica had the highest compressive strength. At 7.5% microsilica and nano-silica, the concrete's electrical resistance was at its maximum. The results show that the combination of 3% micro silica and 1.5% nano-silica has the lowest capillary absorption rate. Dhinakaran et 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. Zhu et al. (2004) 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. According to research, nano-silica can be used to improve the properties of concrete mixtures to the greatest extent feasible. Numerous studies have demonstrated that adding nano-silica to a concrete mix increases its compressive, tensile, and flexural strengths while decreasing setting times and water penetrability and increasing resistance to chemical attacks (Javni et al., 2002; Senff et al., 2009; Shih et al., 2006). According to studies conducted on nano-silica particles, they are not only environmentally safe but also produce superior outcomes than concretes that contain microsilica (Ajay et al., 2012; 2010; Mondal et al., 2010; Al-Mutairi et al., 2010). Nano-silica performed better overall in terms of durability and mechanical qualities than concrete containing macrosilica (Said et al., 2012 and Ghasemi et al., 2010).

II. Materials And Methods

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. 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 97.81%, and particle size of 10.4nm, ordered from Nanjing Yaojie Energy-Saving Technology Co., Ltd was used in this investigation. Nano-silica content in concrete ranged from 0% to 17% by total weight of cement.

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 $22^oC + 2^oC$. In this study, Conplast SP430 was added to concrete at a constant dosage of 1.0% by weight of cement. This admixture is in accordance with ASTM C494.

Table 1. Metal Oxide Analysis of Nanosilica

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

Table 2. Metal Oxide Analysis of Nanosilica

Appearance	Brown liquid
Specific gravity (BSEN 934-2)	1.18 @ 22°C + 2°C
Water Soluble Chloride (BSEN 934-2)	Nil
Alkali content (BSEN 934-2)	Typically less than 55g Na_2O equivalent/litre of admixture

Fig. 1: (A) Portland Limestone Cement (B) Nano-silica (C) Sieve analysis readings (D) Curing of NSB Concrete Cube Specimens in Water Tank (E) NSB Concrete Cube Specimens (F) Compressive Strength Test on NSB Concrete Cube Specimen

Methods

The Scheffe's analytical model was used in this study. The diagrammatical representation of the factor space for a 5-component component concrete mixture, which are water, cement, nano-silica, sand and granite (W:C:NS:S:G) respectively, used in this study is as shown in Figure 3.2. The response is a function of the component factors X1, X2, X3, X4 and X5 respectively. The mix ratios shown in Tables 3.2 and 3.3 are based on Scheffe's (5, 2) factor space.

Table 3. Design Matrix for Trial Mix Ratios Based on Scheffe's (5, 2) Factor Space.

Batch Label	X_1	X_2	X_3	X_4	X_5	Response	S_1	S_2	S_3	S_4	S_5	S
TC1	1	0	0	0	0	Y_1	0.29	0.95	0.05	1.51	2.04	26
TC2	0	1	0	0	0	Y_2	0.3	0.92	0.08	1.2	2.2	21
TC3	0	0	1	0	0	Y_3	0.34	0.89	0.11	1.32	2.14	29
TC4	0	0	0	1	0	Y_4	0.35	0.86	0.14	1.28	2.56	135
TC5	0	0	0	0	1	Y_5	0.28	0.83	0.17	1.33	2.36	115
TC6	0.50	0.50	0	0	0	Y_{12}	0.295	0.935	0.065	1.355	2.12	175
TC7	0.50	0	0.50	0	0	Y_{13}	0.315	0.92	0.08	1.415	2.09	165
TC8	0.50	0	0	0.50	0	Y_{14}	0.32	0.905	0.095	1.395	2.3	105
TC9	0.50	0	0	0	0.50	Y_{15}	0.285	0.89	0.11	1.42	2.2	155
TC10	0	0.50	0.50	0	0	Y_{23}	0.32	0.905	0.095	1.26	2.17	38
TC11	0	0.50	0	0.50	0	Y_{24}	0.325	0.89	0.11	1.24	2.38	26
TC12	0	0.50	0	0	0.50	Y_{25}	0.29	0.875	0.125	1.265	2.28	3
TC13	0	0	0.50	0.50	0	Y_{34}	0.345	0.875	0.125	1.3	2.35	22
TC14	0	0	0.50	0	0.50	Y_{35}	0.31	0.86	0.14	1.325	2.25	192
TC15	0	0	0	0.50	0.50	Y_{45}	0.315	0.845	0.155	1.305	2.46	104

Table 4. Design Matrix for Control Mix Ratios Based on Scheffe's (5, 2) Factor Space.

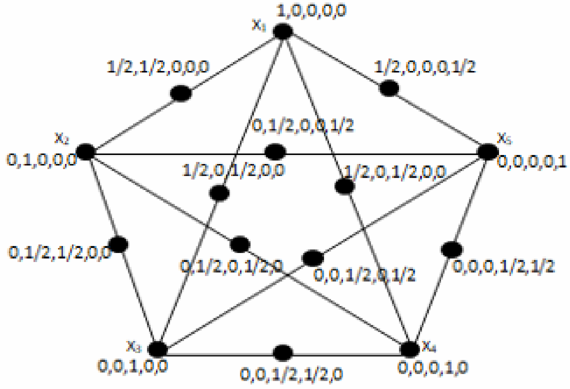


Fig 1. A Factor Space for a 5-Component Concrete Mixture used in this Study.

Scheffe Regression Technique Design Method

Scheffé (1958) assumed a polynomial function of degree m in the q variables X1, X2,…, Xq subject to the constraint of Equation (1) is of the form:

$$\hat{y}_i = b_o + \sum_{1\le i\le q} b_i X_i + \sum_{1\le i\le j\le q} b_{ij} X_i X_j + \sum_{1\le i\le j\le k\le q} b_{ijk} X_i X_j X_k + \sum bi_1 i_2 --- i_n X_{i1} X_{i2} X_{in} \quad (1)$$

where 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)

(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)

(3)

Equation (3) is the regression model that predicts the compressive strength and static modulus of elasticity of a 5-component concrete mixture.

Production and Testing of NSB Concrete Cube Specimens

The various masses of the NSB concrete constituents (water, cement, river sharp sand, granite, nano-silica and superplasticizer) were weighed kept in their different containers. The cement/nano-silica and river sand were dry mixed together until a homogenous mixture was achieved, then the granite was added to the cement-sand mixture. Water mixed with a constant dosage of 1.0% of superplasticiser to weight of binder was added to the dry mixture of cement/nano-silica, sand and granite, while mixing the entire concrete constituents together to get a homogenous fresh concrete. Slump test was carried out on the fresh concrete to determine its workability. The moulds were water tight, accurately dimensioned and thoroughly cleaned and prepared to ensure that there were no left over debris of concrete in the moulds before casting and adequately lubricated with oil so as to prevent adhesion of the concrete to the moulds, as well as, allow for easy removal of the nano-silica blended concrete test cube specimens. The prepared fresh nano-silica blended concrete mix was pouring into the cube mould (150mm x 150mm x 150mm) in 3 layers of 35 blows with a tamping rod to ensure even distribution of the concrete within the moulds and also ensure adequate compaction. Hand trowel was used to level and smoothen the surface of the concrete and batch label were written on the concrete surface with a steel ruler. The nano-silica blended concrete cube specimens were left in the moulds for 24 hours at room temperature after casting, and then the concrete specimens were de-moulded and cured by total immersion in water, the cube specimens were tested for 7, 14, 21and 28 days of curing ages respectively. After curing, the specimens were tested in compression testing machine having capacity of 2000kN. The maximum load at failure was recorded and the compressive strength was calculated using Eq. (4). The static modulus of elasticity was determined from the empirical relationship between concrete density and compressive strength (Neville & Brook, 1990) calculated using Eq. (5).

(4)

(5)

Where,;; ;; ;

III. Results And Discussion

The results of the sieve analysis tests for the fine and coarse aggregates are presented in Fig. 2 and Fig. 3 respectively. The results from the analysis of the river sand, gave a coefficient of uniformity (Cu) value of 2.81 and a coefficient of curvature (Cc) value of 1.47. Therefore, the river sand can be categorized as a well-graded and, since Cc=1-3and is classified as zone 2 based on the grading limits for fine aggregate, as stipulated under the Unified Soil Classification System (USCS). The granite chippings recorded a Cu value of 1.90 and a Cc value of 1.16. This also shows that the granite is well graded.

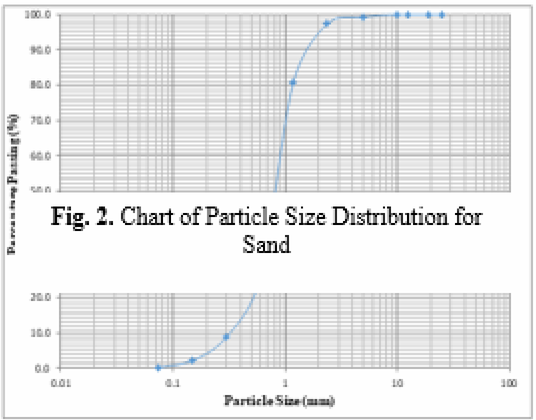


Fig. 2. Chart of Particle Size Distribution for Sand

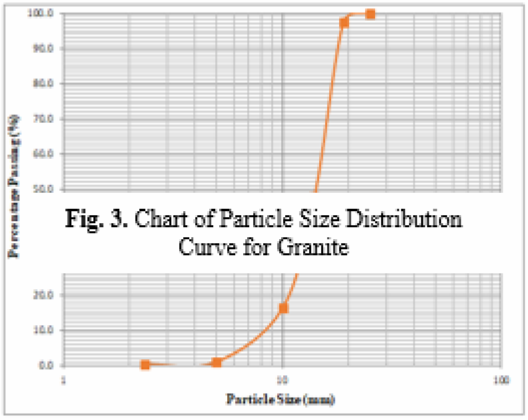


Fig. 3. Chart of Particle Size Distribution Curve for Granite

Results of Slump Test on CCFRP 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. 4 and Fig. 5 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 Shih et al. (2006); El-Baky et al. (2013); Hussain and Sastry, (2014), 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.

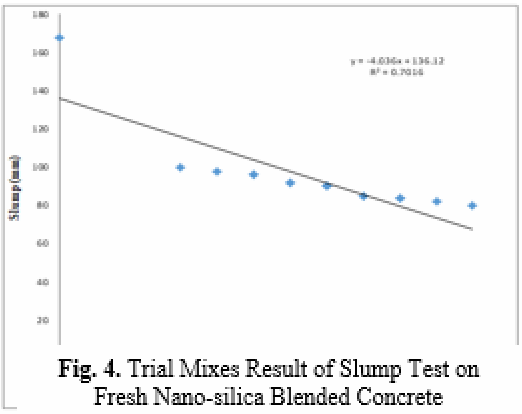


Fig. 4. Trial Mixes Result of Slump Test on Fresh Nano-silica Blended Concrete

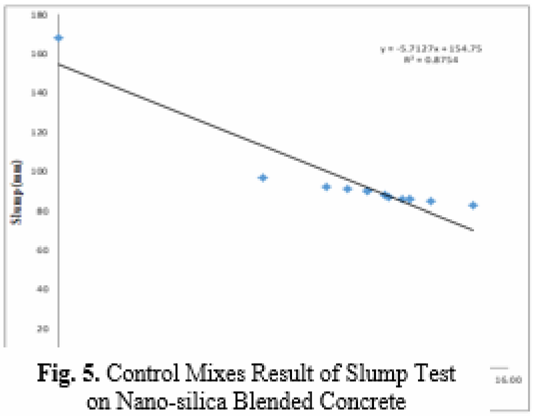


Fig. 5. Control Mixes Result of Slump Test on Nano-silica Blended Concrete

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. (6) and (7) 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 (6)

Slump (Control Mixes) = - 5.71268 NS (%) + 154.7506 (7)

Result of Compressive Strength Test

Compressive strength test results for the trial and control mixes are presented in Fig. 6 and Fig. 7 correspondingly. For the trial mixes a clear trend was observed. At 0% NS content (TC0), the compressive strength was 35.56 N/mm^2; the maximum compressive strength of NSB concrete was 68.09N/mm^2 at 5% NS content, with a strength improvement of 47.78%. However, with further addition of NS, the compressive strength plateaus steadily and slightly drops to 67.98N/mm^2 at 14% NS content (TC14) with an effective compressive strength improvement of 47.70%, reaching a minimum value of 61.34N/mm^2 at 12.50% NS content (TC12) with an effective strength improvement of 42.04% when compared with the compressive of concrete mix with 0% NS content (TC0). The result is in agreement with the finding of Heidari and Tavakoli (2012); Alireza et al. (2012); Alirza et al. (2010); Givi and Rashid (2011); Ji (2005); Javni et al. (2002); Senff et al. (2009); Shih et al. (2006); El-Baky et al. (2013); Hussain and Sastry, (2014) which showed that the replacement of cement with NS can significantly improve the strength properties and physical quality of concrete.

Interestingly, the graph also suggests that after reaching the optimal 5% NS content, further increases in NS content do not yield any significant improvements in compressive strength. This indicates that there is an upper limit to the beneficial effects of NS on compressive strength performance El-Baky et al. (2013); Hussain and Sastry, (2014), likely due to factors such as reduced workability, and increased porosity at higher fibre contents. The results presented in Fig. 7 for the control mixes show a very similar trend to the trial mixes as in Fig. 6. At 0% NS content (CC0), the compressive strength was 34.13 N/mm^2; the maximum compressive strength of NSB concrete was 67.30N/mm^2 at 14.75% NS content, with an effective strength improvement of 49.28%. However, with further increment or decrement of NS, the compressive strength slightly drops to 67.21N/mm^2 at 12.5% NS content (CC10) with an effective compressive strength improvement of 49.22%, reaching a minimum value of 63.91N/mm^2 at 11% NS content (CC12) with an effective strength improvement of 46.59% when compared with the compressive of concrete mix with 0% NS content (TC0). Beyond this point, the compressive slightly decreases with further increases in NS. This confirms the findings from the trial mixes and suggests that 5-7.5% is the peak NS content range for maximizing the compressive performance of this type of concrete, which is in line with observations made by Li et al. (2004), that at 6% addition of NS improved the mechanical properties of the mortar, and Heidari and Tavakoli (2012); Alireza et al. (2012); Alirza et al. (2010); Givi and Rashid (2011).

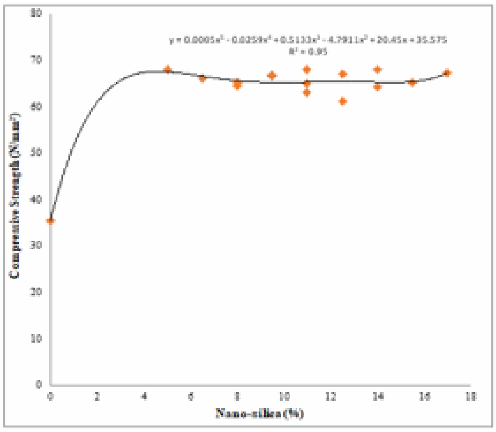


Fig. 6. Result of Compressive Strength of Hardened NSB Concrete Cube Specimens of Trial Mixes at 28 Days

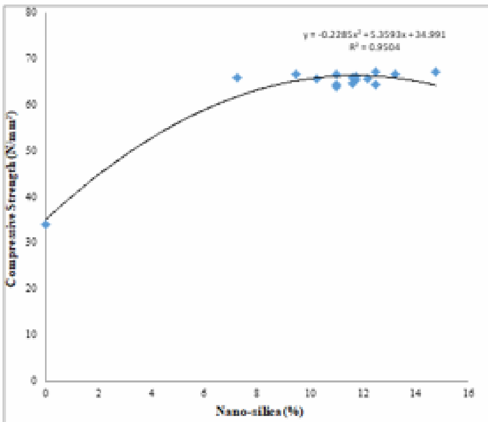


Fig. 7. Result of Flexural Strength of Hardened NSB Concrete Cube Specimens of Control Mixes at 28 Days

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 compressive strength demonstrated in both figures highlights the effectiveness of NS as a supplementary cementitious material to enhance the compressive properties of concrete, which is in line with the observations made by Mukharjee and Barai (2020); Wu et al. (2017); Ganesh et al. (2016); Chithra et al. (2016); Zareei et al. (2019); Gopinath et al. (2012); Atmaca et al. (2017); Du et al. (2014).

Result of Static Modulus of Elasticity Test

Static modulus of elasticity 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. As the NS content in the concrete mix increases, the static modulus of elasticity strength also initially increases and peaked at 9.5% NS content. At 0% NS content (TE0), the static modulus of elasticity was 31.422GPa. However, with the addition of NS, the static modulus of elasticity steadily rises, reaching a maximum value of 40.569 at 9.5% NS content (TE8). This represents an increase of about 22.55% in static modulus of elasticity as compared to the unreinforced concrete mix (TE0). The results corroborate findings from previous studies, such as the work by Givi and Rashid (2011); Ji (2005); Javni et al. (2002), which showed that the incorporation of NS as cement replacement can significantly improve strength properties of concrete.

Interestingly, the graph also suggests that after reaching the optimal 9.5% NS content, further increases in NS content do not yield any significant improvements in static modulus of elasticity. This indicates that there is an upper limit to the beneficial effects of NS on the static modulus of elasticity on concrete, likely due to factors such as reduced workability Qing et al. (2007), and increased porosity at higher NS contents. The results presented in Fig. 9 for the control mixes show a very similar trend to that of the trial mixes as in Fig. 8. The static modulus of elasticity increases steadily with NS content, reaching a maximum of 39.497GPa at 7.25% NS (CE8). Beyond this point, the static modulus of elasticity plateaus and slightly decreases with further increases in NS content.

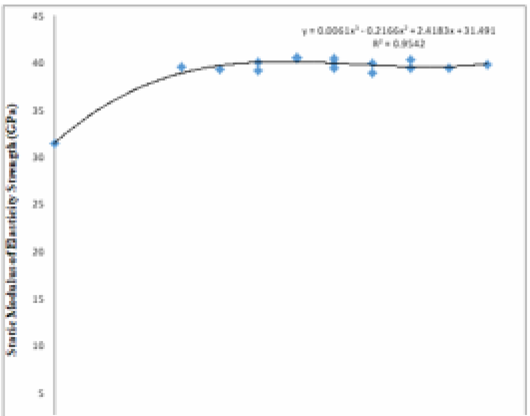


Fig. 8. Results of Static Modulus of Elasticity of Hardened NSB Concrete Specimens of Trial Mixes at 28 Days

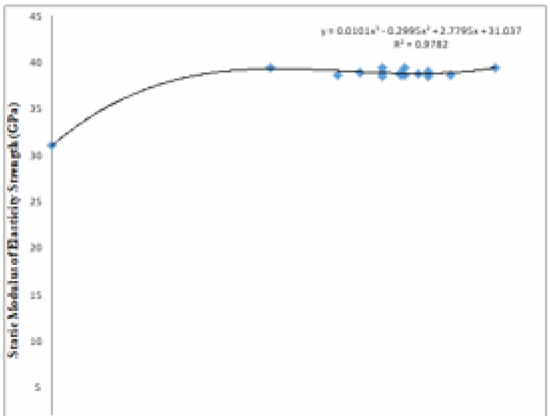


Fig. 9. Results of Static Modulus of Elasticity of Hardened NSB Concrete Specimens of Control Mixes at 28 Days

Mathematical Model for the Prediction of Compressive Strength and Static Modulus of Elasticity

Eqns (8) and (9) are the regression models for the prediction of compressive strength and static modulus of elasticity of NSB concrete respectively.

(8)

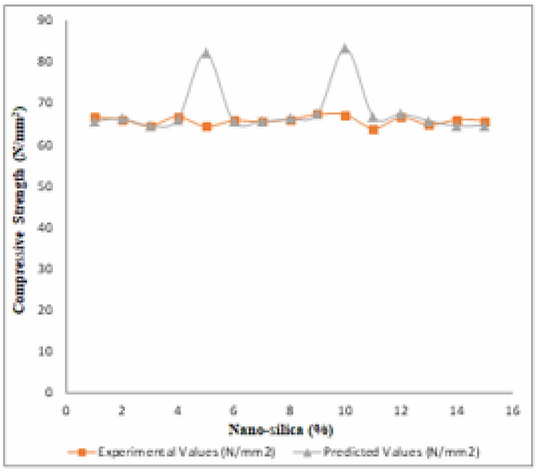
(9)

The experimental and predicted values of the compressive strength and static modulus of elasticity are presented in Tables (5) and (6) respectively.

Results of Experimental and Predicted Values and Model Validations

The Scheffe's mathematical model was used to predict the compressive strength. The predicted values were compared with the 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 chart for the compressive strength showing experimental values vs. predicted values is presented in Fig. 10. The results of compressive strength F-statistic values, for F-computed and F-critical are 0.3 and 0.4026 respectively. This showed that the F-computed is less than the F-critical as shown in Table 5. This proves that the experimental and predicted values coincide at all the experimental points for the control readings, therefore, the null hypothesis is accepted for the compressive strength model developed showing that the model is adequate for predicting the compressive strength.

The chart for the static modulus of elasticity showing experimental values vs. predicted values is presented in Fig. 11. The result of static modulus of elasticity F-statistic values, for F-computed and F-critical are 0.0092 and 0.4026 respectively. This showed that the F-computed is less than the F-critical as shown in Table 6. This proves that the experimental and predicted values coincide at all the experimental points for the control readings, therefore, the null hypothesis is accepted for the static modulus of elasticity model developed showing that the model is adequate for predicting the static modulus of elasticity.



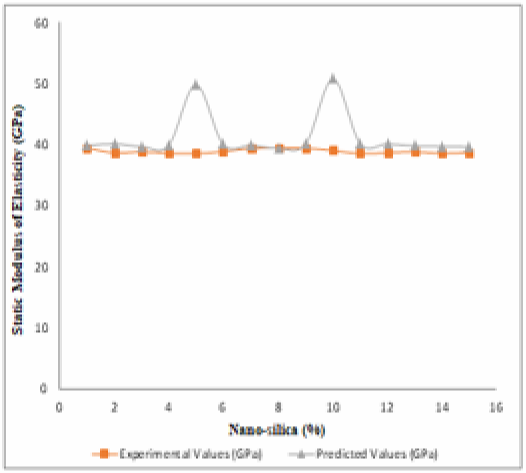


Table 5. Result of Compressive Strength Experimental and Predicted Values F-Statistic

	Experimental Values	Predicted Values
Mean	65.839921	68.10895
Variance	1.0775604	35.80271
Observations	15	15
df	14	14
F	0.0300972	
P(F<=f) one-tail	2.671E-08	
F Critical one-tail	0.4026209	

Table 6. Result of Static Modulus of Elasticity Experimental and Predicted Values F-Statistic

	Experimental Values	Predicted Values
Mean	38.938	41.3095
Variance	0.125481	13.57814
Observations	15	15
df	14	14
F	0.009241	
P(F<=f) one-tail	8.83E-12	
F Critical one-tail	0.402621	

IV. Conclusions

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

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

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

(iii) All mix ratios containing NS have higher compressive strength and static modulus of elasticity values when compared with the mixes without NS.

(iv) Compressive strength and static modulus of elasticity increased and then reached a maximum value of 68.09N/mm^2 at 5% NS content and 40.569GPa at 9.5% NS content respectively.

(v) Compressive strength optimum NS content is 5%, and the percentage effective compressive strength improved by 47.78% at 28 days.

(vi) Static modulus of elasticity optimum NS content is 9.5%, and the percentage effective static modulus improved by 22.55% at 28 days.

(vii) Mathematical model was developed to predict the compressive strength and static modulus of elasticity of NSB concrete using the Scheffe's regression technique.

(viii) The predicted values of compressive strength and static modulus of elasticity of NSB concrete were tested for adequacy at 95% confidence level using F-statistic test, the results showed that the calculated F-value were 0.0301 and 0.0092 respectively , 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 compressive strength and modulus of elasticity of NSB concrete.

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

(x) The addition of NS in concrete production is very adequate in advancing the compressive 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 was found to improve the compressive strength and static modulus of elasticity of nano-silica blended (NSB) concrete considerably. However, there were a few drawbacks in the workability as the percentage of nano-silica increases resulting in reduced workability. It is recommended that further study be carried out to establish an optimum and suitable water reducer compound for controlling workability.

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