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Evaluation of Mechanical Properties and Chemical Composition of Some Selected Steel Reinforcements Used in Nigeria

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ABSTRACT

Mechanical properties and chemical composition of some selected steel reinforcement bars used for construction works in Nigeria were investigated. Six nominal sizes of bars from four selected brands, including: Real steel reinforcing pty Limited, code name Red; Phoenix steel mills, code name White; Pulkit alloy and steel limited, code name Blue; and African foundries limited, code name Black were evaluated. The tensile test was carried out at the mechanical engineering department, University of Ilorin using Universal Testing Machine (UTM) while the chemical compositions of the steel samples were analyzed using optical emission spectrometer at the laboratory of African foundries limited, Ikorodu Lagos State. The results obtained were compared with BS 449:2005 +A3:2016 standard provision. The outcome of the study showed that 70.8 % of the tested steel bars failed the characteristic tensile strength test, though with a very good percentage elongation satisfying the required specification. Chemical composition tests revealed that most of the failed samples contained low carbon content or excess phosphorus composition plus other impurities.

1 Introduction

Reinforced Concrete (RC) is probably the most used construction material in Nigeria due to its high strength and durability properties. It is a composite material in which the reinforcing steel resists the tensile stresses while the concrete supports the compressive stresses. Reinforcing steels are also introduced in compression zones in cases where the developed compressive stresses are in excess of the concrete strength. Steel reinforcement also complements the concrete strength in counteracting the shear stresses in RC structures [1]. Therefore, adequate quality control checks on the mechanical properties of the reinforcing steels are required to ensure strict compliance with standard provisions so as to forestall failure of engineering structures. The quality of reinforcement steels used for construction works are measured in terms of their yield strength, ultimate tensile strength and percentage elongation (ductility) [2].

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The fact that steel and concrete act as a unit to withstand the induced forces forms the basis for the design of RC structures [2]. Also, the closeness in the co-efficient of thermal expansion of steel and concrete reduces the relative movement between the embedded bars and concrete in the RC work to barest minimum when subjected to temperature changes. In addition, steel has excellent bendability and bond effectively with concrete for reinforcement. Steel rods are indented on the surface during rolling process to enhance bonding with concrete by mechanical interlocking. It is also known that steel does not corrode in cement and sand environment Vlack, (1982) cited in Ganiyu et al. [2].

In Nigeria, the incident of collapse of RC structures have in recent time become frequent occurrences especially for buildings resulting into loss of many lives and valuable properties. As reported in [3], not less than 264 deaths were recorded from about 25 cases of building collapses between 2005 and 2010. Sulymon, Bello, Dahunsi, & Nwaigwe [4] also reported 54 occurrences of building collapse in 16 states of the federation accounting for 317 deaths and several people injured between 2013 and 2017. The most prominent of the incident occurred on September 12, 2014, in which a guest house under construction within the premises of Synagogue Church of All Nations (SCOAN) in the Ikotun area of Lagos collapsed leading to death of 116 people.

More recently in the year 2019, many building failures have also been recorded including a 3-storey building under construction at bode street, Sogoye area of Ibadan on 15th of March; an old 3-storey building at 54 kakawa street, Lagos Island on 25th of March with no casualties recorded; and a 3-storey building with penthouse at 14, Massey street, Ita-faji, Lagos state on the 13th of March in which 20 lives were reportedly lost and several injured. Many studies have investigated the causes of incessant building collapse in Nigeria. Among the factors identified include the use of substandard building materials, incompetence, poor supervision/poor workmanship, faulty structural design/ absence of structural design, carelessness, weak/faulty foundation, overloading loading, illegal conversion, non-compliance with approved building plan & disregard for building regulation/plan, hasty construction/faulty construction, ignorant/greed and corrupt tendencies etc. [4].

In the recent past, some works have investigated the mechanical properties of reinforcing steel used in Nigeria. Umeonyiagu & Ikhazuagbe [5] examined the mechanical properties of some selected reinforcing steel bars used in the Nigerian to ascertain their level of conformity to the BS 4449: 1997 provisions. The study concludes that eighty-five percent of the samples tested fell short of BS 4449: 1997 provision.

Ede, Egunjobi, Bamigboye, & Ogundeji [6] also assessed the quality of steel reinforcements used for construction in Lagos state on samples collected from project sites and the findings of the study show that, on the average, 70% of the samples considered met BS 4449: 1997 standard specifications. The carbon content of steel bars obtained from collapsed buildings in Nigeria has also been suggested to exhibit brittle properties due to presence of brittle globules of Fe_3P and FeS in its microstructure [7]. It is however worthy to state that most of the studies did not relate the mechanical behaviour of the material to its chemical composition.

Therefore, this study focused on the investigation of the mechanical properties and chemical composition of some selected steel reinforcement brands used for construction work in Nigeria. The objectives were to determine: the tensile strength and ductility properties of the reinforcing steels; the characteristics strength of the bars; the chemical compositions of reinforcement steels and compare them to standard provisions.

2 Materials and Methods

2.1 Sample Collection

Samples of reinforcing steels produced by four indigenous manufacturers namely: Real Steel Reinforcing pty Limited (code named Red), Pheonix Steel Mills (code named White), Pulkit Alloy and Steel Limited (code named Blue) and African Foundries Limited (code named Black) were purchased from Igando Iron Market, Lagos State, Nigeria. Six bar samples were randomly selected from each of the four manufacturers representing 8 mm, 10 mm, 12 mm, 16 mm, 20 mm and 25 mm nominal sizes totalling twenty-four lengths. Three (3) identical specimens (Figure 1) from each length of bars (totalling 72 specimens) were tested for the mechanical properties while twenty-four (24) specimens, each measuring 50 mm long, were subjected to chemical analysis.

Fig. 1 – Some of the samples before standardization

2.2 Mechanical Property Test

The Mechanical properties of reinforcement steels are characterized in terms of yield and ultimate strength in tension and percentage elongation otherwise referred to as ductility. In the present study, the mechanical test was carried out at the mechanical engineering laboratory of the university of Ilorin, Kwara State, Nigeria using Testometric Universal Testing Machine (UTM) model FS 50AT having 50 kN capacity. The specimen lengths were initially standardized in accordance with standard provisions since the UTM cannot test specimen with diameter greater than 8 mm. A lathe machine was used to machine the raw samples to overall length of 200 mm having two shoulders measuring 50mm each in length with shoulder width of 10mm. The distance between the shoulders was 100mm with gauge having width varying from 7.0 to 8.0 mm. The gauge has a smaller cross section so that the deformation and failure can occur in this area. The experimental setup is shown in Figure 2.

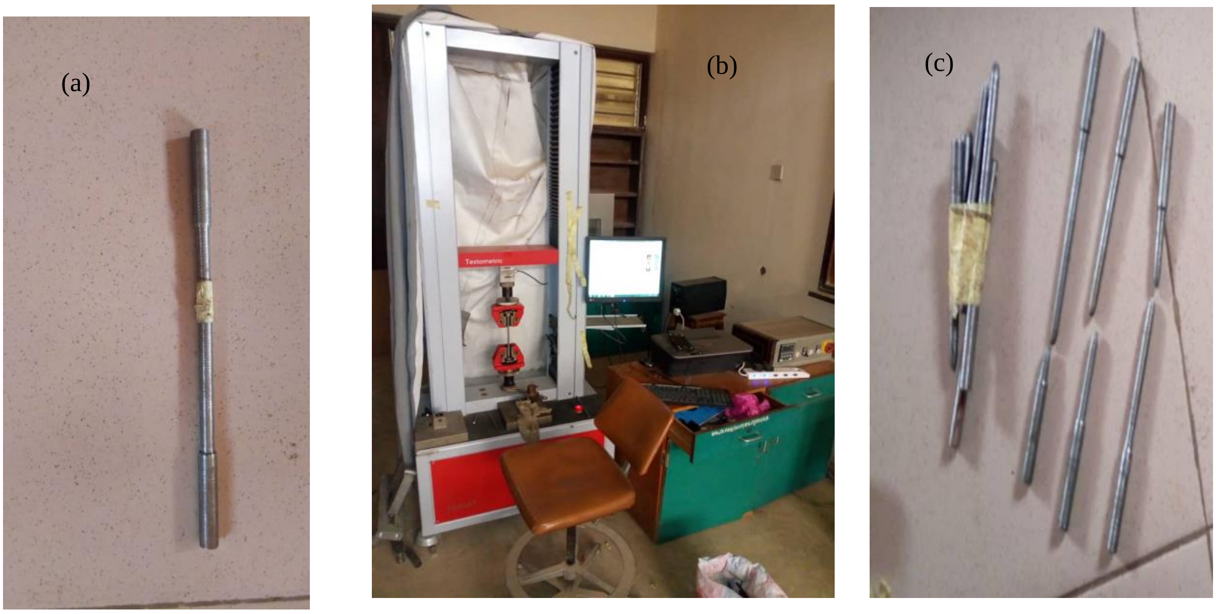

Fig. 2 - (a) Standardized Specimen; (b) Steel tensile test using UTM; (c) Specimens after testing

The characteristic yield strength, $\boldsymbol{f_k}$ of the steel specimens was obtained using equation 1

$$f_k = \bar{x} - 1.64\sigma \tag{1}$$

Where: $\bar{x}$ = mean yield strength; σ = Standard deviation.

2.3 Elemental Composition Test

In order to obtain the elemental composition of the steel specimens, spectrometer analysis otherwise refer to as spark atomic emission spectrometer test was carried out on the samples at the laboratory of African foundries limited, Ikorodu, Lagos using Spectro analytical instrument (Model 130948). The instrument has the capacity to analyse steel specimen into twenty-nine (29) element concentration and display the result on computer screen as shown in Figure 3.

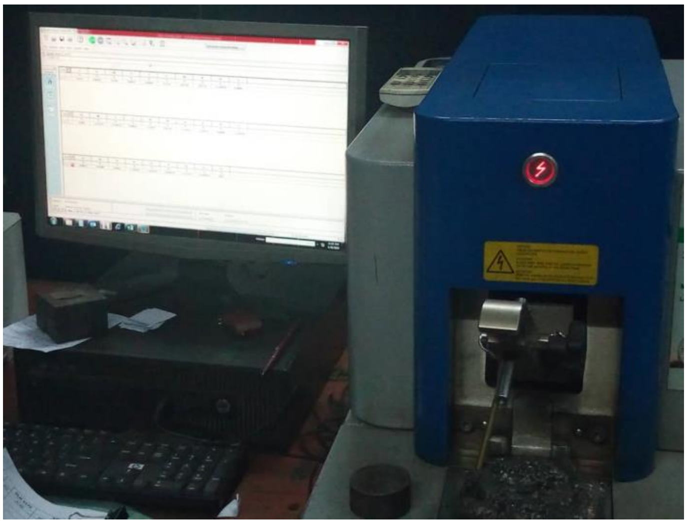

Fig. 3- Spectro Analytical Instrument

The instrument operates on the principle of light and sparking. The test specimen was earthen. As the instrument was energized, its electrode triggered spark lights as it contacted the specimen's surface repeatedly. As the sparking continued, the emitted light rays were received on array of lens based on the wavelengths. The light rays from the elements present in the steel specimens differ in wave length and the intensities of the lights determine the element concentrations. The computer attached to the measuring device has been programmed to detect the intensity of the light and convert it to element concentration. The marks made by the electrode on the tested specimens is shown in Figure 4.

Fig. 4- Specimens after spectrometer test

The result of the analysis was compared with BS 4449:2005 [8] standard provisions. The code limits the concentration of the major element in the construction steel to the values given in table 1. The carbon equivalent content was obtained from equation 2 as given in the code.

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

Table 1-Recommended maximum elemental composition in construction steel

Element	**Carbon**	**Sulphur**	**Phosphorus**	**Copper**	**Carbon equivalent**
% maximum composition	0.24	0.055	0.055	0.85	0.52

Source: BS 4449:2005

3 Results and Discussion

3.1 Mechanical Property Test

The summary of the mechanical property test results on the 24 steel samples from the four companies is presented in Table 2. The parameters measured are the bar diameter, yield and ultimate strength, stress ratio and percentage elongation.

Table 2 - Yield stress, Ultimate tensile stress and stress ratio

Company	**Bar Nominal Diameter (mm)**	**Measured Bar Diameter (mm)**	**Yield Stress (N/mm^2)**	**Ultimate Stress (N/mm^2)**	**Stress Ratio**	**Elongation (%)**
RED	8.00	7.90	622.22	695.96	1.119	16.503
	10.00	10.00	461.80	669.17	1.449	13.415
	12.00	11.50	472.61	655.00	1.386	13.070
	16.00	14.00	517.67	726.34	1.400	13.950
	20.00	18.50	504.12	645.14	1.230	13.480
	25.00	23.00	384.96	604.49	1.570	19.210
WHITE	8.00	8.00	488.12	574.80	1.178	14.646
	10.00	10.00	437.21	574.26	1.313	15.919
	12.00	11.80	444.61	545.28	1.226	15.437
	16.00	15.00	403.44	603.84	1.500	17.300
	20.00	19.00	341.43	462.03	1.350	21.060
	25.00	23.00	420.76	498.53	1.180	17.320
BLUE	8.00	8.00	620.17	693.95	1.119	17.544
	10.00	10.00	450.67	644.44	1.429	15.707
	12.00	11.80	554.68	657.10	1.185	11.690
	16.00	15.00	516.45	677.16	1.310	14.710
	20.00	19.50	544.34	682.02	1.250	11.500
	25.00	24.00	499.00	659.43	1.320	13.230
BLACK	8.00	7.90	620.48	699.16	1.127	16.873
	10.00	10.00	551.80	682.63	1.237	13.609
	12.00	11.60	709.10	709.39	1.000	11.016
	16.00	14.50	520.28	672.12	1.290	14.340
	20.00	19.50	508.38	655.83	1.290	12.760
	25.00	24.00	435.77	627.32	1.450	13.060

3.1.1 Characteristic Strength

Figure 5 compares the characteristic strength of the tested samples with the standard code provision. As seen in the figure, 70.8 % of the samples tested fell below the characteristic code value of 500 N/mm^2 specified in the BS 4449:2005 [8] standard. The company black mostly complied with the standard provision with four out of six nominal sizes having strengths above the recommended limit. Only two samples from company BLUE passed the standard test. For company RED, only the 8mm bar met the code requirement while all the samples produced by company WHITE did not satisfy the code provision with regards to the characteristic strength requirements.

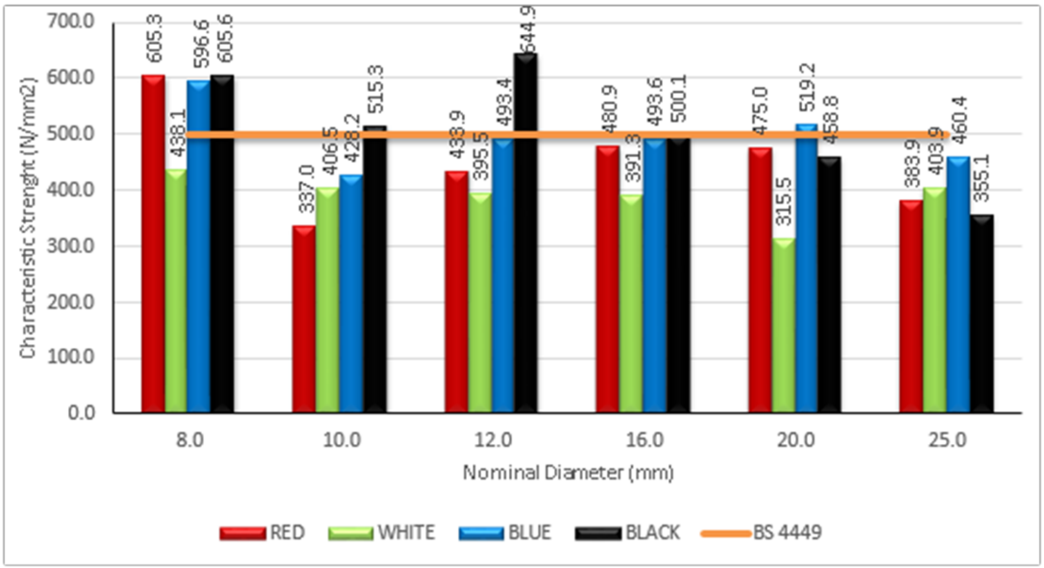

Fig. 5 - Comparison of Characteristic strength with BS 4449:2005 standard provision

3.1.2 Percentage Elongation

Elongation is the percentage of stretch from the original length of the steel to the point of failure, showing how ductile the steel is. Ductility is the capability of the steel to be stretched out without becoming more brittle or weaker in the process. The more ductile it is, the more malleable the product is. The recommend minimum elongation as per BS 4449:2005 [8] is 5%. Comparison of the ductility parameter of the samples, as shown in Figure 6, reveals that all the samples meet the standard provision. Therefore, it could be concluded that the materials are very ductile. This is due to low carbon content in the specimens as will be discussed in the chemical composition result.

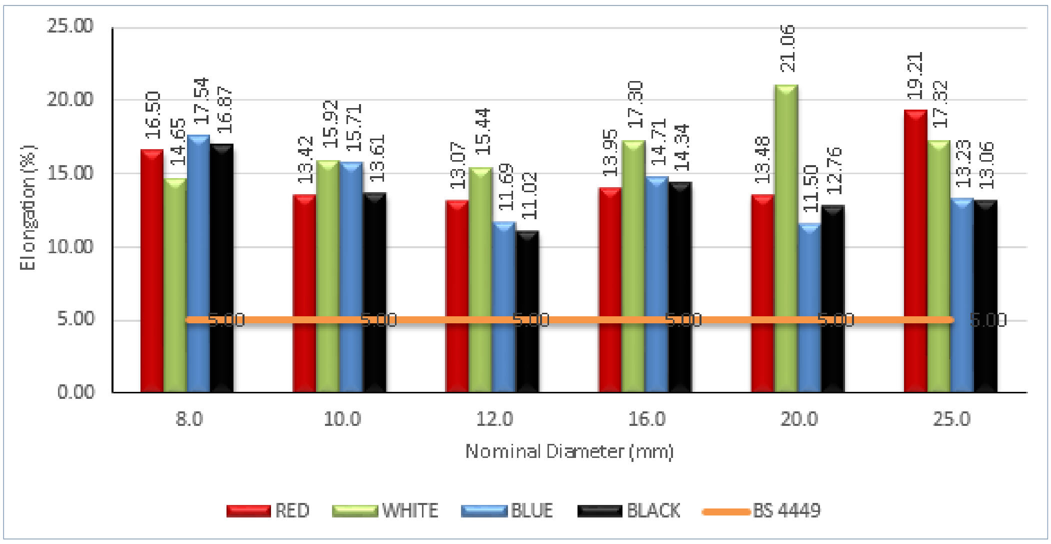

Fig. 6 - Comparison of percentage elongation with BS 4449:2005 standard provision

3.1.3 Tensile/yield strength Ratio

Comparison of tensile/yield strength ratio with recommend code value is shown in Figure 7. From the result, it could be observed at a glance that all the samples except the 10 mm Black product satisfied the strength ratio requirement. It is an indication that the material could sustain additional loads in the plastic region, that is, at high deformation. This property is desirable in the design of RC structures to prevent brittle failure that is typical of unreinforced concrete structures.

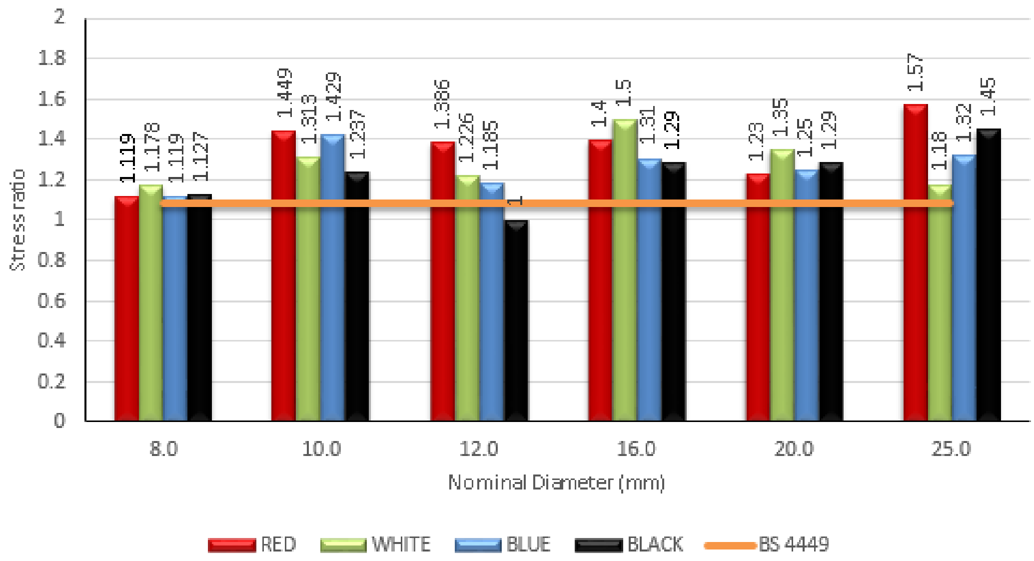

Fig. 7 - Comparison of percentage elongation with BS 4449:2005 standard provision

3.2 Elemental composition

Table 3 shows the result of the elemental compositions analysis of different diameters of steel rods sampled from products of four different manufacturers code named RED, WHITE, BLUE and BLACK respectively.

The twenty nine elements identified in the test are Aluminum (Al), Arsenic (As), Boron (B), Bismuth (Bi), Calcium (Ca), Carbon (C), Chromium(Cr),Cerium (Ce), Cobalt (Co), Cupper (Cu), Iron(Fe), Lanthanum (La), Lead (Pb), Manganese (Mn), Molybdenum(Mo), Nickel (Ni), Niobium (Nb), Phosphorus (P), Selenium (Se) Silicon(Si), Sulphur (S), Tin (Sn), Tantalum (Ta), Tellurium (Te), Titanium (Ti), Tungsten (W), Vanadium (V), Zinc (Zn) and Zirconium (Zr). The influence of the major elements on the mechanical behaviour of the samples is subsequently discussed.

The result of spectrometer analysis was compared with BS 4449:2005+A2:2005 standard provisions as displayed in Figures 8-11. The major elements considered in the code are carbon, copper, phosphorus and sulphur.

Others elements expressed in form of carbon equivalent content are manganese, chromium, vanadium, molybdenum, copper and nickel. From the figures, it is clear that all the specimens, except the 12mm RED product, satisfied the specified maximum 0.24 % carbon content requirement. Next to iron, Carbon is known to be the most significant element in steel. According to Ponle et al (2014) [9] , high carbon content improves the tensile strength but compromises the ductility property of the material while low carbon content produces a ductile material with reduced strength. The authors also specified a lower limit of 0.15 % carbon content for structural steel as smaller values negatively influence the yield strength of the material. The failure of the products of the White Company could be attributed to the low carbon content in the samples. For instance, the 16 mm and 20 mm of White products have carbon contents of 0.091 % and 0.082 % respectively (Figure 9).

The corresponding characteristic strength of the specimens, as presented in Figure 5, are 391.3 N/mm^2 and 315.5 N/mm^2 respectively. These values are not satisfactory. Additionally, all the investigated specimens satisfied the recommend 5 % elongation (Figure 6). This is an indication that all the specimens are very ductile which could be linked to the of low carbon content in the steel samples.

Table 3 - Percentage Elemental composition of Steel bars from different manufactures

Company	diameter (mm)	Elemental Composition (%)												
		C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co	Cu	Nb	Ti
RED	8.0	0.1520	0.1020	0.5730	0.0517	0.0457	0.3130	0.0286	0.1460	0.0005	0.0114	0.2670	0.0010	0.0002
	10.0	0.2320	0.2260	0.6670	0.0486	0.0336	0.1680	0.0213	0.0972	0.0005	0.0047	0.1690	0.0010	0.0002
	12.0	0.2590	0.1840	0.4960	0.0586	0.0509	0.2450	0.0203	0.1180	0.0005	0.0098	0.3070	0.0010	0.0002
	16.0	0.2220	0.2000	0.6350	0.0639	0.0524	0.1910	0.0136	0.0978	0.0005	0.0112	0.2260	0.0010	0.0002
	20.0	0.1460	0.1490	0.5190	0.0853	0.0538	0.2930	0.0139	0.0967	0.0005	0.0090	0.2630	0.0010	0.0003
	25.0	0.1970	0.1940	0.5660	0.0471	0.0500	0.2400	0.0160	0.0806	0.0005	0.0069	0.1880	0.0017	0.0002
WHITE	8.0	0.1460	0.1050	0.5830	0.0447	0.0454	0.3210	0.0288	0.1460	0.0005	0.0094	0.2670	0.0010	0.0002
	10.0	0.1910	0.2010	0.6790	0.0484	0.0434	0.2200	0.0179	0.0815	0.0050	0.0056	0.2000	0.0010	0.0002
	12.0	0.1930	0.1820	0.7350	0.0591	0.0436	0.2620	0.0231	0.0923	0.0005	0.0058	0.1980	0.0010	0.0002
	16.0	0.0818	0.0878	0.4460	0.0457	0.0536	0.1930	0.0173	0.0659	0.0050	0.0081	0.2180	0.0010	0.0002
	20.0	0.0909	0.0735	0.3870	0.0490	0.0477	0.2500	0.0196	0.0854	0.0005	0.0087	0.2130	0.0012	0.0002
	25.0	0.1630	0.1850	0.6720	0.0351	0.0351	0.3690	0.0277	0.1170	0.0001	0.0083	0.2490	0.0017	0.0002
BLUE	8.0	0.1570	0.1110	0.6980	0.0392	0.0404	0.3310	0.0226	0.1460	0.0005	0.0088	0.2670	0.0010	0.0002
	10.0	0.2260	0.2470	0.6690	0.0439	0.0507	0.1730	0.0208	0.0960	0.0007	0.0070	0.1660	0.0010	0.0005
	12.0	0.2200	0.1770	0.5190	0.0433	0.0442	0.2090	0.0243	0.1070	0.0005	0.0115	0.2990	0.0010	0.0002
	16.0	0.1880	0.2030	0.6530	0.0502	0.0528	0.2760	0.0181	0.1050	0.0011	0.0083	0.2860	0.0012	0.0013
	20.0	0.1760	0.1640	0.5970	0.0727	0.0502	0.2680	0.0222	0.1140	0.0005	0.0085	0.2160	0.0018	0.0002
	25.0	0.1760	0.1780	0.5770	0.0627	0.0603	0.2320	0.0202	0.0983	0.0005	0.0074	0.2300	0.0010	0.0002
BLACK	8.0	0.1550	0.1650	0.4330	0.0607	0.0545	0.2410	0.0198	0.0932	0.0005	0.0051	0.2220	0.0010	0.0002
	10.0	0.1480	0.1750	0.4520	0.0678	0.0487	0.2250	0.0182	0.0856	0.0005	0.0057	0.1990	0.0011	0.0002
	12.0	0.0956	0.1290	0.4400	0.0446	0.0583	0.1960	0.0201	0.0926	0.0005	0.0055	0.2170	0.0011	0.0002
	16.0	0.1740	0.1910	0.6820	0.0515	0.0463	0.2270	0.0164	0.0774	0.0005	0.0078	0.2100	0.0010	0.0002
	20.0	0.2350	0.2200	0.8330	0.0582	0.0446	0.2540	0.0136	0.0809	0.0005	0.0102	0.1960	0.0010	0.0002
	25.0	0.2440	0.2360	0.8150	0.0553	0.0454	0.0205	0.0149	0.0827	0.0005	0.0098	0.2140	0.0012	0.0002

Table 3 (Cont'd) - Percentage Elemental composition of Steel bars from different manufactures

Company	diameter (mm)	Elemental Composition (%)														
		V	W	Pb	As	Zr	Bi	Ca	Ce	Sb	Se	Ta	B	Zn	La	Te	Fe
RED	8.0	0.0072	0.0050	0.0028	0.0010	0.0010	0.0117	0.0001	0.0022	0.0203	0.0105	0.0070	0.0002	0.0010	0.0003	0.0045	98.20
	10.0	0.0046	0.0050	0.0031	0.0010	0.0010	0.0089	0.0001	0.0001	0.0165	0.0020	0.0070	0.0006	0.0044	0.0003	0.0028	98.30
	12.0	0.0060	0.0050	0.0020	0.0010	0.0010	0.0089	0.0004	0.0016	0.0177	0.0021	0.0070	0.0074	0.0010	0.0030	0.0030	98.20
	16.0	0.0045	0.0050	0.0026	0.0010	0.0010	0.0062	0.0001	0.0029	0.0168	0.0020	0.0070	0.0012	0.0010	0.0003	0.0042	98.20
	20.0	0.0054	0.0050	0.0026	0.0010	0.0010	0.0050	0.0003	0.0028	0.0269	0.1110	0.0070	0.0003	0.0010	0.0030	0.0065	98.30
	25.0	0.0066	0.0050	0.0026	0.0010	0.0010	0.0077	0.0006	0.0025	0.0171	0.0171	0.0022	0.0070	0.0010	0.0030	0.0038	98.40
WHITE	8.0	0.0073	0.0050	0.0023	0.0010	0.0010	0.0107	0.0001	0.0012	0.0171	0.0034	0.0070	0.0002	0.0010	0.0003	0.0036	98.20
	10.0	0.0057	0.0050	0.0023	0.0010	0.0010	0.0081	0.0001	0.0010	0.0159	0.0020	0.0070	0.0005	0.0012	0.0004	0.0034	98.30
	12.0	0.0060	0.0050	0.0025	0.0010	0.0010	0.0078	0.0001	0.0011	0.0130	0.0020	0.0070	0.0002	0.0011	0.0006	0.0026	98.20
	16.0	0.0050	0.0050	0.0040	0.0010	0.0010	0.0060	0.0010	0.0040	0.0124	0.0020	0.0070	0.0002	0.0014	0.0003	0.0037	98.80
	20.0	0.0057	0.0050	0.0020	0.0001	0.0010	0.0081	0.0001	0.0024	0.0198	0.0048	0.0070	0.0002	0.0010	0.0003	0.0042	98.70
	25.0	0.0079	0.0050	0.0024	1.0000	0.0010	0.0083	0.0004	0.0024	0.0150	0.0020	0.0070	0.0006	0.0010	0.0003	0.0041	98.10
BLUE	8.0	0.0078	0.0129	0.0067	0.0010	0.0010	0.0074	0.0001	0.0057	0.0089	0.0020	0.0206	0.0002	0.0029	0.0026	0.0021	98.20
	10.0	0.0049	0.0050	0.0046	0.0010	0.0010	0.0105	0.0020	0.0022	0.0153	0.0020	0.0070	0.0013	0.0052	0.0003	0.0038	98.20
	12.0	0.0055	0.0050	0.0033	0.0010	0.0010	0.0075	0.0001	0.0031	0.0130	0.0020	0.0070	0.0002	0.0019	0.0013	0.0027	98.30
	16.0	0.0062	0.0050	0.0020	0.0010	0.0010	0.0074	0.0037	0.0020	0.0152	0.0020	0.0070	0.0002	0.0010	0.0003	0.0041	98.10
	20.0	0.0063	0.0050	0.0027	0.0010	0.0010	0.0090	0.0013	0.0027	0.0170	0.0033	0.0070	0.0002	0.0010	0.0003	0.0037	98.20
	25.0	0.0062	0.0050	0.0025	0.0010	0.0010	0.0073	0.0001	0.0025	0.0165	0.0020	0.0070	0.0007	0.0010	0.0003	0.0041	98.30
BLACK	8.0	0.0065	0.0050	0.0018	0.0010	0.0010	0.0100	0.0001	0.0010	0.0218	0.0070	0.0070	0.0017	0.0010	0.0003	0.0039	98.50
	10.0	0.0074	0.0050	0.0020	0.0010	0.0010	0.0087	0.0001	0.0012	0.0226	0.0081	0.0070	0.0019	0.0010	0.0003	0.0037	98.50
	12.0	0.0064	0.0050	0.0017	0.0010	0.0010	0.0087	0.0001	0.0010	0.0205	0.0053	0.0070	0.0005	0.0010	0.0003	0.0033	98.60
	16.0	0.0046	0.0050	0.0032	0.0010	0.0010	0.0064	0.0017	0.0032	0.0175	0.0020	0.0070	0.0007	0.0013	0.0003	0.0050	98.30
	20.0	0.0045	0.0050	0.0030	0.0010	0.0010	0.0054	0.0006	0.0027	0.0216	0.0059	0.0070	0.0007	0.0021	0.0003	0.0053	98.00
	25.0	0.0058	0.0050	0.0026	0.0010	0.0010	0.0071	0.0010	0.0019	0.0158	0.0020	0.0070	0.0018	0.0013	0.0003	0.0040	98.00

The phosphorus impurities in the investigated construction steel bars exceeded the standard provision in eight (8) specimens including 12 mm, 16 mm and 20 mm Red; 12 mm White; 20 mm and 25 mm Blue; 8 mm and 10 mm Black as shown in figures 8, 9, 10 and 11 respectively. Although phosphorus content enhances the strength and corrosion resistance in steel, higher content makes it brittle owing to the formation of low euctoid phosphicles in the grain boundary [10]. It is worthy to state that five (5) out of the eight (8) specimens with excess phosphorus content could not achieve the desired tensile strength as per BS 449:2005 +A3:2016 provisions.

Copper and sulphur are other major elements that could influenced the mechanical properties of the steel specimens. Copper serves as a pearlite stabiliser that improves the tensile strength and corrosion resistance property of steel [10]. Sulphur is an impurity in steel that induces brittleness in steel. BS 4449:2005 [8] limits the maximum percentage of copper and sulphur in structural steel to 0.85 and 0.55 respectively. All the tested specimens meet the standard code recommendations for copper and sulphur as shown Figures 8, 9, 10 and 11.

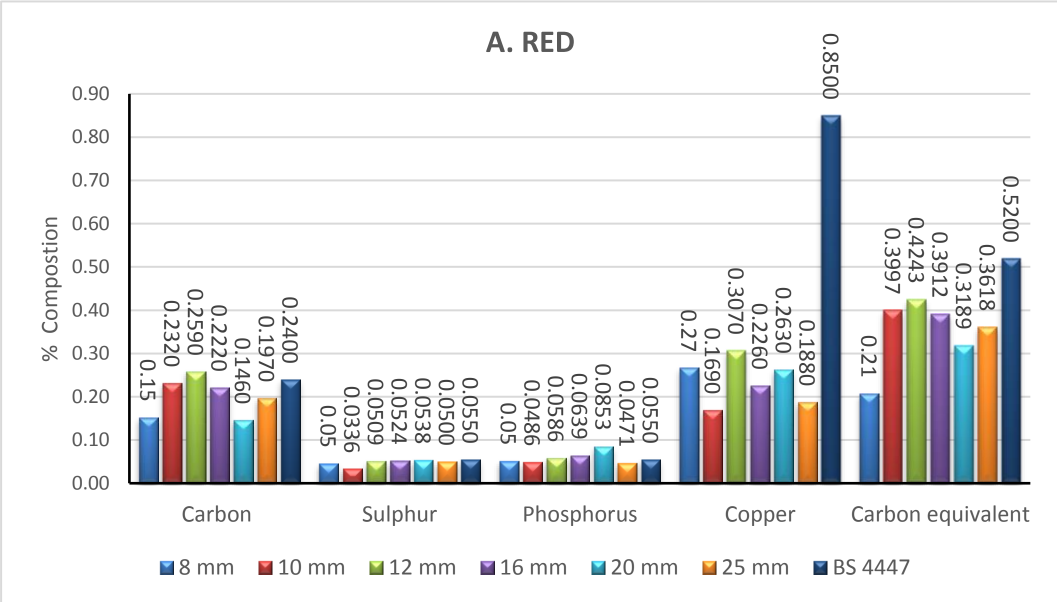

Fig. 8 - Comparison of percentage chemical composition of Red products with BS 449:2005 +A3:2016 standard provision

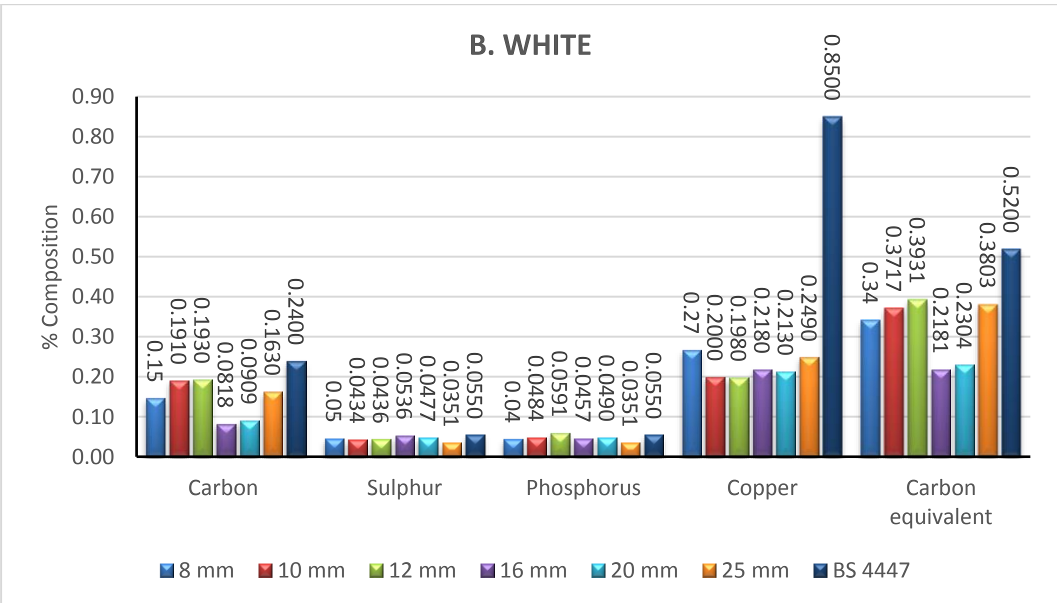

Fig. 9 - Comparison of characteristic strength of White steel samples with BS standard

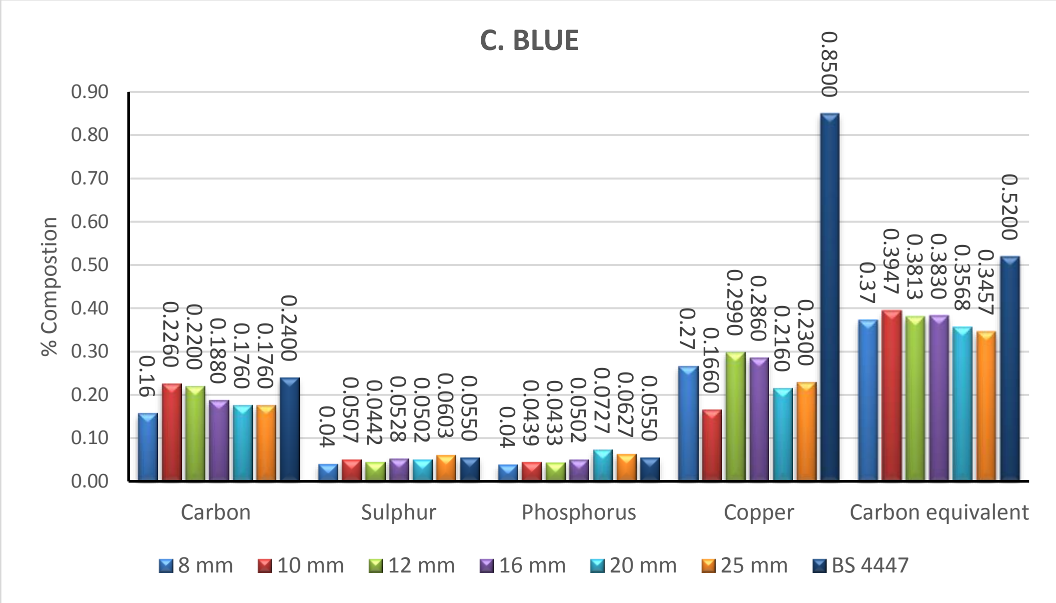

Fig. 10 - Comparison of characteristic strength of Blue steel samples with BS standard

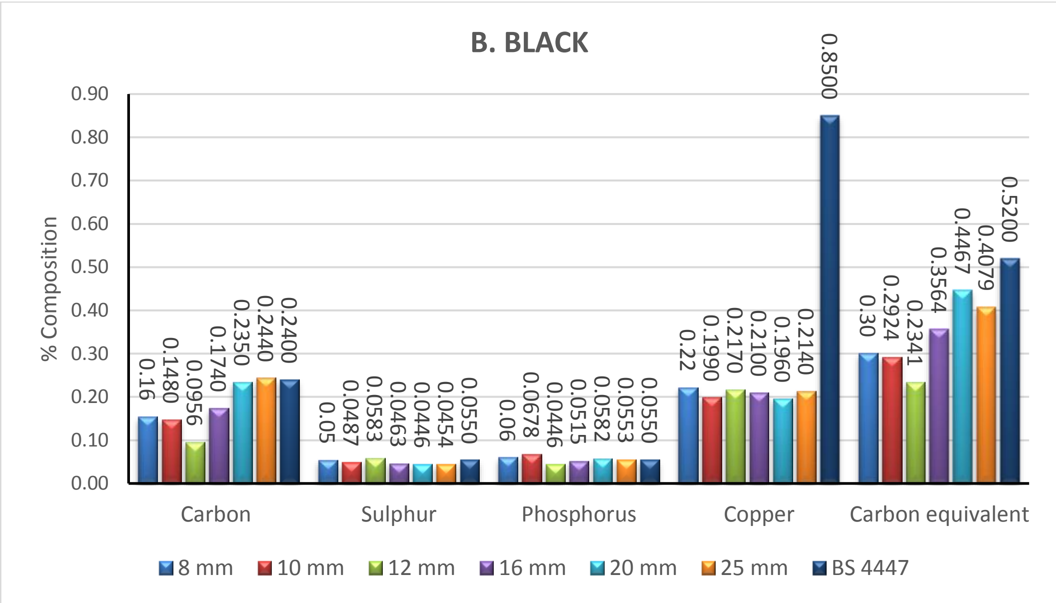

Fig. 11 - Comparison of characteristic strength of Black steel samples with BS standard

4 Conclusions

Based on the mechanical test and chemical analysis conducted on the steel reinforcements used for construction works in Nigeria, the following conclusions are drawn:

Tensile test result showed that 70.8 % of the tested samples failed the characteristic strength requirement. The Black company products showed the best performance with four out of its six nominal sizes meeting the yield and characteristic strength requirement. All the White products did not satisfy the strength criteria.

All the four brands of the reinforcing steels satisfy the ductility requirement as per BS 4449:2005.

Chemical analysis result revealed that all the samples satisfied the maximum carbon content requirement. This accounts for high ductile behaviour observed in the samples. The carbon content was however lower than the recommended 0.15 % in some of the specimens leading to low yield strength.

The phosphorus content was also found to be higher than the recommended value in eight specimens. Approximately 63% of the specimens with higher phosphorus content failed the yield and characteristic strength requirement.

Copper and sulphur content were found to be within the recommended maximum limit, although the copper content appears too low since it also influences the steel strength properties. Other alloy impurities found in trace quantities could also have affected the yield and tensile strength behaviour of the steel samples.

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