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A Comparative Assessment Of The Bend, Chemical And Tensile Properties Of Reinforcing Steel Bars In The Nigerian Construction Industry

By

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ABSTRACT

Bend, chemical concentration/ percentage composition and tensile tests were conducted to ascertain the properties of reinforcing steel in the Nigerian Construction Industry in relation to their conformity with the BS4449 : 1997 standards. A total of fourteen (14) companies supplied nineteen(19) samples with each sample containing ten(10) specimens making a total of four hundred and eighteen(418) specimens that were used to record one thousand five hundred and twenty (1,520) data on bend, chemical concentration, percentage composition, yield, ultimate : tensile to yield strength ratio, and percentage elongation tests conducted. It was found that a sample out of the nineteen (19) tested out rightly failed the bend test despite two other samples from the same company passed. It was also noted that the tested reinforcing steel bars have significant deviation in terms of chemical composition, as most of the tested samples seem to contain a lot of impurities as evidenced by the uncontrolled presence of sulphur, phosphorus and nitrogen. Although the Carbon equivalent (C.eqv.) values are within acceptable range, there is a conspicuous absence of some critical elements such as Vanadium and molybdenum that are supposed to be important determinants of strength and ductility in many of the samples and this must have contributed to the low strength performances of the local reinforcing steel bars. Similarly, most of the samples examined did not meet the requirements of BS4449:1997 in respect of Characteristic Strength, Ductility, Tensile / yield ratio, bend, chemical percentage composition or a combination of the parameters. For example, the thirteen local reinforcing bars recorded low values of characteristic strength with a minimum of 317N/mm2 and a maximum of 410N/mm2 , with most values in between them falling within the lower quartile. While the six foreign bar performed well in characteristic strength, their corresponding elongation values of 1.67 and 2.67 are considered not only very low, but dangerous for structural applications as they can fail without warning.

Key Words: Bend, Concentration, Percentage Composition, Yield, Elongation, C.eqv.

1.0 INTRODUCTION

The reinforcing steel plays a key role as a construction material whose properties should be known to the users before being used for design or construction purposes.

According to The UK Certification Authority for Reinforcing Steels (UK CARES Part 1) satisfactory reinforcing steel must be able to be bent and placed in shape with precision to fit structural elements in all aspects.

Steel reinforcing bars available in the Nigeria's Construction Industry are obtained from both internal and external sources. The former comes mainly from the major steel plants in Nigeria, while imported steel bars are mainly from Russia and Ukraine. Others are those imported for specific uses by multinational companies. Most construction companies in Nigeria obtain all their reinforcing steel procurements from the open markets without any technical information that guide users on the appropriate use.

Arum, C. (2008) tensile tested some few local & foreign bars with O 10, 12, 16, 20 & 25 bars comprising Local bars were taken from Lagos, Ibadan , Akure & Ife to represent Nigeria. Buliaminu, K(2009) conducted some tensile and chemical analyses on some selected few bars. Charles, K .K. & Mark, A. (2002), tested steel in Ghana produced from metal scraps and knocked engine parts. Inuwa , I.K.(2011) under took a study of the operations of Ajaokuta Steel Rolling Company. Sanmbo, B., David, E.,Samson,A., Olatunde,S.(2009) varied production conditions of steel in the Nigeria's Steel Industry and also worked on the challenges of producing quality reinforcement in West Africa. Shumatcher , K & Sathaye, J. (1998) examined production methods such as Blast Furnace , Direct.Reduction, Mini Mills methods as well as COREX being the latest tech. Various codes such as European Pr EN 10080 (E) , Russian Scientific Research Institute of Steel, Chinese std (GB/T 17107 : 1997) , ASTM A 30, BS 4449 , etc, also researched on the steel properties but not in an integrated manner.

Thus, experiments such as bend tests, chemical concentration, percentage composition tests, tensile tests, characteristic strength and ductility were carried out. The results of the comparisons show that most of the samples failed in at least one of the tests conducted.

2.0 MATERIALS AND METHODS

2.1 Samples' Labeling

All the fourteen companies from where the samples were collected were labeled in an alphabetical order as A, B, C, …N. The order of identification does not mean A is better than B , as the designations are only for identification purposes. For example: $A_{12}T_1$ and $A_{10}T_2$ imply company A 12 mm diameter sample one for tension test and company A 10 mm diameter sample two for tension test respectively. Similarly $A_{12}B_1$ and $A_{10}B_2$ imply company A 12 mm diameter sample 1 for bend test and company A 10 mm sample 2 for bend test respectively.

$A_{12}C_1$ and $A_{10}C_2$ imply company A 12 mm diameter samples 1 for chemical concentration and company A 10 mm for sample 2 chemical concentration respectively. While $A_{12}P_1$ and $A_{10}P_2$ refer to company A 12 mm diameter millimeters diameter sample 1 for percentage composition and company A 10 mm diameter sample 2 for percentage composition respectively. $B_{12}T_1$ and $B_{10}T_2$ imply company B twelve millimeter diameter sample onefor tension test and company B ten millimeter diameter sample 2 for tension test respectively, and so on.

2.2 Samples Preparation

2.2.1 Bend Test

Ten samples were tested for each diameter with each sample consisting of a length of 500 millimeters. Each sample was bent around a former in accordance with the BS4449:1997 provisions. The test results are shown in table 1 and also plate 1 below:

Table 1 : Bend Test Results For Fourteen Companies

S/No.	IDENTIFICATION NO.	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST
01	$A_{12}B$	12.0	39.0	No Cracks
02	$A_{10}B$	10.0	33.0	No Cracks
03	$B_{10}B$	10.0	33.0	No Cracks
04	B_8B	8.0	27.0	No Cracks
05	$C_{16}B$	16.0	51.0	Total Breakage
06	$C_{10}B$	10.0	33.0	No Cracks
07	C_8B	8.0	27.0	No Cracks
08	D_8B	8.0	27.0	No Cracks
09	$E_{25}B$	25.0	78.0	No Cracks
10	$E_{20}B$	20.0	63.0	No Cracks
11	$F_{12}B$	12.0	39.0	No Cracks
12	$G_{12}B$	12.0	39.0	No Cracks
13	$H_{16}B$	16.0	51.0	No Cracks
14	$I_{12}B$	12.0	39.0	No Cracks
15	J_8B	8.0	27.0	No Cracks
16	$K_{10}B$	10.0	33.0	No Cracks
17	$L_{12}B$	12.0	39.0	No Cracks
18	$M_{10}B$	10.0	33.0	No Cracks
19	$N_{16}B$	16.0	51.0	No Cracks

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Plate I: Some Test Specimens after The Bend Tests.

2.2.2 Tensile Tests

Ten samples were tested for each diameter. Each sample consists of a length of 500 millimeters, with sample diameter measured and then subjected to tension in accordance with the BS4449:1997 provisions. The test results are shown in table 2 and also plate II below:

Table 2 : Tensile Test Results For Fourteen Companies

S/No	Mark	Characteristic Strength(N/mm^2)	Percentage Elongation	Ultimate to Yield Strength Ratio
1	$A_{12}T$	350.00	16.50	1.55
2	$A_{10}T$	410.00	13.90	1.60
3	$B_{10}T$	390.00	19.60	1.46
4	B_8T	368.00	23.82	1.31
5	$C_{16}T$	482.00	8.33	1.84
6	$C_{10}T$	357.00	19.93	1.52
7	C_8T	387.00	21.17	1.35
8	D_8T*	463.00	1.67	1.39
9	$E_{25}T$	363.00	19.83	1.64
10	$E_{20}T$	317.00	24.27	1.43
11	$F_{12}T$	334.00	19.07	1.52
12	$G_{12}T$	408.00	14.83	1.69
13	$H_{16}T$	493.00	14.53	1.22
14	$I_{12}T$	369.00	14.50	1.69
15	J_8T*	573.00	2.67	1.21
16	$K_{10}T$*	549.00	10.07	1.22
17	$L_{12}T$*	500.00	14.93	1.21
18	$M_{10}T$*	547.00	11.77	1.08
19	$N_{16}T$*	545.00	13.90	1.26

Plate II: Some Broken Test Specimens after Tensile Tests

2.2.3 Chemical Tests

Under the Chemical tests, two types of experiments were performed (a) Chemical concentration and (b) percentage composition. The actual difference is that the former is the concentration with respect to milligrammes of the element per litre and the later refers to the percentage composition of the reinforcement by weight.

A. Determination of Chemical Concentration in Milligrams per Litre

In the determination of the elemental concentrations in milligrams per litre of the samples, stock solutions were prepared by the NARICT personnel using analar. An analar is a compound that matches with the element to be identified and capable of digesting same to form a stock solution. For example, to identify Calcium, Calcium Chloride ($CaCl_2$) or Calcium Carbonate ($CaCO_3$) used serial dilutions were made from the prepared stock solution within the range 1ppm, 2ppm, 3ppm, 4ppm and 5ppm. Each of the Samples was subjected to Atomic Spectrometer – Shimadzu model fuelled by acetylene/ air whose output comes as a calibration curve relating the absorbance of the element and concentration. The concentrations in mg/litre are read directly from the digitized system.

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Vol. 2 Issue 3, March - 2013

The tests were carried out in the National Research Institute for Chemical Technology, Zaria. The result is as shown in tables 3a and 3b.

Table 3a: Chemical Concentration of Sample Bars in Milligrams/ Litre For Companies A To F.

Elements	$A_{12}C$	$A_{10}C$	$B_{10}C$	B_8C	$C_{16}C$	$C_{10}C$	C_8C	D_8C	$E_{25}C$	$E_{20}C$	$F_{12}C$
Aluminium (Al)	3.9	2.16	3.06	1.45	1.51	3	1.35	1.77	11.1	7.87	7.1
Cobalt (Co)	1.55	2.23	2.03	0.7	1.99	0.32	0.48	1.88	2.44	2.27	0.9
Copper (Cu)	7.1	7.26	8.74	2.74	7.89	1.38	1.54	9.59	8.85	8.98	2.09
Chromium (Cr)	3	3.05	4.26	0.88	2.39	0.84	0.71	1.36	2.82	2.98	1.23
Manganese (Mn)	6.05	5.9	5.96	6.09	6.03	6.08	6	6	5.91	6.07	5.85
Iron (Fe)	40.7	32.4	22	33.3	20.7	23.3	25	19	23.5	31.9	31.8
Lead (Pb)	0.98	0.46	0.27	0.18	0.64	0.95	0.3	0.49	0.24	0.33	0.22
Nickel (Ni)	2.36	2.45	2.83	0.97	2.55	0.5	0.61	2.95	2.57	2.88	1.09
Nitrogen(N)	0.14	0.7	0.4	0.1	2.8	4.2	4	0.31	0.08	0.7	0.8
Zinc (Zn)	1.05	0.66	0.13	0.06	1.05	0.1	0.09	0.26	0.52	0.77	0.37
Phosphate (Po3)	5.3	13.6	3	3	7.3	1.6	13	3.5	8	0.6	11.8
Sulphide (S)	0.24	2.34	2.5	0.5	0.02	0.1	0.45	1.5	2.01	0.02	0.2

Table 3b: Chemical Concentration of Sample Bars in Milligrams/Litre For Companies G To N.

Elements	$G_{12}C$	$H_{16}C$	$I_{12}C$	J_8C	$K_{10}C$	$L_{12}C$	$M_{10}C$	$N_{16}C$
Aluminium (Al)	1.19	3.55	2.42	1.1	3.68	4.77	2.23	5.26
Cobalt (Co)	1.94	2.25	3.32	2.11	1.49	2.24	1.57	2.38
Copper (Cu)	6.64	9.14	9.59	10.9	9.32	9.98	9.07	
Chromium (Cr)	1.96	2.98	4.65	2.24	2.66	1.55	2.07	3.21
Manganese (Mn)	6	6.08	6.01	6.04	6.06	5.94	5.88	6.01
Iron (Fe)	26.9	29.9	20.7	15.8	34.1	26.3	31.3	32
Lead (Pb)	0.92	0.22	0.64	0.42	0.49	0.67	0.48	0.55
Nickel (Ni)	2.3	3.83	3.82	2.8	3.26	3.05	3.83	
Nitrogen(N)	2.4	3.1	0.05	0.95	0.02	0.3	0.01	2.05
Zinc (Zn)	0.7	0.37	1	0.52	0.51	0.4	0.31	0.34
Phosphate (Po3)	0.4	39	0.3	3.4	47.7	4.8	20.3	2.1
Sulphide (S)	0.21	0.06	0.15	0.04	3.2	0.03	0.05	0.01

B. Determination of Elemental Percentage Composition By Weight

The Chemical Composition of the samples were carried out using the XRF spectrometer at the Centre for Energy Research and Training , at Ahmadu Bello University, Zaria and the results are as shown in the tables 4a and 4b below:

Table 4a: Percentage Chemical Composition of Sample Steel Bars : Companies A To F

Elements	$A_{12}P$	$A_{10}P$	$B_{10}P$	B_8P	$C_{16}P$	$C_{20}P$	C_8P	D_8P	$E_{25}P$	$E_{20}P$	$F_{12}P$
Aluminium (Al)	0	2	3	0	0	0	0	3	1.6	3.1	3
Barium (Ba)	0.14	0	0	0	0	0.13	0	0.24	0	0	0
Bromine (Br)	2.2	2.6	2.4	0	0	0	0	2.3	0	2.2	2.4
Cadmium (Cd)	4	3	4.9	3.9	2	3.1	2.5	5.8	4.3	3	3.5
Calcium (Ca)	0.06	0.02	0.09	0.66	0.28	0	0.01	0.48	0.11	0.13	0.07
Carbon (C)	0.05	0.13	0.04	0.07	0.06	0.07	0.09	0.08	0.07	0.04	0.07
Chlorine (Cl)	0.1	0.07	0.9	0.09	0.07	0.11	0.07	0.13	0.08	0.07	0.08
Chromium (Cr)	0.31	0.24	0.27	0.14	0.11	0.19	0.14	0.24	0.2	0.28	0.22
Copper (Cu)	0.31	0.27	0.33	0.12	0.37	0.1	0.1	0.31	0.33	0.28	0.32
Galium (Ga)	0.18	0	0.06	0.07	0	0.08	0.03	0.06	0	0.15	0.09
Iron (Fe)	89.4	89.3	86.8	93.6	94.8	92.8	94.1	84	87.8	88	87.4
Irridium (Ir)	0	0	0	0	0	0.55	0.5	0	0	0	0
Manganese(Mn)	0.75	0.9	0.84	0.71	0.65	0.74	0.83	0.84	1.01	0.91	0.76
Molibdinum (Mo)	0	0	0.04	0	0	0	0	0	0	0	0
Nickel (Ni)	0.1	0.05	0.06	0	0.07	0	0	0.07	0.06	0.09	0.06
Nitrogen (N_2)	0.014	0.007	0.04	0.01	0.28	0.42	0.40	0.31	0.008	0.007	0.08
Osmium (Os)	0.56	0.39	0.28	0.35	0.31	0.42	0.37	0.31	0.35	0.46	0.35
Phosphorus (P)	0	0	0.06	0.09	0.08	0	0.1	0.04	0	0	0
Platinium (Pt)	0.1	0	0	0	0	0	0	0.05	0	0	0
Redium (Re)	0.2	0.1	0.1	0	0.24	0.24	0.2	0.07	0.2	0.1	0.1
Rhodium (Rh)	0.68	0.42	0.25	0.34	0.28	0.57	0.48	0.24	0.35	0.62	0.42
Silicon (Si)	0.7	0.7	0.9	0.6	0.7	0.59	0.41	1.7	3.53	0.72	1
Sulphur (S)	0	0	0.03	0	0	0	0	0	0	0.14	0
Telerium (Te)	0	0	0	0	0	0.05	0.14	0	0	0	0
Titanium (Ti)	0.16	0	0	0	0	0.15	0	0.13	0	0	0
Vanadium (V)	0	0	0.03	0	0	0	0	0	0	0	0
Zinc (Zn)	0.17	0.04	0.07	0	0.01	0.02	0.02	0.13	0.08	0.15	0.04
Zirconium (Zr)	0	0	0	0	0	0	0	0	0	0	0
Total (%)	100	100	99.99	99.99	100	99.98	100	100	100	100	99.98

Table 4b : Percentage Chemical Composition of Sample Steel Bars : Companies G To N.

Elements	$G_{12}P$	$H_{16}P$	IP_{12}	J_8P	$K_{10}P$	$L_{12}P$	$M_{10}P$	$N_{16}P$
Aluminium (Al)	3	2	2	1	2	2	3	0.5
Barium (Ba)	0	0	0	0	0	0	0.15	0
Bromine (Br)	1.9	1.8	1.8	2.7	2.5	2.6	1.9	0
Cadmium (Cd)	1.2	1.7	1.8	3.4	3.8	3.8	2.2	3
Calcium (Ca)	0	0	0	0.11	0.06	0.09	0.88	0.06
Carbon (C)	0.03	0.15	0.09	0.02	0.08	0.14	0.13	0.18
Chlorine (Cl)	0.15	0.16	0.13	0.05	0.09	0.07	0.66	0.08
Chromium (Cr)	0.22	0.28	0.31	0.14	0.21	0.16	0.24	0.26
Copper (Cu)	0.07	0.18	0.15	0.41	0.32	0.34	0.36	0.44
Galium (Ga)	0	0	0	0.05	0.07	0	0	0
Iron (Fe)	80.1	77	74.5	89.7	87.9	87.6	86.7	92
Irridium (Ir)	0	0	0	0	0	0	0	0
Manganese(Mn)	0.9	0.87	0.94	0.56	0.89	0.88	0.91	0.71
Molibdinum (Mo)	0	0	0	0	0	0	0.3	0
Nickel (Ni)	0.06	0.09	0.07	0.05	0.07	0.06	0.11	0.18
Nitrogen (N_2)	0.24	0.31	0.005	0.095	0.002	0.03	0.001	0.21
Osmium (Os)	0.42	0.37	0.34	0.25	0.27	0.32	0.62	0.61
Phosphorus (P)	0	0	0	0.06	0.08	0	0	0
Platinium (Pt)	0	0	0	0.04	0	0	0	0
Redium (Re)	0.1	0	0	0.1	0.1	0.1	0.2	0.3
Rhodium (Rh)	0.32	0	0	0.2	0.39	0.32	0.63	0.6
Silicon (Si)	0.5	0.25	0.27	0.91	0.84	1.1	1	1.1
Sulphur (S)	0	0	0	0	0	0	0.31	0
Telerium (Te)	0	0	0	0	0	0	0	0
Titanium (Ti)	0	0	0	0	0	0	0.18	0
Vanadium (V)	0	0.05	0	0	0	0.02	0	0
Zinc (Zn)	0.06	0.05	0.06	0.04	0.06	0.61	0.15	0.14
Zirconium (Zr)	0	0	1.1	0	0	0	0	0
Percentage Total	99.89	100	99.87	99.89	99.79	100	99.99	100

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3.0 ANALYSES AND DISCUSSION OF RESULTS

3.1 Cross Sectional Area

From table 1 below, one can clearly observe that the assumed market diameters for all the reinforcing steel bars are less than the measured diameters for all the bars considered. A very large discrepancy was also observed on sample J_8T which is designated and sold in the market as 8 mm bar against its measured diameter of 6.5mm.

Table 5: Measured and Market Diameter Differences for Fourteen Companies

S/No	Mark	Market Designated Diameter (mm)	Measured Diameter (mm)	Percentage Difference
01	$A_{12}T$	12.00	11.88	1.00
02	$A_{10}T$	10.00	9.65	3.50
03	$B_{10}T$	10.00	9.56	4.40
04	B_8T	8.00	7.44	7.00
05	$C_{16}T$	16.00	15.82	1.13
06	$C_{10}T$	10.00	9.55	4.50
07	C_8T	8.00	7.46	6.75
08	D_8T	8.00	7.23	9.63
09	$E_{25}T$	25.00	24.56	1.76
10	$E_{20}T$	20.00	19.57	2.15
11	$F_{12}T$	12.00	11.40	5.00
12	$G_{12}T$	12.00	11.48	4.33
13	$H_{16}T$	16.00	15.52	3.00
14	$I_{12}T$	12.00	11.40	5.00
15	J_8T	8.00	6.50	18.75
16	$K_{10}T$	10.00	9.36	6.40
17	$L_{12}T$	12.00	11.82	1.50
18	$M_{10}T$	10.00	9.23	7.70
19	$N_{16}T$	16.00	15.60	2.25

Where the diameter cannot be approximated to the assumed market diameter, then there is a problem. For example, sample B_8T 7.44mm cannot be approximated to 8mm, D_8T cannot approximate to 8mm, $F_{12}T$, 11.40 cannot be 12.0mm, $I_{12}T$ and $K_{16}T$. These were the problems observed.

3.2 Effective Cross Sectional Areas and Tolerances

In line with BS4449: 1997 requirements which specify ± 6.0 % for 8mm and 10 mm bars and ± 4.5% for 12mm bars and above, it can be seen from table 6 that the percentage tolerances for most of the reinforcement bars irrespective of origin fall out of range. Thirteen bars are out of range, while only six fall within the acceptable range.

Table 6: Difference in Measured And Effective Cross Sectional Areas of Bars.

S/N	Mark	Measured Cross-Sectional Area (mm^2)	Effective Cross-Sectional Area (mm^2)	Tolerance Differences (%)	BS4449/1997 Min. Tolerance (%)	Remarks
1	$A_{12}T$	110.79	86.14	+22.25	± 4.5	Out of Range
2	$A_{10}T$	73.10	71.96	+1.56	± 6.5	Within Range
3	$B_{10}T$	71.74	70.98	+1.06	± 6.5	Within Range
4	B_8T	43.45	48.37	-11.32	± 6.5	Out of Range
5	$C_{16}T$	196.46	160.14	+18.49	± 4.5	Out of Range
6	$C_{10}T$	71.59	72.42	-1.16	± 6.5	Within Range
7	C_8T	43.69	49.85	-14.10	± 6.5	Out of Range
8	D_8T*	41.03	36.27	+11.60	± 6.5	Out of Range
9	$E_{25}T$	473.51	316.93	+33.07	± 4.5	Out of Range
10	$E_{20}T$	300.64	281.13	+6.49	± 4.5	Out of Range
11	$F_{12}T$	102.02	88.84	+12.92	± 4.5	Out of Range
12	G_8T	103.46	85.17	+17.68	± 6.5	Out of Range
13	$H_{12}T$	189.08	95.77	+49.35	± 4.5	Out of Range
14	$I_{16}T$	100.24	87.47	+12.74	± 4.5	Out of Range
15	$J_{12}T$*	33.17	34.74	-4.73	± 6.5	Within Range
16	$K_{10}T$*	68.77	70.12	-1.96	± 6.5	Within Range
17	$L_{12}T$*	109.07	110.30	-1.13	± 6.5	Within Range
18	$M_{10}T$*	66.88	71.77	-7.31	± 4.5	Out of Range
19	$N_{16}T$*	191.04	211.28	-10.60	± 6.5	Out of Range

* Implies foreign bars

This indicates that the thirteen bars that are out of range have varying diameter along the length which is not the best for reinforcing bars. This should be carefully checked to ensure an average close diameter throughout the length. Thus, most of the steel in the construction industry in Nigeria have varying diameters along the length.

3.3 Bend Test

Eighteen out of the nineteen samples have passed the bend test as neither micro cracks , nor any form of unacceptable deformation were observed. It is worthy to note that $C_{16}B$, $C_{10}B$ and C_8B are from the same company.

If such reinforcement like $C_{16}B$, which is company C with bar diameter 16 millimetres are used in structural elements, the element may fail without warning. On observing the bar carefully, the ultimate to yield strength ratio is 1.84, characteristic strength is 482N/mm^2 , the cross sectional area percentage tolerance is +18.49 which is out of range. The elongation is 8.3 percent which is far below the 14 percent. The company has to check the production line carefully. This situation indicates high content of carbon with no elements for ductility. There is a need to reduce high carbon content.

3.6 Characteristic Strength

The characteristic strengths computed from the yield strengths are shown in table 8 and are compared with the code requirements.

Table 7: Characteristic Strength Values for The Nineteen Samples

S/No	Mark	Characteristic Strength(N/mm^2)	Min. BS4449/1997 Provisions	Remarks
1	$A_{12}T$	350.00	460.00	Below => Unsatisfactory
2	$A_{10}T$	410.00	460.00	Below => Unsatisfactory
3	$B_{10}T$	390.00	460.00	Below => Unsatisfactory
4	B_8T	368.00	460.00	Below => Unsatisfactory
5	$C_{16}T$	482.00	460.00	Above => Satisfactory
6	$C_{10}T$	357.00	460.00	Below => Unsatisfactory
7	C_8T	387.00	460.00	Below => Unsatisfactory
8	D_8T*	463.00	460.00	Above => Satisfactory
9	$E_{25}T$	363.00	460.00	Below => Unsatisfactory
10	$E_{20}T$	317.00	460.00	Below => Unsatisfactory
11	$F_{12}T$	334.00	460.00	Below => Unsatisfactory
12	$G_{12}T$	408.00	460.00	Below => Unsatisfactory
13	$H_{16}T$	493.00	460.00	Above => Satisfactory
14	$I_{12}T$	369.00	460.00	Below => Unsatisfactory
15	J_8T*	573.00	460.00	Above => Satisfactory
16	$K_{10}T$*	549.00	460.00	Above => Satisfactory
17	$L_{12}T$*	500.00	460.00	Above => Satisfactory
18	$M_{10}T$*	547.00	460.00	Above => Satisfactory
19	$N_{16}T$*	545.00	460.00	Above => Satisfactory

* Implies foreign bars

Observing carefully, eleven out of nineteen samples fall below the characteristic strength. This is not good enough.

3.7 Ultimate to Yield Strength Ratio

Table 8 below shows the ratio of the ultimate to yield strength. It can be seen that the ultimate to yield strength ratio values in respect of all the nineteen samples are above the minimum code provisions. The values obtained for the fourteen local samples are relatively higher than those obtained for the foreign bar samples, which are very close to the minimum.

Table 8: Ultimate to Yield Strength (U : Y) Ratio Values for The Nineteen Samples

S/No	Mark	U : Y Ratio	BS4449/ 1997 Provisions Minimum .	Remarks
1	$A_{12}T$	1.55	1.15	Above => Satisfactory
2	$A_{10}T$	1.60	1.15	Above => Satisfactory
3	$B_{10}T$	1.46	1.15	Above => Satisfactory
4	B_8T	1.31	1.15	Above => Satisfactory
5	$C_{16}T$	1.84	1.15	Above => Satisfactory
6	$C_{10}T$	1.52	1.15	Above => Satisfactory
7	C_8T	1.35	1.15	Above => Satisfactory
8	D_8T*	1.39	1.15	Above => Satisfactory
9	$E_{25}T$	1.64	1.15	Above => Satisfactory
10	$E_{20}T$	1.43	1.15	Above => Satisfactory
11	$F_{12}T$	1.52	1.15	Above => Satisfactory
12	$G_{12}T$	1.69	1.15	Above => Satisfactory
13	$H_{16}T$	1.22	1.15	Above => Satisfactory
14	$I_{12}T$	1.69	1.15	Above => Satisfactory
15	J_8T*	1.21	1.15	Above => Satisfactory
16	$K_{10}T$*	1.22	1.15	Above => Satisfactory
17	$L_{12}T$*	1.21	1.15	Above => Satisfactory
18	$M_{10}T$*	1.08	1.15	Below => Unsatisfactory
19	$N_{16}T$*	1.26	1.15	Above => Satisfactory

* Implies foreign bars

It can be observed that bars samples $M_{10}T$ which is a foreign sample is below 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 may lack ductility.

3.8 : Percentage Elongation

From the table 10 below, it can be seen that most of the local bar samples met the minimum code requirements on elongation, while most of the foreign bars did not meet the minimum codes requirements. Serial numbers 5, 8, 15, 16 and 18 failed to reach the value of 14 percent and on observing carefully sample nos. 5, 6 and 7 are of the same company, but sample no. 5 failed to satisfy the elongation requirement. Secondly, samples nos. 15 to 19 and also no. 8 are foreign companies and only the sample with serial number 17 passed.

Table 9: Percentage Elongation Values For The Nineteen Samples

S/No	Mark	Percentage Elongation	Min. BS4449/1997 Provisions	Remarks
1	$A_{12}T$	16.50	14.00	Above => Satisfactory
2	$A_{10}T$	13.90	14.00	Below => Unsatisfactory
3	$B_{10}T$	19.60	14.00	Above => Satisfactory
4	B_8T	23.82	14.00	Above => Satisfactory
5	$C_{16}T$	8.33	14.00	Below => Unsatisfactory
6	$C_{10}T$	19.93	14.00	Above => Satisfactory
7	C_8T	21.17	14.00	Above => Satisfactory
8	D_8T*	1.67	14.00	Below => Unsatisfactory
9	$E_{25}T$	19.83	14.00	Above => Satisfactory
10	$E_{20}T$	24.27	14.00	Above => Satisfactory
11	$F_{12}T$	19.07	14.00	Above => Satisfactory
12	$G_{12}T$	14.83	14.00	Above => Satisfactory
13	$H_{16}T$	14.53	14.00	Above => Satisfactory
14	$I_{12}T$	14.50	14.00	Above => Satisfactory
15	J_8T*	2.67	14.00	Below => Unsatisfactory
16	$K_{10}T$*	10.07	14.00	Below => Unsatisfactory
17	$L_{12}T$*	14.93	14.00	Above => Satisfactory
18	$M_{10}T$*	11.77	14.00	Below => Unsatisfactory
19	$N_{16}T$*	13.90	14.00	Below => Unsatisfactory

These samples that failed in elongation should not be used in reinforcement as they will not give warning prior to failure due to low ductility.

3.4 Chemical Tests:

A total of fourteen (14) elements were identified for the Chemical Concentration in Milligrams Per Litre using the analar , while twenty eight (28) elements were discovered in the Determination of Elemental Percentage Composition By Weight using the XRF spectrometer.

The highest concentration element for all the samples is Iron (Fe) , which is followed by manganese and copper.The behaviour of Manganese, Carbon, Copper and Chromium being strength and coefficient of weldability determinants across the nineteen samples was further investigated. Similarly, the behaviour of Iron being the principal steel constituent checked. It is worthy to note that these five important elements considered showed no convergence at any point between elements from the same country of origin or company source. For example, a company that produced two or three of these samples was showing different percentage composition for each sample, implying a negative signal with the production process, quality control, personnel, equipment or their combination. These have been represented in graphs I and II respectively.

3.9 Some Measured Parameters:

Table 10a Parameter Summary for Tensile Tests (Companies A To E):

S/No.	SAMPLE PRARAMETER	$A_{12}T$	$A_{10}T$	$B_{10}T$	B_8T	$C_{16}T$	$C_{10}T$	C_8T	D_8T	$E_{25}T$	$E_{20}T$
01	Diameter(mm)	12	10	10	8	16	10	8	8	25	20
02	Characteristic Strength(N/mm^2)	350.0	410.0	390.3	368.2	482.0	357.0	387.0	463.0	363.0	317.0
03	Standard Deviation	4.65	0.0	0.0	0.0	13.0	4.4	11.1	0.0	2.4	1.0
04	Average Elongation (%)	16.5	13.9	19.6	23.8	8.3	19.9	21.2	1.7	19.8	24.3

Table 10b Parameter Summary for Tensile Tests(Companies F To N):

S/No.	SAMPLE PRARAMETER	$F_{12}T$	G_8T	$H_{12}T$	$I_{16}T$	$J_{12}T$	$K_{10}T$	$L_{12}T$	$M_{10}T$	$N_{16}T$
01	Diameter(mm)	12	8	12	16	12	10	12	10	16
02	Characteristic Strength(N/mm^2)	334.0	573.0	408.0	493.0	369.0	549.0	500.0	547.0	546.0
03	Standard Deviation	49.6	0.0	6.8	3.7	0.0	15.71	2.9	10.1	3.7
04	Average Elongation (%)	19.1	2.7	14.8	14.5	14.5	10.1	14.9	11.8	13.9

The value of standard deviation will determine the skilled people that are under employment. The small the value indicates high skilled personnel were employed. Values below or equal to five are an indicative of highly skilled personnel and above five indicates employment of low skilled men which lead to bad products, etc. About five samples from company C, F, H, K and M have values above five. A balance must be maintained for effective administration and good output.

Table 11: Elements observed as per Chemical Percentage Composition (Companies A To F).

Elements	$A_{12}P$	$A_{10}P$	$B_{10}P$	B_8P	$C_{16}P$	$C_{20}P$	C_8P	D_8P	$E_{25}P$	$E_{20}P$	$F_{12}P$
Total Elements	28	28	28	28	28	28	28	28	28	28	28
Appearance per Sample	19	16	21	13	15	17	17	21	15	18	17
Differences	8	11	6	14	12	10	10	6	12	9	10

Table 12: Elements observed as per Chemical Percentage Composition (Companies G To N).

Elements	$G_{12}P$	$H_{16}P$	IP_{12}	J_8P	$K_{10}P$	$L_{12}P$	$M_{10}P$	$N_{16}P$
Total Elements	28	28	28	28	28	28	28	28
Appearance per sample	15	14	14	19	18	17	20	15
Differences	12	13	13	8	9	10	7	12

3.13: Determination of Carbon Equivalent Value

The weldability of the reinforcing steel bars can be understood from the table as relevant code and standards (BS 4449: 1997) stipulates a maximum value of 0.51 for high tensile steel given that Carbon equivalent value is usually a function of the percentages composition of C, Mn, Ni, Cu, Mo, V, and Cr. The weldability statistics of the tested steel bars are hereby presented in table 13 below.

Table 4 of BS4449 prescribes a maximum value of 0.51 for high tensile steel bars. Thus, data obtained was used to compute the carbon equivalent value using the formula:

$Ceqv = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15$ as provided by the code and confirmed by Sanmbo B., David E., Samson A., and Olatunde S., (2009).

TABLE 13: CARBON EQUIVALENT VALUE (WELDABILITY COEFFICIENT) OF STEEL BAR

S/No	Mark	Calculated Carbon Equivalent Value (Ceq.)	Remarks
C	$A_{12}P$	0.26	Code compliant
2	$A_{10}P$	0.35	Code compliant
3	$B_{10}P$	0.27	Code compliant
4	B_8P	0.23	Code compliant
5	$C_{16}P$	0.22	Code compliant
6	$C_{10}P$	0.24	Code compliant
7	C_8P	0.26	Code compliant
8	D_8P*	0.29	Code compliant
9	$E_{25}P$	0.31	Code compliant
10	$E_{20}P$	0.27	Code compliant
11	$F_{12}P$	0.26	Code compliant
12	$G_{12}P$	0.24	Code compliant
13	$H_{16}P$	0.38	Code compliant
14	$I_{12}P$	0.32	Code compliant
15	J_8P*	0.17	Code compliant
16	$K_{10}P$*	0.29	Code compliant
17	$L_{12}P$*	0.34	Code compliant
18	$M_{10}P$*	0.42	Code compliant
19	$N_{16}P$*	0.39	Code compliant

3.11 Cross - Checking Samples with the Parameters Tested

From table 14 below, five tested parameters were checked with each diameter samples.

TABLE 14: BEND AND TENSILE TEST PARAMETERS.

S/No	Mark	Tolerances- Areas & Masses (%)	Characteristic Strength-N/mm^2	Ult :Yield Str Ratio	Percentage Elongation (%)	Bend Test	Remarks
1	$A_{12}T$	×	×	√	√	√	Not Totally Complied
2	$A_{10}T$	√	×	√	×	√	Not Totally Complied
3	$B_{10}T$	√	×	√	√	√	Not Totally Complied
4	B_8T	×	×	√	√	√	Not Totally Complied
5	$C_{16}T$	×	√	√	×	×	Not Totally Complied
6	$C_{10}T$	√	×	√	√	√	Not Totally Complied
7	C_8T	×	×	√	√	√	Not Totally Complied
8	D_8T*	×	√	√	×	√	Not Totally Complied
9	$E_{25}T$	×	×	√	√	√	Not Totally Complied
10	$E_{20}T$	×	×	√	√	√	Not Totally Complied
11	$F_{12}T$	×	×	√	√	√	Not Totally Complied
12	$G_{12}T$	×	×	√	√	√	Not Totally Complied
13	$H_{16}T$	×	√	√	√	√	Not Totally Complied
14	$I_{12}T$	×	×	√	√	√	Not Totally Complied
15	J_8T*	√	√	×	√	√	Not Totally Complied
16	$K_{10}T$*	√	√	√	×	√	Not Totally Complied
17	$L_{12}T$*	√	√	√	√	√	Partially Complied
18	$M_{10}T$*	×	√	×	√	√	Not Totally Complied
19	$N_{16}T$*	×	√	√	×	√	Not Totally Complied

TABLE 15a: PERCENTAGE CHEMICAL COMPOSITION PARAMETERS COMPANIES (A - F)

S/No	Element	$A_{12}P$	$A_{10}P$	$B_{10}P$	B_8P	$C_{16}P$	$C_{10}P$	C_8P	D_8P	$E_{25}P$	$E_{20}P$	$F_{12}P$
1	Al	–	x	x	–	–	–	–	x	x	x	–
2	C	√	√	√	√	√	√	√	√	√	√	√
3	Cr	x	√	√	√	√	√	√	√	√	√	√
4	Cu	x	√	x	√	x	√	√	x	x	√	x
5	Mn	√	√	√	√	√	√	√	√	x	x	√
6	Ni	√	√	√	√	√	√	√	√	√	√	√
7	N_2	x	x	x	√	x	x	x	x	√	x	x
8	P	–	–	×	×	×	–	×	×	–	–	–
9	Si	x	x	x	x	x	x	x	x	x	x	x
10	**S**	–	–	×	×	×	–	×	×	–	–	–

TABLE 15b: PERCENTAGE CHEMICAL COMPOSITION PARAMETERS COMPANIES (G - N)

S/No	Element	$G_{12}P$	$HA_{16}P$	$I_{12}P$	J_8P	$KA_{10}P$	$L_{12}P$	$M_{10}P$	$N_{16}P$
1	Al	–	–	–	–	–	–	–	–
2	C	√	√	√	√	√	√	√	√
3	Cr	√	√	√	X	√	√	√	√
4	Cu	√	√	√	X	x	X	x	X
5	Mn	√	√	x	√	√	√	x	√
6	Ni	√	√	√	√	√	√	√	√
7	N_2	x	x	√	X	√	X	√	X
8	P	–	–	–	×	×	–	–	–
9	Si	x	x	x	x	x	X	x	X
10	**S**	–	–	–	×	×	–	–	–

Legend :√=> Within Code Provision; X=> Outside Code Provision; - => No Trace of the Element

Tables 15a and 15b were prepared for only elements whose specifications were given by the code.

4.0 CONCLUSION

Based on the tensile test conducted and the analyses/ observations carried out the following conclusions were made.

1. There is a variation between the actual and measured bar diameters for the nineteen samples. There is also variation of diameters along the length of each diameter bar.
2. The characteristic strength values for most of the locally produced bar samples are low compared to the BS4449:1969,1995& 1997 standards for high tensile steel which is 460N/mm^2 minimum value.
3. The characteristic strength values in respect of the local bars suggest similarities with characteristics strength of mild steel. This implies the products are actually mild steel rolled and openly sold as high tensile steel after rethreading.
4. Most of the reinforcement bar samples complied with the minimum ultimate to yield strength ratio as specified by BS 4449: 1969 and 1997 code provisions.
5. The percentage elongation values for most of the locally produced bar samples are within acceptable code limits, the values for most of the foreign bar samples are below the minimum standard provisions.
6. Despite the evidence of brittleness in the foreign bars, only one out of the three samples from company C (C_{16} B) failed the bend test.
7. Elongation and bend tests are to be carried out to confirm brittleness or lack of ductility.

8. The chemical concentration test results showed thirteen elemental constituents only, while the chemical percentage composition tests gave twenty seven.
9. All the ten elements mentioned by the BS4449 code were identified in addition to seventeen other elements adding up to twenty seven.
10. Most of the elements whose composition limits were not specified by any code showed presence in traces.
11. There is an indication of the presence of impurities as evidenced by the traces of silicon, phosphorus, sulphur or their combination in most of the samples tested.
12. Elements that add to strength and carbon equivalent value like Molybdenum, Vanadium, etc. were present in the samples.
13. Iron being the principal component of reinforcement steel varies from seventy four percent (74.5%) to ninety eight point four percent (98.4%) in the samples.
14. All the nineteen samples tested complied with code value on carbon equivalent values.
15. Evidence of products technical information is absent in the open market where bulk of the products are sold to the construction industry, even for the locally produced bars.
16. From the field survey carried out it is confirmed that only clients of corporate projects pay serious attention to materials testing at site for proper documentation.

4.1 RECOMMENDATIONS

On the basis of the findings of this study, the following recommendations are hereby made.

1. Reinforcement steel users must ensure that all reinforcement to be used in any construction work must be selected / tested for all vital parameters as checked in this research in accordance with the BS4449 (1997 or 2005) provisions.
2. All imported reinforcing steel must be checked for compliance prior to accepting it in Nigeria and such consignment must be accompanied by with an accredited certification.

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