[1.]Y.L. SHUAIB-BABATA, [2.]R.A. ADEWUYI, [3.]K.S. AJAO, [4.]I.O. AMBALI, [5.]N.I. AREMU, [6.]H.K. IBRAHIM, [7.]J.M. ABDUL

QUALITY EVALUATION OF COMMERCIALLY AVAILABLE STEELS IN SOME SELECTED NIGERIAN MARKETS

[1,3,4,5.] Department of Materials & Metallurgical Engineering, University of Ilorin, NIGERIA
[2.] Olusegun Obasanjo Centre for Engineering Innovation, The Federal Polytechnic, Ado-Ekiti, NIGERIA
[6.] Department of Mechanical Engineering, University of Ilorin, Ilorin, NIGERIA
[7.] Department of Mechanical Engineering, Federal Polytechnic, Offa, NIGERIA

Abstract: The incessant building collapse and structural failures in Nigeria has renewed interests in the evaluation of the basic properties of reinforcing steel bars in Nigeria markets, since local markets serve as major source of supply for the steels used in construction and structural development. Thus, this study evaluated the quality of commercially available reinforcing steel bars in some selected markets with a view to determine their suitability for structural applications. Various steel bars samples were obtained from markets in four Nigeria cities. The basic physico-mechanical properties of the samples were examined and the obtained results were compared with the specified parameters in Nigerian Industrial Standard (NIS), ASTM and British Standards. Visual inspections revealed that most of the parameters that must to be indicated in identification marks on reinforcing steel bars were absent. Results also showed that the samples contained the basic chemical constituents of steel and possessed significant strengths and hardness values, but with noticeable inconsistencies in their contents. Thus, the level of compliance with the specified properties in the standards needs improvement. To avoid incessant structural failures in the country, regular and effective monitoring of the quality of steel bars in the markets for structural applications becomes imperative.
Keywords: compliance to standards, steel bars, strength, reinforcement, structural failures

1. INTRODUCTION

Steel is one of the prominent engineering materials in use today for construction purposes (Sambo *et al.*, 2009). Essentially, it is an alloy of iron and carbon, with carbon content up to roughly 2% (Higgins, 1998). In construction and modern structures, such as building, bridges, dams, steel is predominantly used in reinforcing concrete. Appropriate knowledge of properties and characteristics of steel is essential to ensure that reliable, safe and durable structures are attained in structural development. Commercially available steels in Nigeria construction industries are obtained from both within and outside the country (Shuaib-Babata & Tanimowo, 2016). Most indigenous construction companies in Nigeria procure their reinforcing steels from open markets without any guiding technical information on their appropriate use. These steels are tagged as foreign and local products in the markets, which are available in the sizes ranging from 8, 10, 12, 16, 20, 25 to 32 mm. Experience has shown that most structural failures are caused by improper selection and application of materials (Shuaib-Babata & Tanimowo, 2016; Olanitori, 2011). Thus, the quality of concrete structure and its reinforcing component (steel rods) are questionable in an event of building collapse or failure of structure (Arayela & Adam, 2001). Reinforcement of concrete became imperative and indispensable because of the fact that steel bars embedded in the concrete resisted all stresses in the concrete structures (Joshua, *et al.*, 2018). In addition to the widespread use of steel as a crucial material in the construction industries, steel also found applications in military hardware, power generation plants, telecommunications, aviation, medical equipment, automobile components, as well as oil and gas sector. However, the increasing recycling of scraps of iron and steel for steel production in Nigeria has adversely affected the quality of available steel in Nigerian markets (Ohimain, 2013).

Several research works had been carried out on steel rods produced in Nigeria. The quality of steel rods available in Onitsha markets was assessed and results showed that some products fall short of standard (Benneth & Julius, 2010). Ejeh and Jibrin (2012) examined the tensile behaviour of reinforcing steel bars used in the Nigeria construction industries to ascertain their level of conformity with relevant standards. A comparative assessment of the chemical and mechanical properties of locally produced reinforcing steel bars from four indigenous steel industries that uses scraps as their major raw materials was carried out. It was observed that steel rods used in Nigerian construction industries conformed to NIS 117:2004 standards' specifications (Alabi & Onyeji, 2010). Also, an assessment of suitability of Nigerian made steel bars for structural applications was done. The mechanical properties of selected reinforcing steel bars produced from two rolling mills in Osun State, Nigeria were studied and observed that the investigated reinforcing steel bars samples possessed reasonably high strength and ductility when compared with available standards (Alabi *et al.*, 2016).

Conversely, the incessant rates of building collapse and structural failure in Nigeria call for re-evaluation of the basic mechanical properties of steel samples in our local markets, since local markets serve as major source of supply for the steels used in construction and structural development (Shuaib-Babata & Tanimowo, 2016). Figure 1 shows some of the recently collapsed buildings in Ilorin as a result of inappropriate application of reinforcing steel bar. Thus, the objective of this work is to evaluate the mechanical and chemical properties of commercially available steel samples in some selected Nigerian markets, with a view to determine their suitability for structural applications, so as to proffer solution to the incessant building collapse and structural failure in Nigeria.

Figure 1: Some collapsed buildings in Ilorin (2017-2018). **Source**: Nigerian Society of Engineers, Ilorin Branch, 2019)

2. MATERIALS AND METHODS

— Materials

Samples of reinforcement steel bar were obtained from major steel markets in Ilorin, Benin, Lagos and Kaduna (Figure 2). The samples of each selected steel bars obtained were cut and machined to standard dimensions in line with the ASTM Standards (A370-03a, 2005). The Samples were designated as presented in Table 1. The diameters (sizes) of the selected samples bars for this study were 10, 12 and 16 mm, in accordance with affirmation of Arum (2008) that 10,12 and 16 mm bars are among the most widely used bar for local concrete reinforcement.

Table 1: Samples' Designation

S/N	DESIGNATION	SOURCES
1	A, B, C, D	Benin
2	E, F, G, H	Ilorin
3	I, J, K, L	Kaduna
4	M, N, O, P	Lagos

Figure 2: Some reinforcing rods at the building materials market sites in some of the selected cities in Nigeria

— Physical Assessment of the Test Specimens

The appearance of each of the steel samples was visually inspected at various market locations, to assess the following parameters as indicated in Nigerian Industrial Standards (NIS 117:2004). The parameters include NIS mark, Batch reference, Grade identification, Cast number, Name of manufacturer and Standard Organisation of Nigeria (SON) certification mark. The sizes of the steel samples were measured using Digital Vernier Calliper.

— Chemical Analysis of the Test Specimens

Chemical composition analysis of the samples was carried out using Optical Emission Spectrometer (Spectromaxx LMF06 Spectrometer, Serial Number: 15007384) at Midwal Engineering Services Limited, Lekki, Lagos, Nigeria. Three specimens of each of the samples were grinded for 5 seconds on a metallographic abrasive grinding machine to reveal the cores of the samples after which the flat surface was rinsed with methanol to eliminate contaminants. The samples were mounted one after the other on the Optical Emission Spectrometer. The average percentage chemical composition of each steel samples was obtained.

— Tensile Test

Practically, tensile strength of steel is difficult to determine without resulting to tensile test experiment (Kareem, 2009). Therefore, to determine the strengths of the sample, tensile test was carried out. The tensile specimens were prepared in accordance with the specifications in NIS 117:2004, as presented in Table 2. The tests were carried out in accordance with the method of yield and tensile strengths determination specified in NIS 166:1982. The tensile properties of the specimens were determined using Win Test Analysis on Testometric Materials Testing Machine (Type DBBMTCL-5000 Kg, Serial No. 17819) at National Centre for Agricultural Mechanization Universal testing Machine (NCAM UTM) Laboratory, Ilorin, Nigeria, based on ASTM A370-03a (2005) guidelines. Each of the machined specimens was firmly gripped between the jaws of the machine. The jaws were pulled apart at strain rate of 10 mm/minute until the specimens are fractured. The values of the tensile stress and tensile strain at various points (yield, peak, and fracture) for each specimen were obtained and documented from the system.

Table 2: Guage Length and Total Length of the Specimens

S/N	NOMINAL DIAMETER (mm)	GUAGE LENGTH (mm)	TOTAL LENGTH (mm)
1	10.0	50.0	260.0
2	12.0	60.0	280.0
3	16.0	80.0	540.0

— Hardness Test

The hardness of each of the tested specimens was determined using Brinell hardness tester. The steel samples were placed on the anvil of Brinell hardness testing machine one after the other and the capstan hand-wheel was turned until the samples touch the indenter. A load of 3000 kg was gradually applied perpendicular to the surface of the steel specimens through a steel ball indenter of 5mm diameter. This load was maintained for 15 seconds on each specimen. The diameter of the indentations were viewed and measured with a graduated low power Brinell microscope. The values thus obtained were converted to Brinell hardness number (BHN) using a Brinell hardness number chart.

3. RESULTS AND DISCUSSION

The results of the chemical analysis and mechanical testing of the reinforcing steel samples are presented in Tables 3 – 5 and Figures 3 – 14. These properties, such as chemical composition, strength and hardness, are important parameters for evaluation of the steel quality.

— Physical Assessment of the Test Specimens

Through visual inspection of the steel samples right from the market sites, it was observed that most parameters stipulated in NIS 117 (2004) to be indicated on label attached to every bundle of bars or each coil of reinforcing bars in Nigeria market were virtually absent. The parameters include NIS mark, Batch reference, Grade identification, Cast number, Name of manufacturer and Standard Organisation of Nigeria (SON) certification. This implies that most steel bars in Nigerian markets as at the time of this study were of non-recognised origin.

The sizes of the reinforcing bars measured varied from the specified nominal diameters in the standards. For instance, reinforcing bars of nominal diameter of 10 mm were found to be in the range of 9.58 to 9.80 mm, which implies that the samples were within allowable range of sizes as specified in NIS 117 (2004). The standard specifies ± 6.5% and ± 4.5% as allowable tolerance sizes for 8mm to10mm and 12 mm and above reinforcing steel bars respectively (NIS 117, 2004). There is need for effective routine monitoring (inspection and testing) of steel products in Nigeria markets by the appropriate authorities, especially SON, to measure the level of compliance to the standards and ascertain strict compliance to it. This will help to prevent turning Nigeria building materials markets to dumping grounds and also reduce drastically the incessant rates of structural failures in Nigeria. The use of inappropriate materials, especially reinforcing bars, of lesser quality is one of the major factors leading to structural failures in Nigeria (NIS 166:1982; Ayodeji, 2011).

— Chemical Composition Analysis of the Test Specimens

In designation of steel, chemical composition plays prominent roles (Khurmi & Gupta, 2005). Most institutes and professional bodies, like American Iron and Steel Institute considered chemical composition as important factor in categorization of steels (AZoM, 2012; MIT, 1999). To define mechanical properties of steel, chemical composition is a fundamental factor (AZO Minning, 2018). From evaluation of carbon percentage contents of steel through chemical analysis, the class of steel can be determined (Kareem, 2009). Tables 3 - 5 show the level of various elemental components in Nigerian commercial reinforcement steel bar samples. The standard values are presented with the obtained results in Table 3 for better evaluation.

The experimental results in Tables 3- 5 show that the samples' constituents were essentially iron and carbon with some other minor elements, such as Nitrogen, Silicon, Manganese, Copper, Chromium and Sulphur, as expected of a steel sample (The Balance, 2019). The percentage of iron in 10 mm size samples ranged between 97.3 and 98.6% as the highest elemental concentration in the steel (Table 3). Specimens A – D, E – H, I - L, and M – P respectively contained 97.7 – 98.1%, 97.4 – 98.6%, 97.8 – 98.3% and 97.3 – 98.8%. Generally, the percentages of carbon in the samples range between 0.17 and 0.28%, with samples A, B, C and D having 0.17 - 0.28%, samples E, F, G and H having 0.2 – 0.4%, samples I, J, K and L having 0.17 – 0.31% and samples M,N,O and P possessed 0.21 – 0.32%.

Table 3: Elemental constituents of commercial 10mm reinforcement bars and specified values in the standards

Samples	Percentage Elemental Composition (Wt %)								
	Fe	C	Ni	Si	Mn	P	Cu	Cr	S
A	97.7	0.27	0.130	0.016	0.36	0.190	0.37	0.33	0.20
B	98.1	0.17	0.210	0.150	0.37	0.510	0.31	0.10	0.05
C	98.0	0.20	0.150	0.180	0.61	0.031	0.47	0.21	0.09
D	97.8	0.28	0.060	0.015	0.53	0.110	0.30	0.26	0.17
E	98.3	0.35	0.140	0.240	0.81	0.021	0.05	0.04	0.01
F	98.6	0.20	0.140	0.210	0.41	0.016	0.05	0.12	0.01
G	98.1	0.27	0.002	0.160	0.72	0.013	0.40	0.17	0.02
H	97.4	0.40	0.180	0.220	0.72	0.093	0.28	0.16	0.07
I	98.3	0.30	0.090	0.015	0.48	0.052	0.23	0.03	0.18
J	97.8	0.21	0.160	0.021	0.69	0.012	0.40	0.21	0.04
K	98.0	0.17	0.230	0.050	0.31	0.510	0.29	0.10	0.11
L	98.1	0.20	0.130	0.191	0.63	0.050	0.37	0.19	0.11
M	98.8	0.21	0.160	0.030	0.39	0.012	0.30	0.02	0.04
N	97.3	0.31	0.210	0.072	0.51	0.510	0.29	0.21	0.17
O	97.7	0.31	0.190	0.210	0.49	0.190	0.13	0.19	0.11
P	98.1	0.32	0.070	0.230	0.31	0.040	0.21	0.30	0.07
STANDARD VALUES									
NIS 117		0.35	0.012	0.300	1.20	0.040	0.25		0.04
ASTM A615		0.3		0.400	1.00	0.050			0.05
BS 4449		0.25		0.400	1.00	0.050			0.05
AISI 1018	99.26	0.2	0.050		0.90				0.04

The percentage level of carbon in the samples (Tables 3-5) conforms to the view that the carbon steel contains tiny amount of carbon much less than 1.0% carbon (Total Materia, 2019). Thus, the steel samples can be classified as carbon steel. Though, the level of compliance to the NIS 117 (2004) and BS 4449 (2005) standards regarding the carbon contents in 10 mm size reinforcement bars available commercially in Nigeria markets was 56.25%. This implies that 43.75% of the samples contained percentage carbon less than 0.25% stipulated in NIS117 (2004) and BS 4449 (2005) standards as minimum requirement.

Manganese (Mn) plays a vital role in the properties of the steel, most especially on its hardness and strength (Herring, 2010; AZoM, 2016). In the steel samples, Mn ranged between 0.31 and 0.72%. This implies that the values were lesser than 0.9 – 1.0% stipulated as required values in the steel (BS 4449; ASTM A615-72; AISI 1018). This is likely to affect the strength and hardness of the steel samples, as Mn is a key component of steel (AZoM, 2016). In the samples, values of silicon (Si) were found to be in the range of 0.015 – 0.24%, which were lesser than 0.4% required value in reinforcement steel bars as specified in the standards (BS 4449; ASTM A615-72). Due to lower value of Si in the steel, the ductility, tensile and yield strength and hardness of the steel may be low, since Si as a deoxidizer and degasifier increases ductility, tensile and yield strength, hardness, forgeability and magnetic permeability of steel (Special Steel China Supplier, 2019).

Sulphur (S) in the samples was within 0.01 and 1.18%. NIS 117:04 recommended 0.04% as required value in reinforcement rod in Nigeria, while ASTM A370-03a (2003), BS 4449 (2005) and AISI 1018 stipulated 0.05% as the Sulphur standard value in the steel rod. The results (Table 3) reveal that 62.5% of the samples had sulphur contents greater than the NIS 117:04 specified value (0.05%). However, 12.5% samples had exactly 0.04% Sulphur content as specified in ASTM A615-72, BS 4449 and AISI 1018, while 25.0% samples had less than 0.04% Sulphur content. Presence of Sulphur in steel has the tendency to lower its ductility and notched impact toughness, but improves toughness (Jeremey, 2015). Machinability of steel is improved if sulphur is combined with manganese, but lowers the steel ductility and impact strength (Leonghuat, 2019). With Sulphur, manganese has the ability to form manganese sulphide (MnS) that is of beneficial to machining (Leonghuat, 2019). The most pronounced segregation of all steel accompanying elements is produced, if steel is high in sulphur and low in manganese (Satyendra, 2014).

In all the 10 mm samples, the Nitrogen (Ni) contents ranged between 0.002 and 0.23%, which were greater than either 0.012% or 0.05% recommended in NIS 117:04 and AISI 1018 standards respectively. This may enhance the tensile strength, hardness and machinability of the steel, but may also have embrittling effect on the steel (Jeremey, 2015). Presence of high content of nitrogen in the steel samples may also reduce their toughness and ductility. The results (Table 3) show that the phosphorous content in 10 mm samples was between 0.012 and 0.51%. Though, NIS 117:04 and AISI 1018/BS

4449/ASTM A615-72 respectively recommended 0.04 and 0.05% (BS 4449; ASTM A615-72; AISI 1018) as the level of Phosphorous in reinforcement steel bar. The analysis of the results shows that the steel samples with phosphorous values below 0.04% were 50.00%, while 6.24% samples had exactly 0.04% and 76.00% samples had phosphorous beyond the specified value. The presence of phosphorous in steel improves its strength, machinability and atmospheric corrosion resistance, but decreases ductility and notch toughness (Satyendra, 2014). To improve machinability of steel, higher phosphorous (P) is specified in low carbon steel (Leonghuat, 2019; Total Materia, 2017).

Table 4: Elemental constituents of commercial 12mm reinforcement bars

Samples	Percentage Elemental Composition (Wt %)								
	Fe	C	Ni	Si	Mn	P	Cu	Cr	S
A	97.6	0.40	0.200	0.26	0.60	0.057	0.27	0.11	0.20
B	98.4	0.36	0.040	0.10	0.62	0.021	0.05	0.37	0.01
C	98.2	0.28	0.220	0.21	0.05	0.060	0.40	0.02	0.18
D	97.8	0.32	0.020	0.21	0.35	0.020	0.37	0.17	0.32
E	97.5	0.35	0.190	0.19	0.53	0.090	0.33	0.19	0.16
F	98.3	0.25	0.120	0.18	0.31	0.057	0.37	0.31	0.07
G	98.2	0.31	0.250	0.34	0.18	0.030	0.37	0.20	0.11
H	97.8	0.23	0.152	0.10	1.11	0.040	0.31	0.04	0.20
I	97.5	0.39	0.110	0.22	0.34	0.161	0.34	0.31	0.18
J	97.9	0.41	0.261	0.15	0.74	0.063	0.05	0.25	0.01
K	97.8	0.37	0.031	0.33	0.66	0.050	0.17	0.04	0.15
L	98.4	0.27	0.210	0.16	0.34	0.030	0.04	0.31	0.03
M	97.6	0.23	0.131	0.29	0.24	0.124	0.25	0.39	0.28
N	98.5	0.20	0.172	0.27	0.15	0.041	0.33	0.20	0.09
O	98.1	0.25	0.150	0.20	0.41	0.070	0.31	0.29	0.17
P	98.3	0.31	0.131	0.21	0.61	0.020	0.05	0.14	0.11

The iron content in 12 mm samples of the bar generally ranged between 97.5 and 98.5%. Samples A – D, E – H, I – L and M – P respectively possessed 97.6 – 98.4%, 97.5 – 98.3%, 97.5 – 98.4%, and 97.6 – 98.5% iron contents. The carbon contents in the steel bar samples were between 0.20 and 0.4%, which shows that the samples are carbon steels which may either belong to low or medium carbon steel class. The samples' nitrogen (Ni) contents (Table 4) were also between 0.03 and 0.26%, which were higher than the NIS 117 (2004) specified value (0.012%). Though, nitrogen enhances mechanical and corrosion properties of steel, but high nitrogen content in steel may also cause inconsistency in the mechanical properties of the steel (Sureshkumar *et al.*, 2011; Satyendra, 2013; Elmaghrabi, 2015). The steel samples contained silicon (0.1 – 0.34%), values below the ASTM and BS recommended value (0.4%) (BS 4449, 2005; ASTM A615-72, 1973). This may adversely affect the ductility, tensile and yield strength and hardness of the steel (Special Steel China Supplier, 2019). Manganese (Mn) in the steel samples (0.05 – 1.11%) were also lower than recommended value of 0.90% (AISI 1018) and 1.00% (BS 4449, 2005; ASTM A615-72, 1973), except sample H that contained 1.11%. Presence of Mn has the tendency to increase hardness of the steel (Leonghuat, 2019; Total Materia, 2017; Satyendra, 2013).

The phosphorous content in the samples was between 0.020 and 0.057%. The specified level of phosphorous in reinforcement steel bar in the standards are 0.04 (NIS 117, 2004) and 0.05% (BS 4449, 2005; ASTM A615-72, 1973). Analysis of the results reveals inconsistency in phosphorous content in Nigerian commercial reinforcement bars. The value varied from one specimen to another, in respect of size and location of purchase. Sulphur content in the steel samples varied from 0.01 to 0.32%. Though, 0.04 (NIS 117, 2004) and 0.05% (BS 4449, 2005; ASTM A615-72, 1973; AISI 1018) are specified as required sulphur level in reinforcement steel bar in the standards. These results also revealed inconsistency in the chemical compositions of the steel samples in Nigeria markets, since wide variations in the content were obtained.

Table 5: Elemental constituents of commercial 16mm reinforcement bars

Samples	Percentage Elemental Composition (Wt %)								
	Fe	C	Ni	Si	Mn	P	Cu	Cr	S
A	97.9	0.24	0.160	0.14	0.37	0.030	0.40	0.16	0.20
B	98.3	0.23	0.020	0.31	0.26	0.060	0.27	0.12	0.18
C	97.5	0.33	0.110	0.26	0.81	0.060	0.30	0.15	0.25
D	97.7	0.42	0.070	0.23	0.91	0.004	0.25	0.33	0.01
E	98.1	0.13	0.160	0.32	0.90	0.021	0.12	0.15	0.06
F	98.0	0.30	0.170	0.21	0.77	0.031	0.11	0.02	0.2
G	98.5	0.13	0.090	0.15	0.47	0.050	0.19	0.03	0.19
H	98.1	0.17	0.110	0.12	0.70	0.020	0.12	0.17	0.17
I	97.8	0.31	0.130	0.33	0.61	0.070	0.17	0.14	0.05
J	98.3	0.21	0.170	0.03	0.45	0.034	0.27	0.21	0.13
K	97.9	0.31	0.170	0.15	0.50	0.050	0.23	0.07	0.18
L	97.7	0.23	0.130	0.19	0.67	0.050	0.37	0.20	0.11
M	98.7	0.23	0.070	0.15	0.37	0.050	0.20	0.03	0.17
N	97.9	0.33	0.170	0.21	0.71	0.020	0.17	0.11	0.10
O	97.6	0.33	0.270	0.27	0.67	0.070	0.21	0.11	0.21
P	98.3	0.19	0.210	0.03	0.27	0.310	0.29	0.10	0.17

Table **5** shows the iron and carbon contents in 16 mm commercial reinforcement bar. The iron content in the steel bar samples of 16 mm size ranged between 97.6 and 98.7%, while the carbon content ranged between 0.13 and 0.42%. Analysis of the results indicates that 25% of the samples had carbon below the required 2.0% carbon content for carbon steel. This critically needs to be looked into, as carbon content plays significant role in determining the strength, hardness and ductility of the steel (Dmitri, 2019; Al-Janabi, 2018; Jena, 2017; Effect of Adding Carbon to Steel, 2019). The levels of other elements in 16 mm steel samples (Table 5) followed the trend in 10 and 12 mm samples. The steel either belongs to low or medium carbon steel class, irrespective of their sizes, considering the samples' carbon contents. There were variations in contents of phosphorous, Mn, Si and other elements in the steel samples.

— Mechanical Properties

In classifying structural steels, mechanical properties are fundamental factors (AZO Mining, 2018). Hence, it is highly important to investigate the minimum standards for the mechanical properties in order to determine the steels' performance characteristics. The vital mechanical properties considered in this study include yield strength, tensile strength, ductility and hardness. Are very important mechanical properties of steel (AZO Mining, 2018). This is line with the view of Azo mining that yield and tensile strength Thus, the discussion of the results in this study will be fundamentally based on yield strength, tensile strength, ductility and hardness.

Figures 3 - 14 show the results of tensile properties of the samples and that of some standards, which comprise of yield stress, ultimate tensile stress and ductility values. In selection and inspection of steel, tensile stress or yield stress serves as the main criterion (Khurmi & Gupta, 2005).

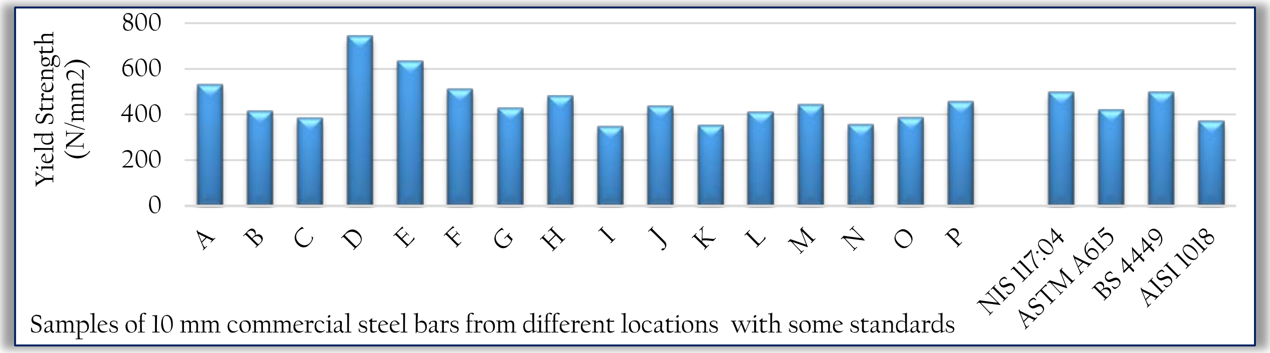

Figure 3: Yield strength values for various 10 mm commercial reinforcement steel bars and standards

In Figure 3, some of the samples yield strength values were comparable with various standards, such as ASTM A615, AISI 1018, BS 4449 and NIS 117 values. The samples' yield strength values for reinforcement bars obtained from Benin (samples A – D), Ilorin (samples E – H), Kaduna (samples I – L) and Lagos (samples M – P) respectively were in the range of 347.43 – 437.67 N/mm^2, 357.10 – 745.09 N/mm^2, 352.14 – 457.80 N/mm^2 and 384.42 – 530.92 N/mm^2. Generally, 18.75% samples had yield strength values lesser than 360.00 N/mm^2 AISI 1018 recommended yield strength value for reinforcement iron bar, 43.75% samples had strength lesser than 420.00 N/mm^2 ASTM A615 recommended yield strength value for reinforcement iron bar, and 56.25% had yield strength values greater than 420.00 N/mm^2 ASTM A615, 1973 recommended yield strength. NIS 117, 2004 and BS 4449, 2005 recommended 500.00 N/mm^2 as specified yield strength for the bar. By these standards, only 25.00% had values equal to or greater than the specified strength. The level of the yield strength in Nigerian commercial reinforcement steel bars was not uniform. This calls for the need to be sure of the materials' parameters, through experimental analysis, before they are employed for any engineering application to avoid structural failure in service.

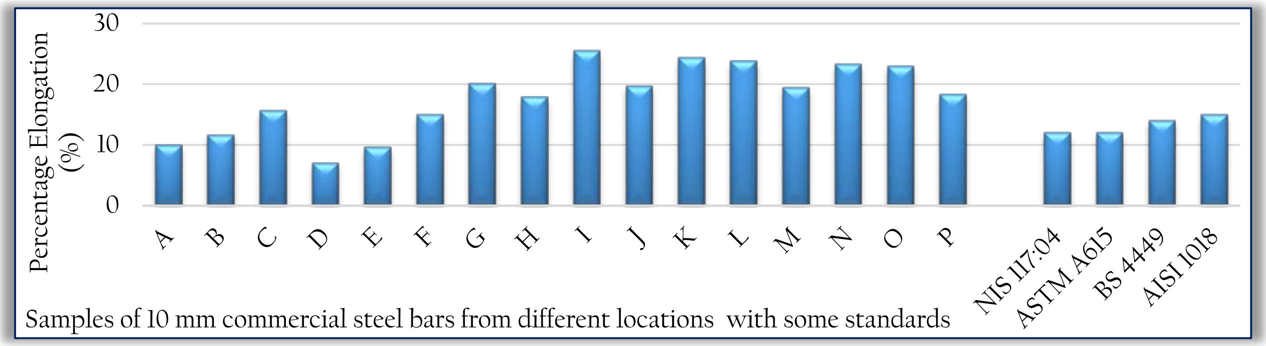

Figure 4: Percentage elongations for various 10 mm commercial reinforcement steel bars and standard

Figure 4 shows 10 mm samples' percentage elongation values compared with various standards. NIS 117/ASTM A615, BS 4449 and AISI 1018 respectively recommended 12, 14 and 15% as specific elongation value for reinforcement steel bar.

The samples exhibited percentage elongation between 7.02 and 25.51%. Samples with percentage elongation value below the standards' recommended values (Arum, 2008; BS 4449, 2005; ASTM A615-72, 1973; AISI 1018; AZoM, 2016) were 25% (4 out of 16 samples).

The samples ultimate tensile strength (UTS) as shown in Figure 5 ranged between 329.92 and 722.22 N/mm^2, with 12.5% samples having UTS value below 400 N/mm^2 AISI 1018 recommended value (AZoM, 2016) and 37.50% samples with UTS below NIS 117:04 and BS 4449/ASTM A615 recommended values of 500 and 620 N/mm^2 respectively.

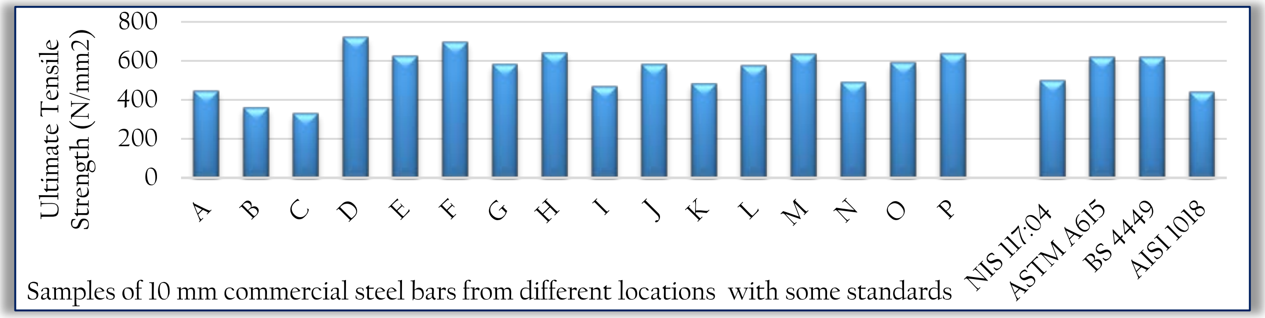

Figure 5: Ultimate tensile strengths for various 10 mm commercial reinforcement steel bars and standards

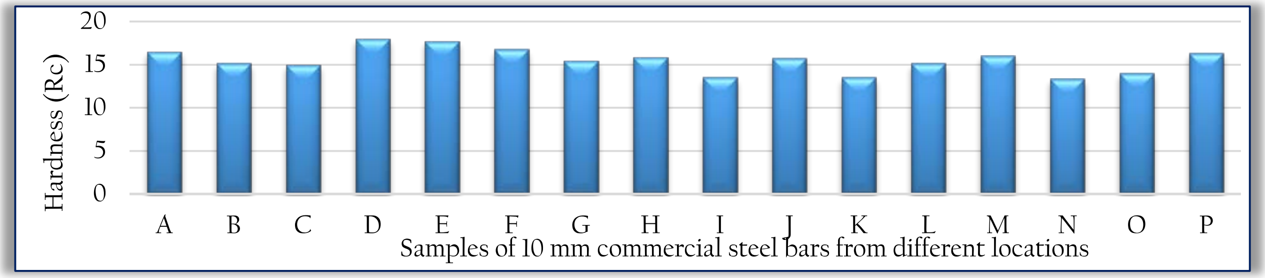

Figure 6: Hardness values for various 10 mm commercial reinforcement steel bars and standards

Figure 6 shows variation in the hardness values of the samples, ranging from 13.47 to 18.01. The hardness values were relatively high; this might be reflection of the high carbon contents in the steel samples. Carbon content enhances the hardness of steel (Al-Janabi, 2018; Capudean, 2003; Quora, 2019).

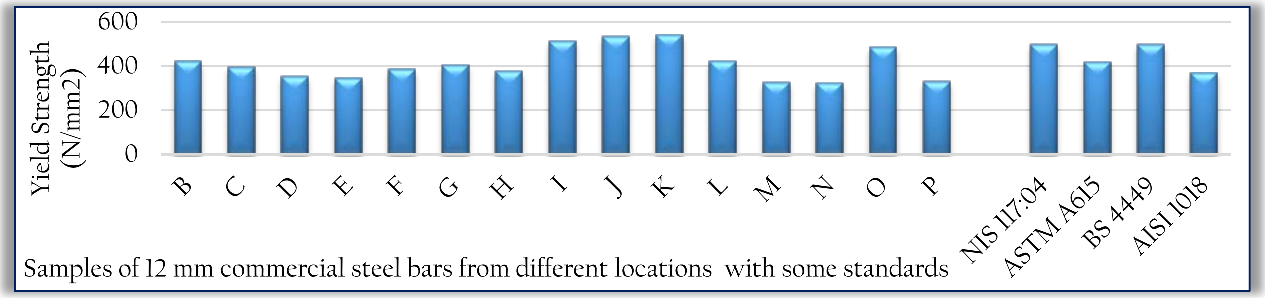

Figure 7: Yield strength values of various 12 mm commercial reinforcement steel bars and standards

In 12 mm samples as shown in Figure 7, the value of the yield strength exhibited were between 325.87 and 542.80 N/mm^2 with specimens A – D, E – H, I – L and M – P respectively having values ranged from 386.56 – 542.80 N/mm^2, 332.01 – 421.19 N/mm^2, 377.64 – 534.20 N/mm^2 and 325.87 – 396.97 N/mm^2. Analysis of this result shows that 50% of the samples exhibited yield strength value below the NIS, ASTM and BS specified values of 420.00 N/mm^2 (NIS 117, 2004; BS 4449, 2005; ASTM A615-72, 1973), while 31.25% samples were with values below 370.00 N/mm^2 AISI 1018 specified yield strength (AISI 1018).

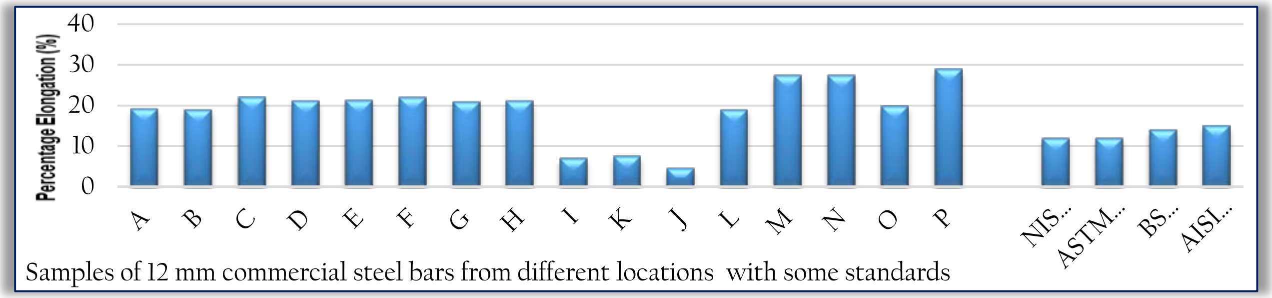

Figure 8: Percentage elongations of various 12 mm commercial reinforcement steel bars and standards

The percentage elongations exhibited by the samples were between 4.7 and 28.9% (Figure 8). Analysis of the results show that 25% of the samples had percentage elongation below the minimum value (12%) specified in NIS 117 and ASTM A615. Meanwhile, BS 4449 and AISI 1018 respectively specified 14 and 15% as the minimum elongation percentage required. Carbon contents in the steel samples reflect in the value of the samples' ductility. Ductility of steel samples decreases with increase in their carbon contents (Hughes, 2009). The majority of the samples had significant level of ductility which made them to be suitable for applications where appreciable level of ductility is required.

The ultimate tensile strength exhibited by 12 mm samples varied from 471.02 to 612.17 N/mm^2, with samples A – D, E – H, I – L and M – P respectively having strength values of 498.92 – 580.09 N/mm^2, 459.71 – 612.17 N/mm^2, 528.92 – 587.00 N/mm^2, 471.02 – 574.61 N/mm^2 (Figure 9). Considering AISI 1018 specified UTS value (440.00 N/mm^2), all the samples had adequate strength required of reinforcement steel bar. Meanwhile, 75% of the samples had UTS value above 500.00 N/mm^2 specified in NIS 117(2004). Though, none of the samples had strength up to ASTM A615 and BS 4449 requirement (620.00 N/mm^2) (BS 4449, 2005; ASTM A615-72, 1973). Averagely, the strength values exhibited by majority of the samples were satisfactory as meeting the required strength for reinforcement steel bar application in Nigeria. However, there is still the need to put in place strategy to eliminate the existence of little proportion of reinforcement steel bars in the market with deficiency in strength requirements.

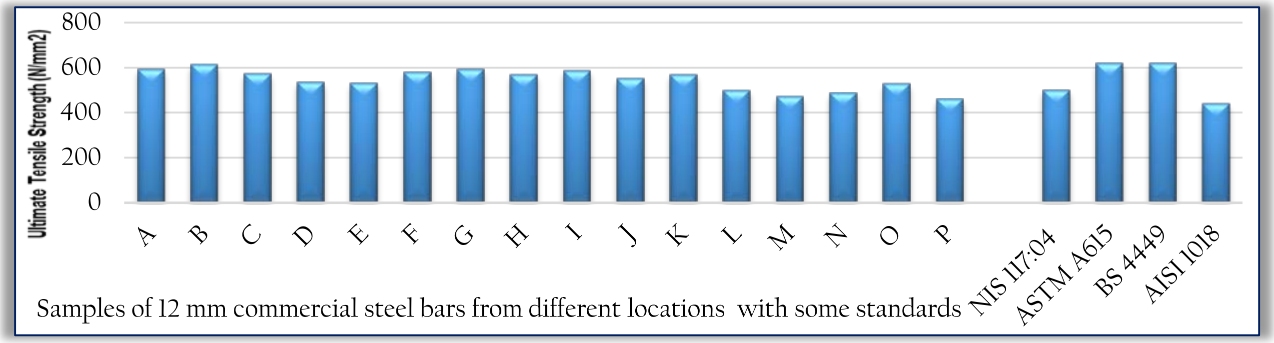

Figure 9: Ultimate tensile strengths for various 12 mm commercial reinforcement steel bars and standards

The value of the samples' hardness ranged between 11.6 and 21.0 as shown in Figure 11. The samples' strength and hardness values are higher as the level of carbon in the samples, while the percentage elongation reduces. Studies have shown that beyond 1.5% carbon in steel causes appreciable reduction in its ductility and malleability (Al-Janabi, 2018; Shodhganga, 2019). Sample H with 1.11% Mn, which was a bit higher than the specified Mn value (0.9 – 1.0%) in BS 4449, ASTM A615 and AISI 1018, exhibited 14.5 as its hardness value. This is a reflection of Mn having tendency to increase hardness of steel (AZoM, 2016; Leonghuat, 2018; Cabrea, *et al.*, 2014). By increasing the hardenability of the steel, Mn promotes its greater strength (Satyendra, 2013).

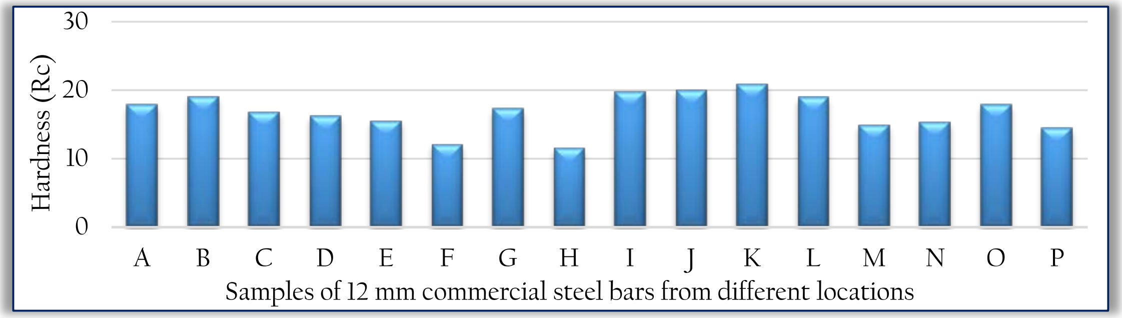

Figure 10: Hardness values for various 12 mm commercial reinforcement steel bars and standards

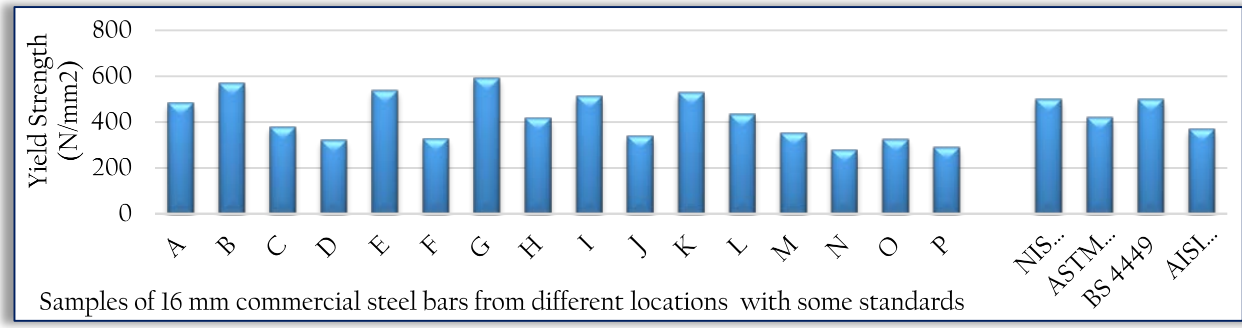

Figure 11: Yield strength values of various 16 mm commercial reinforcement steel bars and standards

The 16 mm diameter Samples had yield strength ranged from 278.39 to 593.01 N/mm^2 as shown in Figure 11. The samples' yield strengths were within the AISI 1018 specified strength (370.00 N/mm^2) (AISI 1018). Meanwhile, 56.30% of the samples had yield strength below ASTM A615 (1973) and NIS 117 (2004) specified yield strength (420.00 N/mm^2). The study reveals that carbon has effects on the samples' strength.

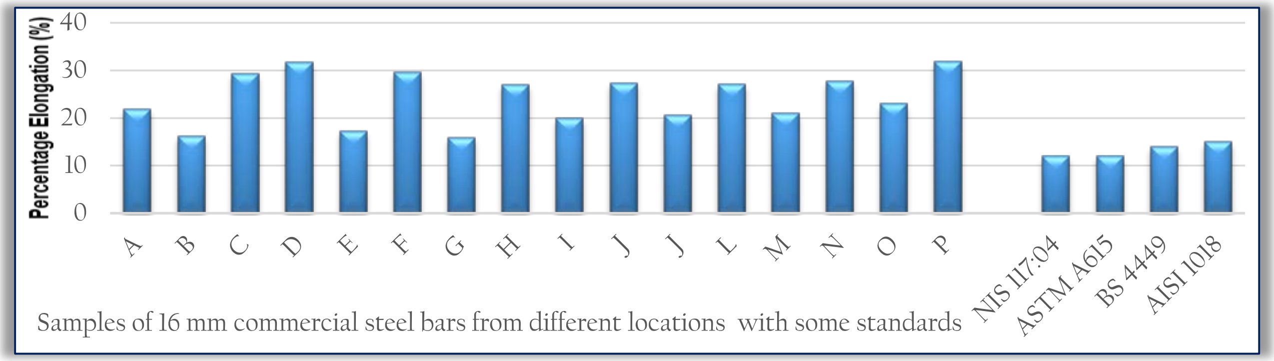

Figure 12: Percentage elongations of various 16 mm commercial reinforcement steel bars and standards

The 16 mm samples had percentage elongation greater than the minimum specified value in the standards (NIS 117, 2004; BS 4449, 2005; ASTM A615-72, 1973; AISI 1018) as shown in Figure 12. It implies that the available 16 mm size commercial reinforcement steel bars in the selected areas were suitable for applications that required the use of ductile steel bars. The UTS exhibited by the samples in Figure 13 were also within 328.85 and 719.83 N/mm^2. Analysis of the results in Figure 13 indicates that 56.25% of the samples had UTS below the specified values in the standards (NIS 117, 2004; BS 4449, 2005; AISI 1018). Though, 75.00% of the samples had UTS either equal or greater than 440 N/mm^2 specified in AISI 1018 as minimum UTS required in steel reinforcement bar. The higher carbon content in the steel samples resulted to higher yield stress and ultimate tensile stress, and probably good wear resistance (Calik *et al.*, 2010).

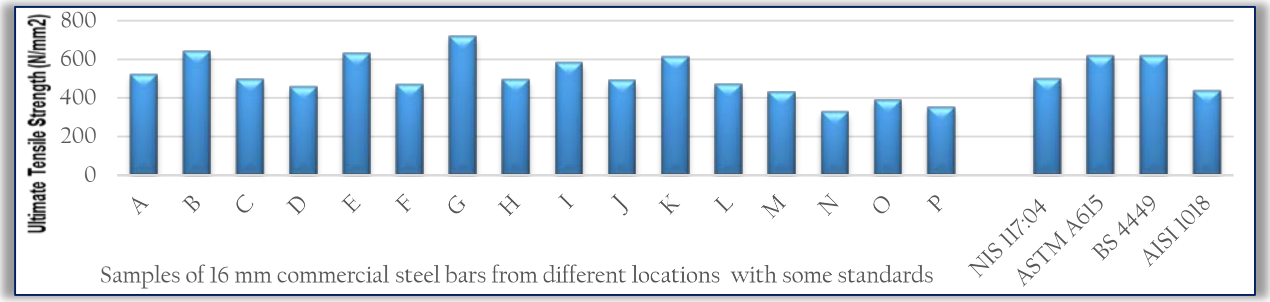

Figure 13: Ultimate tensile strengths for various 16 mm commercial reinforcement steel bars and standards

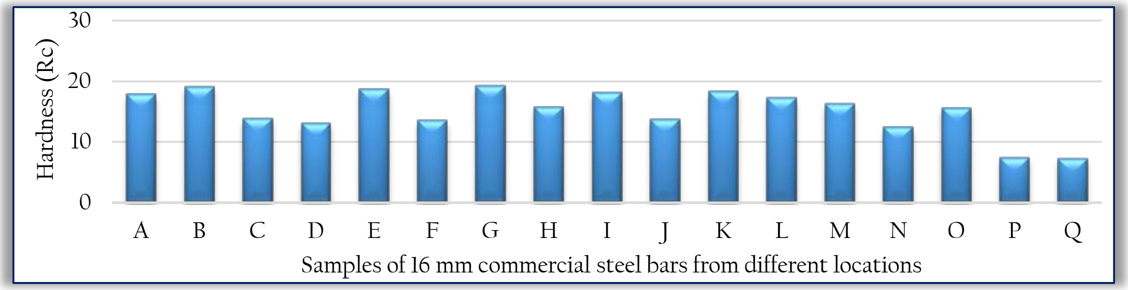

Figure 14: Hardness values for various 16 mm commercial reinforcement steel bars and standards

Majorly, low carbon contents in the steel reflects low strength and hardness; and higher percentage elongation, except in the case of samples D, F, H, L and P. Sample C with low carbon content of 0.13% exhibited high hardness value of 12.4% (Figure 14). This might be attributed to presence of moderately high value of Mn (0.9%) in the sample. Sample G with 0.47% Mn and 0.13% carbon also exhibited low hardness of 7.43%. This is a reflection of effect of Mn. Generally, there were indications that the mechanical properties of the steel bar were sensitive to the carbon content, as the results show increased in the strength and hardness of the samples with increased carbon contents, while their percentage elongation values reduced. This is in line with the view that higher carbon content in iron leads to higher strength, hardness and wear resistance, but lower ductility, weldability and toughness capabilities of the iron (of the Properties and Applications of Materials, 2019).

The level at which the mechanical properties of the samples complied with the specified values in the standards were low. This is an indication of poor quality assurances on available commercial reinforcement bars in Nigeria, which might have contributed to frequent structural failure in the country. Studies revealed that the use of substandard materials, non-availability of local standards, the use of quacks of professionals, non-enforcement of codes or regulations, corruption, poor maintenance culture, lack of adequate supervision, design error, natural phenomenon and excessive loading were major factors contributing to frequent structural failures in Nigeria (Ayodeji, 2011; Tyagher *et al.*, 2011; Kolawole, 2018; Ayedun *et al.*, 2011; Akinyemi *et al.*, 2011). Out of all these contributing factors, greater than 50% was attributed to poor quality of materials and workmanship (Ayodeji, 2011; Ayedun *et al.*, 2011). This study thereby calls for the need to enhance the authority (power) of the regulatory bodies in Nigeria, such as SON, Custom services, among others, for effective regulatory of in-flow of steel bars into Nigeria steel markets. There is also a need for significant and regular inspection of steel bars in the markets and products from locally available industries. The workers of the regulatory bodies need to be well trained, equipped with necessary and modern facilities, and well remunerated to avoid corruption.

Regular and effective experimental analysis of commercially available steel bars in Nigeria is highly essential. This will help to reveal the level of compliance with the standards' specified values in terms of steel properties. This process will also help to trace the source of less quality bars in the market. The engineering professionals and other users of the available reinforcement steel bars in Nigeria need to collaborate (cooperate) with the regulatory bodies to expose the source and availability of less quality steel bars in Nigeria markets. This can be effectively carry out through their various professional bodies, like Nigerian Society of Engineers (NSE), National Association of Technologists in Engineering (NATE), National Association of Engineering Craftsmen (NAEC), among others.

CONCLUSIONS

The following conclusions were drawn from the results and analysis of this study:

- The steels in Nigeria markets had sizes within allowable range of nominal sizes as specified in Nigerian Industrial Standards. But, the available steels in the markets were of unknown source, since the required parameters in the identification marks were not provided. Meanwhile, there were wide variations in their carbon contents which call for proper analysis of the material before use for any structural development. Though, significant numbers of the steels in market had ductility values within the specified range in the standards.
- The study discovered inconsistencies in the values of elements in the steel samples, which may lead to inadequacies in the mechanical properties of the steel.
- Generally, the level of compliance to the specified properties in the standards was low, which requires much improvement. This is an indication of poor quality assurances on available commercial reinforcement bars in Nigeria, a major factor that might have been contributing to incessant structural failures in the country.
- There is need to put strategies in place by the regulatory bodies in Nigeria to effectively control in-flow of steel bars into the markets from un-identified sources. This calls for regular and effective inspection / monitoring of steels in the market to ensure adequate compliance with the specifications in the standards.

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