INVESTIGATION OF THE TENSILE CHARACTERISTICS OF REINFORCING STEEL USED IN THE NIGERIAN CONSTRUCTION INDUSTRIES

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ABSTRACT

This paper examines the mechanical properties of the reinforcing steel bars used in the Nigerian Construction Industry. Tensile test were conducted to ascertain the tensile characteristics of the steel bars with regards to their level of conformity to the BS 4449: 1997 provisions. Four hundred and eighteen samples of bars from fourteen steel producing companies were used in the experiment and seven hundred and sixty test results obtained. It was found that eighty five percent of the samples tested fell short of BS 4449: 1997 provision. The research draws the attention of the regulatory bodies to the quality of reinforcing steel bars in the market. The study finally recommends that all imported reinforcing steel bars should be checked for quality compliance with an accredited certificate before entering into the country.

Keywords: Steel bar, Tensile tests, BS4449:1975, Mechanical properties, Percentage elongation)Chukwudi, B.C and Onyeka, J.O.

INTRODUCTION

Steel is an important solid substance needed by people to meet their needs and desires. It is part of everyday operations, in urban development, rural development, the developed and developing countries. It is extensively used in automobiles and railroads, small housing to large multi-family dwellings, construction industries, delivering energy such as electricity and natural gas, and supplying water through pumps and pipelines. Steel is an iron-based material containing low amounts of carbon and alloying elements that can be made into thousands of compositions with exacting properties to meet a wide range of needs. Between twenty-four to twenty-six different elements are used in various proportions and combinations in the manufacture of both carbon and low alloy structural steels. However, all finished steel bars for reinforced work are ensured sound, free from cracks, neatly rolled to the dimension and weight as specified. Several studies have been carried out on improving the mechanical properties of steel. Arum, C. (2007) did a study on methods to classify defects such as cracks, dark spots, and sharp marks, of steel Bar Coil (BIC) with cylindrical shape. Each of these defects was qualified serious, and could harm the quality of the product relatively. Amir and Morteza (2013) did a study and presented comparative experimental data on the mechanical properties of reinforcing steel rods. The URW1050 steel fibres and HPP45 synthetic fibres, both with the same concrete design mix, were used to make cube specimens for compression tests, cylinders for tensile split tests and beam specimens for flexural tests. The experimental data demonstrated the steel fibre reinforced concrete is stronger in flexure at early stages, while both fibre reinforced concrete types displayed comparatively the same performance in compression, tensile splitting and 28-day flexural strength. In terms of post-crack control, HPP45 was found to be preferable. This work is a comparative study of the mechanical properties such as yield strength, ultimate tensile strength, percentage elongation

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and hardness, of locally made steel bars from scraps and imported steel bars. These properties are then compared to the values provided by the BS code to ascertain the level of conformity.

LITERATURE REVIEW

Requirements for Reinforcing Steel

The UK Certification Authority for Reinforcing Steels, Part 1 (1999) has prescribed that satisfactory reinforcing steel must be able to:-

1. Be bent into shape with precision to fit complicated structures.
2. Possess a minimum strength to discharge its load bearing function.
3. Possess ductility to satisfy formability requirements to be bent into the designed shape and also sufficient ductility to provide progressive failure under certain conditions.
4. Possess good weldability in part, for site fabrications and in part to minimize damage. For many structures of particular design, possess good fatigue properties.

Mechanical Properties of Reinforcing Bars

According to the BS 4449 (1997), the main mechanical properties of reinforcing steel bars are shown in table 1.0

Table 2.1 Tensile Properties of Reinforcing Bars

Grade	*Yield Strength N/mm2*	*Tensile Yield Ratio*	*Elongation at fracture %*	*Total elongation at Maximum Force %*
250	250	1.15	22	-
460A	460	1.05	12	2.5
460B	460	1.08	14	5

Source: BS4449 (1997)

According to Alabi, A.G.F and Onyeji L.I; (2010), tensile properties indicate how reinforcing steel bar will react when subjected to tensile forces. A tensile test is a fundamental mechanical test where a carefully prepared specimen is loaded in a very controlled manner while measuring the applied load and the elongation of the specimen over some distance. Tensile tests results are used to deduce the modulus of elasticity, elastic limit, elongation, proportional limit, reduction in area, tensile strength, yield point, yield strength amongst various others. Ejeh, S.P and Jibrin, M.U (2012):

MATERIALS AND METHOD

Samples Collection

Samples were collected from fourteen different sources. Six of the sources were foreign and their actual names were not mentioned, but only the countries of origin were specified. Thus, there were nineteen samples from fourteen different companies including the foreign ones which were considered in the test. The samples of bars collected from different sources are as shown in table 1.

Table 1. Steel Reinforcing Bar Samples Collection and Identification

S. No	*Company/Country*	*Identification*	*Diameter Collected (mm)*
01	Sunflage Steel Company, Lagos, Nigeria.	A	10,12
02	Universal Steel Company, Lagos, Nigeria	B	8, 10
03	Mayor Steel Company, Lagos, Nigeria	C	8, 10, 16
04	Sankyo. Lagos, Nigeria	D	20, 25
05	Nigeria-Spanish. Kano	E	12
06	Katsina Steel Rolling Mill. Katsina. Nigeria	F	12
07	Delta Steel Company Ltd. Warri. Nigeria	G	16
08	Oshogbo Steel Rolling Company Ltd. Oshogbo. Nigeria	H	12
09	Ukraine. Asia	I	8
10	Cote D''ivoire, West Africa.	J	8
11	Russia, Asia	K	12
12	Brazil, South America.	M	10
13	Holland, Europe.	N	16
14	Unknown-Foreign Source	O	10

Sample Labelling

The fourteen companies from which samples were collected have been labelled in an alphabetical order such as A, B, C, D, E, F, G, H, I, J, K, M, N and O for identification purposes (Table 1)

Sample Preparation

For the tension test, ten samples were tested for each diameter and consists a length of five hundred millimetres (500mm) each. The sample diameter was measured in three places and the average was taken as the sample diameter. The results are as shown in Table 2. The tests were done in accordance with BS 4449: 1997, clause 1.9 and BS 4449 (1969) clause 15.

Basic Equations

The basic equations used in this research are

Effective cross sectional area Aeff = M/ 0.0785 (i)

Alternatively, Area $= \frac{\pi d^2}{4}$ (ii)

Yield Stress $= \frac{Yield\ Load}{Cross - Sectional\ Area}$ (N/mm^2) (iii)

Ultimate Stress $= \frac{Ultimate\ Load}{Cross - Sectional\ Area}$ (N/mm^2) (iv)

Ultimate/Yield Ratio $= \frac{Ultimate\ Stress}{Yield\ Stress}$ (N/mm²)

Characteristic strength: $f_c = f_m - 1.64\ ð$ (v)

Average Mean Strength $(F_m) = \frac{\sum Yield\ Strss}{Number\ of\ Specimen(N)}$ (vi)

Stress $= \frac{Load}{Area}$ (vii)

Design strength $= \frac{Characteristics\ strength\ \mathbf{fc}}{Partial\ factor\ of\ safety\ ym}$ (viii)

Average Elongation $= \frac{\sum Elongation}{Nunber\ of\ Specimen(N)}$ (ix)

Percentage Elongation $(e_f) = \frac{L_{f-L_o}}{Lo} \times \mathbf{100}$ (x)

Average Ultimate strength $= \frac{\sum Ultimate\ Stress}{\sum N}$

Standard deviation $(ð) = \sqrt{\frac{\sum fd^2}{\sum f}}$ (xi)

Table 2. Measured Diameters and Cross Sectional Areas for Samples

S/NO	*Mark*	*Market Assumed Diameter (mm)*	*Average Measured Diameter (mm)*	*Average Mass (kg)*	*Average Cross-Sectional Area (mm2)*
01	$A_{12}T$	12.00	11.88	0.338	86.14
02	$A_{10}T$	10.00	9.65	0.282	71.96
03	$B_{10}T$	10.00	9.65	0.279	70.98
04	B_8T	8.00	7.44	0.189	48.37
05	$C_{16}T$	16.00	15.82	0.629	160.14
06	$C_{10}T$	10.00	9.55	0.284	72.42
07	$E_{25}T$	25.00	24.56	1.244	316.93
08	$E_{20}T$	20.00	19.57	1.103	281.13
09	$F_{12}T$	12.00	11.40	0.349	88.84
10	$G_{12}T$	12.00	11.48	0.334	85.17
11	$H_{16}T$	16.00	15.52	0.376	95.77
12	$I_{12}T$	12.00	11.40	0.343	87.47
13	$K_{10}T$	10.00	9.36	0.276	70.12
14	$L_{12}T$	12.00	11.82	0.430	110.30
15	$M_{10}T$	10.00	9.23	0.282	71.71
16	$N_{16}T$	16.00	15.60	0.829	211.28

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RESULTS AND DISCUSSIONS

Tensile Tests

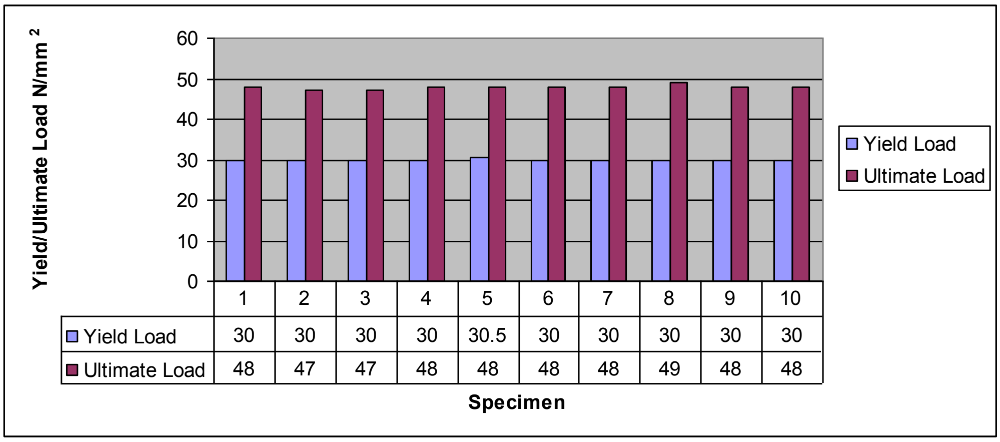

Figure 1. A Chart showing Yield Load against Ultimate load for 10mm bars

Figure 1 shows the graph of the tensile test result for a 10mm diameter rod. While the yield load was constant at 30 N/mm^2, the ultimate load varied from 4-49 N/mm^2

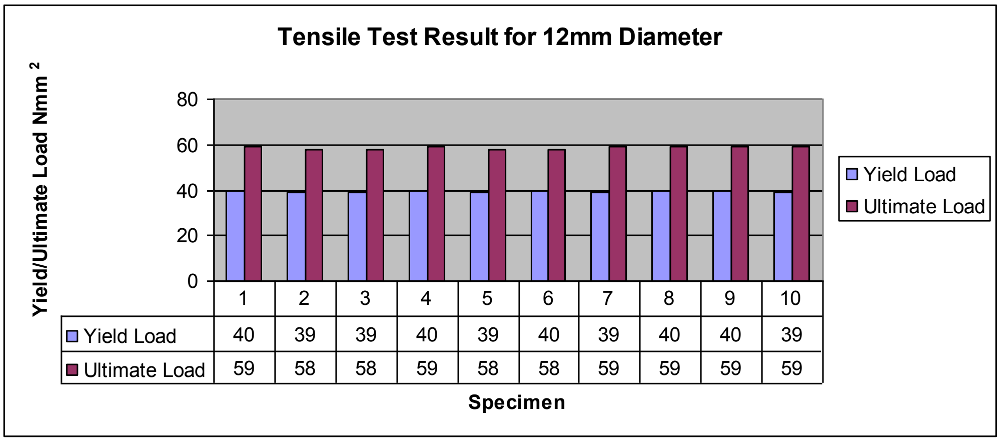

Figure 2. A Chart showing Yield Load against Ultimate Load for 12mm bars

Figure 2 shows the graph of the tensile test result for a 12mm diameter rod. The yield load varies from 39-40 N/mm^2, while the ultimate load varied from 58- 59 N/mm^2

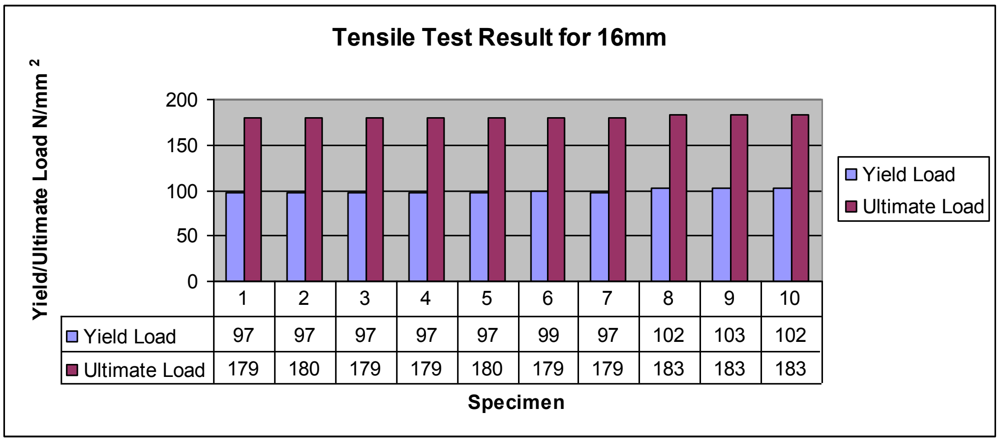

Figure 3. A Chart showing Yield Load against Ultimate Load for 16mm bars

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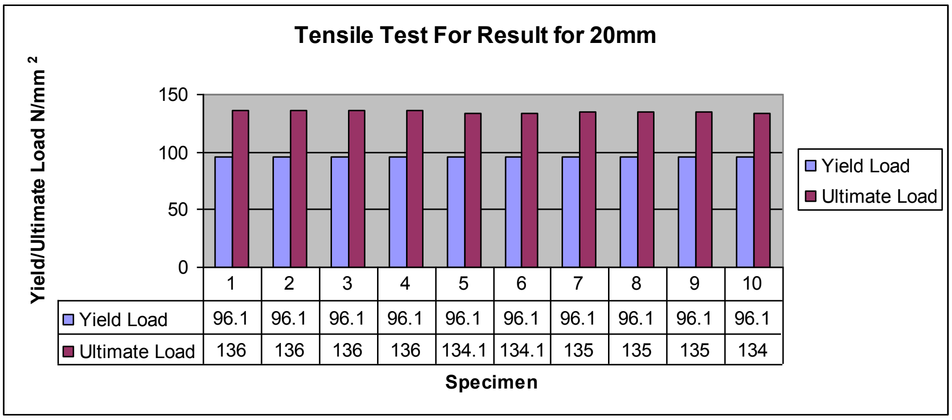
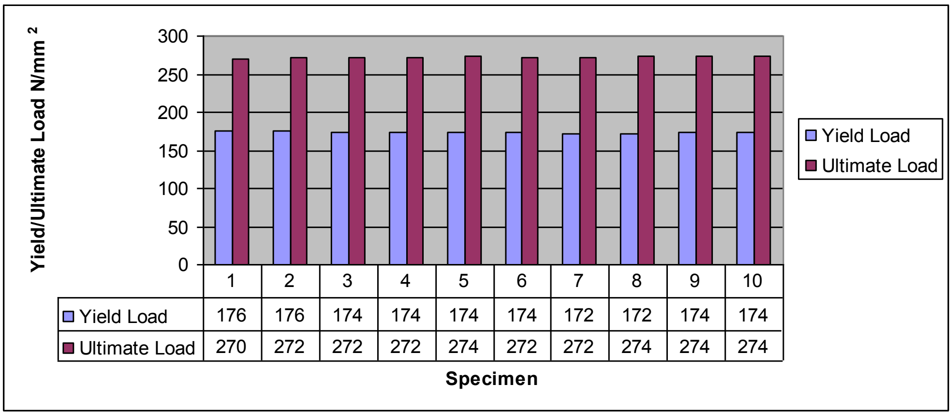
Figure 3 shows the graph of the tensile test result for a 16mm diameter rod. The yield load varies from 97-103 N/mm^2, while the ultimate load varied from 179-183N/mm^2



	1	2	3	4	5	6	7	8	9	10
Yield Load	96.1	96.1	96.1	96.1	96.1	96.1	96.1	96.1	96.1	96.1
Ultimate Load	136	136	136	136	134.1	134.1	135	135	135	134

Figure 4. A Chart showing Yield Load against Ultimate Load for 20mm bars

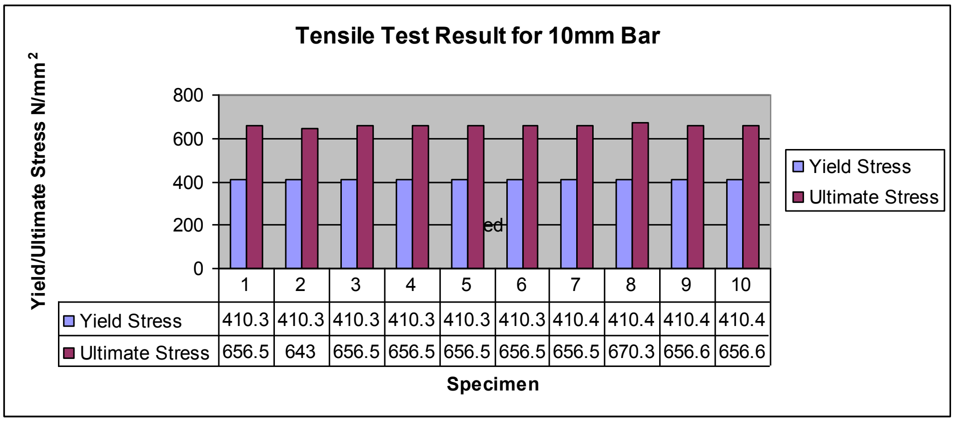
Figure 4 shows the graph of the tensile test result for a 20mm diameter rod. While the yield load was constant at 96 N/mm^2, the ultimate load varied from 134-136 N/mm^2



	1	2	3	4	5	6	7	8	9	10
Yield Load	176	176	174	174	174	174	172	172	174	174
Ultimate Load	270	272	272	272	274	272	272	274	274	274

Figure 5. A Chart showing Yield Load against Ultimate Load for 25mm bars

Figure 5 shows the graph of the tensile test result for a 25mm diameter rod. The yield load varies from 172-176 N/mm^2, while the ultimate load varied from 270-274N/mm^2. Tensile properties indicate how reinforcing steel bar will react when subjected to tensile forces. Tensile tests results are used to deduce the modulus of elasticity, elastic limit, elongation, proportional limit, reduction in area, tensile strength, yield point, yield strength amongst various others.



	1	2	3	4	5	6	7	8	9	10
Yield Stress	410.3	410.3	410.3	410.3	410.3	410.3	410.4	410.4	410.4	410.4
Ultimate Stress	656.5	643	656.5	656.5	656.5	656.5	656.5	670.3	656.6	656.6

Figure 6. Tensile test result for 10mm diameter bars

Figure 6 shows the graph of the tensile test result for a 10mm diameter rod. While the yield stress was varies slightly from 410- 410.4 N/mm^2, the ultimate stress varied from 643-670N/mm^2

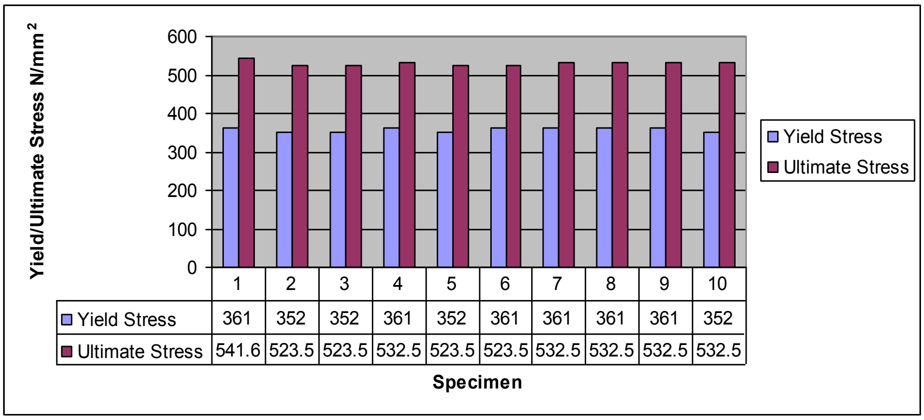


Figure 7. Tensile test result for 12mm diameter bars

Figure 7 shows the graph of the tensile test result for a 12mm diameter rod. While the yield stress varies from 352-361 N/mm^2, the ultimate stress varied from 523.5-541.6N/mm^2

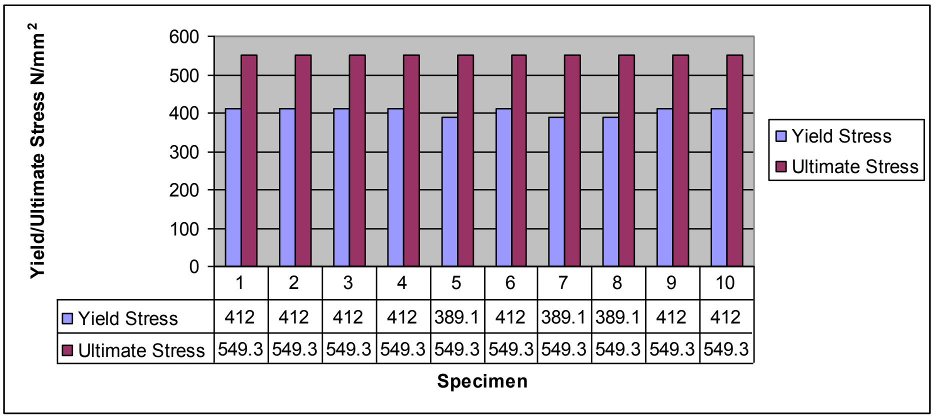


Figure 8. Tensile test result for 16mm diameter bars

Figure 8 shows the graph of the tensile test result for a 16mm diameter rod. While the yield stress varies from 389-412 N/mm^2, the ultimate stress was constant at 549N/mm^2

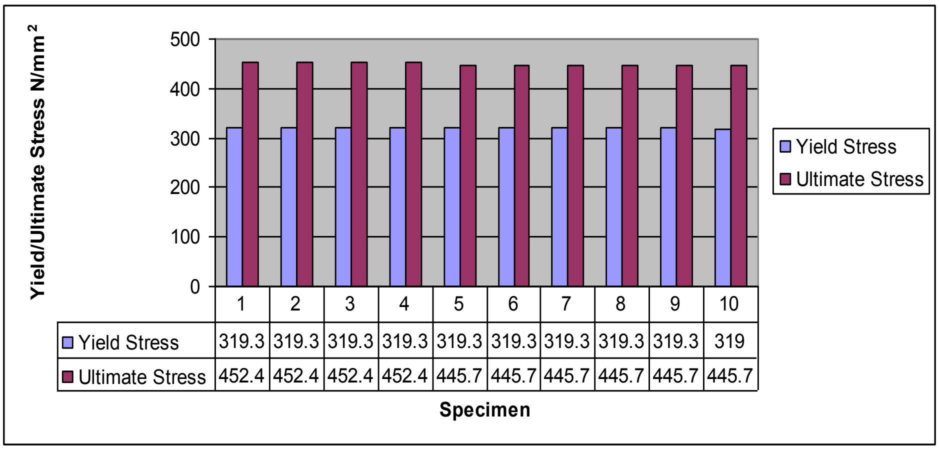


Figure 9. Tensile test result for 20mm diameter bars

Figure 9 shows the graph of the tensile test result for a 20mm diameter rod. While the yield stress was constant at 319N/mm^2, the ultimate stress varies from 446-452N/mm^2

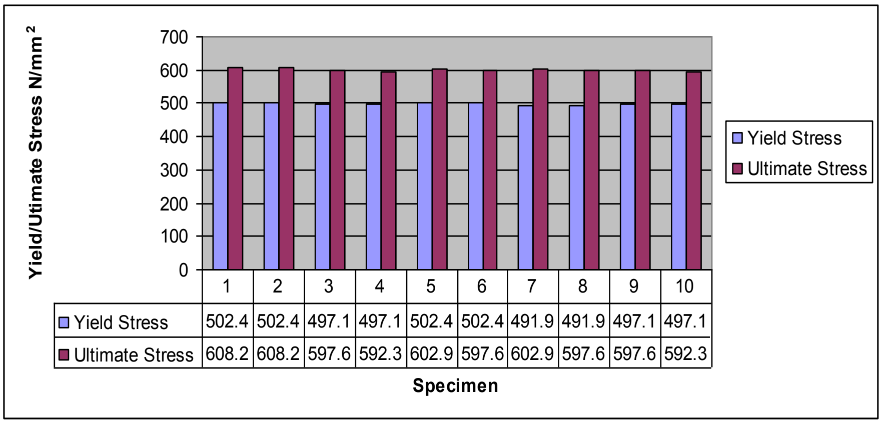


Figure 10. Tensile test result for 25mm diameter bars

Figure 10 shows the graph of the tensile test result for a 25mm diameter rod. While the yield stress varies from 492-502 N/mm^2, the ultimate stress varied from 592-608N/mm^2

Percentage Tolerance

Fig 4.11 of specify BS 4449 (1997) requirements for tolerances as ± 6.0 % for 8mm and 10mm bars and ± 4.5% for 12mm bars and above. It was observed that most of the reinforcement bars irrespective of their origin fell out of range of tolerance.

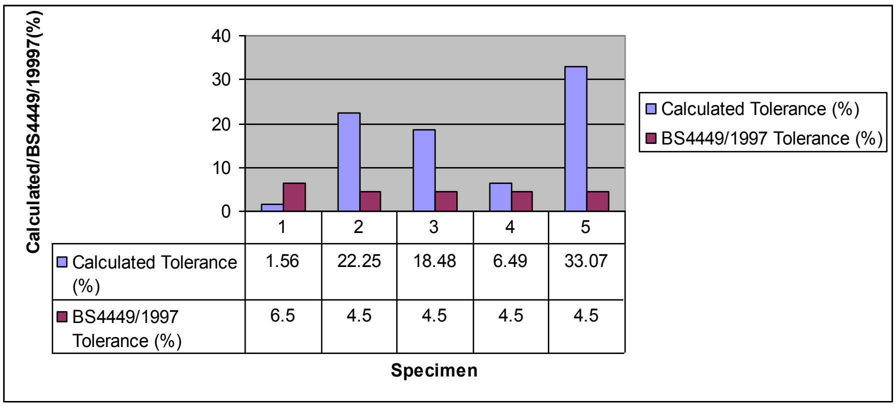


Figure 11. Percentage Difference in Tolerance

Figure 11 shows the graph result for the percentage difference in tolerance for 10mm, 12mm 16mm 20mm and 25mm diameter rod between BS4449:1997 and calculated tolerance.

Characteristic Strengths

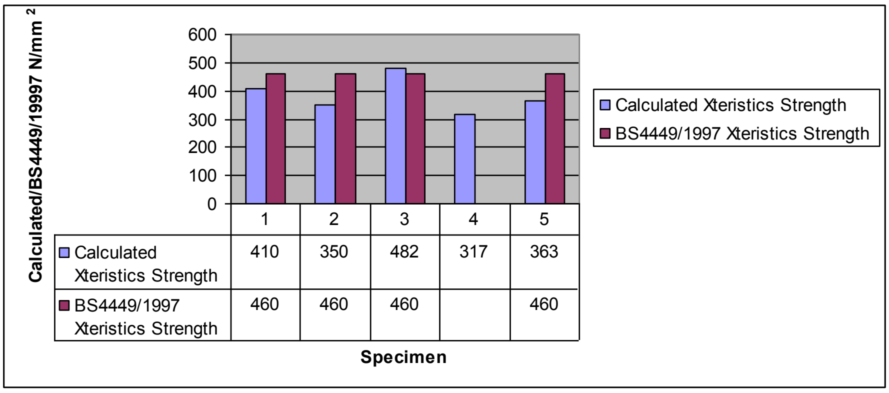


Figure 12. Graph of calculated Characteristic Strength vs. BS4449:1997 standard

Figure 12 shows the graph result for the characteristic strength difference for 10mm, 12mm 16mm 20mm and 25mm diameter rod between BS4449:1997 and calculated the characteristic strength for both local and foreign bars.

Percentage Elongation

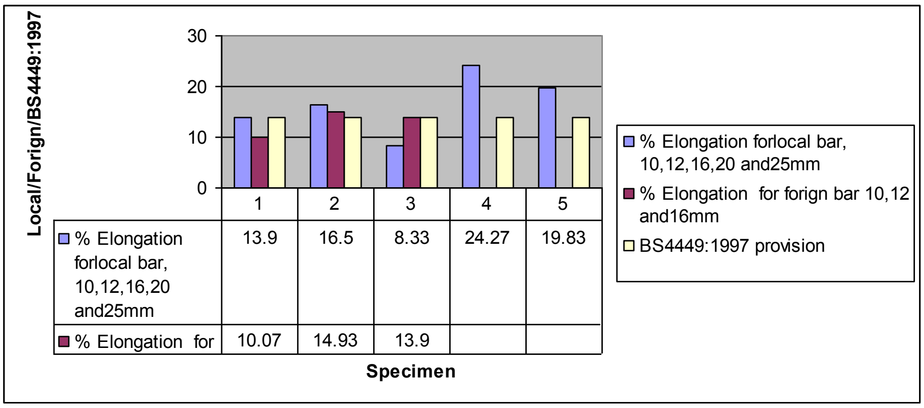


Figure 13. Gragh of Percentage Elongation

Figure 13 shows the graph result for the elongations difference for 10mm, 12mm 16mm 20mm and 25mm diameter rod among BS4449:1997 provision, local and foreign bars.

Table 4. Parameter Summaries for Tensile Tests (Companies A-E)

S/No.	*Sample Parameter*	$A_{12}T$	$A_{10}T$	$B_{10}T$	$C_{16}T$	$C_{10}T$	D_8T	$E_{25}T$
01	Diameter(mm)	12	10	10	16	10.0	8	25
02	Characteristic Strength (N/mm^2)	350	410	390.3	482	357	463	363
03	Standard Deviation	4.65	0.0	0.0	13.0	4.4	0.0	2.4
04	Average Elongation %	16.5	13.9	19.6	8.3	19.9	1.7	19.8

Table 5. Parameter Summaries for Tensile Tests (Companies F-N)

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

The value of standard deviation will determine the quality of the product. The small the value, indicates high quality product. Values below or equal to five (5) is an indicative of highly skilled quality product and above five (5) indicates low skilled product. Five samples from company C, F, H, K and M have values that are above five (5). Equilibrium must be maintained for effective quality and good product.

Measured Parameters

Table 3. Comparison of Characteristic Strength with Design Strength

S/ No	Mark	Market Assumed Diameter (mm)	Measured Diameter (mm)	Cross Sectional Area (mm^2)	Tolerances	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Ultimate: Yield Ratio	Elongation %	Xtics Strength (N/mm^2)	Computed Design Strength (N/mm^2)	Reccomm Design Strength (N/mm^2)
01	$A_{12}T$	12.00	11.88	110.79	+22.25	357.43	529.83	1.55	16.50	350.00	400.00	304.50
02	$A_{10}T$	10.00	9.65	73.10	+1.56	410.40	656.60	1.60	13.90	410.00	400.00	356.70
03	$B_{10}T$	10.00	9.56	71.74	+1.06	390.30	536.60	1.46	19.60	390.00	400.00	339.30
04	$B_{8}T$	8.00	7.44	43.45	-11.32	368.24	483.31	1.31	23.82	368.00	400.00	320.16
05	$C_{16}T$	16.00	15.82	196.46	+18.49	503.41	918.82	1.84	8.33	482.00	400.00	419.34
06	$C_{10}T$	10.00	9.55	71.59	-1.16	364.58	531.10	1.52	19.93	357.00	400.00	310.59
07	$E_{25}T$	25.00	24.56	473.51	+33.07	367.05	576.12	1.64	19.83	363.00	400.00	315.81
08	$E_{20}T$	20.00	19.57	300.64	+6.49	318.95	449.38	1.43	24.27	317.00	400.00	275.79
09	$F_{12}T$	12.00	11.4	102.02	+12.92	415.60	633.21	1.52	19.07	334.00	400.00	290.58
10	$G_{12}T$	12.00	11.48	103.46	+17.68	419.56	715.25	1.69	14.83	408.00	400.00	354.96
11	$H_{16}T$	16.00	15.52	189.08	+49.35	499.26	599.75	1.22	14.53	493.00	400.00	428.91
12	$I_{12}T$	12.00	11.40	100.24	+12.74	369.11	612.53	1.69	14.50	369.00	400.00	321.03
13	$K_{10}T$	10.00	9.36	68.77	-1.96	574.38	660.17	1.22	10.07	549.00	400.00	477.63
14	$L_{12}T$	12.00	11.82	109.07	-1.13	505.18	599.62	1.21	14.93	500.00	400.00	435.00
15	$M_{10}T$	10.00	9.23	66.88	-7.31	563.70	642.94	1.08	11.77	547.00	400.00	475.89
16	$N_{16}T$	16.00	15.60	191.04	-10.60	551.72	645.41	1.26	13.90	545.00	400.00	474.15

It was observed that nine samples out of fourteen local ones failed to meet the minimum design strength of 400N/mm^2. This means sixty five percent (65%) of the local samples failed to meet the minimum design strength.

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Cross - Checking Samples with Parameters Tested

Table 6 sixteen tested parameters are cross checked against each Sample to find out if each sample met the provision of the code such as tolerance on cross - sectional area, Characteristics Strength, Ultimate to Yield strength ratio, Elongation.

Table 6. Testing of Selected Tensile Test Parameters

S/No	*Mark*	*Source*	*Percentage Tolerances on Area and Masses*	*Characteristic Strength (N/mm^2)*	*Ultimate to Yield Str. Ratio*	*Percentage Elongation*	*Remarks*
1.	$A_{12}T$	Local	X	X	T	T	Not Satisfactory
2.	$A_{10}T$	Local	T	X	T	X	Not Satisfactory
3.	$B_{10}T$	Local	T	X	T	T	Not Satisfactory
4.	$C_{16}T$	Local	X	T	T	X	Not Satisfactory
5.	$C_{10}T$	Local	T	X	T	T	Not Satisfactory
6.	$E_{25}T$	Local	X	X	T	T	Not Satisfactory
7.	$E_{20}T$	Local	X	X	T	T	Not Satisfactory
8.	$F_{12}T$	Local	X	X	T	T	Not Satisfactory
9.	$G_{12}T$	Local	X	X	T	T	Not Satisfactory
10.	$H_{16}T$	Local	X	T	T	T	Not Satisfactory
11.	$I_{12}T$	Local	X	X	T	T	Not Satisfactory
12.	J_8T	Foreign	T	T	X	T	Not Satisfactory
13.	$K_{10}T$	Foreign	T	T	T	X	Not Satisfactory
14.	$L_{12}T$	Foreign	T	T	T	T	Satisfactory
15.	$M_{10}T$	Foreign	X	T	X	T	Not Satisfactory
16.	$N_{16}T$	Foreign	X	T	T	X	Not Satisfactory

Legend: T=>Within Code Provision: X=> Outside Code Provision:

Three companies out of five foreign company bars are within the range of code provision, while two companies bar is outside code provision in percentage tolerance. Three companies out of eleven local company bars are within the range of code provision, while eight companies bar are outside code provision in percentage tolerance. Two companies out of eleven local company bars are within the range of code provision, while nine companies bar are outside code provision in characteristic strength. Five companies out of five foreign company bars are within the range of code provision in characteristic strength. Eleven companies out of eleven local company bars are within the range of code provision in ultimate to yield ratio. Three companies out of five foreign company bars are within the range of code provision, while two companies' bars are outside code provision in ultimate to yield ratio. Nine companies out of eleven local company bars are within the range of code provision, while two companies' bars are outside code provision in percentage elongation. Three companies out of five foreign company bars are within the range of code provision, while two companies bar are outside code provision in percentage elongation.

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CONCLUSION AND RECOMMENDATIONS

Conclusion

Based on the results of the tests conducted, the following conclusions were made.

1. 40% of the bars could not comply with the rolling deviations over and under nominal mass as provided by BS 4449:1969, 1995 and 1997 respectively.
2. The characteristic strength values for 92% of the locally produced bar samples are low, compared to the BS 4449:1969, 1995 and 1997 standards for high tensile steel which is 460N/mm^2 minimum value.
3. The characteristic strength values in respect of the local bars are the same to that of mild steel as showed by the tensile test.This means that, theproducts are mild steel rethreaded and sold as high tensile steel.
4. 95 % 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 the locally produced bar samples are within acceptable code limits of 92%.
6. The percentage elongation values for 67 % of the foreign bar samples are below 33% of the minimum standard provisions.

Recommendations

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

1. Development of a local standard, which will give clear advice on the characteristics strength, elongation and percentage elemental compositions as obtained in the laboratory for applications in structural design, is imperatives.
2. There should be technical information on all steel reinforcement sold in the open markets so as to guide the designers on their strength and deformation characteristics.
3. Regulatory authorities such as the Standards Organisation of Nigeria, Council for the Regulation of Engineering in Nigeria and tertiary institutions should strengthen their collaborations on ensuring quality standards through materials testing.
4. Steel rolling mills in the country should be compelled to make their quality testing facilities available to regulatory and other quality enforcement agencies for periodic inspection and compliance.
5. All imported reinforcement steel must be checked for quality compliance prior to accepting such consignment into the country and such must be accompanied with an accredited certification.

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