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# Investigations on the chemical composition and tensile strength of steel bars in the Nigerian construction industry

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**Abstract.** Steel reinforcement bar compliments concrete in reinforced concrete structures to provide the required strength, rigidity and durability. This study investigates the level of conformity of reinforced steel bars available in the Nigerian construction industry through investigations on the percentage of chemical composition and tensile properties in relation to relevant local and international standards. Samples from 12 different companies were considered in this research. The chemical analysis results discovered 16 elements, some of which are residual elements in minute quantities. 9 samples had carbon content of less than 0.27%, 17 samples had phosphorus content less than 0.055%, 16 samples had sulphur content less than 0.055%, 9 samples had copper content less than 0.25% and 17 samples had carbon equivalent of less than 0.54% which are all requirements of NIS 117. Similarly, most of the samples examined did not meet the requirements of NIS 117 and BS4449 in respect of steel bar diameter, characteristic strength, ductility, ultimate to yield strength ratio, or a combination of the parameters with the yield strength ranging from 462.02 N/mm<sup>2</sup> to 558.27 N/mm<sup>2</sup>. An indication of the level of quality of steel bars available in Nigerian construction industry can be deduced from the results of this research.

## 1. Introduction

Steel reinforcement bar is a versatile constructional material widely used in the production of reinforced concrete. Reinforced concrete structure is designed on the principle that steel and concrete act together to withstand induced forces. Concrete has high compressive strength but low tensile strength. Steel bars, on the other, can resist high tensile stresses but will buckle when subjected to comparatively low compressive stresses. By providing steel bars within a concrete member predominantly in those zones which will be subjected to tensile stresses, an economical structural material can be produced which is both strong in compression and tension [1]. The properties of thermal expansion for both steel and concrete are approximately the same; this along with excellent bendability property makes steel the best material for reinforcement in concrete structures [2-4].

The incidences of building failures and collapses have become major issues of concern in the Nigerian construction industry. The frequencies of their occurrence and the magnitude of the losses in relation to lives and properties are now becoming very alarming [5-7]. It has been identified that the use of poor quality and substandard steel rods are among the causes of building failure in Nigeria [8-10]. The large-scale conversion of imported scrap in form of scrap rails, automobile scrap, defence



scrap, scrap from ship etc. of unknown or unsuitable quality into steel rebars, possibly under ineffectively controlled conditions, raises apprehensions about the quality and reliability of steel rebars used in the construction industry[11, 12].

In this research, the chemical composition of reinforcing steel bars used in the Nigerian construction industry was determined using optical emission spectrometry to compare the chemical composition with relevant standards and codes. Further, the tensile properties of the bars were determined and a check on the diameter of the tested reinforcement was done. In essence, the quality of the reinforcing steel bar used in the construction sites in Nigeria is being evaluated in this research.

## 2. Methodology

The reinforcing steel rod samples were collected from 3 different construction material markets at Ibadan namely; Iwo road, Agodi Gate and Iyana Church. These samples were obtained under 2 major sources namely; locally produced steel bars and imported products. Samples from 12 different steel mills were considered for the research. Table 1 shows the list of the steel mills and the diameter of the reinforcement sourced from each.

**Table 1.** Steel reinforcing bar samples.

S/n	Name of manufacturer	Label & Diameter (mm)
1	PJSC ArcelorMittal Kryvyi Rih, Ukraine	UKR(12,16)
2	African Foundries Limited Ogijo, Ogun	AFL(16,20)
3	Brazil Steel Mills, Brazil	BSM(12,16)
4	Eurotherm Steel Ife, Osun	ETM(12,16)
5	Landcraft steel Industries Limited, Lagos	LCI(16,20)
6	Mayor Engineering limited Ikorodu, Lagos	MYE(12)
7	Rashtriya Ispat Nigam Ltd India	RIL(12,16)
8	Hongzing Steel Company Limited Lagos	RSS(12,16)
9	Sankyo Steel Mills Company Limited, Lagos	SSM(16)
10	African Industries (Tiger TMT), Lagos	TGT(12,16)
11	Top Steel Nigeria Limited	TOP(20)
12	Turkey Reinforcing Steel Bar, Turkey	TKY(12,16)



**Figure 1.** Tensile strength test using Universal Testing Machine.

The dimensional requirement for each sample for the chemical composition test in the form of a solid mass depends on the dimensions of the sample chamber. Each steel bar sample to be tested was cut into 50mm length which is the chamber size of LabSpark 750B Optical emission spectrometer, after which the surface to be tested was well grinded using a grinding machine so as to achieve smooth, flat and impurity free surface to be analyzed. LabSpark 750B Optical emission spectrometer was used in the determination of the chemical composition of the samples in this research. The test was carried out at the Quality Control Laboratory of Universal Steel Mill Ikeja Lagos. SM1000 TQ Universal Testing Machine (UTM), having a maximum load of 100 kN was used to carry out the tensile strength test [13]. The tensile strength test was carried out at material testing and research laboratory of Federal University of Technology, Akure. The UTM was connected to jack hammer which was used to applied load to the specimen at a rate of 0.02 mm/min (Figure 1).

### 3. Results and discussions

#### 3.1. Chemical composition

Sixteen elements were discovered in this test. The main elements apart from Iron (Fe) were Carbon (C), Silicon (Si), Manganese (Mn), Sulphur (S), Phosphorus (P), and Copper (Cu). Other elements present in residual amounts were Chromium (Cr), Nickel (Ni), Niobium (Nb), Aluminium (Al), Boron (B), Tungsten (W), Molybdenum (Mo), Vanadium (V), and Titanium (Ti). The obtained results of the chemical composition with particular references to the main elements [C, Si, Mn, S, P & Cu] are presented in Table 2 along with their comparison with specifications of international standards; the BS4449 [14], ASTM A706 [15], ISO 6935-2 [16] and the Nigerian National Standard, NIS 117 [17]. Further analysis of the implications of the variations in the composition of each of the respective elements results are presented in sub-sections 3.1.1-3.1.6.

**Table 2.** Percentage chemical composition of elements and Code provisions.

Samples	C			S			P			Cu		Si		Mn		
	Measured value	BS4449 [0.27%]	NIS 117 [0.24%]	ASTM A706 & ISO 6935-2 [0.33%]	Measured value	BS4449 & NIS 117 [0.055%]	ASTM A706 [0.053%]	ISO 6935-2 [0.048%]	Measured value	BS4449 & NIS 117 [0.055%]	ASTM A706 [0.053%]	ISO 6935-2 [0.048%]	Measured value	NIS 117 [0.25%]	Measured value	Measured value
UKR <sub>(12)</sub>	0.191	✓	✓	✓	0.030	✓	✓	✓	0.014	✓	✓	✓	0.030	✗	0.08	0.554
UKR <sub>(16)</sub>	0.292	✗	✗	✓	0.068	✗	✗	✗	0.041	✓	✓	✓	0.027	✗	0.298	0.907
AFL <sub>(16)</sub>	0.145	✓	✓	✓	0.027	✓	✓	✓	0.016	✓	✓	✓	0.019	✓	0.077	0.515
AFL <sub>(20)</sub>	0.199	✓	✓	✓	0.037	✓	✓	✓	0.038	✓	✓	✓	0.121	✓	0.185	0.584
BSM <sub>(12)</sub>	0.178	✓	✓	✓	0.056	✗	✗	✗	0.069	✗	✗	✗	0.217	✓	0.259	0.666
BSM <sub>(16)</sub>	0.233	✓	✓	✓	0.053	✓	✓	✓	0.049	✓	✓	✗	0.228	✓	0.212	0.681
ETM <sub>(12)</sub>	0.316	✗	✗	✓	0.047	✓	✓	✓	0.044	✓	✓	✓	0.231	✓	0.25	0.572
ETM <sub>(16)</sub>	0.437	✗	✗	✗	0.053	✓	✓	✗	0.056	✗	✗	✗	0.358	✗	0.202	0.528
LCI <sub>(16)</sub>	0.212	✓	✓	✓	0.064	✗	✗	✗	0.068	✗	✗	✗	0.315	✗	0.273	0.794
LCI <sub>(20)</sub>	0.324	✗	✗	✓	0.067	✗	✗	✗	0.057	✗	✗	✗	0.319	✗	0.288	0.662
MYE <sub>(12)</sub>	0.341	✗	✗	✗	0.047	✓	✓	✓	0.042	✓	✓	✓	0.350	✗	0.18	0.892
RIL <sub>(12)</sub>	0.247	✓	✗	✓	0.055	✓	✗	✗	0.054	✓	✗	✗	0.309	✗	0.23	0.559
RIL <sub>(16)</sub>	0.376	✗	✗	✗	0.058	✗	✗	✗	0.046	✓	✓	✓	0.273	✗	0.183	0.679
RSS <sub>(12)</sub>	0.415	✗	✗	✗	0.041	✓	✓	✓	0.035	✓	✓	✓	0.172	✓	0.142	0.384
RSS <sub>(16)</sub>	0.345	✗	✗	✗	0.045	✓	✓	✗	0.029	✓	✓	✓	0.147	✓	0.138	0.546
SSM <sub>(16)</sub>	0.338	✗	✗	✗	0.050	✓	✓	✗	0.049	✓	✓	✗	0.371	✗	0.246	0.938
TGT <sub>(12)</sub>	0.277	✗	✗	✓	0.037	✓	✓	✓	0.044	✓	✓	✓	0.166	✓	0.224	0.561
TGT <sub>(16)</sub>	0.220	✓	✓	✓	0.036	✓	✓	✓	0.039	✓	✓	✓	0.151	✓	0.242	0.612
TOP <sub>(16)</sub>	0.373	✗	✗	✗	0.044	✓	✓	✗	0.048	✓	✓	✓	0.293	✗	0.252	0.693
TKY <sub>(12)</sub>	0.210	✓	✓	✓	0.03	✓	✓	✓	0.034	✓	✓	✓	0.465	✗	0.233	0.669
TKY <sub>(16)</sub>	0.205	✓	✓	✓	0.043	✓	✓	✓	0.032	✓	✓	✓	0.612	✗	0.153	0.638

**3.1.1. Carbon.** The principal determinant of the steel's strength and hardness is Carbon. From Table 2, 9 samples met the requirement in NIS 117 [17] of maximum carbon content of 0.27% while 10 samples met the requirement in BS4449 [14] of maximum carbon content of 0.24% and 14 samples met the requirement in ASTM A706 [15] and ISO 6935-2 [16] of maximum carbon content of 0.33%. Other researchers have also reported higher carbon content than the maximum requirement by the NIS standard [18-21]. The higher the carbon content the greater the hardness, the strength, hardness and wear resistance of the steel [22, 23]. However, ductility, weldability and toughness are reduced with increasing carbon content [20].

**3.1.2. Sulphur.** This is an undesirable impurity in steel, special effort is usually made to eliminate or minimize sulphur during steelmaking. Sulphur decreases notch impact toughness, reduces weldability, surface quality and decreases ductility. It generally appears as sulphide inclusions in the steel which decreases its strength. From Table 2, 16 samples were found to meet the requirement in NIS 117 [17] and BS4449 [14] of maximum sulphur content of

0.055% while 15 samples were found to meet the requirement in ASTM A706 [15] of maximum sulphur content of 0.053% and 11 samples were found to meet the requirement in ISO 6935-2 [16] of maximum sulphur content of 0.048%.

*3.1.3. Phosphorus.* Phosphorus increases steel embrittlement which reduces the toughness and ductility of the reinforcing steel. From Table 2, 17 samples were found to meet the requirement in NIS 117 [17] and BS4449 [14] of maximum phosphorus content of 0.055% while 16 samples were found to meet the requirement in ASTM A706 [15] of maximum phosphorus content of 0.053% and 14 samples were found to meet the requirement in ISO 6935-2 [16] of maximum carbon content of 0.048%. An increase in the percentage of phosphorus leads to increased hardness and strength, and decreased ductility, thus making the bars brittle [24].

*3.1.4. Copper.* Copper is often found as a residual agent in steels. It is also added to produce precipitation hardening properties and increase corrosion resistance. From Table 2, 9 samples were found to meet the requirement of maximum copper content of 0.25% of NIS 117 [17]. All samples were found to meet the requirement in BS4449 [14] of 0.85%.

*3.1.5. Silicon.* Silicon is one of the principal deoxidizers for structural steel. It improves strength, elasticity, acid resistance and results in larger grain sizes; thereby, leading to greater magnetic permeability. From Table 2, all samples met the requirement in ASTM A706 [15] and ISO 6935-2 [16] of maximum Silicon content of 0.55% and 0.60% respectively.

*3.1.6. Manganese.* Manganese has a large impact on strength, ductility and hardenability. It helps to reduce oxides and also counteract the presence of Iron Sulphide. Manganese content also helps in improving the abrasive resistance of reinforcing steel. It is a very important determinant of the steel's carbon equivalent value. From Table 2, all samples met the requirement in ASTM A706 [15] and ISO 6935-2 [16] of maximum Manganese content of 1.56%.

*3.1.7. Carbon Equivalent.* Carbon Equivalent ( $C_{eq}$ ) is an empirical value in weight percent, relating the combined effects of different alloying elements used in the making of carbon steels to an equivalent amount of carbon (Equation 1). It was developed to give a numerical value for a steel composition which would give an indication of hardenability, hydrogen cracking susceptibility, and other properties that may be linked to hardness, such as toughness and strength of steel. Table 3 shows the carbon equivalent of the tested steel bars. The percentage composition of sample steel bars considered showed no convergence at any point between its constituent elements from samples from the same steel mill/company. For example, a company that produced two tested samples of different diameter showed different percentage composition for each sample, implying a negative signal with the production process, scrap treatment, quality control, personnel, equipment or their combination [11, 25].

$$C_{eq} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \quad (1)$$

**Table 3.** Carbon equivalent and Code provisions.

Samples	Carbon Equivalent	BS4449 [14] 0.52%	NIS 117 [17] 0.54%	ISO 6935-2 [16] 0.56%
UKR <sub>(12)</sub>	0.29	✓	✓	✓
UKR <sub>(16)</sub>	0.45	✓	✓	✓
AFL <sub>(16)</sub>	0.24	✓	✓	✓
AFL <sub>(20)</sub>	0.32	✓	✓	✓
BSM <sub>(12)</sub>	0.35	✓	✓	✓
BSM <sub>(16)</sub>	0.41	✓	✓	✓
ETM <sub>(12)</sub>	0.47	✓	✓	✓
ETM <sub>(16)</sub>	0.59	✗	✗	✗
LCI <sub>(16)</sub>	0.42	✓	✓	✓
LCI <sub>(20)</sub>	0.52	✓	✓	✓
MYE <sub>(12)</sub>	0.54	✗	✓	✓
RIL <sub>(12)</sub>	0.40	✓	✓	✓
RIL <sub>(16)</sub>	0.56	✗	✗	✓
RSS <sub>(12)</sub>	0.54	✗	✓	✓
RSS <sub>(16)</sub>	0.48	✓	✓	✓
SSM <sub>(16)</sub>	0.55	✗	✗	✓
TGT <sub>(12)</sub>	0.41	✓	✓	✓
TGT <sub>(16)</sub>	0.36	✓	✓	✓
TOP <sub>(16)</sub>	0.55	✗	✗	✓
TKY <sub>(12)</sub>	0.38	✓	✓	✓
TKY <sub>(16)</sub>	0.38	✓	✓	✓

### 3.2. Mechanical properties

3.2.1. *Cross-sectional area.* Table 4 shows that the marketed diameters are greater than the measured diameters for all the reinforcing bars considered except for UKR<sub>(12)</sub>, AFL<sub>(20)</sub>, RIL<sub>(16)</sub> and TOP<sub>(20)</sub> whose average measured diameter is slightly higher than the marketed diameter. The average measured diameter of MYE<sub>(12)</sub> is the same with the marketed diameter. A very large discrepancy was observed on sample RSS<sub>(16)</sub> which is designated and sold in the market as 16mm bar against its average measured diameter of 14.47mm.

3.2.2. *Effective cross-sectional areas and tolerances.* In line with BS4449 [14] requirements which specify  $\pm 6.0\%$  for  $\leq 8\text{mm}$  bars and  $\pm 4.5\%$  for diameter greater than 8mm bars. It can be seen from Table 4 that the tolerances for some of the reinforcement bars irrespective of origin fall out of the specified range. 12 bars are out of range while 9 fall within the acceptable range. This indicates that the 11 bars that were out of range have varying diameters along the length which is not best for reinforcing bars. This should be carefully checked to ensure an average close diameter throughout the length.

3.2.3. *Characteristic strength and percentage elongation.* The characteristic strengths computed from the yield strengths and compared with the code requirements are shown in Table 5. From the table, it is clear that only 8 samples out of 35 bars tested met the minimum code

provisions by BS4449 [14] with Ultimate to Yield Strength Ratio less than 1.15. It can be observed that some of the bar samples both local and foreign are below the minimum requirement. This could be as a result of cooling process which is a manufacturing fault within the line of production. However, when the ratio is high, it is not good either. It implies high carbon content which means the bars lack ductility.

**Table 4.** Comparison of measured and market diameters, cross-sectional areas and strength values

Samples	Diameters (mm)			Area (mm <sup>2</sup> )		Strength					
	Market Assumed	Average Measured	Percentage Difference (%)	Measured Cross-Sectional	Nominal Cross-Sectional	NIS 117 Tolerance	Remarks	Yield Strength (N/mm <sup>2</sup> )	Ultimate Tensile Strength (N/mm <sup>2</sup> )	Ultimate to Yield Strength Ratio	Elongation (%)
UKR <sub>(12)</sub>	12	12.05	-0.42	114.04	113.00	±5.7	✓	468.89	894.13	1.91	24.37
UKR <sub>(16)</sub>	16	15.75	1.56	194.83	201.00	±7.6	✓	548.65	646.75	1.18	15.86
AFL <sub>(16)</sub>	16	15.91	0.56	198.81	201.00	±7.6	✓	481.27	743.83	1.55	17.22
AFL <sub>(20)</sub>	20	20.57	-2.85	332.32	314.00	±9.6	✗	490.89	588.21	1.20	23.46
BSM <sub>(12)</sub>	12	11.07	7.75	96.25	113.00	±5.7	✗	468.61	735.39	1.57	17.61
BSM <sub>(16)</sub>	16	15.13	5.44	179.79	201.00	±7.6	✗	481.02	504.73	1.05	21.57
ETM <sub>(12)</sub>	12	10.89	9.25	93.14	113.00	±5.7	✗	462.02	593.83	1.29	24.29
ETM <sub>(16)</sub>	16	15.13	5.44	179.79	201.00	±7.6	✗	486.66	645.53	1.33	10.64
LCI <sub>(16)</sub>	16	15.68	2.00	193.10	201.00	±7.6	✗	558.27	662.54	1.19	5.15
LCI <sub>(20)</sub>	20	19.53	2.35	299.57	314.00	±9.6	✗	481.33	574.00	1.19	14.65
MYE <sub>(12)</sub>	12	12.00	0.00	108.80	113.00	±5.7	✓	462.02	732.73	1.59	25.05
RIL <sub>(12)</sub>	12	11.81	1.58	109.54	113.00	±5.7	✓	471.64	539.39	1.15	13.04
RIL <sub>(16)</sub>	16	16.45	-2.81	212.53	201.00	±7.6	✗	462.02	496.27	1.10	7.82
RSS <sub>(12)</sub>	12	12.00	0.00	113.29	113.00	±5.7	✓	463.95	484.06	1.04	18.89
RSS <sub>(16)</sub>	16	14.47	9.56	164.45	201.00	±7.6	✗	488.58	543.54	1.11	6.45
SSM <sub>(16)</sub>	16	15.24	4.75	182.41	201.00	±7.6	✗	481.27	508.52	1.06	20.89
TGT <sub>(12)</sub>	12	11.45	4.58	102.97	113.00	±5.7	✗	481.27	508.52	1.05	15.71
TGT <sub>(16)</sub>	16	15.71	1.81	193.84	201.00	±7.6	✓	500.52	521.00	1.04	14.20
TOP <sub>(16)</sub>	20	20.46	-2.30	328.78	314.00	±9.6	✓	471.70	529.78	1.12	6.37
TKY <sub>(12)</sub>	12	11.36	5.33	101.36	113.00	±5.7	✗	468.89	894.13	1.64	14.96
TKY <sub>(16)</sub>	16	15.71	1.81	193.84	201.00	±7.6	✓	500.52	806.18	1.61	30.59

#### 4. Conclusion

The study employed micro-structure test to obtain the percentage elemental constituents of reinforcing steel bars in the Nigerian construction industry. Also, the tensile properties in terms of tensile strength, yield stress and elongation of the reinforcing bars were determined. In addition, the diameters of the bars available in the market were measured and compared to their nominal values.

Based on the results of the tests conducted, it was observed that most of the reinforcing steel bars in the Nigerian construction industry do not comply with the provisions of the percentage chemical composition stipulated in the NIS 117 [17], BS4449 [14], ASTM A706 [15] and ISO 6935-2 [16] standards. Further, there is inconsistency in percentage composition of all important elements for different sample sizes produced by the same steel mill in almost all the samples tested; this portends a laxity in the production process and a major cause of variabilities in the strength of reinforced concrete elements made from reinforcements of the same grade from the same source.

However, reinforcing steel bar samples tested complied with the carbon equivalent value prescribed in NIS 117 [17]. AFL reinforcing steel bars is the only bar that satisfied all the chemical composition requirements in the four codes used. A discrepancy in the nominal and measured

diameter and cross-sectional area of most of the steel bars was also observed, the tolerance on effective cross-sectional area for some of the bars fall out of range due to non-compliance with the actual bars diameter in the BS4449 [14].

Furthermore, the characteristic strength values for most of the tested bar samples are low compared to the BS4449 [14] standards for high tensile steel. Most of the reinforcement bar samples did not complied with the minimum ultimate to yield strength ratio as specified by BS 4449 [14] provisions. The percentage elongation values for the tested samples did not comply with the requirements prescribed by the codes, such bars have low ductility and should not be used in reinforced concrete structures because they will not give warning prior to failure.

The research provided an insight on the variations of chemical composition and tensile properties of reinforcing bars in the Nigerian construction industry with respect to the provisions of available standards. The results affirm the view on the culpability of reinforcements in the recurring incidents of building failures and collapses in the Nigerian construction industry. The available reinforcements in the markets mostly do not meet the quality required in terms of chemical composition, dimensions, characteristic strengths and percentage elongation. The outcome of this research will assist with necessary data required for quality assurance and implementation of compliance measures by regulatory bodies on steel bars being used in the Nigerian construction industry.

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