APWEN Journal of Engineering, Science and Technology

ISSN: 2714-2396, Volume 7 Issue 1

INVESTIGATION OF THE MECHANICAL AND CHEMICAL PROPERTIES OF REINFORCEMENTS FOUND IN NIGERIAN MARKETS: A CASE STUDY OF SOUTH WESTERN NIGERIA

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Received Date: 1st May 2024 Accepted Date: 15th July 2024 Published Date: 15th Sept., 2024

ABSTRACT
The frequency of building collapse in Nigeria is alarming. Reinforcement steel has been identified as one of the possible factors responsible by researchers. This study evaluated the Mechanical and Chemical composition properties of six brands of locally produced reinforcement steel (coded as ST1, ST2, ST3, ST4, ST5 and ST6) from southwestern Nigeria markets for use in reinforced concrete application. Mechanical and Physical tests were carried out using the Universal testing machine (UTM- Model C0820/C having a maximum capacity of 2000kN capacity) in the Building Research Laboratory at NLC, Ota. In contrast, the Chemical composition test was done at the material testing laboratory of Nigerian Foundries Limited (NFL) in Ogun state. Physical tests revealed up to 1.5% discrepancies when the measured diameters were compared with the Nominal diameters. Characteristic strength, however, showed that all sampled materials comply with either BS 449:2005 +A3:2016 or NIS 117. However, the chemical composition analysis showed that a few companies fell short of the recommendation of BS449, NIS 117 or ASTM A709 regarding some important elements in steel, such as C, Si, S, P and Cu. Overall, the compliance level of reinforcement produced locally within Southwestern Nigeria tested was good for reinforced concrete application.
Keywords: Reinforcements, mechanical properties, chemical properties, building-collapse, South-western Nigeria

1. INTRODUCTION
Building structure is a vital component in human lives. Buildings come in various designs, shapes, sizes, etc., based on purpose. There are various reasons why buildings are constructed, most of the time, they are purposely for shelter in the form of residential, commercial or industrial. Most of the time, the developmental growth of a given state or nation can be determined by the available building infrastructures. This made building structures an important entity for humans. Buildings are purposely designed to support certain calculated loads based on intended use safely. A building can either be structural, i.e., containing elements that can support their self-weight and other loads that will be transferred safely, or non-structural. Over the years, urbanisation has brought about the regular use of structural buildings in cities of Nigeria as found in most other parts of the world. Concrete and steel are the most common materials used for this purpose.

Concrete is a material that primarily comprises binder (cement), fine and coarse aggregates and water. It is a strong material that has been widely used worldwide for various types of construction since the advent of Ordinary Portland Cement (OPC) as far back as 1824 by Joseph Aspdin. Concrete is a flexible material that can form different kinds of desired shapes, contributing to its friendliness as a construction material. However, unlike compressive strength, concrete is poor in tensile strength, and steel material has been introduced to compensate for this property. The combination of these two materials is called reinforced concrete (RC), the second generation. Reinforced concrete is a composite material of excellence, and it is widely used because of the complementary properties of concrete and steel (Ede et al., 2015). Concrete's very good compressive strength property is efficiently combined with the high tensile strength of steel, thereby providing the most accepted material that has built the world's buildings and infrastructures. Concrete and steel provide complementary support to each other, compensating for the weaknesses in the properties of the two materials (Ede et al., 2015), thereby making it a universal construction material.

Reinforcing steels are often introduced in compression zones where the developed compressive stresses exceed the concrete strength. Steel bars can also complement the concrete strength in counteracting the shear stresses in reinforced concrete (RC) structures (Mosley et al., 2012). Steel reinforcement imparts great strength and toughness to concrete. Reinforcement also reduces creep and minimises the width of cracks as it is used as an anti-crack in some structural elements (Zhu et al., 2023). Steel is a suitable reinforcement material because its coefficient of thermal expansion (5.8 x 10-6 to 6.4 x 10-6) is nearly the same as that of concrete (5 x 10-6 to 7 x 10-6). This means there will be no relative movement between embedded bars and concrete in the reinforced concrete work due to temperature changes (Ede et al., 2015). Steel rods are indented on the surface during the rolling process to enhance bonding with concrete by mechanical interlocking. The quality of reinforcement steels used for construction works is measured in terms of their yield strength, ultimate tensile strength and percentage elongation (ductility) Ganiyu et al., (2016).

In Nigeria, the incidents of building collapse have become a general concern to the professionals of built environment both in Academia and Industry. In 2022, about 17 building collapse occurrences were recorded by the Nigerian Building and Road Research Institute (NBRRI) including the 21-storey building at Bassey Street, Ikoyi, Lagos, where not less than 45 deaths were reported with scores fear death; also, that of 2 story building at Akanbi street in Akoka, Lagos; 3 story collapse at Ibadan street, Ebute-Metta, Lagos to mention few. Previous investigations on possible causes of building collapse, according to researchers like Odusote and Adeleke (2012) and Sulymon et al. (2019), have shown that substandard materials are among the identified possible reasons for building collapse in Nigeria. Steel reinforcement is a key material in reinforced concrete. Therefore, the importance of reinforcement steel in reinforced concrete structures cannot be neglected as the proper combination of steel and concrete forms a major component that ensures a building structure is in perfect condition. Therefore, quality must be ensured in both materials (concrete and steel) so that each material can perform optimally during the service life of building structures.

Generally, there are two main products in the Nigerian steel markets: imported products and local or indigenous products. An easy way of differentiating between these two products in markets is their price. Foreign products are usually more expensive than local products. However, there are price differences even within the local products. Based on affordability, most Nigerians settle for local products for their building construction projects. It has also been observed through surveys that there are numerous local products across steel markets in the country. Therefore, this has necessitated an intensive study on all available reinforcement' products within the Nigerian market, particularly on local products that are mostly being consumed locally for building construction, such as reinforced concrete for global objectives.

In the last decade, there has been an alarming rate of building collapse cases across Nigeria. According to Sulymon et al. (2019), some of these collapses were buildings under construction, in-service buildings or completed buildings but in dilapidated condition, all of which are, unfortunately, RC structures. Building collapse is often accompanied by loss of human lives and valuable properties, and this usually has adverse effects on a nation's economy. Among the identified factors of building collapse are; the use of substandard building materials (steel and components of concrete), 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. (Sulymon et al., (2019). Emphasis is placed on reinforcement steel bars in this study because it has been observed that most reinforcement steel used in the construction industries across Nigeria is locally made, mostly produced from scraps of various kinds. This singular factor could contribute to the diminishing properties of reinforcement steel bars available in the market, which has been highlighted to be a syndicate to building collapse occurrences in the country as reported by Sulymon et al. (2019), Arum (2008), Alabi and Onyeji (2010) and Adekunle et al., (2013) among others.

Pursuant to the Nigerian Building and Road Research Institute's (NBRRI) mandate, part of which is to conduct applied integrated research and development into various aspects of the Nigerian construction Industry and build capacity in indigenous construction technology. This study was set to evaluate steel reinforcement used in building construction, particularly the ones used to produce reinforced concrete for mechanical and chemical compositional adequacies, to further ascertain the quality of rebars in our market and possibly reduce the menace of building collapse in Nigeria. Through sensitization of the populace on the quality of building materials, particularly reinforcement steel bars, the incidences of building collapse attributed to low-quality rebars could be brought to as low as minimally practicable as far as reinforcement for RC building structures is concerned. Umeonyiagu and Ikhazuagbe (2017) studied the mechanical properties of some selected reinforcing steel bars used in Nigeria to investigate conformity to BS 4449: 1997 provisions. Their study concluded that about eighty-five per cent of the samples tested fell short of the provision of BS 4449: 1997. On the other hand, Ede et al. (2015) examined the quality of steel reinforcements used for construction in Lagos state. Their study collected reinforcement steel samples from different construction project sites. The findings showed that 70% of the samples studied complied with the provisions of BS 8110: 1997 standard specifications based on mechanical strength properties. Inconsistencies in diameter size along the length of a particular steel, which brought about different characteristic strength values from the same steel, were reported by Ajagbe et al. (2023). The study of Odusote and Adeleke (2012) investigated the properties of reinforcing steel bars from collapsed building sites in Nigeria. Findings from their microstructure analysis unveiled the presence of brittle globes of 〖Fe〗_3 P and FeS. This implies that the quality of steel reinforcement used is inadequate to guarantee the ductile behaviour expected of the reinforced concrete structures and could, therefore, result in building collapse. Similarly, Ponle et al. (2014) deduced from their study on Chemical analysis of rebars produced from scraps that certain samples, such as 12mm, contain adequate carbon content with respect to standards, while 16mm was found to contain carbon content short of standard specifications. In the same vein, Salman and Djavanroodi (2018) studied the variability of chemical analysis of reinforcing bars produced in Saudi Arabia. Results showed that some products were above the upper limit, while about 3% were found to be less than the minimum specifications of ASTM A706.

From the foregoing, it is clear that it is almost inevitable to have a fixed or common composition of constituent materials in steel as a result of different manufacturers, different material sources, etc. However, there are standards and specifications for each constituent material for different steel applications, as detailed in Table 1.

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 449:2005 +A3:2016

This study is limited to the steel reinforcement available within the steel markets of south-western Nigeria. The following states were considered viz; Lagos, Ogun, Oyo, Ekiti, Ondo and Osun state. The Mechanical and chemical composition were evaluated by determining the characteristics strength and ductility properties of the reinforcing steels, determining the chemical compositions of reinforcement steels and comparing the obtained results with existing standard provisions.

2. MATERIALS AND METHOD

This section explains the materials used in this study. The sourcing and preparation approaches for the samples were also explained.

2.1. Material Collection and Sample Preparation

A reinforcing steel bars market survey was carried out within the Southwestern states of Nigeria, and six (6) of the most available products were sourced for this study. The product names are Real Steel Reinforcing Limited (coded as ST1), PSL (coded as ST2), African Foundries Limited-AFL (coded as ST3), Federated Steel-FED (coded as ST4), Tiger-TMT (coded as ST5) and ASM (coded as ST6) were purchased from within the southwestern states in Nigeria. Six commonly used bar samples were randomly selected from the market for each product representing 8 mm, 10 mm, 12 mm, 16 mm, 20 mm and 25 mm nominal sizes. During the material survey, it was gathered from reinforcement steel sellers that some companies major in the production of some particular sizes of reinforcement steel. Perhaps they produce some others on a request basis, while some do not produce some particular diameters at all. This could be why the 20mm reinforcement steel is unavailable across board. Based on availability, it can easily be concluded that 10, 12 and 16mm reinforcement steel are the most sought sizes of rebars, hence, its availability across board as shown in Table 2.

Table 2 shows the available product size for each of the sampled products. For the purpose of mechanical properties determination, three equal lengths of 1m were sized out from each available nominal size in each sampled product as shown in Figure 1. Similarly, one sample from each product was randomly selected for the purpose of chemical compositional analysis (Elemental Composition). This implies that six specimens were selected for chemical compositional analysis.

Table 2. Available Sizes of Reinforcing Steel Per Product

S/N	CODE	NOMINAL SIZE (MM)					
		8	10	12	16	20	25
1	ST1	✗	✓	✓	✓	✗	✗
2	ST2	✗	✓	✗	✓	✗	✗
3	ST3	✓	✓	✓	✓	✗	✗
4	ST4		✓	✓	✓	✗	✗
5	ST5	✗	✓	✓	✓	✗	✓
6	ST6	✓	✓	✓	✓	✗	✗

Note: ✓ Available in Market ✗ Not Available in Market

Fig. 1: Some of the Prepared Samples before Mechanical Test

Fig. 2: The UTM Machine (Location-NBRRI, NLC, Ota)

2.2. Mechanical Property Test

The yield stress, ultimate stress in tension and percentage elongation otherwise referred to as ductility are the major components for characterization of reinforcing steel in order to determine its mechanical properties. The Mechanical test was carried out at the Building Research Department Laboratory of Nigerian Building and Road Research Institute, National Laboratory

Complex, Ota, Ogun State, Nigeria. The Equipment used was Universal Testing Machine (UTM) Model C0820/C having a maximum capacity of 2000kN capacity and produced in year 2017. The prepared specimens of all sampled products were tested based on the standard provisions embedded in the UTM. The Machine is shown in Figure 2.

2.3. Chemical Composition Test

Material specimens were taken to Nigerian Foundries Limited (NFL) head office in Ifo Local Government Area of Ogun State for the chemical compositional test. The method of testing employed was the XRF Niton Gun Analyser that detects elemental compositions of test samples in percentages.

3. RESULTS AND DISCUSSION

3.1 Mechanical Property Test

The summary of the mechanical property test results on the 21 available rebar samples from the markets within the 6 states of South West is presented in Table 3. The basic Mechanical components measured are the bar diameter, yield and ultimate strength, stress ratio and percentage elongation. Each brand has been coded as ST1 – ST6 as described in section 2.1.

3.2 Bar Diameter

Figure 3 to 8 displays the variation observed in the various bar sizes from different manufacturers that was subjected to mechanical test. The Figures 3 to 8 also reveals the relationship between the Nominal bar diameter and Measure diameter where Figure 3 shows the results for company ST1, Figure 4 shows that of company ST2, Figure 5 is for ST3, Figure 6 corresponds to ST4, Figure 7 is for ST5 and Figure 8 reveals that of ST6. Generally, a cross-sectional assessment of the Measured bar diameters revealed some significant variations when compared with the Nominal market sizes. Variations inform of inadequate diameter size and over-size were observed. In Figure 3 corresponding to ST1, 10, 12 and 16mm nominal sizes were available in the Market for this company as at the time of this study. It can be seen that 3 samples (10, 12 and 16mm) were available and none measure up to standard sizes. A reduction of about 1.3mm, 0.2mm and as much as 2.9mm was observed on 8, 12 and 16mm respectively. ST2 on the other hand have an almost negligible reduction in actual nominal diameter of about 0.2 and 0.4mm respectively for the 10 and 16mm as shown in Figure 4. Figure 5 shows a trend whereby there is slight diameter reduction in the 10, 12 and 16mm whereas; the 8mm bar has a size of 8.164 corresponding to an overage of about 0.2mm. Similar to Figure 5, Figure 6 recorded an overage of 0.164 on the 8mm bar while other sizes fell short of the Nominal except the 16m size having a reduction of almost 3mm which can be considered very significant. Figure 7 and 8 corresponding to ST5 and ST6 also exhibited a similar trend as Figure 5.

Overall, it can be deduced that there are variations in the diameter of rebars. This is a very sensitive issue that should be addressed by the manufacturers of steel reinforcing bars. The implication of this could either be under- designing or over-designing of RC structure which is not desirable for a safe structural design and of course construction. It is obvious from Figure 3 - 8 that the most commonly available rebar sizes are 10, 12 and 16mm diameter sizes. Other sizes are not as available in the Markets as the mentioned sizes. This could simply be indicating that the most sought rebar sizes for most construction projects in Nigeria are 10, 12 and 16mm.

Table 3. Summary of Mechanical Strength Test Results

BRAND CODE	NOMINAL BAR SIZE (mm)	MEASURED BAR SIZE (mm)	YIELD STRESS (N/mm2)	ULTIMATE STRESS (N/mm2)	STRESS RATIO	ELONGATION (%)
ST1	8	NA	NA	NA	NA	NA
	10	8.7	587.743	769.99	1.31011	9.133
	12	11.856	511.287	724.102	1.41626	19.592
	16	13.116	433.524	604.41033	1.39437	23.998
	20	NA	NA	NA	NA	NA
	25	NA	NA	NA	NA	NA
ST2	8	NA	NA	NA	NA	NA
	10	9.865	504.624	745.586	1.5673	10.574
	12	NA	NA	NA	NA	NA
	16	15.598	560.888	666.767	1.18881	15.979
	20	NA	NA	NA	NA	NA
	25	NA	NA	NA	NA	NA
ST3	8	8.164	748.946	810.03633	1.08206	6.246
	10	9.66	459.549	744.831	1.78674	10.896
	12	11.856	529.679	755.392	1.42822	10.51
	16	15.883	608.372	743.483	1.22717	13.541
	20	NA	NA	NA	NA	NA
	25	NA	NA	NA	NA	NA
ST4	8	8.164	743.296	810.12133	1.08992	6.824
	10	9.301	544.154	719.587	0.9265	13.533
	12	11.813	591.685	713.73833	1.20694	10.747
	16	13.756	518.404	607.936	1.17271	12.755
	20	NA	NA	NA	NA	NA
	25	NA	NA	NA	NA	NA
ST5	8	NA	NA	NA	NA	NA
	10	10.068	674.799	773.615	1.4648	9.559
	12	12.236	695.252	789.507	1.3558	10.744
	16	15.724	588.085	645.15333	1.5631	13.054
	20	NA	NA	NA	NA	NA
	25	24.662	599.926	708.861	1.18171	18.955
ST6	8	8.164	743.296	810.12133	1.08992	6.824
	10	9.301	546.797	715.814	1.30936	13.724
	12	11.856	461.953	583.49267	1.26345	16.666
	16	15.844	513.311	718.87	1.40094	15.364
	20	NA	NA	NA	NA	NA
	25	NA	NA	NA	NA	NA

Note: NA means Not Available at the time of sourcing materials from markets

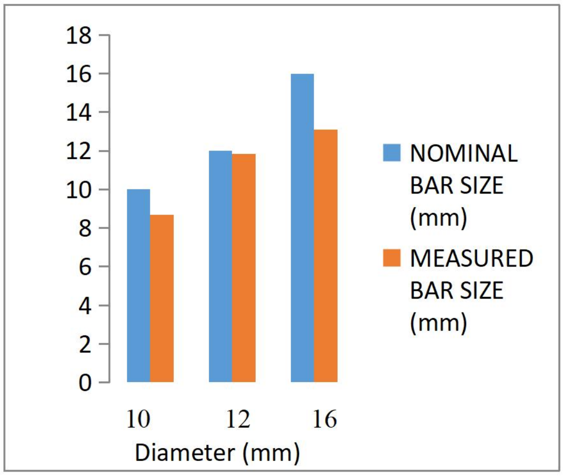

Fig. 3: Variation in Bar Diameter for ST1

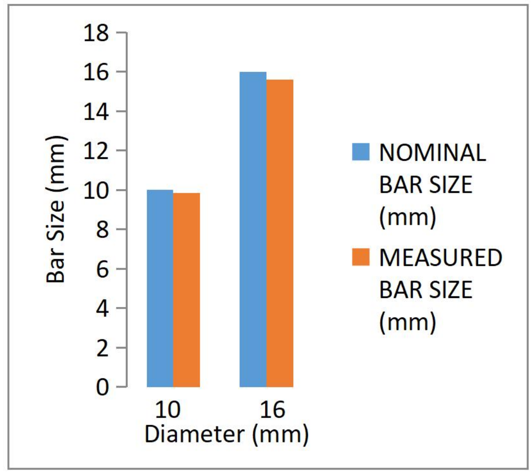

Fig. 4: Variation in Bar Diameter for ST2

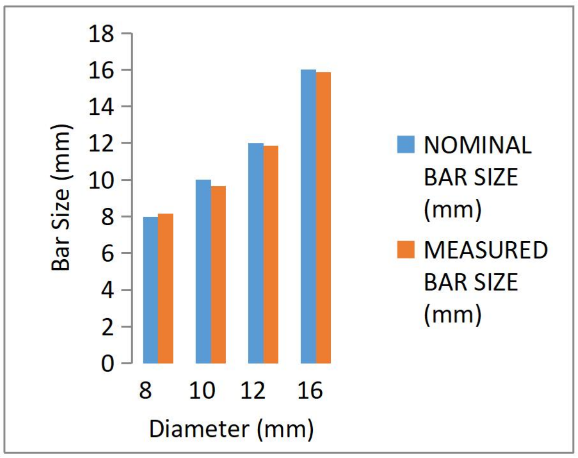

Fig. 5: Variation in Bar Diameter for ST3

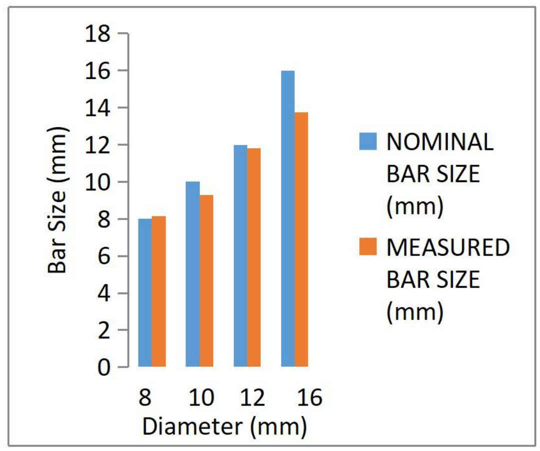

Fig. 6: Variation in Bar Diameter for ST4

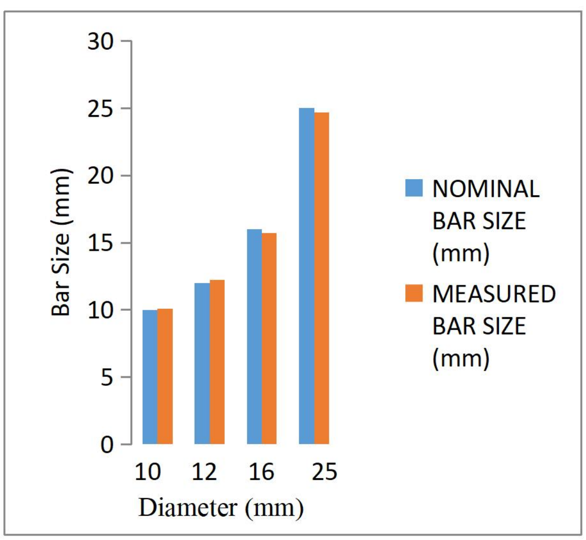

Fig. 7: Variation in Bar Diameter for ST5

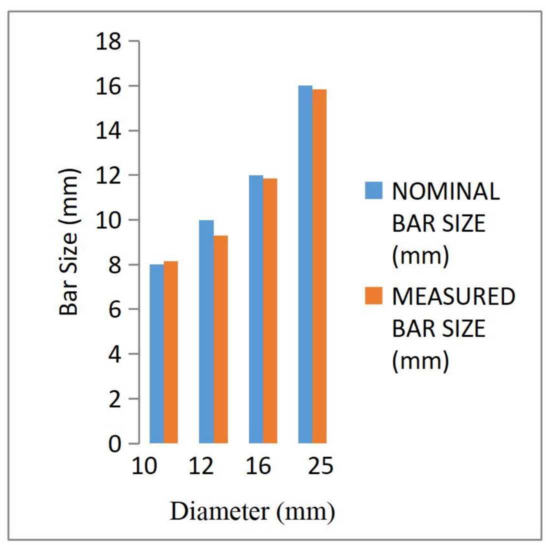

Fig. 8: Variation in Bar Diameter for ST6

3.3 Characteristics Strength

Figure 9 to 13 shows the comparison of the Characteristics strengths of reinforcement bars across the six companies sampled on a size-by-size basis with BS 449:2005 +A3:2016 and NIS 117. It can be seen from Figure 9 that only three companies (ST3, ST4 and ST6) produced 8mm bar size during the time of this study and all were found to have complied with the Standard provisions of BS 4449:2005 +A3:2016 and NIS 117 in terms of strength having characteristics strength above the recommended values of 500 and 420N/mm^2 respectively. All available 8mm samples have similar yield tensile strength in the range of 743 and 748N/mm^2. Unlike the 8mm bars, the 10mm bars were found to be available in all the six companies as shown in Figure 8. All test specimens in this regard fell within the Specification of BS 4449:2005 +A3:2016 and NIS 117 with ST5 recording the highest yield strength value of 674N/mm^2 and ST3 recording 459N/mm^2 as the lowest. Figure 11 displayed the Characteristics strength values of 12mm sizes of reinforcement where it can be seen that all available samples complied with both standards except that ST6 sample in this regard did not meet the Specification of BS 449:2005 +A3:2016 by having a strength of 461N/mm^2 but it is in compliance with NIS 117 standard provision. Similar to the 10mm samples in Figure 10, Figure 12 displaying the characteristics strength of the 16mm samples shows that all the companies as at the time of this study have 16mm bars in the Market and strength values across all the samples showed that none is not in compliance with the Standard provisions of both BS 449:2005 +A3:2016 and NIS 117. As seen in Figure 13, only one company (ST5) has the 25mm diameter size available in the Market during the course of this study. The recorded characteristics strength of the 25mm showed that it is also in compliance with the provisions of the Standards being considered in this study. Overall, all reinforcement specimens from the six manufacturers sampled in this study were found to be in compliance with either BS 449:2005 +A3:2016 or NIS 117 and therefore suitable for reinforced concrete applications.

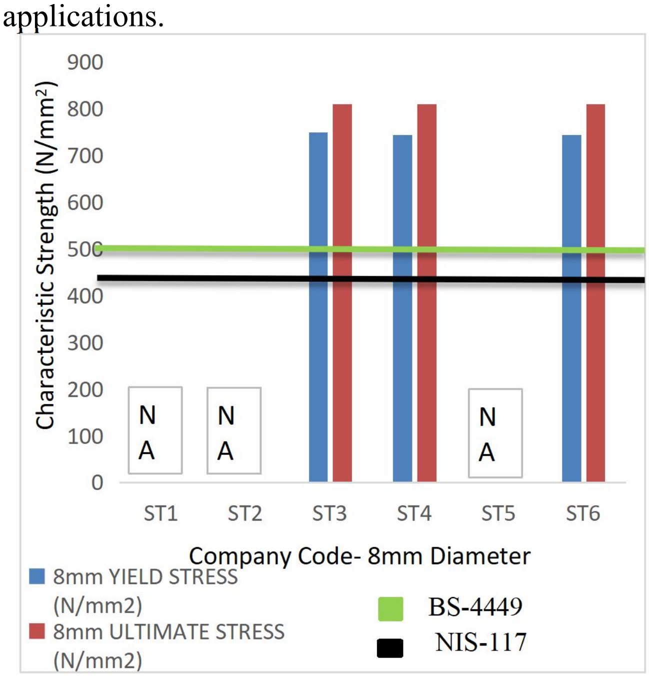

Fig. 9: Characteristics Strength Comparison of 8mm across companies with BS449 and NIS117

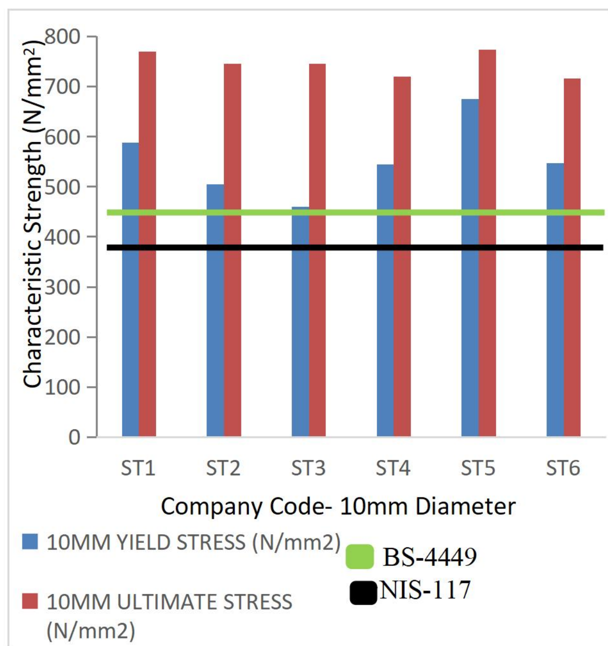

Fig. 10: Characteristics Strength Comparison of 10mm across companies with BS449 and

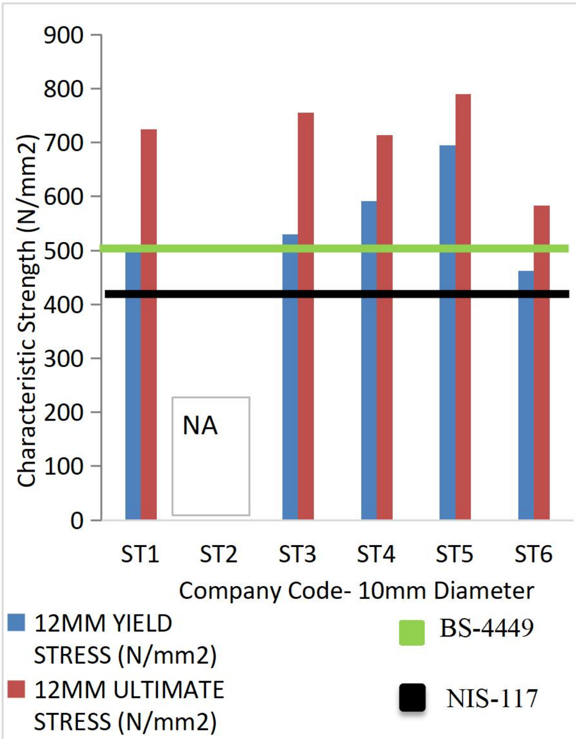

Fig. 11: Characteristics Strength Comparison of 12mm across companies

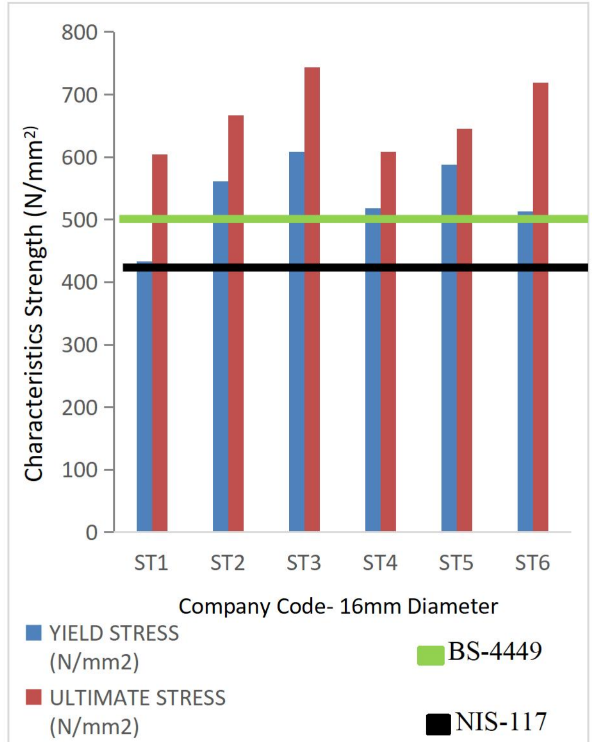

Fig. 12: Characteristics Strength Comparison of 16mm across companies with BS449 and

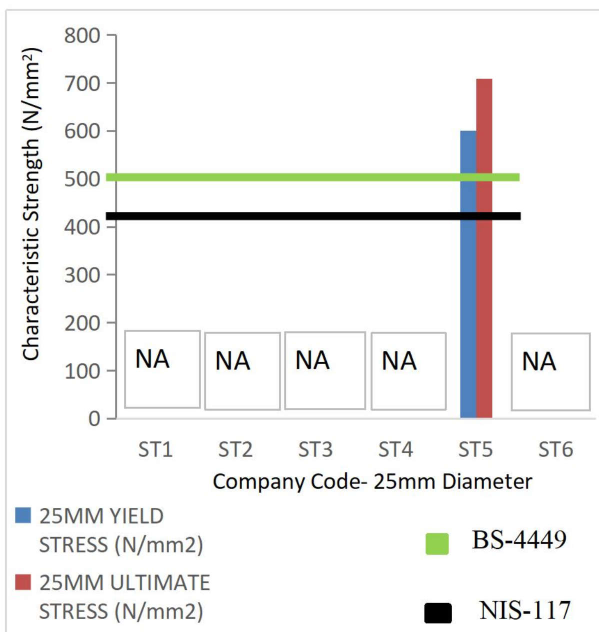

Fig. 13: Characteristics Strength Comparison of 25mm across companies with BS449 and NIS117

Note: NA means Not Available at the time of sourcing materials from markets

3.4 Percentage Elongation

Elongation is a measure of ductility which provides the confidence that metals can be formed without cracking or fracturing. Ductility can as well be described as the capability of steel to be stretched out without becoming more brittle or weaker in the process. According to BS 4449:2005 + A3:2016, the recommended minimum percentage elongation is 7.5 as the total elongation at maximum force (A_{gt} - %). Comparison of the ductility parameters in terms of average percentage elongation of all the samples as shown in Figure 14 depicts that regardless of the companies, all sizes above 8mm are in tandem with the recommended provision of the code with respect to grade B500c reinforcement. On the other hand, all available 8mm samples belonging to ST3, ST4 and ST6 and having 6.246%, 6.824% and 6.824% respectively also comply with 5.0% specified for grade B500b reinforcement according to BS 4449:2005 + A3:2016. Therefore, all sample materials size regardless of the company can be said to be ductile.

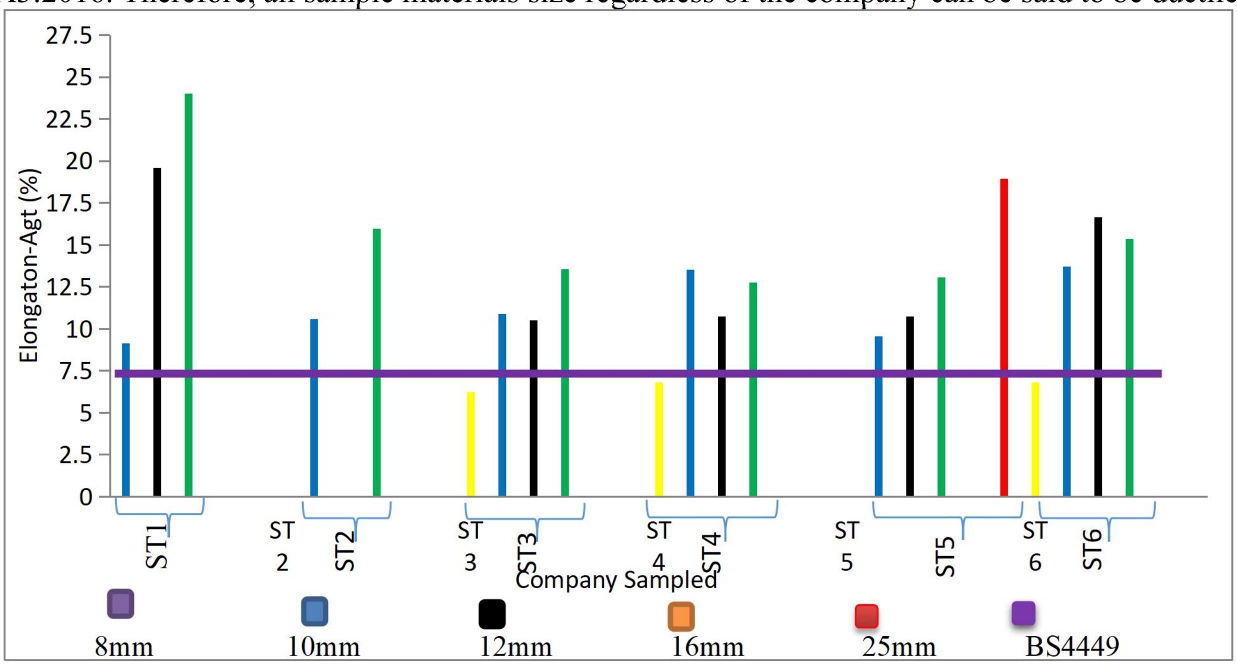

Fig. 14: Comparison of Percentage Elongation with BS 449:2005 +A3:2016 Standard Provision

3.5 Tensile/Yield Strength Ratio

Yield strength is the maximum stress a material can endure beyond which it permanently deforms, i.e. not being able to return to its original dimensions. Tensile strength, on the other hand, is a measure of the maximum tensile stress beyond which a material fails or breaks. They are both critical mechanical properties of the material that measure its resistance to failure, either by deformation or fracture. Despite the similarities, yield and tensile strength are two very different parameters. BS 4449:2005 + A3:2016 specifies a limit of 1.15 or less than 1.35 for stress ratio for grade B500c, 1.08 for grade B500b and 1.05 for grade B500a reinforcement. Figure 15 displays the stress ratio illustration of the tested samples where it can be deduced that about 52.38% of all the tested samples are in compliance the stress ratio value of grade B500c reinforcement. Reinforcement sizes captured under the 52.38% included 10mm of ST1, ST2, ST3, ST5 and ST6 leaving out ST5; 12mm of ST1, ST3 and ST5 leaving out ST4 and ST6; 16mm of ST1, ST5 and ST6 leaving out ST2, ST3 and ST4. This implied that samples tested for ST1 are all in compliance with grade B500c of BS 4449:2005 + A3:2016. Others companies are either complying with grade B500c or B500b of BS 4449:2005 + A3:2016. However, the 10mm sample of ST4 is neither in agreement with B500c, B500b or even B500a. this has not been found to have effect on the stress value as the ultimate and yield stress value were in compliance with the minimum requirements of both BS 4449:2005 + A3:2016 and NIS 117.

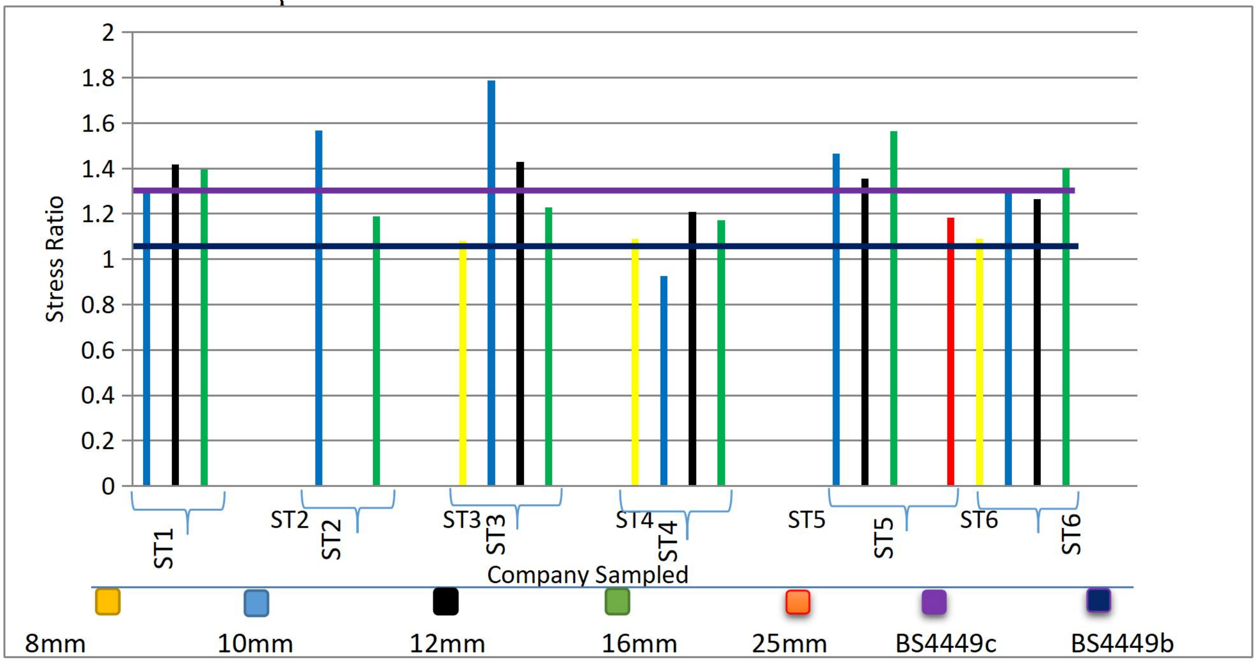

Fig. 15: Comparison of Stress Ratio with BS 449:2005 +A3:2016 Standard Provision

3.6 Elemental composition

Table 4 displays the result of chemical compositions of different diameters viz-a viz manufacturers of reinforcement steel sampled from products of six different manufacturers coded as ST1, ST2, ST3, ST4, ST5 and ST6, respectively. According to Table 4, eleven significant elements were identified based on XRay Fluoresecence (XRF) using Niton Gun Analyzer, viz; Carbon (C), Silicon (Si), Manganese (Mn), Sulphur (S), Phosphorus (P), Cobalt (Co), Cupper (Cu), Chromium (Cr), Nickel (Ni), Molybdenum (Mo), Tin (Sn) and other light element compounds (LEC).

Table 4. Percentage Elemental Composition of Six Brands of Steel Bars from South-Western Markets

COMPANY	Percentage Elemental Composition											
CODE	C	Si	Mn	S	P	Co	Cu	Cr	Ni	Mo	Sn	LEC
ST1	0.22	0.20	0.63	0.05	0.06	0.01	0.22	0.19	0.09	0.01	0.02	0.75
ST2	0.30	0.51	0.52	0.04	0.03	0.21	0.22	0.27	0.10	0.01	0.03	0.75
ST3	0.30	0.31	0.66	0.06	0.04	0.27	0.21	0.25	ND	0.01	0.02	0.75
ST4	0.21	0.52	0.53	ND	ND	ND	0.22	0.17	0.10	0.01	0.03	0.75
ST5	0.31	0.37	0.74	0.04	0.03	ND	0.19	0.26	ND	0.01	0.02	0.75
ST6	0.30	0.33	0.55	0.03	0.03	ND	0.18	0.23	ND	0.01	0.02	0.75

The major elements Carbon, Silicon, Manganese, Sulphur, Phosphorus, and Copper - (C, Cu, P Mn,Si, & Swere evaluated by comparison with the provisions of BS 4449:2005+A2:2005 and NIS 117 as shown in Figure 14. The following are deduced from the figure.

3.6.1 Carbon content (C)

According to BS 4449:2005+A2:2005, Carbon is the principal determinant of strength and hardness of steel. The maximum Carbon content recommended by BS 4449 is 0.27% and two out of six manufacturers (ST1 and ST4) representing 33.33% were found to be in compliance with the recommendation of BS 4449:2005+A2:2005 and NIS 117 of 0.27 and 0.24% respectively. Although, the values 0.30 and 0.31 obtained from other manufacturers were also found to be in compliance with the provision of ASTM A706. However, previous related studies such as Oyelade et al., (2013) and Ocheri and Ibe (2017) had reported higher content of Carbon. High carbon content in steel reduces its ductility, weldability and toughness, which would not be desirable in steel for use in reinforced concrete applications.

3.6.2 Silicon content (Si)

Silicon acts as a deoxidizer in structural steel. It also improves strength, elasticity and acid resistance, which results in larger grain size and greater magnetic permeability. Results from Figure 14 show that Silicon contents across the board were all in compliance with ASTM A706, as all values are not in excess of 0.55%.

3.6.3 Manganese content (Mn)

Results from Figure 14 showed that Manganese content ranged between 0.52 and 0.74%. ASTM A706 recommended a maximum Manganese content of 1.56%. It therefore means that all the Manufacturers complied with the provision of ASTM A706. Manganese has strong, ductility, and hardenability effects on steel. It also counteracts the presence of Iron-Sulphide and reduces oxides.

3.6.4 Sulphur content (S)

Sulphur content in steel is undesirable; therefore, efforts are usually made to reduce its presence to as low as minimally practicable or eliminated completely during the process of steel production. It reduces notch impact resistance, weld-ability, surface quality, and ductility. From Figure 14, it can be observed that Sulphur was not detected in the sample from ST4, while ST3 registered Sulphur content slightly higher than the recommendation of BS 4449:2005+A2:2005 of 0.055%. However, other samples of ST1, ST2, ST5 and ST6 having 0.05, 0.04, 0.04 and 0.03% respectively were found to have complied with the Standard.

3.6.5 Phosphorous content (P)

According to Ajagbe et al. (2018), The presence of phosphorus in steel is deleterious as it reduces toughness due to increased embrittlement. 0.055% is the recommended maximum Phosphorous content by BS 4449:2005+A2:2005 and NIS 117. As shown in Figure 14, all reinforcement samples exhibited phosphorous content below the standard value except ST1, which had 0.06%, representing about a 20% increment, while ST4 had no recorded phosphorous content.

3.6.6 Copper content (Cu)

Copper is an essential constituent during steel making. It is added to give precipitation-hardening properties and increase corrosion resistance. It is often time found as residual agent in steels. Figure 14 shows that the Maximum Copper content in steel is pegged at 0.25% and 0.85% based on NIS 117 and BS 4449:2005+A2:2005 respectively and all tested specimens were found to be in compliance with standard specification.

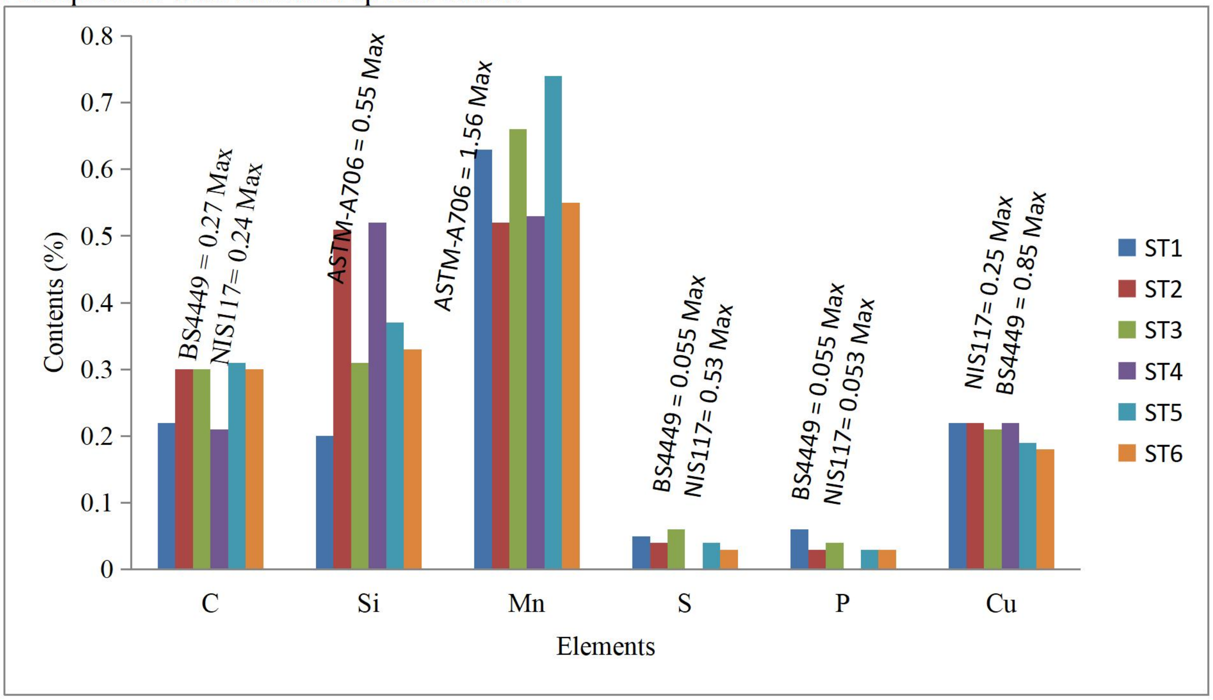

Figure 14. Elemental Comparison with BS4449:2005 +A3:2016, NIS117 and ASTM A-706

4. CONCLUSION

Six different brands of reinforcement, meaning six different manufacturers of steel reinforcement from southwestern Nigeria, were investigated in this study. All available steel reinforcement sizes in 8, 10, 12, 16 and 25mm were sampled across the six companies. Mechanical and Chemical composition test was carried out and from the study, the following conclusions were drawn;

i. All reinforcement specimens from the six manufacturers sampled in this study were found to have exhibited characteristics strength and ductility properties in compliance with either BS 449:2005 +A3:2016 or NIS 117 and therefore suitable for reinforced concrete applications. However, significant variations not measuring up to standard values were recorded on the diameters of some sample materials.

ii. Chemical elemental analysis revealed that not all manufacturers complied with standard specification as regards the major elements of concern, One out of the six Manufacturers (ST1) have Phosphorous which is a deleterious element in steel slightly in excess of the standard specification.

iii. On comparison with standard provisions, the majority, representing about 90% of the sampled steel reinforcement, are good for reinforced concrete applications based on BS 449:2005 +A3:2016, NIS 117 and ASTM A705 that were considered for the evaluation of these materials in this study.

ACKNOWLEDGEMENT
The authors appreciated the Director General and Chief Executive Officer of Nigerian Building and Road Research Institute for the financial support given for the actualization of this study.

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