Verification of Mechanical Properties of Reinforcement Steel Bars Used In Nigerian Local Building and Construction Sites (Imo State as Case Study)

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Abstract- An investigation was conducted on the conformance of the mechanical properties of the reinforcement bars used in local building and construction with the BS8110 design standard adopted in Nigerian considering grade S460 reinforcement bars and using Imo State as case study. In this paper, seven Local Government Areas in Imo State were considered as given in table 3.1. Two samples each of 12mm, 16mm and 20mm ribbed bars were collected from each of the seven Local Government Areas considered. The samples have 100cm gauge length and total length of 114cm each as recommended by the laboratory where they were analyzed. Tensile test was conducted on each sample using Universal Testing Machine (Avery Denison), while the chemical analysis was done after the tensile test using a spectrometer (spectromax). The results obtained show that out of 21 average result, only 5(24%) of the samples satisfy yield strength requirement based on the acceptability range of (420 – 475)N/mm^2 for grade S460 used, which has standard yield strength of 460N/mm^2 according to BS8110 code. 2(10%) satisfy elongation requirement based on acceptability range of (11 – 15)% against 14% for grade S460 steel according to BS4449:1997.(10%) satisfy both yield strength and elongation requirement. It was also observed through the chemical analysis that increase in carbon equivalence increases the strength of the steel but decreases its ductility and for a given carbon equivalence, increase in bar size results to decrease in strength but increase in ductility.

Indexed Terms- Ductility, Elongation, Tensile test, Universal Testing Machine, Yield strength,

I. INTRODUCTION

In the design of reinforced concrete structures like beams, slabs, columns, retaining wall e.t.c, the mechanical properties of the reinforcement bars used are considered as design parameters. The most frequently considered parameter is the yield strength of the reinforcement bars [7]. However, there are cases of failure of even well designed structures in various parts of the world. In Nigeria, reported cases of structural failure have become very frequent, especially for buildings. Several researchers have investigated into the causes of building collapse [1]. One of the most frequently adduced causes is the non-conformance of the structural properties of the materials used to the actual design specification [1[,[2]. The works of Daodu and Raji are instructive in this respect, [3]. The production of concrete for structural applications comes in a very rudimentary way and its quality varies considerably. There are several factors that determine the quality of concrete, they include: aggregates types and particle size distribution, mixing procedures operators skills, placement and consolidation. Water, cement and admixtures also have significant roles in concrete structures. Due to these several variables the quality of concrete can hardly be certified. Concrete and steel provide complementary support to each other, compensating for the weaknesses in the properties of the two materials [4],[5] thereby making it a universal construction material. Steel reinforcement imparts great strength and toughness to concrete.

Reinforcement reduces creep and minimizes crack width [6].
Steel is a suitable reinforcement material because it also has close coefficient of thermal expansion to that of concrete that is (5.8 x 10^{-6} to 6.4 x 10^{-6}) for steel and (5 x 10^{-6} to 7 x 10^{-6}) for concrete. Steel does not corrode rapidly in cement environment, it is relatively cheap and the ribs of the reinforcement bars aid its adhesion to cement mixture, thereby improves the strengthening of the concrete. Haven seen the properties of steel and its relevance in reinforcing concrete, there is need to determine its mechanical properties of interest in structural design and ascertain that the design parameters conforms with the properties of the steel used to ensure safety and good structural performance during the service life of the structure. We cannot not talk about the mechanical properties of steel without talking about is chemical composition. This is so because the mechanical properties are mainly determined by the chemical composition of most engineering materials, including steel.

A. Statement of the Problem

It is suspected that one of the causes of structural failure observed in many parts of Nigeria is the use of substandard materials in structural work. The use of substandard steel bars for structural reinforcement is suspected to be the most constructive factor. Hence this study is aimed at investigating the conformance of the mechanical properties of the reinforcement bars used in Nigerian local sites to ascertain the fact by comparing them with the British standard adopted in Nigerian structural design.

B. Objectives of the Study

The main objective in this work is to determine the mechanical properties of reinforcing steel bars used in Nigerian building and constructions and compare them with the British standard adopted in Nigeria for structural design as to verify the level of substandard bars used in Nigerian Local building and constructions, as adduced to be one of the causes of structural failure seen in most places.

C. Justification of Study

This work will provide a view on the level of quackery in Local steel production and further investigation will reveal the industries producing the substandard bars as to penalize them for others to be cautioned. The results of this investigation shall be relevant in bench marking of our steel mills with those of other countries. Design engineers can use the result of this study as a guide to improve their design and take more factors of safety, since the bars do not conform always to design specifications.

D. Scope of Study

i. This investigation is limited to local building and constructions, hence does not cover special projects like dams and bridges where high quality imported bars are mostly used.
ii. The mechanical properties of reinforcing bars are many, but only yield strength and ductility are verified.
iii. Out of 36 states in Nigeria, this investigation covers only Imo State and out of 27 Local Government Areas in Imo State, only seven (7) are considered.
iv. There are several grades of reinforcement bars and different sizes, but this investigation is done using only high yield structural steel of 460N/mm^2 standard yield strength. There are various sizes of this grade, but only 12mm, 16mm and 20mm were considered in this investigate

II. LITERATURE REVIEW

In this section, an overview of mechanical properties of reinforcement steel bars and works done by previous researchers in literature are presented.

A. Mechanical Properties of Steel

The mechanical properties of steel are the properties that determine its mechanical behaviour. These parameters show the deformation mechanism of a material when subjected to various forms of loading, such as uniaxial, biaxial or multiaxial loading. Mechanical properties of steel include: Yield Strength, Tensile strength, Toughness, Hardness, and Ductility e.t.c.

In reinforced concrete design, the most considered parameter of reinforcing steel bars is yield strength, usually denoted f_y in BS 8110 – 1:1997 [8]. Another property of interest is the ductility, usually expressed as percentage elongation of the material (steel). The ductility of the bars in terms of percentage elongation is considered. The yield strength will enable us know the load limit that will cause plastic deformation while the ductility will reveal the magnitude of plastic stain of the bars prior to failure.

- Stress – Strain Curve

When a material is subjected to loading, the stress on it is given by

$$\sigma = {}^{F}/_{A} \quad (1)$$

and the stain is given by

$$\varepsilon = {}^{\Delta l}/_{lo} \quad (2)$$

Where σ = Engineering stress (MPa), F = load on the material (N), A = Area of cross section at each loading point, Δl = Change in material length, lo= Initial length (before loading). ε = Nominal strain.
Since the cross – sectional area of sample under test at any point on loading is not easily determined; the nominal stress is sometimes used to analyze the deformation of a material. The nominal stress is given by

$$\sigma = {}^{F}/_{A} \quad (3)$$

Where A_o = Initial cross sectional area of the material. In any case, the plot of stress against strain reveals the deformation mechanism of a material, which shows the elastic limit, yield strength, ultimate tensile strength and breaking point of the material as shown in Fig. 1.

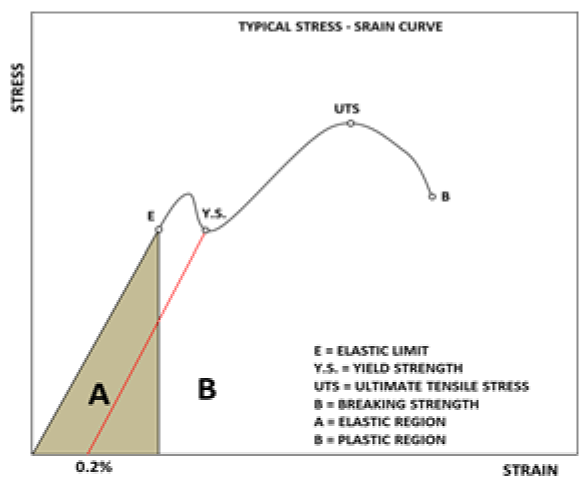

Fig. 1: Typical stress-strain curve

B. Forms of Failure

Crack: This is a significant gap within a structural member or between two or more different members. It occurs when the binding energy holding the separated area of the structure falls. It may be initiated by the stress cycle or vibration of member or by resonance. It may also be caused by thermal expansion or contraction of structural member. Shrinkage due to cement hardening can also initial cracks. Impact and heavy sound from explosion can cause to cracks. Another cause of crack is wind load. Three stages of crack failure are crack initiation, crack propagation and crack failure. These three stages can occur within a very short time, leading to failure without a sign.

In reinforced concrete design, distribution bars are introduced to arrest cracks. If the bars used in the construction do not have the same strength used in design, the performance of that member will be poor and the structure will be in danger of cracks. On this basis, there is need to ensure that the reinforced concrete is composed of steel bars of desirable properties. Hence this research is instrumental.

Shear: Shear failure occurs when shear stresses on the structure cause failure due to slipping of planes within the material. The planes slip when there is high pressure at a point on a material. In the design of reinforced concrete beams, shear links are introduced alongside tension reinforcement bars to resist shear stresses and prevent shear failure. To ensure shear resistance in a structure, the shear links must have desirable properties.

Deflection**:** Structural members like beams and slabs sometimes fail by deflection. Beam deflections occur due to gravitational pull on the centroid of a beam when the structure does not have enough strength to resist the pull. According to Sunny Prabhakar, a Project Associate at Coromandel International limited (2015-present), defection is caused by factors like loads, temperature, construction errors and settlement. He recommended both modulus of elasticity and modulus of rupture as design parameters against deflection. In his article, he stated that reinforced concrete slabs and beams require both tension and compression reinforcement, to resist deflection (www.quora.com/what-causes-deflection). Haven seen the importance of reinforcement bars in concrete through several passages of this write up, there is need to verify the mechanical properties of the material to know whether they conforms to design specifications.

Yield Strength:This is the stress limit beyond which a material undergoes plastics deformation. It is usually taken as 0.2% of initial length of the material, called proof stress. Fig. 1 is a typical example of stress – strain curve, which shows the position of yield strength on the curve.

Ductility: The ductility of a material is a measure of the total deformation the material can undergo prior to failure. Ductility is calculated in nominal way as percentage reduction or percentage elongation. The percentage reduction in cross – sections area is given by:

$$\%R = ((A_O - A)/A_O) \times 100\% \quad (4)$$

while percentage elongation is calculated as

$$\%E = ((L - L_O)/L_O) \times 100\% \quad (5)$$

During loading, the centre of sample reduces in cross sectional area than other parts, leading to necking. As a result of this it is difficult to determine the instantaneous cross sectional area of the bar during loading. Hence an integral method is used to calculate percentage reduction or percentage elongation of the materials which gives more accurate value. That is:

$$\%R = 100 \ln (A_O/A) \quad (6)$$

while for elongation, the formula is

$$\% E = 100\ln(L/L_O) \quad (7)$$

where % E = Percentage elongated, %R = Percentage reduction, A = Cross sectional area (after fracture), A_O =Initial cross sectional area of sample (before loading), L_o = Initial length of sample (before loading), L = Final length of sample (after fracture).

In this study, both the yield strength and ductility are automatically calculated by a program on the UTM machine used. The program calculates the percentage elongation given by Askeland [9]:

$$\% E = 100\ln (L/L_O) \quad (8)$$

where the gauge length of the sample, Lo is 100cm and length of sample at fracture, L is detected automatically by the machine.

C. Grades of Structural Steel

Structural steel is classified using different criteria and it varies with countries. In America, structural steel grades include: S195, S235, S355 and S420 with composition given in the Table 1.

Table1 Structural Steel Grades and Compositions(www.baileymetalprocess.com/tech)

Grade	%C	%S	%Mn	%P	%Si
S235	0.22	0.05	1.6	0.05	0.05
S275	0.25	0.05	1.6	0.04	0.05
S335	0.23	0.05	1.6	0.05	0.05

In Britain, the most commonly used grades are S250 and S460. Their specifications are given in Table 2.

Table 2 Designation of Structural Steel (BS 8110 - 1:1997, Table 3.1, PP.15.)

Designation	Specified characteristic strength
Hot rolled mild steel High yield (hot rolled or cold worked)	$250N/mm^2$ $460N/mm^2$

D. Surface Finishing of Reinforcement Bars

A smooth bar has no significant effect in tension or compression reinforcement. This is because both tensile and compressive forced are axial. In this respects, a good tension or compression reinforcement must have rough surface finishing for gripping the comment and aggregate mixture. This makes the bars effective in service. A smooth bar used in tension or compression reinforced will likely slip axially when the concrete member is under loading, this reduces the effectiveness of the bar. On the other hand, smooth bars may be used as shear links, since shear stresses are transverse. Hence, to aid the self-strength of bars in tension or compression reinforcement, ribs are introduced. There are standards for longitudinal and transverse ribs used in surface finishing of reinforcement bars and this differs by country. In this study, surface finishing of the bars is not considered.

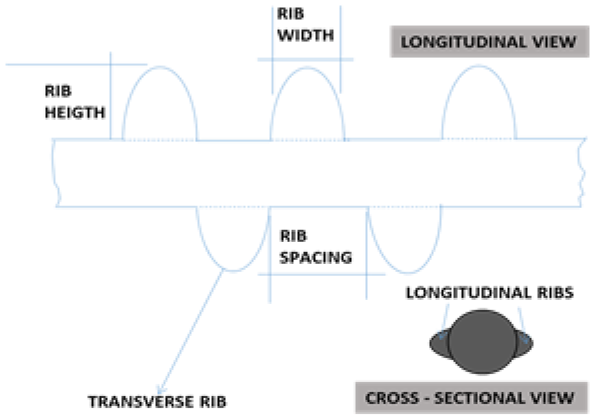

Fig.2 Ribs of Reinforcement Bars [10]

E. Source of Reinforcement Bars in Nigeria

The major sources of reinforcement bars in Nigeria are the local steel mills. Some of the steel mills are given in Table 3 below.

Table 3 Some Steel Mills in Nigeria

Steel Mill	Location
African steel mill ltd	Odogunyan Ikorodu, Lagos State
Pulkit steel mill	Ikorodu, Lagos State
Monac steel	Ogijo,Ogun State
African foundries ltd	Ogijo, Ogun State
Delta steel mill	Delta State
Sun flag steel mill	Odogunyan, Lagos State

F. Limitations in Steel Recycling

Most steel plants in Nigeria make their production by recycling steel scrap. Steel recycling is a crude method of steel production, associated with trials and errors. This is so because the steel scrap that is the major raw material contains different steel alloys of varying composition. In the course of melting, some important alloying element burn off while some remain in high proportion. When the molten steel is deslaged, it is exposed to atmospheric elements like nitrogen, oxygen, hydrogen etc. especially when using open hearth induction furnace.

These atmospheric elements enter the molten steel and automatically vary the steel composition. In most cases, the atmosphere elements are not desirable even though they enter the molten steel naturally. When carbon is high in proportion, some alloying additives like silicomanganes, ferrosilcon or aluminium notch are added to improve the teel quality and reduce the carbon composition. This is not economical because the additives are always expensive. Generally to obtain a certain desirable composition in steel making, there must be charge calculation which gives the exact amount of all the constituents of steel even the possible losses. In steel recycling, there is no charge calculation because the composition of the steel varies from one stage to another. Based on this fact, recycling plants cannot guarantee the quality of steel. This is one of reasons substandard steel bars are everywhere in Nigeria. Fig. 3 shows a typical steel recycling process.

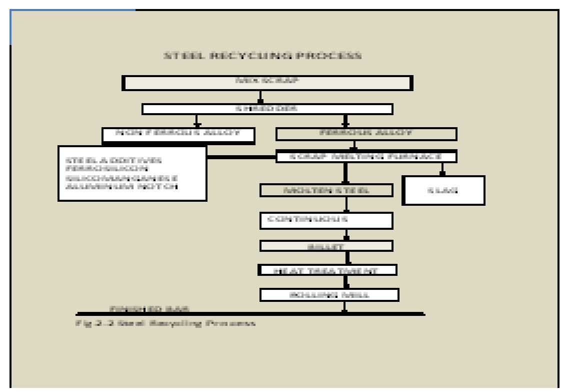

Fig. 3 Steel Recycling Process [10]

III. MATERIALS AND METHODS

A. Materials

The material used in this investigation is only grade 460 bars of sizes 12mm, 16mm and 20mm. Two samples of each of the sizes were taken from the seven sites in the seven local government areas considered in this study as shown in the Table 4. For a particular bar size such as 12mm, one sample is taken from the end and the other from the middle of one full length of bar as shown in figure 3.1 For 12mm bars from site A, sample A1 is taken from the end of full length of bar while A2 is taken from the middle of the full length. This applies to site B, C, D, E, F and G, for 16mm and 20 mm bars also. Generally, in the sample designation, ‘’1’’ denotes end sample while ‘’2’’ denotes middle sample.

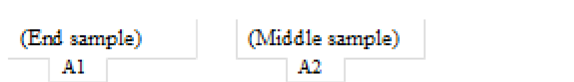

Fig.4 Sample location in Full length (18 ft)

Table 4 Site location and samples collected

Site	Location Local Government Area	Number of Sample Collected					
		12mm		16mm		20mm	
		1	2	1	2	1	2
A	Isiala Mbano	1	1	1	1	1	1
B	Ahiazu Mbaise	1	1	1	1	1	1
C	Obowu	1	1	1	1	1	1
D	Ehime Mbano	1	1	1	1	1	1
E	Onuimo	1	1	1	1	1	1
F	Owerri North	1	1	1	1	1	1
G	Owerri West	1	1	1	1	1	1

B. Method

Each of the samples collected was finished to a total length 114cm, while the gauge length 100cm is recommended by the laboratory where the tests were done. Each sample was subjected to tensile loading, using "Avery Denison" Universal Test Machine (UTM). During the loading by hydraulic system of the machine, the clamped sample gradually elongates and finally fractures at a certain load limit. At this point, the machine automatically stops loading and displays the tensile strength, yield strength and percentage elongation of the material being tested on a computer screen. The UTM is programmed to calculate the tensile strength, yield strength and percentage elongation of the tested sample. The machine program calculates the percentage elongation according to the formula %E = 100ln (L/L_0). Given that gauge length of the sample, L_O = 100cm, length of sample at fracture, L is detected automatically by the machine.

In addition, the stress-strain curve of any tested sample is plotted and printed automatically through the computer system connected to the machine. At the end of the tensile test, the yield strength and percentage elongation of all the 42 samples were determined and recorded accordingly. The average of yield strength and percentage elongation were calculated for a particular bar size for all the sites. For site A, the average result is given as A = 1/2 (A1+A2), and for site B, B =1/2(B1+B2), while for site C, C = 1/2(C1+C2) and so on. The average results are calculated and used for references. For the average results obtained, an acceptability criterion was used to determine the rate at which the samples pass or fail the test, looking at yield strength and percentage elongation.

After the tensile test, each part of the fractured sample is hammered and the flattened. The fat surface is ground with grade 60 abrasive stone and polished with grade 120 abrasive paper. The prepared sample is analyzed for chemical composition using spectrometer (spectromax) which automatically displays the percentage composition of 25 elements in the steel including iron on computer connected to the machine. The machine operates by the principle of photo electric emission and has three spark levels. When the polished face of the sample is placed over the spark hole of machine and the park unit is powered, the spark releases incident light on the material and the sample emits light of different wavelength associated to the various elements in the material tested. By transducer system, the wavelength of the emission by each constituent element is used to determine its proportion in the material tested.

Arum [11], in "verification of properties of concrete reinforcement bars: Nigeria as case study", carried out a similar research in which he compared the yield strength and ductility of the bars used in Nigeria with ISO standard. In his work, acceptability index of 2.33 for is test pieces for failure rate of 5% used, using ISO 6935-2-method, that is $M_{15} – 2.335is \geq = f_k$, M = mean value, S= standard deviation and f_k = required characteristic value [11]. However, he did not consider the effect of chemical composition on the mechanical properties of the bars. He presented his result only in tabular form. Bamigboye et al [12] reported a similar research in which they used acceptability range of (410-460) N/mm^2 for yield strength and (10-14) % for percentage elongation, based on practical experience. They used bar charts to present his results.

In this paper, for higher precision, the research uses acceptability range of (420 - 475) N/mm^2 for yield strength and (11-15) % for percentage elongation and my results are presented both in tabular forms and graphical methods. The British standard yield strength of grade S460 steel is 460N/mm^2 with percentage elongation of 14% [BS4449:1997], as adopted in Nigeria for structural design. The permissible range of strength and ductility are taken based on practical experience and looking at the difficulty in producing bars of exact required strength and ductility. Any value in the result found above or below the permissible range fails the test and the material (sample) responsible for such value is substandard [6].

The results obtained were tabulated as shown in Tables 5, 6 and 7 from which Tables 8 and 9 values were obtained. The tables shows the carbon equivalence, yield strength and percentage elongation of each bar size used. The graph of carbon equivalence against yield strength and carbon equivalence against percentage elongation were plotted as shown in Figures 4, 5, 6, 7, 8 and 9 from which the values in Table 12 were deduced. Table 12 show the strength and ductility of each bar size at given carbon equivalent. The plots of values in table 12 are shown in Fig 7 and 8 which shows the effect of carbon equivalence and bar size on mechanical properties of the reinforcement bars.

IV. ANALYSIS OF RESULT AND DISCUSSION

A. Analysis of Results

The results obtained from laboratory tests are given in tables 4.1, 4.2 and 4.3; for 12mm, 16mm and 20mm bars respectively.

For site A in table 4.1, for 12mm bar result:

Average value, A = ½ (A1+A2). For %C, A1 = 0.2091, A2 = 0.2111,

A = ½ (0.2091+0.2111) = 0.2101, Average carbon content, %C = 0.2101

Average manganese content, %Mn = 0.1800,

Average Molybdenium content, %Mo = 0.0041

Average vanadium content, %V = 0.0025

Average chromium content, %Cr = 0.0033

Average Copper content, %Cu = 0.0024

Average Nickel content, %Ni = 0.0023

Average percentage carbon equivalence is

%CE = %C+ %Mn/6 + (%Cr+%Mo+%V)/5 + (%Cu+%Ni)

= 0.2101 + 0.1800/6 + (0.0033+0.0041+0.0025)/5 + (0.0024+0.0023)/15

= 0.242

The values of yield strength and percentage elongation are generated automatically by the machines used for tensile test, while the percentage chemical compositions are generated by the spectrometer used in chemical analysis of the samples.

Table 5: Result of 12mm bars

SITE	SAMPLE	%CHEMICAL COMPOSITION							%CE	MECHANICAL PROPERTIES	
		C	Mn	Mo	V	Cr	Cu	Ni		YS	%E
A	A1	0.2091	0.1758	0.0055	0.0026	0.0058	0.0025	0.0024	0.2480	250.0	25.1
	A2	0.2111	0.1852	0.0045	0.0026	0.0051	0.0025	0.0022	0.2410	246.0	21.6
	A	0.2101	0.1800	0.0041	0.0025	0.0055	0.0024	0.0023	0.2420	248.0	22.5
B	B1	0.4250	0.1764	0.0040	0.0210	0.0506	0.0027	0.0045	0.4760	486.0	9.2
	B2	0.4252	0.1762	0.0042	0.0210	0.0506	0.0025	0.0041	0.4660	482.0	8.8
	B	0.4251	0.1765	0.0041	0.0210	0.0506	0.0026	0.0042	0.4710	485.0	9.0
C	C1	0.4500	0.9900	0.0052	0.0065	0.0062	0.0095	0.0011	0.6070	520.0	5.7
	C2	0.4520	0.9890	0.0045	0.0062	0.0061	0.0095	0.0011	0.5910	522.0	5.6
	C	0.4510	0.9900	0.0052	0.0062	0.0062	0.0095	0.0011	0.5990	521.0	5.8
D	D1	0.2905	0.0859	0.0040	0.0020	0.0088	0.0071	0.0041	0.5130	565.0	19.5
	D2	0.2915	0.0901	0.0042	0.0022	0.0084	0.0067	0.0045	0.5080	565.0	18.7
	D	0.2911	0.0900	0.0041	0.0021	0.0085	0.0069	0.0042	0.5100	567.0	19.0
E	E1	0.5625	0.8859	0.0025	0.0001	0.0050	0.0085	0.0045	0.5080	495.0	8.1
	E2	0.5651	0.8801	0.0021	0.0021	0.0052	0.0089	0.0041	0.4900	495.0	7.7
	E	0.5650	0.8800	0.0022	0.0011	0.0051	0.0089	0.0042	0.4850	498.0	7.9
F	F1	0.2720	0.4100	0.0025	0.0058	0.0085	0.0055	0.0055	0.5760	451.0	16.7
	F2	0.2680	0.4081	0.0021	0.0056	0.0049	0.0057	0.0057	0.5740	455.0	17.5
	F	0.2700	0.4100	0.0022	0.0055	0.0051	0.0058	0.0056	0.5750	452.0	17.0
G	G1	0.5560	0.7509	0.0069	0.0056	0.0058	0.0052	0.0020	0.6650	476.0	9.9
	G2	0.5560	0.7501	0.0067	0.0056	0.0058	0.0050	0.0018	0.6650	476.0	9.7
	G	0.5550	0.7500	0.0068	0.0057	0.0055	0.0019	0.0019	0.6660	475.0	9.8

Table 6: Result of 16mm bars

SITE	SAMPLE	%CHEMICAL COMPOSITION							%CE	MECHANICAL PROPERTIES	
		C	Mn	Mo	V	Cr	Cu	Ni		YS	%E
A	A1	0.2900	0.8100	0.0033	0.0036	0.0049	0.0049	0.0035	0.1860	388.0	18.7
	A2	0.2900	0.8100	0.0033	0.0034	0.0053	0.0047	0.0037	0.1860	383.0	18.3
	A	0.2900	0.8100	0.0033	0.0035	0.0051	0.0048	0.0036	0.1860	386.0	18.5
B	B1	0.2600	0.9390	0.0048	0.0033	0.0043	0.0018	0.0039	0.1800	386.0	18.1
	B2	0.2600	0.9301	0.0048	0.0033	0.0043	0.0016	0.0039	0.1980	391.0	16.7
	B	0.2600	0.9300	0.0049	0.0033	0.0043	0.0017	0.0039	0.1890	390.0	17.4
C	C1	0.1889	0.8700	0.0026	0.0043	0.0061	0.0043	0.0049	0.4870	481.0	9.7
	C2	0.1861	0.8700	0.0024	0.0043	0.0061	0.0043	0.0049	0.4790	473.0	9.8
	C	0.1880	0.8700	0.0029	0.0043	0.0061	0.0043	0.0049	0.4830	477.0	9.8
D	D1	0.2112	0.5900	0.0061	0.0021	0.0088	0.0069	0.0042	0.3160	311.0	21.0
	D2	0.2108	0.5900	0.0061	0.0021	0.0088	0.0069	0.0042	0.3120	309.0	20.0
	D	0.2110	0.5900	0.0061	0.0021	0.0088	0.0069	0.0042	0.3150	310.0	20.5
E	E1	0.3361	0.7300	0.0039	0.0057	0.0016	0.0068	0.0041	0.4920	458.0	19.4
	E2	0.3304	0.7300	0.0039	0.0057	0.0016	0.0068	0.0041	0.4840	462.0	19.2
	E	0.3300	0.7300	0.0039	0.0057	0.0016	0.0068	0.0041	0.4880	460.0	19.3
F	F1	0.3793	0.8838	0.0044	0.0049	0.0048	0.0484	0.0499	0.4017	403.0	4.4
	F2	0.3771	0.8834	0.0043	0.0049	0.0048	0.0478	0.0321	0.4024	400.0	4.8
	F	0.3783	0.8830	0.0043	0.0049	0.0048	0.0480	0.0810	0.4021	401.0	4.8
G	G1	0.2300	0.8430	0.0041	0.0039	0.0033	0.0034	0.0003	0.3074	364.0	23.7
	G2	0.2300	0.8430	0.0041	0.0039	0.0033	0.0034	0.0003	0.3074	361.0	23.4
	G	0.2300	0.8430	0.0041	0.0039	0.0033	0.0034	0.0003	0.3074	363.0	23.3

Table 7: Result of 20mm bars

SITE	SAMPLE	%CHEMICAL COMPOSITION							%CE	MECHANICAL PROPERTIES	
		C	Mn	Mo	V	Cr	Cu	Ni		YS	%E
A	A1	0.2241	0.8134	0.0031	0.0034	0.0040	0.0047	0.0037	0.336	278.0	23.8
	A2	0.2249	0.8076	0.0035	0.0036	0.0043	0.0049	0.0038	0.336	277.0	22.8
	A	0.2240	0.8100	0.0033	0.0035	0.0041	0.0048	0.0038	0.336	278	23
B	B1	0.3418	0.1850	0.0041	0.0017	0.0031	0.0048	0.0083	0.736	381.0	18.3
	B2	0.3418	0.1850	0.0040	0.0031	0.0031	0.0046	0.0081	0.731	373.0	18.1
	B	0.3417	0.1850	0.0041	0.0034	0.0032	0.0047	0.0083	0.738	377	18.2
C	C1	0.3384	0.8819	0.0035	0.0034	0.0035	0.0044	0.0039	0.497	487.0	12.8
	C2	0.3361	0.8817	0.0035	0.0033	0.0031	0.0044	0.0039	0.498	485.0	11.8
	C	0.3380	0.8818	0.0035	0.0034	0.0033	0.0044	0.0039	0.498	448	12
D	D1	0.2400	0.0031	0.0033	0.0035	0.0081	0.0048	0.0048	0.343	333.0	25.0
	D2	0.2400	0.0031	0.0033	0.0035	0.0081	0.0048	0.0048	0.343	333.0	23.0
	D	0.2400	0.0031	0.0033	0.0035	0.0081	0.0048	0.0048	0.343	333	24
E	E1	0.3318	0.1839	0.0036	0.0034	0.0035	0.0047	0.0081	0.771	374.0	19.9
	E2	0.3316	0.1831	0.0033	0.0034	0.0031	0.0047	0.0083	0.769	370.0	19.7
	E	0.3317	0.1830	0.0034	0.0034	0.0032	0.0047	0.0082	0.768	372	19.8
F	F1	0.2117	0.3880	0.0040	0.0042	0.0040	0.0033	0.0044	0.369	349.0	40.0
	F2	0.2117	0.3880	0.0040	0.0042	0.0040	0.0033	0.0044	0.369	351.0	2.0
	F	0.2117	0.3880	0.0040	0.0042	0.0040	0.0033	0.0044	0.369	350	21
G	G1	0.3808	0.7830	0.0098	0.0079	0.0098	0.0880	0.0810	0.434	483.0	4.3
	G2	0.3852	0.7830	0.0098	0.0079	0.0098	0.0880	0.0810	0.432	483.0	4.1
	G	0.3830	0.7830	0.0098	0.0079	0.0098	0.0880	0.0810	0.431	483	4.7

Table 4.4: 12 mm Average results and 16 mm

Table 8 12mm and 16 mm Average results

SITE	12mm		
	%CE	YS	%E
A	0.242	248	22.5
D	0.310	347	19.0
F	0.375	432	17.0
G	0.464	475	9.8
B	0.471	483	9.0
E	0.489	496	7.9
C	0.599	521	3.8.

SITE	16mm		
	%CE	YS	%E
G	0.307	303	23.3
D	0.313	310	20.5
A	0.355	384	18.5
B	0.359	390	17.4
E	0.453	460	15.3
C	0.483	477	9.6
F	0.502	501	4.5

Table 9: 20 mm Average result

SITE	20mm		
	%CE	YS	%E
D	0.2533	233	24
A	0.3290	276	23
F	0.3490	350	21
E	0.3650	372	19.8
B	0.3750	377	18.2
C	0.4560	445	12
G	0.5231	457	4.7

Table 10: Pass rate of samples

Bar Diameter (mm)	NB	Yield Strength		%Elongation		NYE	%YE
		NY	%PY	NE	%NE		
12	7	2	29	0	0	0	0
16	7	1	14	1	14	1	14
20	7	2	29	1	14	1	14
Total	21	5	24	2	10	2	10

NB = Number of bars tested (on average)
NY = Number of bars that pass yield strength
%P = Percentage of bars that pass yield strength
NE = Number of bars that pass elongation
%NE = Percentage of bars that pass elongation
NYE = Number of bars that pass both yield strength and elongation
%YE=Percentage of bars that pass both yield strength and elongation.

Table 11: Failure rate of samples

Bar Diameter (mm)	NB	Yield Strength				%Elongation			
		ES	%ES	LS	%LS	EE	%EE	LE	%LE
12	7	3	43	2	29	4	57	3	43
16	7	2	29	4	57	4	57	2	29
20	7	0	0	5	71	5	71	1	14
TOTAL	21	5	24	11	52	13	62	6	29

ES = Number of bars of excessive yield strength
%ES = Number of bars of excessive yield strength
LS = Number of bars of low yield strength
%LS = Percentage of bars of low yield strength
EE = Number of bars of excessive elongation
%EE = Percentage of bars of excessive elongation

Table 12: Effect of bar size and carbon equivalence on yield Strength and elongation

%CE	YIELD STRENGHT(N/mm²)			%ELONGATION		
	20mm	16mm	12mm	12mm	16mm	20mm
0.30	270.00	305.00	328.00	21.00	22.00	23.30
0.35	342.00	371.00	396.00	19.20	19.90	21.00
0.40	398.00	422.00	443.00	16.00	16.70	17.40
0.45	435.00	455.00	476.00	10.70	11.32	12.30
0.50	460.00	478.00	499.00	4.40	5.00	6.00

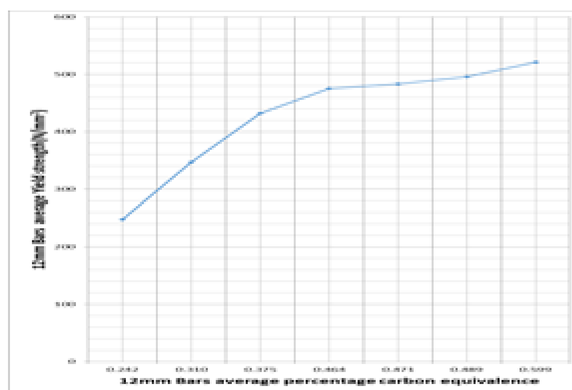

Fig. 4: Plot of average yield strength against average percentage carbon equivalence for 12mm bars

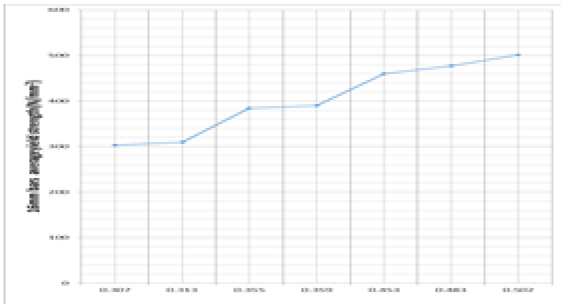

Fig.5: Plot of average yield strength against average percentage carbon equivalence for 16mm bars

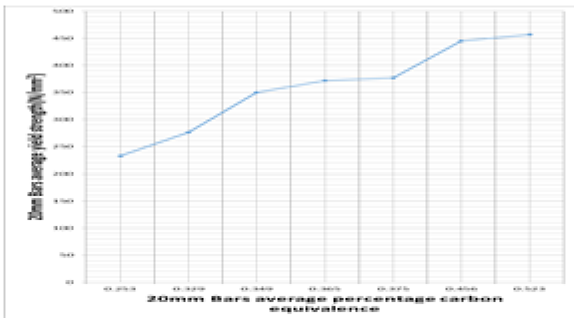

Fig. 6: Plot of average percentage elongation against average carbon equivalence for 20 mm bars

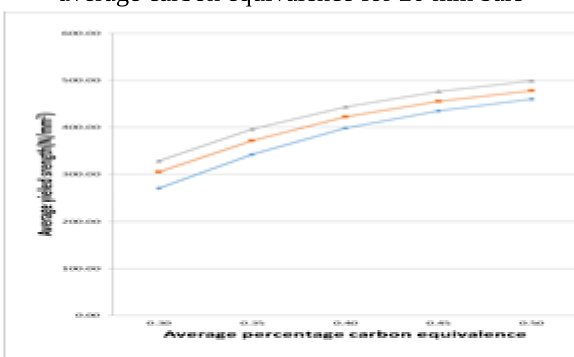

Fig. 7: Plot of average yield strength against average carbon equivalence for 12mm, 16mm and 20mm bars

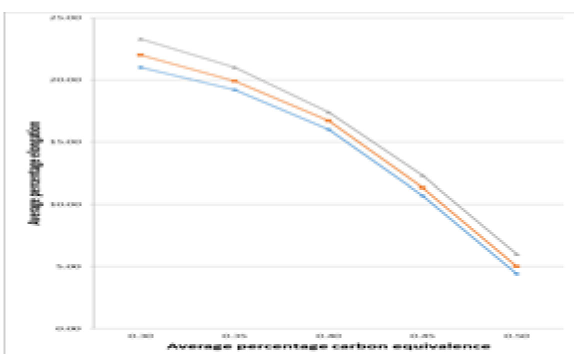

Fig. 8: Plot of average percentage elongation against average carbon equivalence for 12mm, 16mm and 20mm bars

B. Discussion

Pass: The results of this work show that for 7 average results obtained for 14 pieces of 12mm bar samples, 2(29%) pass yield strength, and none pass elongation. For 16 mm bars, 1(14%) pass yield strength and 1(14%) pass elongation. For 20mm bars, 2(29%) pass yield strength and 1(14%) pass elongation. Out of the 21 average results obtained for 12mm, 16mm and 20mm bars, 5(24%) pass yield strength, 2(10%) pass elongation and 1(5%) pass both yield strength and elongation.

Failure: For 12mmbras, 3(43%) fail by excessive strength, 2(29%) fail by low strength 2(29%), 4(57%) fail by excessive elongation and 3(43%) fail by low elongation. For 16mmbras, 2(29%) fail by excessive strength, 4(57%) fail by low strength, 4(57%) fail by excessive elongation and 2(29%) fail by low elongation. For 20mmbras, none fail by excessive strength, 5(71%) fail by low strength, 13(62%) fail by excessive elongation and 6(29%) fail by low elongation.

Looking at the figures 4.7 and 4.8, it is observed that for any carbon equivalence value, the strength of 12mm is greater than that of 16mm and that of 20mm bars is the least. Also for any carbon equivalence value, the elongation of 20mm bars is greater than that of 16mm and 12mm bars has the least elongation. This implies that for a given carbon equivalent, increase in bar size results to decrease in strength but increase in ductility.

V. CONCLUSION

Based on the acceptability indices (420 - 470) N/mm^2 yield strength and (11-15) % elongation used in this investigation, just 5% of the whole samples tested have satisfactory strength and ductility. The rest of the samples failed either by low strength, excessive strength, low elongation or excessive elongation. Hence, this result show that most of the reinforcement bars used in Nigeria local building and construction has substandard quality and contributes significantly to structural failure common around.

Looking at the effect of carbon equivalence on strength and ductility, it is also obvious from this study that the mechanical properties of steel are determined by its chemical composition. From this study, 85% of all the samples tested have substandard strength and ductility. If this result is generalized for all the states in Nigeria, we can say that quality regulatory bodies like Standard Organization of Nigeria (SON) are not doing their work very well.

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