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Mechanical and Chemical Properties of Reinforcement Bars Manufactured in Nigeria

***Oluwaseun B. Hassan, Oluwatobi O. Akin, Adamu Lawan and Yusuf D. Amartey**

Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria
***Corresponding email: oluwaseunbhassan@gmail.com**

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Abstract: Reinforcement bars, or REBAR for short, are mainly produced from metal scrap or iron ore, or a combination of both. Their manufacturing process has a significant effect on their properties, so also are the percentage concentration of various constituent elements and the cooling rate in the production process. This research work aims to study the physical and chemical properties of rebars manufactured in Nigeria vis-à-vis their suitability for construction purposes. The effect of chemical composition in rebar on steel stresses was studied. Rebar samples were collected at various points in Abuja and its environs and tested for their mechanical and chemical properties. The results show some tolerable and intolerable deviations from provisions of BS 4449 B500B 2005 indicating that some of the rebars are satisfactory for use in reinforced concrete works while others are not. Tests conducted on the rebars include Tensile Strength, Relative Rib Area, Percentage Elongation, Bend and Rebend, and Spectrometer tests, among other physical examinations. In some rebars, results showed moderate to vast deviation from minimum acceptable standard values as specified in BS 4449 B500B 2005 for yield stress, elongation, bar diameter, mass per kilogram, carbon equivalent, while there is satisfactoriness for other tested samples.
Keywords: Reinforcement bars, Ultimate Tensile Strength, Yield Strength, Elongation, Rib Geometry, Carbon Equivalent.

1. Introduction

A reinforcement bar is described as a steel product with a circular or practically circular cross-section suitable for the reinforcement of concrete. Steel is at the heart of the economic and sustainable development of any nation. It is one of the materials most widely used by all sectors of the economy, from building structures to transport and infrastructural development. The world's most advanced economies produce and consume large quantities of steel [1-3]. Steel is indeed a versatile material. About twenty-six different elements are used in various proportions and combinations to manufacture both carbon and low alloy structural steels. [4]. In reinforced concrete structures, reinforcement bars play a role as a construction material whose properties must be known to the users before application in either design or construction purposes. Codes such as BS4449: 1967, 1969, 1997, 2005, +A2:2009, and many others have specified limits on the properties of reinforcement bars and their testing procedures amongst others [5]. A reinforcement bar is found in virtually every concrete and masonry structure. It refers to the steel rods installed inside the concrete to help them keep their shape and ensure safe, durable structures that will be reliable for years. Without them, the natural expansion and contraction of concrete will cause weak areas to develop, which will ultimately collapse in the long run. The tensile strength of concrete is only about 10% of its compressive strength. Owing to this fact, nearly all reinforced concrete structures are designed on the assumption that concrete does not resist any tensile stress, and this is where the steel come to play a major role in tensile stress resistance [6].

The manufacturing process of reinforcement bars have a significant effect on their properties even though BS 4449 [7] contains no specific requirements for rebar manufacturing process [8]. It is important that quality norms are exercised in the case of reinforcement bars which should invariably have been rolled from tested billets [9].

In Nigeria, investigation showed that steel of recognizable origin satisfies both local and International Standard Organization (ISO) requirements for strength and ductility. On the other hand, steel of non-recognizable origin failed to satisfy the above requirements for high-yield ribbed bars but satisfies the local specifications if used as mild steel [10]. A lot of behavioral and durability issues affect the performance of this composite material. The in-depth understanding of these issues depends partly on environmental factors, and in this case, Nigeria is peculiar [11]. Reinforcement bars testing in most construction sites have been restricted to tensile tests with little or no information about other mechanical properties such as rebend, elongation, rib geometry and the chemical properties. [5].

The role reinforcement bars play in the construction industry is very important as a result, many researches have been done on reinforcement bars used in Nigeria in the past, but there is still need to constantly revisit it and carry out studies on it as the properties and qualities are always changing, so study should be carried out at regular intervals [12]. Another reason for this is the worrisome trend of building collapse in Nigeria. [13-17]. Some previous studies have shown the suitability of locally produced reinforcement bars in structural works, especially where strength and ductility are of great importance [10, 12]. In a comparative study of four locally-produced steel bars and foreign steel imported to Nigeria, it was discovered that both the local steels and the foreign product met the standard for use in the construction industry [18]. Some researchers reported different results from others, a review by Balogun et.al., [19] showed that some locally manufactured steel in Nigeria and some West African countries fall short of the international standard according to the world average specification for high yield steel bar report [20].

2. Material and Methods

2.1. Material

Reinforcement Bars: The sample materials used in this study are 25mm, 20mm, 16mm, 12mm, and 10mm bars, collected from some Steel Mills across Abuja and its environs (but their product samples are tagged to conceal their identities in the course of the testing), open markets, and construction sites.

Physical Requirements: The finished steel bars for reinforced work were rolled and made ready for construction works, irrespective of their actual weight, dimensions, and defects but free of rust and dust.

Table 1. BS4449:2005 A3 2005 – Nominal Cross -Sectional Area and Mass per Metre

Nominal Diameter (mm)	Cross-Sectional Area (mm)	Mass per Metre (Kg)
6[a]	28	0.222
7[a]	38.5	0.302
8	50.3	0.395
9	63.6	0.499
10	78.5	0.617
12	113	0.888
16	201	1.58
20	314	2.47

25	491	3.85
32	804	6.31
40	1257	9.86
50	1963	15.4
[a] Preferred diameters for the manufacture of welded fabric to BS 4483 only ***Tolerance: Permissible deviation from normal mass/m shall not be more than+/-4.5 on nominal diameters greate than 8mm, and +/-6mm on nominal diameters less than or equal to 8mm.***		

2.2 Methods: Steel Testing for Mechanical Properties

(a) Ultimate Tensile Strength

This test helps in determining the maximum stress that the tested material can withstand while being stretched or pulled before necking, that is, when the specimen's cross section starts to contract significantly.

Test equipment: Universal Testing Machine

(b) Yield Strength

It is the lowest stress that produces a permanent deformation in the tested material.

(c) Elongation

This is the increase in length of the gauge length, expressed as a percentage of the original length.

(c) Rib Geometry

The following are determined under rib geometry for the reinforcement samples tested:

i. Rib inclination angle (α)
ii. Relative rib area (*f*R)
iii. Rib height (h)
iv. Rib spacing (c)

Test Specimen

The length of the test specimen was 400mm to allow for gripping by the RRA machine and to allow automatic measurements of the geometrical characteristics of the test sample for calculating the relative rib area.

Test equipment: Automatic Relative Rib Area Machine (RRA machine)

The relative rib area ***fR*** is calculated using Equation (1) in accordance with BS4449 B500B 2005 by using the results of measurements of the geometrical characteristics discussed:

It is derived mathematically using the formula:

$$fR = (\pi d - \sum e) \times 2a_m / 3\pi dc \quad (1)$$

Where;

*f*R = Relative rib area
a_m = Centre height of the rib
e = Ribless spacing between two rib rows
d = Nominal diameter
c = Centre to centre spacing of two ribs

Table 2: BS4449 – Standard Rib Geometry (mm)

Bar Dia (d)	Transverse Rib: Rib Height (h) Min	Rib Height (h) Max	Rib Spacing (C) Min	Rib Spacing (C) Max	Rib Inclination (β) Min	Rib Inclination (β) Max	Row Distance Min	Flank Inclination (α) Max		Longitudinal Rib: Rib Height Max	Relative Rib Area (RRA)
	0.03d	0.15d	0.4d	1.2d	35^0	75^0	(∑i)	45^0		0.10d	Min
8	0.24	1.20	3.20	9.60	35^0	75^0	6.28	45^0		0.80	0.040
10	0.30	1.50	4.00	12.00	35^0	75^0	7.85	45^0		100	0.040
12	0.36	1.80	4.80	14.40	35^0	75^0	9.42	45^0		1.20	0.040

16	0.48	2.40	6.40	19.20	35^0	75^0	12.57	45^0		1.60	0.056
20	0.60	3.00	8.00	24.00	35^0	75^0	15.71	45^0		2.00	0.056
25	0.75	3.75	10.00	30.00	35^0	75^0	19.64	45^0		2.50	0.056
32	0.96	4.80	12.80	38.40	35^0	75^0	25.13	45^0		3.20	0.056

The characteristic relative rib area is expected to meet the requirement of Table 3.

Table 3: BS4449:2005 – Characteristic Relative Rib Area

Nominal Bar Size, d (mm)	**Relative Rib Area**
$d \leq 6$	0.035
$6 < d \leq 12$	0.040
$d > 12$	0.056

(d) Rebend Test

This test determines the susceptibility of samples to fracture or irregular bending deformation.

Test equipment: Steel Bending Machine

(e) Verification of Mechanical Properties

Test samples were selected from different bars of a batch and they are required to pass the tests to be considered to have conformed to International Standard (BS4449 B500B 2005)

2.3 Chemical Concentration

All the elements in the test samples would be identified, and their concentration in percentage by weight determined.

Test equipment: Spectrometer

Determination of Carbon Equivalent

This property is required to set the cooling parameters in TMT (Thermo mechanically treated) process, and a slight variation in carbon equivalent may alter the physical properties.

The Carbon Equivalent is calculated using the following formula:

$$C_{eq} = C + (Mn/6) + (Cr+Mo+V)/5 + (Ni + Cu)/15 \quad (2)$$

Where: ***Mn*** is the percentage Manganese content

Cr is the percentage Chromiun content

V is the percentage Vanadium content

Mo is the percentage Molybdenum content

Cu is the percentage Copper content

Ni is the percentage Nickel content

3. Results and Discussions

3.1 Mechanical Properties

(a) Physical Properties of Rebar Samples

From the result of the mass per metre of tested rebar samples, 57.7% of rebars tested fell below -4.5% lower limit nominal mass per metre, while the remaining 42.3% fell within the lower limit range. Figure 1 showed that 40% of tested samples conformed to BS4449:2005 [7], even though their mass per metre fell below code standard, they remain within the lower limit of -4.5%.

Out of the fourteen rebar samples tested in the relative rib area machine, twelve samples have precise cross-sectional area while two samples (samples G and M) fell below their factory specified diameter of 16mm by (2mm in each). The RRA machine precisely measured them as 14mm rebars.

From the results presented in Figure 2, the percentage elongation at fracture of the tested samples falls within 16% - 21% while the average percentage elongation within gauge length falls within 6.0% - 8.5%. As per BS 4449:2005 B500B; the total elongation at maximum force, AGT is given as 5.0.

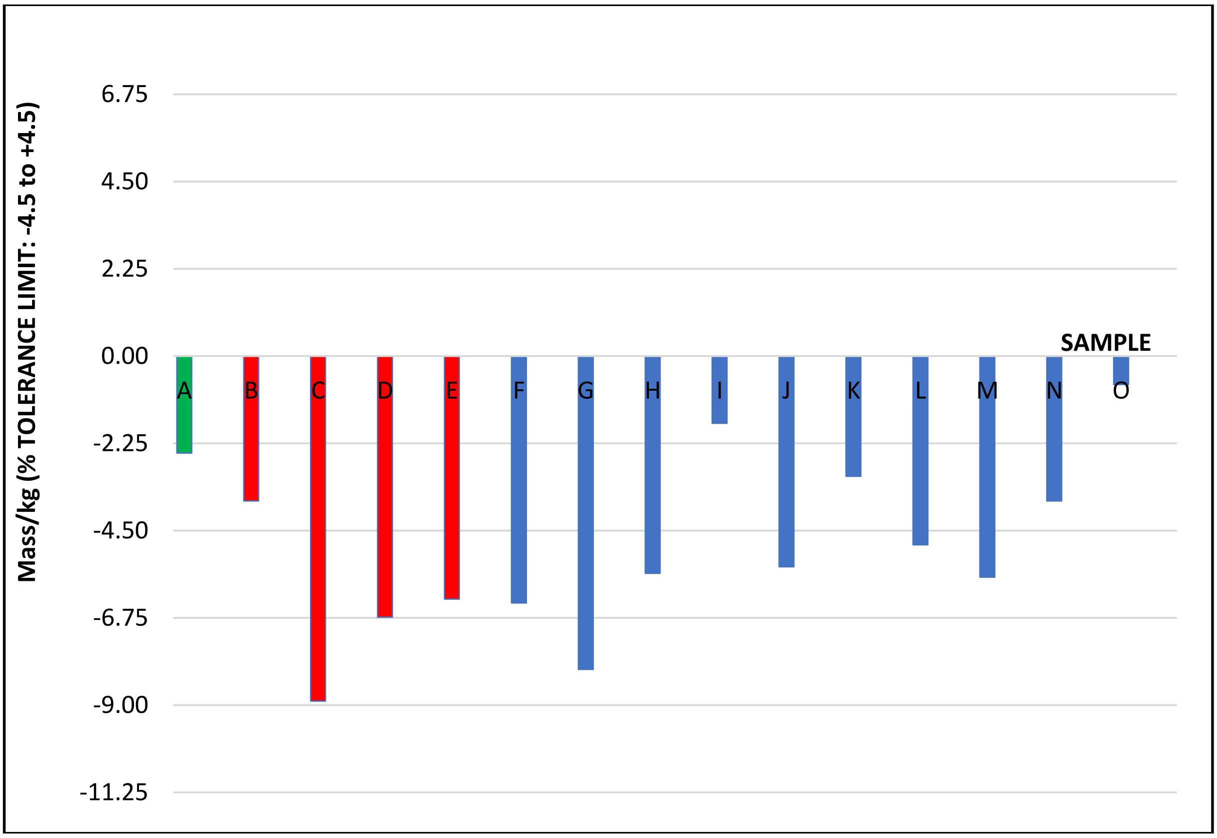

Figure 1: Bar Chart Showing Mean Permissible Deviation from Nominal Mass Per Metre

(c) Elongation

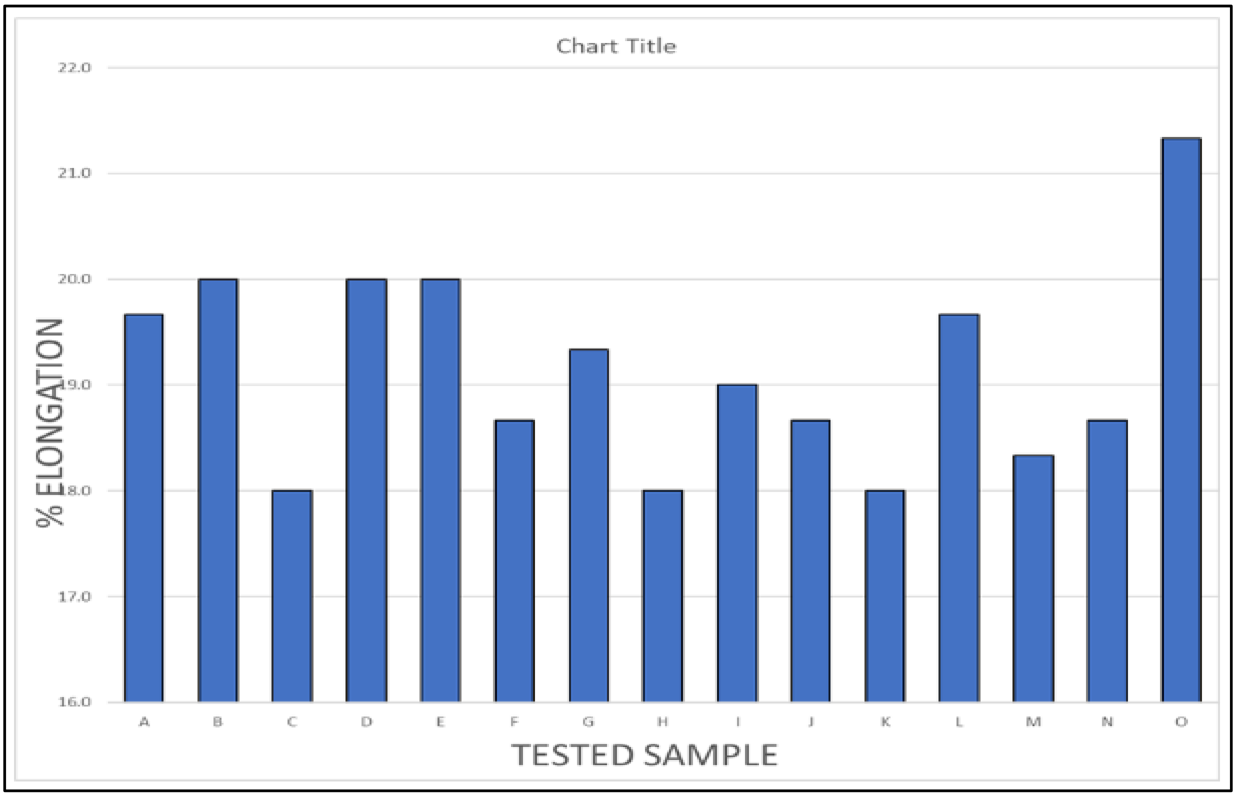

Figure 2: Percentage Elongation at Fracture

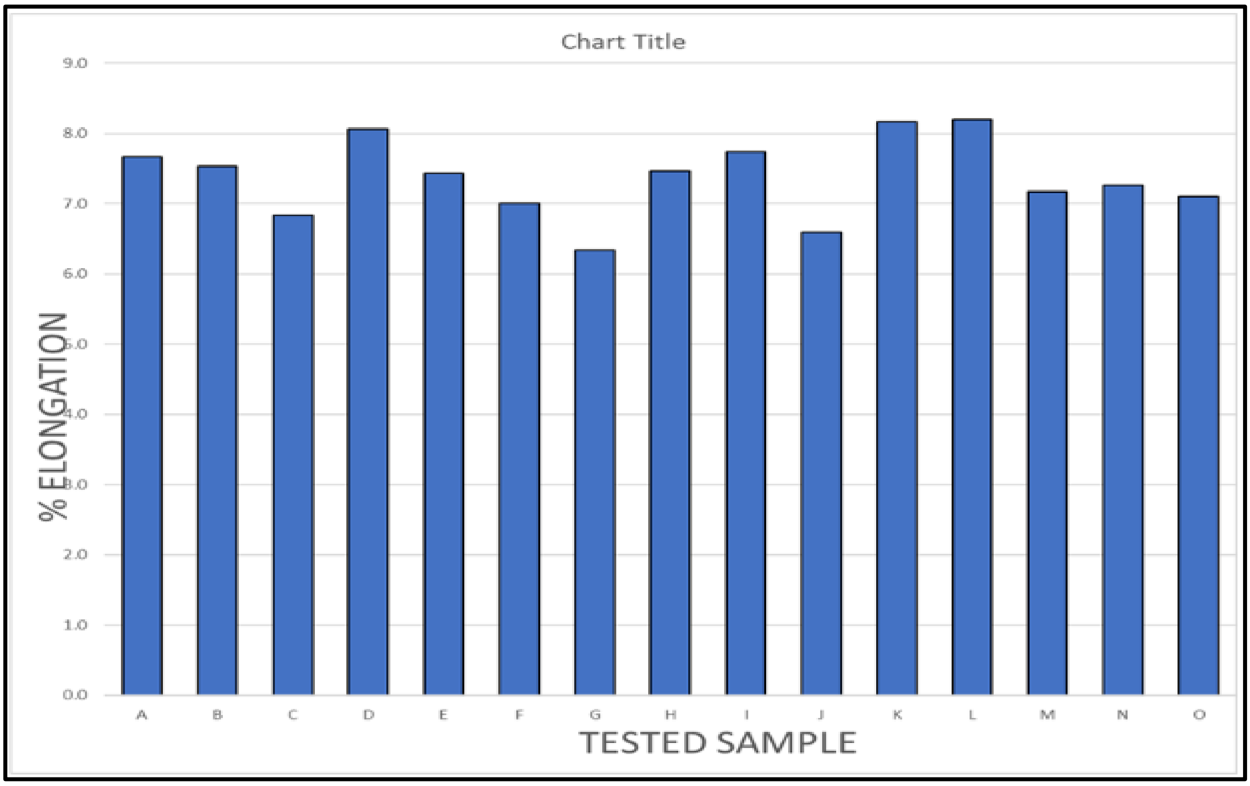

Figure 3: Percentage Elongation at Average Gauge Length

(c) Yield Stress.

Table 4 Mean and Maximum Yield Stress

	Yield stress (n/mm^2)						Ultimate stress (n/mm^2)				
Sample	**1**	**2**	**3**	**Mean**	**Standard Deviation**		**1**	**2**	**3**	**Mean**	**Standard Deviation**
C	503	401	458	454	51.12		565	494	541	533	36.12
D	561	568	571	567	5.13		640	643	637	640	3.00
E	343	329	304	325	19.76		434	418	422	425	8.33
O	434	445	444	441	6.08		615	628	630	624	8.14
B	564	564	567	565	1.73		661	658	659	659	1.53
G	341	355	458	385	63.89		493	541	500	511	25.93
H	458	513	488	486	27.54		576	627	611	605	26.08
M	500	502	503	502	1.53		622	625	621	623	2.08
N	475	468	474	472	3.79		570	565	565	567	2.89
F	327	328	329	328	1.00		501	483	503	496	11.02
J	535	522	530	529	6.56		607	599	605	604	4.16
L	492	498	497	496	3.21		663	654	653	657	5.51
A	567	579	573	573	6.00		684	688	688	687	2.31
K	608	577	594	593	15.52		682	683	683	683	0.58
I	625	525	623	591	57.17		761	702	766	743	35.59

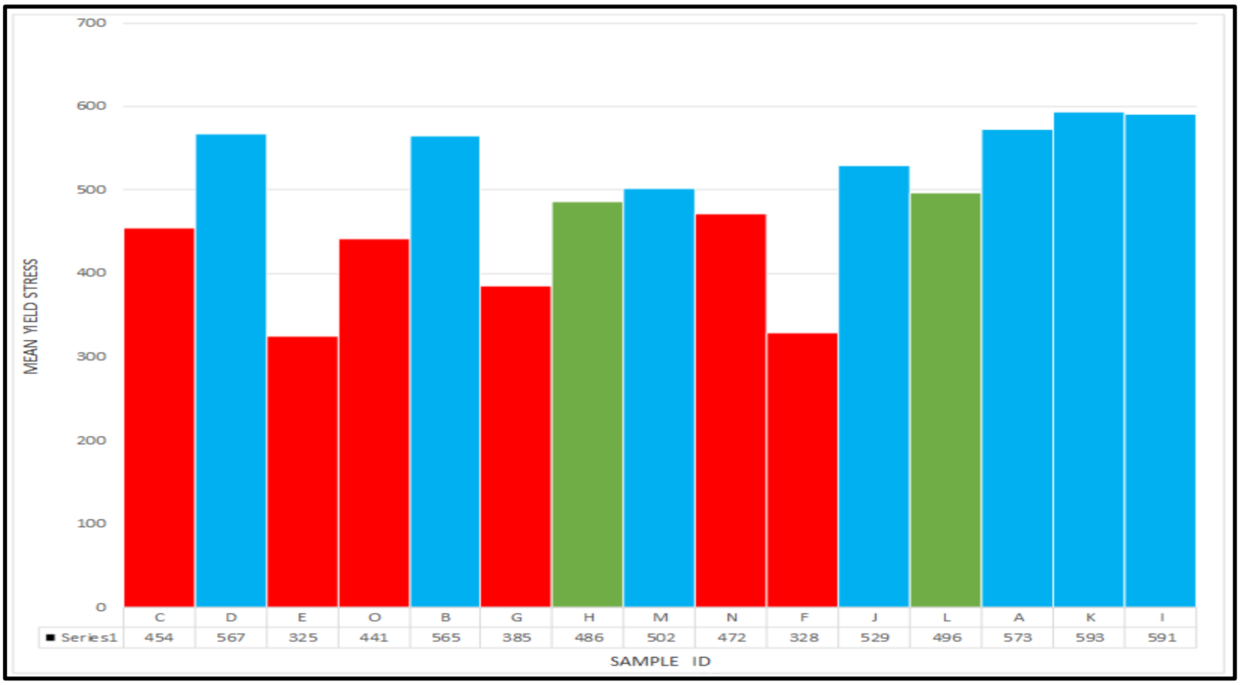

Figure 4: Mean Yield Stress of Tested Rebar Samples

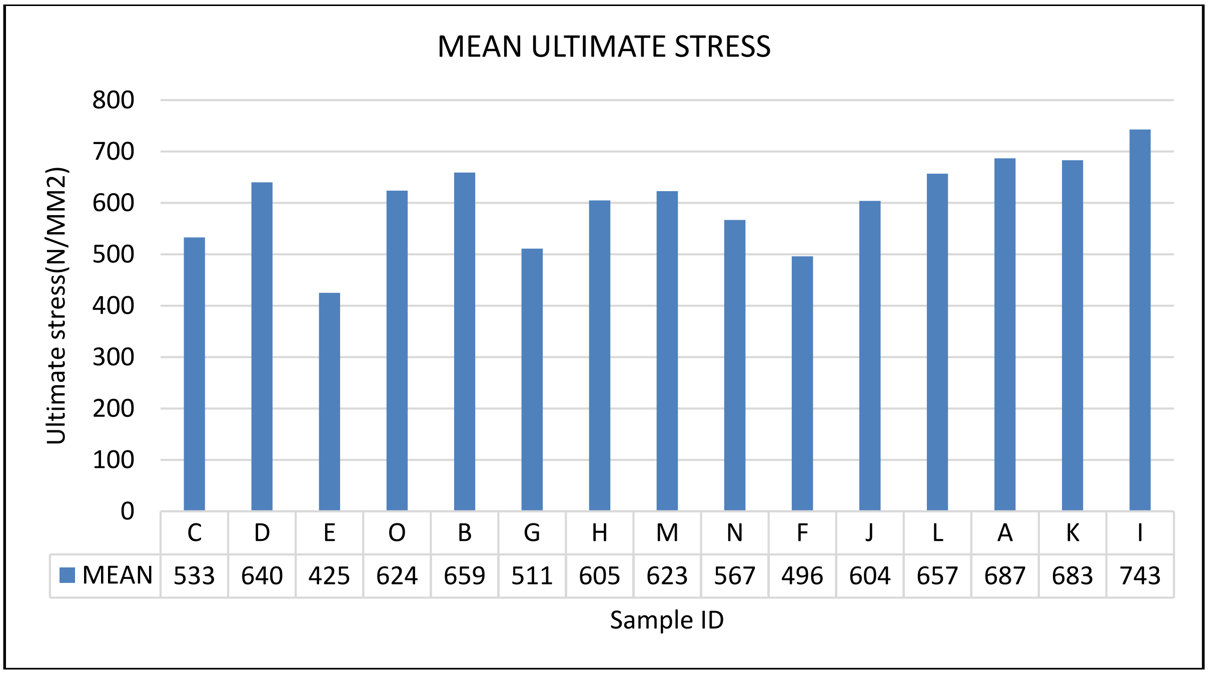

Figure 5: Mean Ultimate Stress of Tested Rebar Samples

From Figure 4, of the fifteen samples tested, only seven have their mean yield stress exceeding 500N/mm^2 as per BS4449:2005 [7], two others fell within the minimum tolerance limit of 485N/mm^2 (BS4449:2005 [7] – Absolute minimum and maximum values of tensile properties), while the remaining six samples fell below the minimum value. These findings are in accordance with the report from Alabi et.al. [21], and other works on yield strength and ultimate tensile strength [18, 22]. Table 4 also indicates the standard deviation (SD) of yield stress results, higher value of SD indicates disparity in individual values of a group of samples which is a pointer to incoherence in properties of the rebar in that group

(d) Relative Rib Area.

Table 5 Computation of Relative Rib Area (Rra) of Tested Samples

S/No	ROW NO	DIAMETER (mm)	RIB HEIGHT (mm)			RIB DIST. C (mm)	INCLINATION		ROW DIST. E (mm)	HEAD WIDTH (mm)	RIB LENGTH (mm)	LONG RIB		RELATIVE RIB AREA fR	RRA Remark
			centre	1/4 pnts	3/4 pnts		Alpha	Beta				height (mm)	width(mm)		
B	1	16	0.93	0.95	1	10.4	50	56	4.08	1.7	23.7	0.53	2.78	0.051*	Failed
	2		1.1	1.04	1.13	10.2	55	56	6.89	1.6	23.7	0.28	3.18		
	Mean		1.02	1	1.07	10.3	53	56	∑: 10.97	1.65	23.7	0.41	2.98	-8.9%	
K	1	25	1.52	1.21	1.44	14.7	53	63	4.9	2.7	36.9	0.85	2.89	0.062	Passed
	2		1.8	1.37	1.35	15	51	62	7.93	1.9	37.2	0.86	3.17		
	Mean		1.66	1.29	1.4	14.9	52	63	∑: 12.83	2.3	37	0.86	3.03	+10.7%	
C	1	10	0.87	0.66	0.72	10.2	38	39	1.8	2.7	19	0.16	1.93	0.043	Passed
	2		0.87	0.64	0.76	10.2	39	40	5.65	2.6	18.6	0.17	1.99		
	Mean		0.87	0.65	0.74	10.2	39	40	∑: 7.45	2.65	18.8	0.17	1.96	+7.5%	
F	1	20	1.76	1.24	1.1	21	32	39	4.64	3.2	41.2	1.29	3.23	0.043*	Failed
	2		1.69	1.34	0.99	22.7	34	39	6.35	4.1	41.2	0.99	3.33		
	Mean		1.73	1.29	1.05	21.9	33	39	∑: 10.99	3.65	41.2	1.14	3.28	-23.2%	
D	1	10	0.61	0.45	0.29	6.9	48	55	2.17	0.7	16.5	0.15	1.28	0.06	Passed
	2		0.83	0.51	0.27	6.9	53	55	2.29	0.8	16.5				
	Mean		0.72	0.48	0.28	6.9	51	55	∑: 4.46	0.75	16.5	0.08	0.64	+50.0%	
E	1	10	0.83	0.83	0.55	7.7	48	49	3.88	1.1	16.5	0.7	2.13	0.054	Passed
	2		0.75	0.66	0.57	7.8	48	48	2.63	1.1	16.8	0.81	2.3		
	Mean		0.79	0.75	0.56	7.8	48	49	∑: 6.51	1.1	16.6	0.76	2.22	+35.0%	
G	1	14*	1.32	1.21	0.69	13.2	40	41	5.83	2.5	25.6	1.2	2.96	0.044*	Failed
	2		0.98	0.95	0.59	13.5	33	41	4.62	2.5	25.6	1.52	3.08	-21.4%	
	Mean		1.15	1.08	0.64	13.4	37	41	∑: 10.45	2.5	25.6	1.36	3.02		
O	1	12	1.28	0.5	1.48	14.3	48	44	6.44	2.3	17.4	-5.34	3.83	0.037*	Failed
	2		1.14	0.81	0.97	13.7	47	46	7.13	1.9	16.8	1.04	4.27		
	Mean		1.21	0.66	1.23	14	48	45	∑: 13.57	2.1	17.1	-2.15	4.05	-7.5%	
M	1	14*	1.45	1.24	1.33	12	56	57	2.87	2	21.9	0.52	2.5	0.064	Passed
	2		1.28	1.2	0.89	11.9	60	58	4.3	1.7	21.7	0.27	1.95		
	Mean		1.37	1.22	1.11	12	58	58	∑: 7.17	1.85	21.8	0.4	2.23	+14.3%	
H	1	16	0.72	0.62	0.6	10	51	52	5.87	1	24.7	0.5	3.43	0.042*	Failed
	2		0.9	0.56	0.58	10	56	52	5.54	0.9	24.7	0.55	3.5		
	Mean		0.81	0.59	0.59	10	54	52	∑: 11.41	0.95	24.7	0.53	3.47	-25.0%	
N	1	16	1.12	0.57	0.8	16.9	51	46	6.21	2.1	26.6	0.88	3.15	0.036*	Failed
	2		1.31	0.45	1.01	17	51	46	5.8	2.1	26.6	0.27	3.05		
	Mean		1.22	0.51	0.94	17	51	46	∑: 12.01	2.1	26.6	0.58	3.1	-37.5%	
J	1	20	1.06	1.07	0.81	14.1	47	56	3.38	1.4	33.5	0.33	2.97	0.042*	Failed
	2		0.97	0.9	0.51	14.1	46	57	3.86	1.5	33.1	1	3.14		
	Mean		1.02	0.99	0.66	14.1	47	57	∑: 7.24	1.45	33.3	0.67	3.06	-0.25%	

L	1	20	1.61	1.12	1.35	21.3	31	41	7.14	3.5	35.8	0.95	3.9	0.041*	Failed
	2		1.51	0.25	0.99	16.6	33	40	8.69	3.8	36.6	0.34	1.98		
	Mean		1.56	0.69	1.17	19	32	41	∑: 15.83	3.65	36.2	0.65	2.94	-26.8%	
A	1	25	2.18	1.11	1.48	14.5	51	56	5.62	2.1	40	1.72	2.89	0.084	Passed
	2		2.18	1.82	1.5	14.6	55	63	6.58	2.3	37.2	1.78	2.56	+50.0%	
	Mean		2.18	1.47	1.5	14.6	53	60	∑: 12.20	2.2	38.6	1.75	2.73		

* Characteristic RRA limit not satisfied.

3.2 Chemical Composition

Table 6 Percentage Chemical Composition

ELEMENTS	Sample I.D and % composition of the elements														
	K	F	I	M	B	C	D	E	G	H	I	N	O	Z	A
Carbon ©	0.16	0.25	0.21	0.2	0.14	0.12	0.12	0.12	0.26	0.17	0.26	0.12	0.25	0.13	0.22
Manganese(Mn)	0.68	0.64	1.44	0.51	0.72	0.55	0.75	0.38	0.42	0.62	0.7	0.53	0.69	0.52	0.94
Silicon (Si)	0.25	0.27	0.3	0.19	0.21	0.19	0.21	0.13	0.16	0.16	0.23	0.26	0.34	0.23	0.2
Copper (Cu)	0.21	0.13	0.25	0.17	0.17	0.22	0.22	0.3	0.17	0.25	0.12	0.25	0.28	0.26	0.033
Phosphorus (P)	0.051	0.029	0.038	0.033	0.038	0.047	0.042	0.045	0.029	0.034	0.054	0.036	0.055	0.039	0.021
Sulphur (S)	0.047	0.037	0.05	0.038	0.038	0.047	0.047	0.062	0.029	0.053	0.058	0.046	0.059	0.055	0.038
Chromium (Cr)	0.31	0.17	0.14	0.13	0.25	0.22	0.16	0.23	0.19	0.33	0.13	0.28	0.26	0.28	0.035
Molybdenum (Mo)	0.02	0.012	0.023	0.012	0.017	0.013	0.015	0.027	0.011	0.016	0.008	0.024	0.03	0.025	0.001
Nickel (Ni)	0.097	0.065	0.11	0.078	0.092	0.1	0.095	0.11	0.088	0.2	0.064	0.096	0.11	0.099	0.018
Vanadium (V)	0.003	0.003	0.04	0.001	0.003	0.003	0.002	0.003	0.003	0.003	0.002	0.004	0.005	0.004	0.001
Nitrogen (N)	0.0066	0.0194	0.0128	0.014	0.0073	0.0066	>0.0381	0.018	0.0045	0.0062	0.0143	0.007	0.002	0.0063	0.0132
Boron (Bo)	0.0011	0.0003	<-0.0004	<-0.0002	0.001	0.0013	<0.0000	0.0009	<0.0001	<-0.0004	<-0.0001	0.0003	<-0.0005	<-0.0007	<-0.0003
Aluminum (Al)	0.003	0.006	0.003	0.002	0.002	0.004	0.002	0.003	0.005	0.002	0.004	0.008	0.002	0.006	0.006
Calcium (Ca)	0.002	0.002	0.0006	0.0002	0.0003	0.0001	0.001	0.0003	0.0002	0.0006	0.006	0.01	0.0006	0.004	0.002
Cobalt (Co)	0.009	0.005	0.015	0.007	0.008	0.008	0.007	0.009	0.009	0.008	0.006	0.007	0.006	0.006	<0.0003
Zinc (Zn)	<-0.0002	0.001	<0.0004	0.001	<-0.0003	<-0.0002	<0.0001	<-0.0003	0.005	<-0.0004	0.003	<-0.0002	<-0.0004	<-0.0003	<0.0001
Arsenic (As)	0.004	0.003	0.007	0.003	0.002	0.003	0.002	0.001	0.002	0.002	0.004	0.002	0.002	0.002	0.003
Antimony (Sb)	0.012	0.008	0.011	0.008	0.009	0.011	0.009	0.008	0.008	0.009	0.006	0.007	0.009	0.011	0.005
Tin (Sn)	0.029	0.01	0.016	0.013	0.024	0.021	0.034	0.025	0.023	0.037	0.014	0.019	0.019	0.021	0.002
Titanium (Ti)	<0.0001	0.0007	<-0.0001	<-0.0003	<-0.0003	0.0003	<-0.0008	<-0.0006	0.0007	<0.0001	0.0006	0.0009	<-0.0002	0.0003	0.0002

Carbon Equivalent Results

Table 7 Chemical Composition and Computation of Carbon Equivalent of Samples

SAMPLE LABEL	%N	% C	% Mn	% Cr	% Mo	% V	% Ni	% Cu	%P	%S	C_{eqv}
A2	0.0132	0.22	0.94	0.035	0.001	0.001	0.018	0.033	0.021	0.038	0.3875
B1	0.0073	0.14	0.72	0.25	0.017	0.003	0.092	0.17	0.038	0.038	0.3315
C1	0.0066	0.12	0.55	0.22	0.013	0.003	0.1	0.22	0.047	0.047	0.2802
D1	0.0381	0.12	0.75	0.16	0.015	0.002	0.095	0.22	0.042	0.047	0.3014
E1	0.0180	0.12	0.38	0.23	0.027	0.003	0.11	0.3	0.045	*0.062	0.2627
F1	0.0194	*0.25	0.64	0.17	0.012	0.003	0.065	0.13	0.029	0.037	0.4067
G1	0.0045	*0.26	0.42	0.19	0.011	0.003	0.0045	0.17	0.029	0.029	0.382
H1	0.0062	0.17	0.62	0.33	0.016	0.003	0.2	0.25	0.034	0.053	0.3731
I1	0.0128	0.21	1.44	0.14	0.023	0.04	0.11	0.25	0.038	0.05	0.5146
K1	0.0066	0.16	0.68	0.31	0.02	0.003	0.097	0.21	0.051	0.047	0.3604
L1	*0.0143	*0.26	0.7	0.13	0.008	0.002	0.064	0.12	0.054	*0.058	0.4169
M1	0.0002	0.2	0.51	0.13	0.012	0.001	0.078	0.17	0.033	0.038	0.3301
N1	0.0070	0.12	0.53	0.28	0.024	0.004	0.096	0.25	0.036	0.046	0.293
O1	0.0020	*0.25	0.669	0.26	0.03	0.005	0.11	0.28	0.055	*0.059	0.4465

* % by mass exceeded.

Fourteen samples were tested and diameter of rebars range from 10mm – 25mm. of the fourteen samples, six crossed the minimum threshold specified in Table 9 of BS4449:2005 [7]. The remaining nine samples failed, indicating that their rib geometry did not conform to standard.

This is an indication that the bonding of the rebars which failed the RRA test when used in reinforced concrete works will be unreliable.

(e) Bend and Rebend

After the bend and rebend tests, all fifteen (15) tested rebar samples were checked. They showed no sign of fracture or cracks visible to a person of normal or corrected vision. Therefore, the requirements of BS4449:2005 [7] Clause 7.2.5 were satisfied by the rebar samples

The twenty elements discovered in this test are Aluminium (Al), Boron (Bo), Calcium (Ca), Carbon (C), Chlorine(Cl), Chromium(Cr), Copper (Cu) antimony (Sb) Arsenic (As), Iron(Fe), Manganese (Mn), Molybdenum(Mo), Nickel (Ni), Nitrogen (N), Phosphorus (P), Silicon(Si), Sulphur, Titanium (Ti), Vanadium (V), Zinc (Zn).

The asterisked data under the columns: %carbon %Sulphur and % Nitrogen in Table 7 indicate that Carbon, Sulphur, and Nitrogen contents by mass for the samples were exceeded, however, for Carbon for instance. The values are permitted to exceed the maximum values 0.03% by mass, provided that the carbon equivalent value is decreased by 0.02% by mass.

The carbon equivalent, C_{eqv}, for all the tested samples fell below the maximum of 0.52% by mass in accordance with BS4449:2005 [7].

4. Conclusion

The following conclusions were drawn based on the results presented and practical observations made on the mechanical and chemical properties of reinforcement bars manufactured in Nigeria:

i. About 15% of the tested rebar samples have their measured diameter smaller than their nominal diameter, which may indicate the level of quality control of the local bar manufacture.
ii. It was observed that 57% of the tested rebar samples failed the RRA test, which indicates that the surface geometry of the tested rebars did not conform to the standard.
iii. It was found that only 40% of tested rebars fall within permissible deviation from nominal mass per meter, while the remaining 60% weigh less than the tolerant limit of the permissible mass per meter.
iv. About 47% of the tested rebars have yield stresses above the BS4449:2005 stipulated minimum standard, 13% fall within allowable minimum while 40% others failed. This is an indication that there is a 40% chance of procuring rebars from local manufactures which would not pass the yield stress test
v. It was found that the chemical composition of tested rebars conformed very largely to standards, and where values marginally exceeded (in the case of carbon %) the corresponding values carbon equivalent fall below the maximum specified in the code.

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Conflict of Interest

The authors declare no conflict of interest.

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