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Mechanical assessment of steel rebar types milled from scrap metals and billets as used in Nigerian construction industries

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Abstract

This study investigated the mechanical properties of steel reinforcement bars from five local Nigerian steel industries—Prism Steel Mills, Ikirun (PR), Dust Steel Mills Ilorin (DT), Euro Therm Steel Mills Ife (ET), Top Steel Nigeria Ltd Ikorodu, (TOP) and Tiger TMT Steel Mills Ogijo (TMT) and two foreign brands, Star Steel Rebars from the UAE (ST) and PSL Steel Rebars from India (PSL), where four of the local companies (Prism, Dust, Euro Therm, and Tiger TMT) produced their rebars using recycled scrap metals, Top Steel (TOP) and the two (2) foreign brands (ST and PSL) used billets as raw materials. Tests were carried out following BS 4449 and ASTM A706M standards to assess hardness and tensile strength (Yield Strength (YS), ultimate tensile strength (UTS), and elongation) at ambient conditions, using the Mechanical Workshop of the National Centre for Agricultural Mechanization (NCAM) in Kwara State for tensile tests and Finlab Nigeria Ltd in Lagos for Vickers hardness testing, with results showing that imported rebars had yield strength between 432.5–495.6 N/mm^2, ultimate tensile strength between 610.8–622.4 N/mm^2, and elongation between 13.9–14.5%, while locally produced rebars showed yield strength between 345.8–497.8 N/mm^2, ultimate tensile strength between 575.3–623.3 N/mm^2, and elongation between 12.9–15.2%, and all rebars met the minimum required stress ratios of 1.08 (BS 4449) and 1.15 (ASTM A706M), with Vickers hardness values ranging from 352HV to 526HV for all samples except Prism Steel, which recorded a value of 662HV—slightly above the maximum limit of 650HV—demonstrating that although all tested rebars met Nigerian standards, regular testing is necessary, especially for scrap-based rebars, to ensure quality, consistency, and safe use in construction projects across the country.

Keywords: Steel Rebars; Scrap Metals; Yield Strength (YS); Ultimate Tensile Strength (UTS); Percentage Elongation

1. Introduction

A structure with sound analysis and design could still fail if the quality of the materials used for the construction is substandard or unknown [1]. The rising cost of construction materials has significantly increased overall construction expenses [2]. The two main materials used for reinforced concrete structures are concrete and steel rebars. The influence of heat on concrete specimens was characterized by four distinct stages namely, the incipient, growth, burning and decay [3]. However, its high cost and heat of hydration have led to research on alternative materials for partial replacement in concrete [4]. The workability of the concrete is affected by the replacement of coarse aggregate with tyre fibre [5]. As the demand for concrete increases, the demand for cement also increases. Thus, there is a linear relationship between the demand for concrete and volume of cement needed [6]. The steel manufacturing industries have been identified as one of the most important sectors that dictate the level of economic development of any nation, because steel is very useful virtually in all sectors of economy such as machine building and factory infrastructures [3]. Therefore, a special attention should be directed to steel manufacturing industries so that they can meet up with the global challenges in the steel industry in the area of nano-steel material development [4]. Steel is the most recycled

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material on the planet, more than all other materials combined. Like copper, the amazing metallurgical properties of steel allow it to be recycled continually with no degradation in performance from one product to another. Steel is the engine that drives the recycling of many consumer goods. Estimates are that 84 percent of the iron and steel used in foundries is recycled scrap. Recycling steel requires 56 percent less energy than producing steel from iron ore, and reduces CO2 emissions by up to 58 percent. Recycling also reduces the need for mining virgin ore [5]. In Denmark waste materials such as scrap iron and slag, and materials such as pig iron, burned chalk, anthracite and ferro compounds are used to produce steel. About 880 kg of scrap iron, 140 kg of pig iron, 20 kg of ferro compounds and 40 kg of burned chalk are used to produce 1ton of reinforcement bars. Fundia Bygg Ltd., Mo in the northern part of Norway produces billets and reinforcement bars from scrap iron. About 60% of the scrap iron comes from Norway; the rest is imported. Swedish production of reinforcement bars is entirely based on scrap iron. The main steps for reinforcement production are scrap preheating, steel production, casting of billets and rolling to the finished products [6].

Metal recycling is significantly developed in Africa. In Nigeria a lot of objects or materials are recycled, including metals, in order to produce convenience goods [7]. Steel rods are iron that has most of the impurities removed and they are used mainly for construction projects (i.e. buildings, bridges, hydraulic structures, etc.), automobile, furniture, and manufacturing and in fabricating industries [8]. Steel exhibits a wide range of mechanical characteristics of which the strength factor is the dominant property. Engineering strength is however, evaluated in terms of yield strength σy, ultimate tensile strength (UTS), modulus of elasticity (E), percentage elongation and impact strength. Thus, any increase in the strength characteristics of steel will enhance the reliability and durability of the structure/machine in which it is used [9]. In common engineering applications mild steel, 0.1-0.3%C are used in preference to different grades of plain carbon steels. The bars, mostly produced by hot rolling, constitute the bulk (90% by weight) of all structural steel profiles commonly employed in construction and allied engineering works [10]. The production of quality high-yield reinforcing steel bars continues to receive attention from researchers across the globe due to its importance and contribution to a country GDP. In most of the developing countries, particularly Nigeria, empirical studies have shown that bars produced through conventional rolling requires appropriate modification of its chemical composition in order to obtain the desired mechanical properties such as strength [11]. Strength, ductility and corrosion resistant properties of rebars are important from design considerations. From construction point of view, bendability and weld ability of rebar are two important characteristics. The required ductility of rebars could be guaranteed against all type of loadings, that is, monotonic, repetitive and reversed loading by elongation [12]. In examining the reinforcing steel according to the bar diameter, no remarkable difference was found from the yield and ultimate strength point of view; that is, it is not stated that if the bar diameter increases, whether yield strength increases or not [13]. However, if the reinforcing steel bar diameter increases, the amount of elongation of reinforcing steel decreases [14]. Therefore, there is inference that the reinforcing steel having small diameter makes a positive contribution to the ductility of structure [13]. One important parameter in assessing the carrying capacity of reinforced concrete (RC) structures is steel strength. While several factors affect the hardness of the metal, the quality differs within the same metal material [17]. Structural steel products are manufactured to conform to near specification given in the standards [18, 41 and 42]. The previously used for weld able structural steels [19] has been replaced by a series of Enormous specifications for technical delivery requirements, dimensions and tolerance. Though lower carbon content reduces the strength of steel, higher value makes steel brittle and unweldable [5, 20]. Much lower carbon content of less than 0.1% will reduce strength, while higher carbon content of 0.3% and above makes the steel bars unweldable and brittle [20]. Similar to phosphorous, sulphur indicates the presence of impurity in steel which increases impurity. The presence of higher sulphur content makes the bar brittle during twisting, as higher sulphur content brings the hot shot problems during rolling [21]. Although no specific limiting values were found for chromium content in steel rebars, extensive literature has shown that the presence of the element influences the weldability and corrosion resistance of steel bars [20]. Oftentimes, chromium is present as an impurity from the scraps and influences carbon equivalent [22]. Tempcore rebar is produced through a special quench and self-temper mill process resulting in a composite which consists of a hardened outside layer and unhardened core [23]. Tempcore rebars are characterized by high mechanical properties, excellent weldability, ductility and bendability [24]. The mechanical properties of Tempcore rebar have been the subject of several studies [25, 26]. In particular, different studied on the impact toughness, the transition temperature of approximately 500C [25], the fatigue behaviour [27], the weldability for seismic application [28], and the behaviour at elevated temperature [29, 30, 31]. From available literature, different investigation as being done on the tensile and chemical analysis of selected steel bars produced in Nigeria with samples collected from the Osogbo Steel Rolling Company (OSRC), Osogbo [32], quality verification of made in Nigeria steel bars [33], comparative assessment of the chemical and mechanical properties of locally produced reinforcing steel bars for structural purposes from four indigenous steel industries that use scraps as their major raw materials [34], the mechanical properties of 12mm steel rod from some parts of Nigeria [35]. An investigation conducted to evaluate the level of conformity of reinforced steel rods used for structural purpose in Nigeria with relevant to local and international standards but the sample of steel products was limited to three indigenous steel industries and imported steel of unknown source [36]. Generally, it can be said that there is inadequate information on the actual behaviour of most reinforcing steel bars produced by Nigerian

Steel Industries the steel bars are used in structural concrete for the construction of all types of buildings, bridges, hydraulic structures, etc., and are classified as mild steel in design specifications. This may be one of the reasons for high records of structural failures in Nigeria [37]. The tensile test experiment is being monitored by Nigeria Standards Organization (SON) with the establishment of Nigeria Industrial Standard (NIS) on steel production that is basically measured in term of chemical composition and tensile strength analyses. Carbon is the cheapest and one of the most effective alloying elements for hardening iron. The higher the carbon content the greater the hardenability, the strength, hardness and wear resistance of the steel. However, ductility, weldability and toughness are reduced with increasing carbon content [40].

All the previous researchers advised that the mechanical properties of Nigerian made steel rebar need to be assessed from time to time before it is used for construction purposes to avoid the problem that may arise due to inconsistency. The focus of this study is to look more in the area of tensile and Hardness behaviour of the made in Nigeria steel bars from re-cycled metals and compared such with the imported steel rebars used in the Nigerian Construction Industry before ascertain the level of conformity of the tested parameters with the related standards.

2. Materials and methodology

Steel rebar samples of 12 mm and 16 mm diameter were collected from all the seven steel industries and cut into two different sizes, 360 mm for tensile test analysis as shown in figure 1 below, and 20 mm for hardness analysis as shown in figure 2 below. The tensile tests were carried out on all the steel samples from the seven different steel manufacturers using Universal Testing Machine (UTM) at the Mechanical Workshop of the National Centre for Agricultural Mechanization, Idofia Kwara State. Each of the steel samples of diameter 12 mm and 16 mm and length 360 mm were machined into tensile specimens for tensile tests. Then each specimen was subjected to tension in accordance with ASTM A706 and BS4449:1997 provisions, and after fracture, the properties investigated include yield strength (YS), Ultimate Tensile Strength (UTS), Stress Ratio (SR) and percentage elongation. All these are critical to determining the ductility, bendability and plasticity of the steel rebars types.

Bulk hardness testing (HV) was carried out on the steel samples of sizes 20 mm from different steel manufacturers in Vickers hardness tester of Model MV1-PC and Serial number 07/2012 - 132 in the Vickers hardness testing machine at Finlab Nig. Limited, Lagos Nigeria, to examine the hardness value throughout the locations from centre to the edge of the rebar samples. During testing, an applied load of 30 kgf was used and several indentations were made to determine the average HV. The diagonals of the resulting indentation are measured, and the hardness number was calculated by dividing the load by the surface area of indentation as stated in equation 1 below. The Vickers hardness value should be between the ranges 150HV to 650HV. As specified by [18]

$$HV = 2\,P\sin\left(\frac{\frac{ø}{2}}{D^2}\right) = 1.8544P/D^2 \qquad \text{.......................... equation 1}$$

Where P is the applied load in Kg, D is the mean diagonal of the indentation in mm, and ø is the angle between opposite faces of the indenter (1360).

Figure 1 360 mm cut sizes of steel bars for tensile test analysis

Figure 2 20 mm cut sizes of steel bars for hardness analysis

3. Results and discussion

The results of the tensile strength tests properties for the locally acquired steel bars and foreign steel bar for 16mm and 12mm steel bars are presented below in Table 1 and Table 2 respectively.

Table 1 Tensile strength properties test results for 16mm

Test No	Specimen 16 mm	Yield Stress (N/mm²)	UTS (N/mm²)	Stress Ratio	Breaking Stress (N/mm²)	Force @ Break (KN)	Elong. @ Peak (mm)	Elong. @ Break (mm)	Youngs Modulus (N/mm²)
1	EURO (IFE)	350.7	572.2	1.63	479.4	30.5	10.55	14.1	4404.0
2	DUST(ILORIN)	347.6	575.3	1.66	472.5	28.0	10.23	13.2	4535.5
3	PRISM(IKIRUN)	345.8	580.5	1.68	466.9	29.7	9.61	12.9	4546.03
4	TOP (Lagos)	428.5	620.5	1.45	485.3	32.0	9.56	13.8	4945.5
5	TIGER TMT (Ogun)	415.0	598.8	1.44	551.2	21.3	9.06	14.6	4466.04
6	STAR(UAE)	432.5	622.4	1.43	481.0	29.0	9.32	13.2	5823.5
7	PSL (India)	429.9	619.2	1.44	477.2	30.4	9.72	13.9	4831.31
	BS4449(2001)	410	550	1.08					
	ASTM A706M	420	550	1.15				14%	

Table 2 Tensile strength properties test results for 12 mm

Test No	Specimen 12 mm	Yield Stress (N/mm^2)	UTS (N/mm^2)	Stress Ratio	Breaking Stress (N/mm^2)	Force @ Break (KN)	Elong. @ Peak (mm)	Elong. @ Break (mm)	Youngs Modulus (N/mm^2)
1	EURO	358.6	596.7	1.66	484.5	13.7	5.02	7.5	6021.8
2	DUST	353.5	585.2	1.67	478.7	9.3	5.4	7.8	5652.5
3	PRISM	350.9	581.7	1.66	457.9	9.0	5.6	7.8	5550.1
4	TOP	491.1	621.2	1.26	481.3	11.2	5.7	7.4	5765.5
5	TIGER	497.8	623.3	1.25	492.5	10.6	5.0	10.1	5657.1
6	STAR	495.6	610.8	1.23	483.2	13.0	5.8	7.2	5985.3
7	PSL	493.7	620.1	1.26	401.6	9.7	5.9	6.6	5154.7
	BS4449	410	550	1.08					
	ASTM A706M	420	550-620	1.15					

From the table above EURO THERM steel rebars showed that the yield strength (YS) for 16mm steel bar was 350.7 N/mm2 and that of 12mm was 358.6 N/mm^2, the ultimate tensile strength (UTS) for 16mm was 572.2 and 12mm was 596.7 N/mm^2, the stress ratio (SR) ranged from 1.63 to 1.66 for 16mm and 12mm respectively, and the percentage elongation ranged from 14.3% to 16.7% for16mm and 12mm respectively.

For DUST steel rebars, the tensile strength results were as follows: yield strength between 347.6 and 353.5 N/mm^2 for16mm and 12mm respectively, ultimate tensile strength between 575.3 and 585.2 N/mm^2 for16mm and 12mm respectively, stress ratio between 1.66 and 1.67 for16mm and 12mm respectively, and percentage elongation between 14.3% and 15.7% for16mm and 12mm respectively.

PRISM steel rebars showed yield strength values ranging from 345.8 to 350.9 N/mm^2 for16mm and 12mm respectively, ultimate tensile strength values from 580.5 to 581.7 N/mm^2 for16mm and 12mm respectively, stress ratios from 1.66 to 1.68 for16mm and 12mm respectively, and percentage elongation from 12.0% to 15.1% for16mm and 12mm respectively.

For TOP steel rebars, the yield strength was between 620.5 and 621.2 N/mm^2 for16mm and 12mm respectively, ultimate tensile strength between 575.3 and 585.2 N/mm^2 for16mm and 12mm respectively, stress ratio between 1.66 and 1.67 for16mm and 12mm respectively, and percentage elongation between 14.3% and 14.7% for16mm and 12mm respectively.

TIGER TMT steel rebars demonstrated a yield strength range of 415.0 to 497.8 N/mm^2 for16mm and 12mm respectively, ultimate tensile strength from 598.8 to 623.3 N/mm^2 for16mm and 12mm respectively, stress ratio from 1.25 to 1.44 for16mm and 12mm respectively, and percentage elongation from 14.3% to 16.2% for 16 mm and 12mm respectively.

3.1. For the imported steel rebars

- STAR steel rebars had yield strength values ranging from 432.0 to 495.6 N/mm^2 for16mm and 12 mm respectively, ultimate tensile strength values from 610.8 to 619.2 N/mm^2 for 16 mm and 12mm respectively, stress ratios from 1.23 to 1.44 for 16 mm and 12 mm respectively, and percentage elongation between 14.4% and 15.2% for 16 mm and 12 mm respectively.
- PSL steel rebars showed yield strength values from 429.9 to 493.7 N/mm^2 for16 mm and 12 mm respectively, ultimate tensile strength values from 619.2 to 620.1 N/mm^2 for16mm and 12 mm respectively, stress ratios from 1.26 to 1.44 for16mm and 12mm respectively, and percentage elongation between 14.4% and 14.9% for16mm and 12mm respectively.

From these results, it can be concluded that all seven types of steel rebars, both local and imported, met the minimum required stress ratio values of 1.08 (as specified by BS 4449:2001) and 1.15 (as specified by ASTM A706M), as illustrated in Figures 3 and 4. However, it is evident that the yield strength values for 16mm and 12mm steel for EURO THERM, DUST, and PRISM steel rebars were lower than the standard requirements of 410 N/mm^2 (BS 4449:2001) and 420 N/mm^2 (ASTM A706M). In contrast, the yield strength values of TOP and TIGER TMT steel rebars, along with those of the imported STAR and PSL steel rebars for 16mm and 12mm rebars, satisfied the minimum standard requirements, as shown in table above. In addition, all the steel rebars tested—both locally made and imported—complied with the minimum ultimate tensile strength requirement of 550 N/mm^2, according to BS 4449:2001 and ASTM A706M standards, Moreover, 12mm rebars of TOP and TIGER TMT, with 16mm STAR steel rebars recorded ultimate tensile strength values higher than 620 N/mm^2, which exceeds the standard benchmark. The percentage elongation at fracture for all the tested steel rebars was above the 12% minimum recommended by BS, the 10% recommended by ASTM A706, and the 14% recommended by Nst 65Mn for reinforcing steel bars, as shown in Figure 5 and figure 6.

This high elongation performance may be attributed to the lower manganese content of these samples compared to what the standards specify.

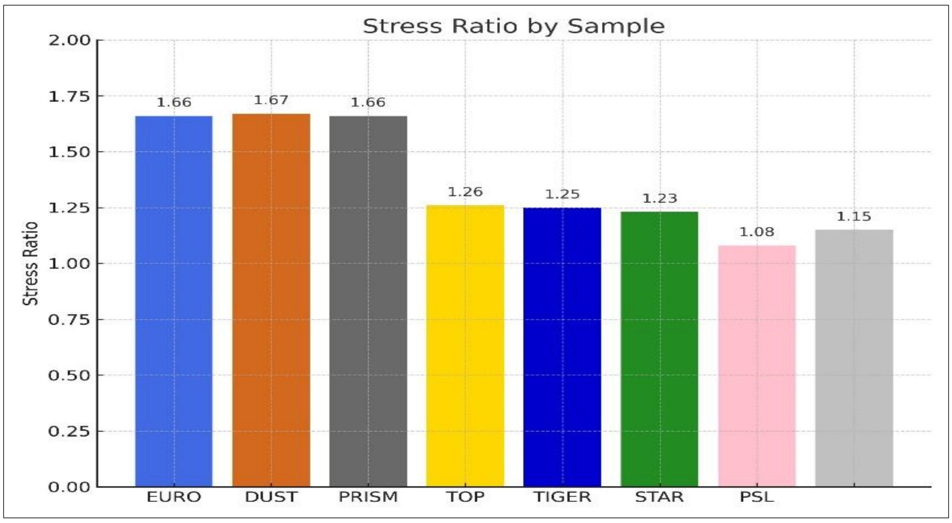

Figure 3 Chart showing stress ratio for 16 mm steel rebar types

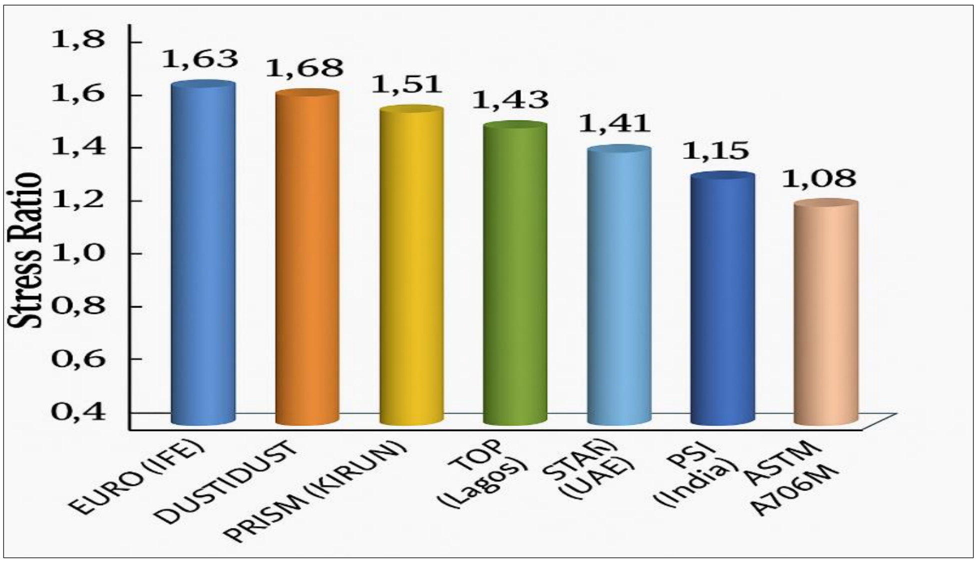

Figure 4 Chart showing stress ratio for 12 mm steel rebar types

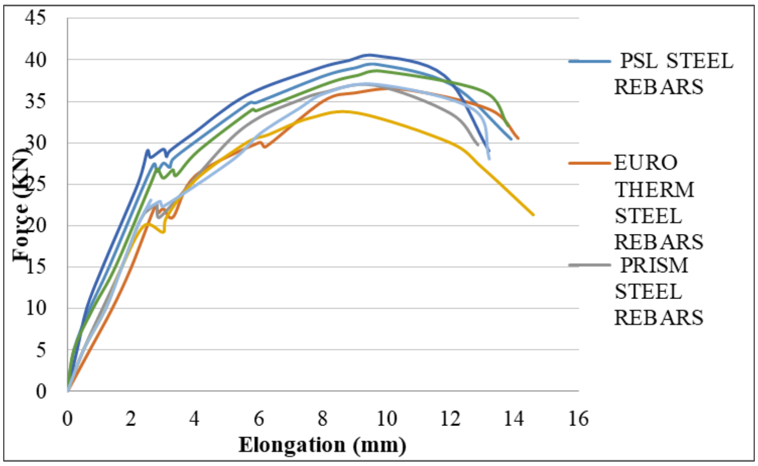

Figure 5 Elongation plots for 16 mm steel rebar type samples

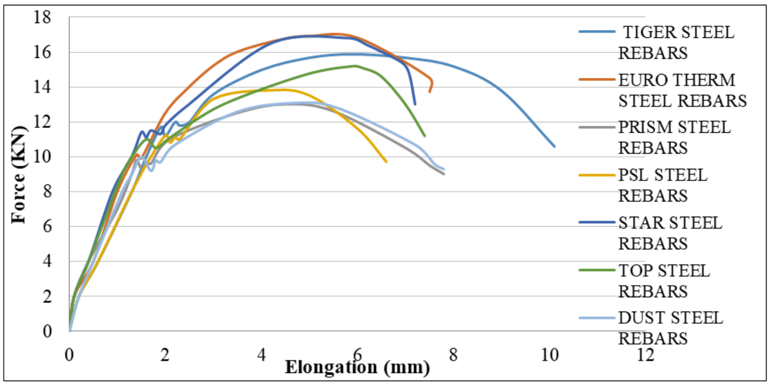

Figure 6 Elongation plots for 12 mm steel rebar type samples

The Vickers Hardness value as shown in Figure 7 below for EURO THERM steel rods is 526 HV; 510 HV for DUST steel; 662 HV for PRISM steel; 362 HV for TOP steel; 491 HV for TIGER TMT steel; 420 HV for STAR Steel and 352 HV for PSL Steel Rebar as shown in figure 7. The minimum and maximum required values of Vickers Hardness (HV) for carbon steel by ASTM A760 are 150 HV and 650 HV respectively. The steel rod from PRISM had a Vickers Hardness of 662 HV which is above the standard, increasing with increase in Carbon content [40]. However, the hardness values of all other steel samples investigated were found to be more than the estimated minimum standard values (150HV) for reinforcing steel bars.

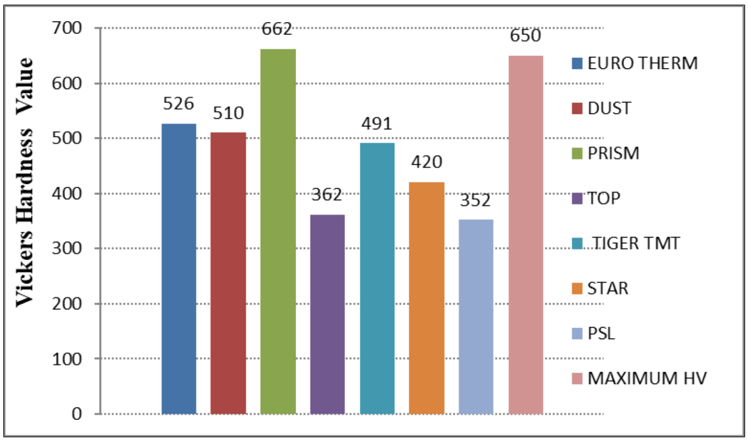

Figure 7 Vickers Hardness value

4. Conclusion

The imported bars show high characteristic yield strength and Ultimate Tensile Strength thereby hard and less ductile than the Steel rebars produced locally from recycled scraps metals in Nigeria. The values of the percentage elongation at fracture for all the tested steel products surpassed the 12% recommended by BS, 10% recommended by ASTM A706 and 14% recommended by Nst 65Mn for reinforcing steel bars expect for 12mm PRISM Steel rebar with percentage elongation of 12%. This may be due to the lower manganese contents of these samples.

All bar sizes satisfied the minimum stress ratio requirement value of 1.08 and 1.15 as specified by BS 4449 (2001) and ASTM A706M respectively. Vickers Hardness values of all the steel samples investigated were found to be more than the estimated minimum standard values of (150HV) for reinforcing steel bars, which ranges from 352HV to 526HV expect for PRISM steel rebar with 662HV, which is higher than the maximum as stated in the standard (650HV).

Compliance with ethical standards

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Disclosure of conflict of interest

*The authors, Oluwole Aderogba Olaniyi *, Adekunle Philips Adewuyi and Afeez Kolapo Oyelami, thereby disclosed that is no conflict of interest during the research work. All names of product mentioned in the research work were original and real.*

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