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Research Article

Assessment of Compressive Strength Variations of Concrete Poured in-Site of Residential Buildings in Isoko District, Delta State, Nigeria

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ABSTRACT

Concrete with appreciable compressive strength is required for building constructions, to minimize the occurrence of building failures. Determination of the compressive strength of in-situ concrete produced in Isoko region of Nigeria was carried in this study. Concrete used for the construction of foundation wall footings for twenty residential buildings were sampled in the study. The compressive strength of the in-situ concrete was determined in accordance with ASTM standards. Field survey depicted that most (60%) of the concrete quality production process fell below the approved standard of 17 MPa, for residential buildings. The findings of the study revealed that the compressive strength of the in-situ concrete varied between 8.1 MPa and 19.8 MPa. Furthermore, the result of the compressive strength test showed that most (70%) of the in-situ concrete failed to meet the NIS recommended standard. Also, it was observed from the findings that proportionally, the concrete produced by conventional building/construction engineers was of a higher compressive strength, when compared to the concrete produced solely by masons. Based on observations obtained result obtained from this study, it is recommended that the Government should constantly educate building sites managers, on the need to adhere strictly to standard recommendations, in order to improve the quality of in-situ concretes produced.

RESEARCH ARTICLE

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- Compressive strength,
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INTRODUCTION

Concrete is a cement-based composite material that is widely utilized in civil engineering construction work, due to its high compressive strength, it's good thermal and radiation resistance, and it's durability, amongst other related factors (Kumbhar and Murnal, 2012; Akpokodje *et al.*, 2020). Some parts of building structures that are largely utilize concrete include: foundation footings, floors, basement walls, columns, beams, slabs, etc. The quantity of fine and coarse aggregates, the volume and cement grade, the production process, the curing methods, the water-cement ratio and the admixtures added, amongst other factors, significantly affect the physic-mechanical properties of the concrete (Okumu *et al.*, 2016; Ribeiro *et al.*, 2016; Akpokodje *et al.*, 2021). Although concrete strength is dependent on the water volume present in the fresh concrete, excessive water affects the quality of concrete gel produced (C-S-H) and predisposes the concrete so produced to failures (mostly in the form of shrinkage and cracking). Marar and Eren (2011) stated that the workability of fresh concrete is dependent on the mix ratio and the water-cement ratio; a higher cement or water volume usually result in a higher workability of the fresh concrete.

Concrete compressive strength is one of the leading factors that determines the stability and durability of concrete structures. Careful planning and supervision are necessary to avert poor quality in-situ concrete, resulting mostly from human deficiencies; that is laborer related short comings and sharp practices. Visual evidences of poor quality concrete include: scaling, discoloration, cracking, etc., Scanlon (2013), which are caused by poor quality materials, overloading, poor production, poor quality control and inadequate designs for the expansion and contraction characteristics of the concrete (Richard, 2002). Strict adherence to recommendations made by Nigeria Industrial Standard (NIS) for the construction of structures is a presently a mirage in Nigeria. Apart from buildings owned by government and corporate organizations, a vast majority of buildings in Nigeria are constructed by artisans with inadequate design and construction certification, and largely using sub-standard materials during building construction (Oloyede *et al.*, 2010; Obukoeroro and Uguru, 2021). According to Adewole *et al.* (2014) craftsmen typically carried out building constructions without prior soil tests and other required professional steps, but rather, adopt assumptive methods, to the detriment of their clients.

Building failures are becoming frequent in Nigeria, and were particularly extensive in 2020 and 2021. Nigerian Institute of Structural Engineers (NISE) has attributed most of the building failures in Nigeria to poor design, low quality concrete, faulty construction, poor supervision, substandard materials, etc., (Oloyede *et al.*, 2010; Amadi *et al.*, 2012; Oyawa *et al.*, 2016; Uguru, 2016). Likewise, the Council for the Regulation of Engineering in Nigeria (COREN) has blamed structural failures in Nigeria on poor structural designs and substandard building materials. Chendo and Obi (2015) stated that imperfection in structural design is one of the major causes of building failures globally. Furthermore, Adebayo (2010) reported that some structures failed mainly due to inadequate soil tests, deviations from the original design (which add an extra loads to the footings), earthquakes, and poor supervision. To prevent failures (indiscriminate cracking) which can ultimately lead to poor serviceability or catastrophic conditions, control or expansion joints should be inserted into large concrete slabs or floors, at regular intervals (Scanlon, 2013).

Approximately 2000 people have died from building failures within the past two decades in Nigeria. According to Sikhakhane (2021), 115 cases of building failures were recorded in Lagos State alone, in southern Nigeria between 2005 and 2016. Major buildings in Nigeria that recorded large casualties include: the Synagogue Church building collapse in 2014 and Reigners Bible Church International building collapse in 2016 (Uguru, 2016; Mathebula and Smallwood, 2017). According to COREN, foundations, floors, beams and column failures, resulting from quackery, poor maintenance, etc., are some of the leading causes of building collapse in Nigeria (Uguru, 2016). To prevent structural failures, it is recommended that concrete used for residential structures should have a compressive strength of not less than 17 MPa; while concrete used for commercial structures, and structures exposed to harsh environmental conditions should not be less than 31 MPa (ACI 318, 2011).

Several researchers (Namyong *et al.*, 2004; Okazaki *et al.*, 2012; Ribeiro *et al.*, 2016) had studied the compressive strength of in-situ concrete used for various building constructions across the world. However, current literature search revealed little information on the compressive strength of concrete used for residential building construction in Delta State, Nigeria. Hence, the objective of this study was to measure the compressive strength of in-situ concretes used for the construction of residential building wall foundation footings within the Isoko region of Delta State, in Southern Nigeria, and to verify if they are in compliance with NIS and other related international approved standards.

MATERIALS and METHODS

Area of study

Isoko is one of the major tribes in Nigeria, with a human pollution of about 800.000 people, comprising of 8 major communities and several rural communities. Isoko inhabits two universities, a technical college, a theological school, numerous small and medium scale enterprises, several oil exploring companies, etc. Resulting from population and industrial expansion, lots of building constructions (including residential buildings) are taking place in the region (Agbi *et al.*, 2020; Uguru and Obukoeroro, 2020). As a result of this, Isoko region was chosen as study area for this research.

Borrow pit sharp sand (Figure 1) is majorly used for civil engineering and building construction works in the region, however, a few site managers employ river bed sharp sand for their construction work. Geographically, Isoko experiences two major seasons (wet and dry). The wet season occurs between March and September, with temperatures of 24±4°C while the dry season occurs between September and March, with a temperature range of 31±4°C. The study was carried between August 2021 and January 2022 - involving the two climatic seasons (wet and dry seasons).

Figure 1. Point of collection of borrow pit sharp sand.

Samples collection

Twenty (20) residential/commercial structures and construction sites (one shown in Figure 2) were visited for the purpose of this study. The sites were selected randomly, but were evenly distributed across the Isoko metropolises to present a fair representation of building population in the region. The sampling number adopted was fairly representative of the number of site managers (masons and engineers) actively available on building projects within the region. A mason here is considered to a site manager without formal tertiary engineering education, but responsible for the construction; while an engineer is the site manager with such formal education, and also responsible for the construction. Double counting was strictly avoided, as only one building site was selected per site manager captured in the study. For uniformity, only single and two storey reinforced concrete structures were captured for this study.

Figure 2. A typical building construction site.

Field observation

At each building site, thorough observations were made in order to obtain valid information, such as: type of cement used, mix ratio, water to cement ratio, concrete production methods, etc. Data collection during the fieldwork was through observations and organized interview questions.

Sieve analysis

The sieve analysis of the fine aggregate used for the concrete production was done in accordance with NIS-87 procedure. 500 g of dry sand (fine aggregate) was poured into a pre-arranged set of sieves, arranged in a descending order. The sieves were shaken vigorously for 15 minutes, and allowed to stand for another 10 minutes, so that the fine particles can settle. Then, each sieve was removed from the set, starting with the uppermost one, and weighed with a digital weighing balance (Figure 3). A particle size distribution curve was plotted as described by (Odeyemi *et al.*, 2015), and the coefficient of uniformity (Cu) was calculated using the expression given in Equation 1 (USCS, 2015).

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

Where:

C_u = uniformity coefficient (ASTM D2487),

D_{60} = 60% of finer grain size soil

D_{10} = 10% of finer grain size soil (USCS, 2015).

USCS stated that a sand is tagged Poorly Graded (P) when the C_u is less than six, and fines are less than 5 percent; and a sand is tagged Well Graded (W) when the C_u is greater than six and the fines are less than 5 percent.

Figure 3. Weight of the sand retained in the sieve.

Concrete cube production and curing

At each building site, four (4) concrete cubes were made, in accordance with ASTM International standard, from the fresh concrete collected from the various construction sites (Figure 4). During concrete cube production; freshly mixed concrete was poured into standard moulds in three equal layers, rammed thirty-five times per layer, and then flattened on the exposed surface with a hand trowel in order to produce a fairly flat surface finish.

Figure 4. Taking of fresh concrete for laboratory analysis.

The produced concrete cubes were shielded from exposure with black polyethylene sheets and left under shaded environments for 24 h, before they were all transported to the laboratory. In the laboratory, the concrete cubes were removed from the moulds, after 24 h, and cured through the total water immersion method for 28 days.

Slump test

At each sampling site, the slump test was used to determined the concrete's determine the consistency. The general procedures for concrete slump testing were performed in accordance with ASTM International standards (Figure 5).

Figure 5. Taking of the slump measurement.

Compressive strength test

The crushing force of concrete was measured in accordance with procedures set by ASTM C109/C109M (2020), using a concrete crushing machine (Figure 6). Four concrete cubes were tested for each construction site, and the average recorded.

Figure 6. A concrete cube undergoing compression testing.

The compressive force was calculated by the formula given in Equation 2 (Akpokodje *et al.*, 2021a).

$$Compressive\ strength = \frac{F}{A} \quad (2)$$

Where:
F = force required to crush the concrete cube (N)
A = effective area of the concrete cube (mm^2)

Statistical analysis

Raw data obtained from this research were statistically presented and analyzed using the pie chart, the bar chart and Analysis of Variance (ANOVA), through the aid of the MS-Word excel package.

RESULTS AND DISCUSSION

Field information

Table 1 shows the result of the analysis of fieldwork. As can be seen in Table 1, only 8 of the sites managers took cognisance of the water-cement (w/c) ratio, which ranged between 0.45 and 0.60. The result revealed that most (12) of the site managers continued to add water to the concrete until it becomes workable. This had led to addition of excess water to the concrete in most cases. From the field survey, out of the 20 sites managers, only 4 (20%) of them were qualified civil or structural engineers, while the remaining 16 (80%) sites managers were Masons. This is in conformity with related reports (Oloyede *et al.*, 2010; Adewole *et al.*, 2015), which stated that about 70% of buildings in Nigeria are constructed by unqualified professionals (e.g. craftsmen).

Generally, batching by volume method was adopted by all the sites managers, and problems of under batching or over batching was conspicuously observed on some building sites; mostly, on sites managed by masons. This can result in deviations or serious decline in the mechanical properties of concrete so produced, hence, making the building susceptible to economic and structural failures.

With respect to the concrete mix ratio, observations made revealed that the concrete mix ratio varied from a lean 1:3:6 mix to a much leaner 1:5:10 mix for the concrete works; many (40%) of the site managers' tended to use mix-ratios that are leaner than appropriate conventional specified grades, and which produced poor and relatively unacceptable concretes. A 1:5:10 mix ratio, closely relating to grade M 5 at curing day 28, had predominantly and previously been observed (Mishra, 2021). It was also observed from the result (Table 1), that all the site managers used a uniform coarse aggregate size (19 mm), for the in-situ concrete production. Moreover, the result revealed that majority (60%) of the managers used manual mixing methods, which they considered to be less expensive; but which were often to the detriment of the property owner in terms of mechanical quality. It had been experimentally verified (Aguwa, 2006) that concrete produced through manual mixing processes, tend to have poorer compressive strengths, when compared to concrete produced through mechanical machine mixing processes. Further analysis of the result revealed that the certified engineers used mechanical machine production processes, which can be attributed to the awareness obtained through their formal education.

Table 1. Concrete proportions adopted.

Building site	Mix ratio	Concrete Grade	w/c (%)	Site supervisor	Mix method	Coarse aggregates size	Batching method
1	1:5:10	M 5	0.45	Mason	Mechanical	19 mm	Volumetric
2	1:3:6	M 10	0.55	Engineer	Mechanical	19 mm	Volumetric
3	1:5:10	M 5	ND	Mason	Manual	19 mm	Volumetric
4	1:4:8	M 7.5	ND	Mason	Manual	19 mm	Volumetric
5	1:4:8	M 7.5	0.50	Engineer	Mechanical	19 mm	Volumetric
6	1:5:10	M 5	ND	Mason	Manual	19 mm	Volumetric
7	1:3:6	M 10	0.5	Engineer	Mechanical	19 mm	Volumetric
8	1:3:6	M 10	ND	Mason	Manual	19 mm	Volumetric
9	1:5:10	M 5	0.55	Mason	Manual	19 mm	Volumetric
10	1:5:10	M 5	0.60	Mason	Manual	19 mm	Volumetric
11	1:4:8	M 7.5	ND	Mason	Manual	19 mm	Volumetric
12	1:5:10	M 5	ND	Mason	Mechanical	19 mm	Volumetric
13	1:3:6	M 10	ND	Mason	Mechanical	19 mm	Volumetric
14	1:3:6	M 10	0.50	Mason	Mechanical	19 mm	Volumetric
15	1:4:8	M 7.5	ND	Mason	Manual	19 mm	Volumetric
16	1:4:8	M 7.5	ND	Mason	Manual	19 mm	Volumetric
17	1:4:8	M 7.5	0.50	Engineer	Mechanical	19 mm	Volumetric
18	1:5:10	M 5	ND	Mason	Manual	19 mm	Volumetric
19	1:5:10	M 5	ND	Mason	Mechanical	19 mm	Volumetric
20	1:3:6	M 10	ND	Mason	Manual	19 mm	Volumetric

ND = not determined

Fine aggregates quality

The result of the sieve analysis of fine aggregates used at the building construction sites is presented in Figure 7. The result showed a great variety in the quality of fine aggregates used for building construction in the region. It could be observed from Figure 1, that out of the 20 building sites, only 39% of the managers used well graded fine aggregates for their concrete production, while the remaining managers (61%) used poorly-graded fine aggregates for their concrete production. This can be attributed to the general high cost of the well-graded fine aggregates. Within the Isoko region, the price of 20 tons of well-graded fine aggregates is twice the price of 20 tons of poorly graded fine aggregates; thus many site managers tend to use the lower cost fine aggregates, usually to the detriment of the concrete's quality. According to USCS and NIS, only well graded fine aggregates are recommended for concrete production, since they tend to produce high quality concrete; thereby, minimizing chances of structural failures (USCS, 2015).

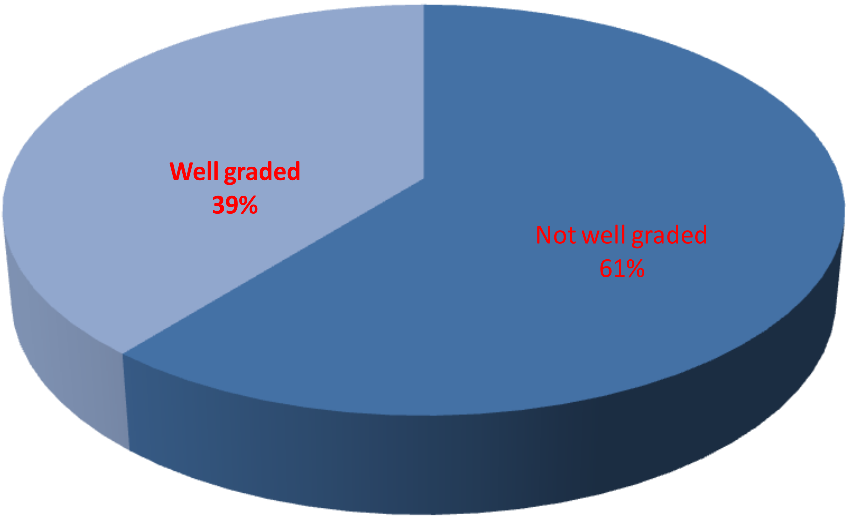

Figure 7. The quality of the fine aggregates.

The concrete slump

The result of the concrete slump from all the building sites is presented in Figure 8. Figure 8 revealed that the concrete slump varied between 39 mm and 71 mm. As shown by the result, concretes produced with unspecified water volumes had higher slump values when compared to concretes produced with specified water volumes. As presented in the chart (Figure 2), building sites 3, 6, 18 and 19, had the highest slumps of 61 mm, 65 mm, 71 mm and 65 mm, respectively; this could influence the quality of hardened concrete produced. Although a higher slump value implies better workability of the concrete, it is however a serious drawback factor to the concrete's mechanical properties (ACI 332.1R-06, 2006), especially if it result from added water. According to Scanlon (2013), higher slump values (due to additional water) tends to produce concrete with weaker compressive strengths, because the cement paste becomes leaner and weaker, and shrinkage occurs within the concrete. Also, concretes with higher slump values, tend to attain poorer quality consolidation during compaction/vibration due to aggregate particle segregation, resulting in the production of a weaker quality of concrete (ACI 303R, 2012).

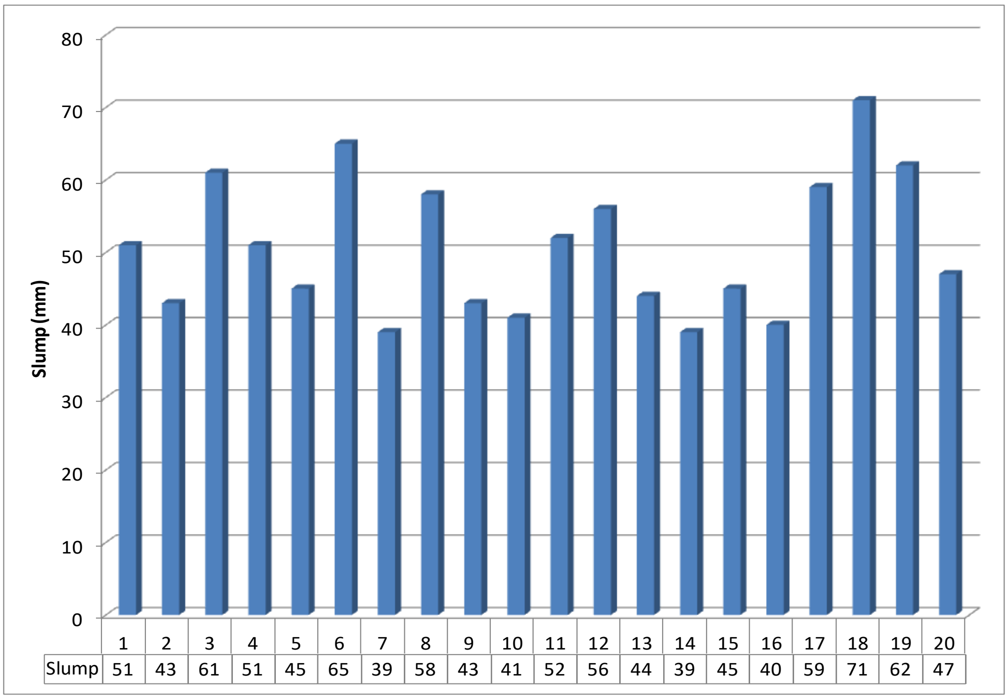

Figure 8. In-situ concrete slump.

Compressive strength

The ANOVA result of the effect of sampling location on the concrete's compressive strength is presented in Table 2. It was observed in Table 2 that there was significant difference between the concrete samples.

Table 2. ANOVA of the effect of building site on the concrete compressive strength.

Source of Variation	SS	DF	MS	F	P-value	F critic
Between Groups	624.43	19	32.86	117.86	3.75E-29	1.85
Within Groups	11.15	40	0.28			
Total	635.58	59				

The mean compressive strength of the in-situ concrete obtained in this study is presented in Table 3. The information in Table 3 portrayed that the compressive strength of in-situ concretes used in the area ranged from 8.1 MPa to 19.8 MPa. As depicted by the result. Only 6 buildings (2, 7, 13, 14, 16 and 20) attained the recommended concrete compressive strength (17 MPa and above) for residential buildings; the concretes for the remaining 14 buildings, failed to meet the allowable compressive strength threshold recommended for residential buildings. It was noticed that in building 19, despite the comparatively leaner mix ratio, a higher concrete compressive strength was obtained. This could be caused by incorrect batching during the concrete production, as a higher cement volume may have been used in the concrete production, thereby producing concrete with a higher compressive strength. Bhattarai and Mishra (2017) reported that improper batching and mixing of concrete constituents, generally affect the concrete quality produced.

It was observed in the result (Table 3) that the buildings that satisfactorily met the compressive strength requirement, were those that the managers utilized lower water-cement ratios and fairly conventional concrete mix ratios. This confirmed a previous report by Ribeiro *et al.* (2016) which stated that water-cement ratios considerably affect the compressive strength of in-situ concretes. The poor quality concrete produced in building 8, despite its better mix ratio, could be attributed to the volume of water and the production method used during the concrete production. Water quality and quantity, the mixing method and the curing method, are some influential factors that affect the compressive strength of in-situ concrete (Abdullahi, 2012; Ribeiro *et al.*, 2016); therefore, site managers should adhered strictly to the required volume of water used for concrete production.

Furthermore, the closely related concrete compressive strengths (13.5 MPa, 10.5 MPa and 14.5 MPa) observed in building sites 8, and 4 and 15 respectively, despite the different concrete mix ratios adopted, could be attributed to variations in the quality of the component materials used for the concrete productions. Okumu *et al.* (2017) in their research observed that, poor quality materials (sand, gravel, etc.) largely affected the compressive strength of the in-situ concrete produced. Result obtained in this study are similar to those obtained by Sisay (2017) who observed great discrepancies in the concrete used for residential building constructions in Ethiopia. Sisay (2017) reported that the in-situ concrete produced in Addis Ababa varied between 15.39 MPa and 33.05 MPa.

Table 3. Compressive strength data of the in-situ concrete used for the building construction.

Building	Compressive strength (MPa)*
1	9.5±1.5
2	18.3±1.9
3	13.4±1.3
4	13.5±2.4
5	15.8±1.7
6	8.1±1.2
7	19.8±2.1
8	10.5±1.7
9	14.3±1.6
10	12.6±1.9
11	15.2±2.1
12	14.6±1.1
13	18.1±1.8
14	17.5±2.2
15	14.5±2.1
16	17.3±2.2
17	14.9±1.4
18	9.2±1.3
19	16.4±1.9
20	17.6 ±2.1

* n= 4; ± standard deviation

Furthermore, the poor concrete quality recorded in some of the building sites, despite the fair mix ratios and good production methods, could be as a result of environmental conditions. During hot weather (as experienced in the dry season in Nigeria), the rate of water evaporation from fresh concrete tends to be higher, thus making the cement dry out and set speedily; thereby, producing concretes with lower compressive strengths, if such concretes are not cured appropriately. In a research carried out by Salem and Pandey (2017), the authors observed that the concrete compressive strength declined from 22.3 MPa to 17.25 MPa, as the water to cement ratio was increased. Similarly, Adeyemi *et al.* (2019) reported that compressive strength tests showed that concrete cubes gained strength with increase in curing age but strength decreased with an increase in the water to cement ratio. As reported by Adeyemi *et al.* (2019), the compressive strength of concrete declined from 25 MPa to 19 MPa, as the water-cement ratio increased from 0.4 to 0.6.

From the study's result, it is advisable for site managers to employ the use of retarders during hot weather concreting, in order to delay the setting of the concrete and reduce evaporation, thereby enhancing the hydration process of the cement. Scanlon (2013) reported that high temperatures facilitate concrete's setting time. Finally, the volume of water utilized for concrete production should be closely monitored, as the findings from this study had corroborated the fact that water volume greatly influences the compressive strength of concrete.

Relationship between the concrete slump and the compressive strength

Figure 9 and Table 4 show the relationship between in the in-situ concrete compressive strength and the slump. As presented in Table 3, significant ($p \leq 0.05$) relationship existed between the concrete slump and its compressive strength. This is an indication that the slump had significant ($p \leq 0.05$) influence on the compressive strength of the concrete produced in the Isoko district. The chat (Figure 9) depicted that the concrete compressive strength was inversely proportional to the slump result. It was noted that the concrete strength declined non-linearly, as the concrete slump increases. This is a confirmation of Scanlon (2013) report that concrete with higher slump values tends to produce poor compressive strength, unless special additives are added to the concrete.

Table 4. The ANOVA result of the effect of slump on concrete compressive strength.

Source of Variation	TSS	df	MSS	F	P-value	F crit
Between Groups	12992.42	1	12992.42	255.74	1.83E-18*	4.09
Within Groups	1930.55	38	50.81			
Total	14922.98	39				

* = Significant at $p \leq 0.05$

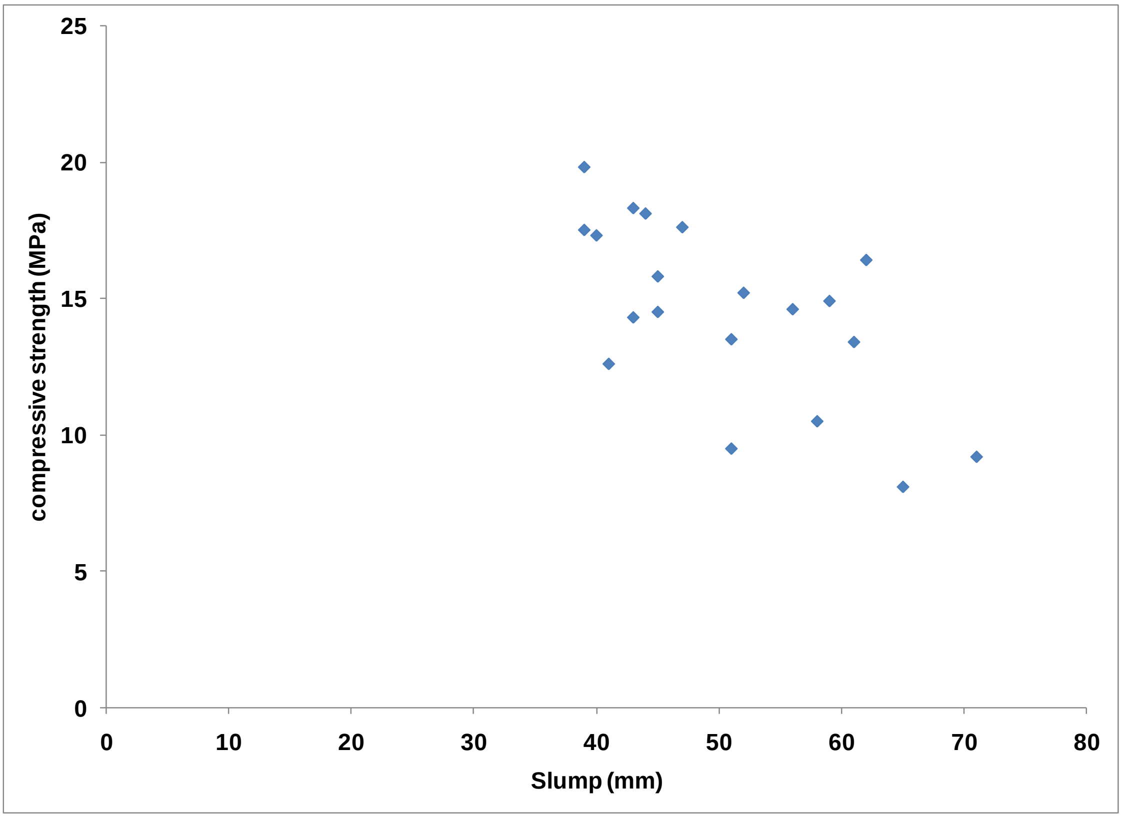

Figure 9. Relationship between concrete compressive strength and its slump.

CONCLUSION

Concrete plays a key function in building structures and residential building construction, but its quality is barely adequately monitored in Nigeria. This study is an appraisal of the concrete used for the construction of foundation wall footings for residential buildings in Isoko region of Nigeria. It identifies the common concrete production hitches and proffers recommendations. Field observations revealed that most (60%) of the in-situ concrete produced do not adhere to the NIS and ASTM recommendations for concrete production. The findings depicted that only 30% of the building sites sampled met the recommended compressive strength (17 MPa) for concrete to be used for residential buildings construction (this is inspite of the general inadequate mix ratios presented); while the concrete used for the remaining 70% of buildings sampled, fell below the 17 MPa approved threshold. Based on the findings of this study, it was ascertained that the conduct and quality of site managers greatly affects the quality of concrete produced; concretes produced by engineers were of a fairly higher compressive strength compared to those produced by masons. It can be concluded from this study that a lack of appropriately qualified professional involvement in the concrete production process contributed considerably to the general poor quality of concrete produced for the foundations of the residential buildings in the region, which has generally reflected as cracking on buildings walls in the region. Based on the findings of this study, the following recommendations can be made:

i. Seminars and regular site visits should be provided by the Government in collaboration with COREN and NSE (Nigerian Society of Engineers) to educate masons and engineers, as part of post qualification and continued education training on construction practice, and on the specific issue of adequate mix ratios and how to effect and improve the quality of in-situ concretes.

ii. Buildings supervisors should ensure the use of standard materials and methods for their building construction. This should be backed by adequate and effective monitoring by appropriate governmental agencies.

iii. Masons should never be sole managers of building sites as they are technically ill equipped for such arrangements; hence, qualified or certified engineer/personnel should superintend.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors declared that the following contributions are correct.
Hilary Uguru: Designed the research
Ovie Isaac Akpokodje: Edited the manuscript.
Goodnews Goodman Agbi: Write the original draft.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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