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Mechanical and Microstructural Properties of Steel Reinforcing Bars Produced from Different Manufacturing Industries as Available in Nigeria Market

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ABSTRACT: The performance of reinforced concrete (RC) infrastructure in service is largely a function of the constituent materials and construction technology. However, lack of reliable information of the physical, mechanical and microstructural properties of construction materials has culminated in structurally deficient and functionally obsolete constructed facilities. This paper reports the study conducted on the quality assurance of steel reinforcing bars produced from different major steel manufacturing industries distributed in the Nigeria and compared with the imported steel bars. The purpose of the study was to investigate the quality assurance of the local and imported steel bars in terms of the geometric, mechanical and microstructural properties.

The findings of the study showed that the imported steel bars were more consistent in size and relative rib area ($0.55\% \leq COV \leq 0.94\%$) than the local bars ($0.80\% \leq COV \leq 1.91\%$). PRISM steel rebar had Vickers Hardness value of 18.5% above the recommended standard value. The tensile test results showed that Eurotherm steel bars were more elastic than other steel types by 10%, but of lesser strength. XRF and SEM showed that STAR and TOP steel bars had less inclusions unlike PRISM and DUST steel rebars with more inclusions which trigger brittle facture in steel bars. The study concluded that PSL steel bars performed better in RC than Prism and TMT steel bars.

KEYWORDS: Steel reinforcing bars, rib area, Vicker Hardness, mechanical and microstructural properties

1.0 INTRODUCTION

Standardization of reinforcing steels manufactured by industries in developing countries such as Nigeria in terms of geometry and strength properties are the bedrock of safe design, sound construction and durable building and civil infrastructure system [1]. The properties of constituent elements of steel reinforcement speak volume about its behaviour when used as reinforcement in concrete [2-4]. Engineers must understand the properties of the materials used for construction purposes in other to guide against failure during and after construction. Reinforcement also reduces creep and minimizes the width of cracks, [5-7]. Five-year analysis market price survey per metric tonne of steel rebars showed that the imported rebars are about 30% more expensive than the corresponding local rebars and the degree of uncertainty in sizes of local bars is almost twice those of imported types [8]. Steel serves as a suitable reinforcement material because its coefficient of thermal expansion (5.8×10^{-6} to 6.4×10^{-6}) is nearly the same as that of concrete (5×10^{-6} to 7×10^{-6}) [9]. Engineering structure response depends on many uncertainty factors such as Geometric, strength, loads, stiffness, mass and damping. Uncertainties about resistances have to do with site conditions, static and dynamic soil properties, structural performance and soil-structure interaction (structural and foundation behaviour). Some uncertainties in dimensional properties include flange thickness, web thickness, I-Sectional Area and Area of reinforcement steel [10]. All engineering material such as steel is subjected to different load conditions, which may be in form of a repeated loading condition, repeated application of force, material may deform, yield or break. Any deformation that causes change in dimension or shapes that occur with a given load on a given load on a material will not be instantaneous but occurs with steady increase until it stops (Construction Standard 2, 2012). A direct correlation exists between steel's microstructures and its mechanical properties [11]. Hence, the development of a relevant structure – property model in steel is therefore, one of the effective methods of improving its mechanical properties [12]. However, appropriate production method needs to be developed to meet increasing global demand for steel bars of superior strength characteristics appreciably at low cost [13 - 14]. Steel reinforcing bars should be free from features such as seams, porosity, segregation and non-metallic inclusions, etc. which would cause the product to fail to meet the specified mechanical properties [15]. The mechanical properties of steel must meet up with the quality specifications and standard codes of practice on which designs are based for effective utilization from available literatures, some works on steel rods produced in Nigeria has been done. 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 [16 -18]. Steel rebar is most commonly used as a tensioning devise to reinforce concrete to help hold the concrete in a compressed state. Although steel rebars have ribs that bind it mechanically to the concrete, it can still be pulled out of the concrete under high stresses, an occurrence that often accompanies a larger scale collapse of the structure. To prevent such a failure, steel rebars are either deeply embedded into adjacent structural members (40 to 60 times the diameter), or bent and hooked at the ends to lock it around the concrete and other steel rebars. This first approach increases the friction locking the steel rebars into place, while the second makes use of the high compressive strength of concrete [19-20]. The characteristic strength values for most of the locally produced rebar samples examined by [21] are low compared to the BS4449:1969, 1995 & 1997 standards for high tensile steel which is 460N/mm^2 minimum value. Sixty percent of the samples fall below Code Value. Elemental analysis, tensile, hardness test was carried out on the sample of steel products from three indigenous steel industries and imported in accordance with ASTM A706 (2013). The results of the elemental analysis showed that the indigenous steel samples have higher carbon contents than the 0.30% recommended standards [22]. The concrete reinforcement steel bar investigated fell within the acceptable region provided in the NIS 177-1992 standard with the carbon content of 0.17% and 0.24% respectively [23]. These results fell within the acceptable limits of 0.14 - 0.20%C for ST44-2 and 0.18 - 0.24%C for ST66-2 as imposed by the NIS (1992). The proportions of other elements such as Silicon, Manganese, Phosphorous, Sulphur, Copper, and Nitrogen were also in agreement with the NIS standard. The results obtained from tensile test showed that tensile strength and yield strength of average of 485.40 N/mm^2 and 317.38 N/mm^2 for ST44-2 and 677.19 N/mm^2 and 448.06 N/mm^2 (on average) for ST66-2 steel bar were satisfactorily in agreement with what is obtainable in NIS (1992) [24]. They studied the chemical compositions and the microstructures of reinforcing steel bars obtained from three different collapsed building sites. They used Optical emission spectrometer to carry out the chemical analysis, while the microstructure was examined using an optical microscopy. They concluded that the carbon contents of the steel bars were found to be higher than BS4449 and ASTM706 standards, but they are in close range with the Nst-65-Mn standard. The manganese contents of the steel bars are lower, while the sulphur and phosphorus contents are quite higher than the BS4449, ASTM706 and Nst-65-Mn standards. The hardness values of the investigated bars are higher than recommended BS4449 standard but lower than Nst-65-Mn standard. Brittle globules of Fe_3P and FeS were observed within the structure possibly due to higher contents of deleterious sulphur and phosphorus. Thus, the reinforcement used in the collapsed building site was brittle [25 - 27].

2.0 MATERIALS AND METHODOLOGY

2.1 Tensile Properties

High yield steel rebars samples of diameter ranging from 10 mm to 25 mm were obtained from local market in South Western part of Nigeria which comprises of Lagos, Abeokuta, Ibadan, Akure, Ado Ekiti, Osogbo, Ile-Ife, Ogbomoso and Ilorin under two major sources namely; locally produced steel rebars and imported steel rebars with the name of the manufacturers engraved on the steel. The locally produced reinforcing steel bars were products of five steel industries in Nigeria that use re-cycled scraps metals as their major raw materials for producing steel. The industries include; Prism Steel mills, Ikirun (PR), Dust Steel Mills, Ilorin (DT), Euro Therm Steel Mills, Ife (ET), Top Steel Nigeria Ltd, Ikorodu, Lagos (Top) and Tiger TMT Steel Mills, Ogijo, Ogun State (TMT) and two foreign steels namely Star Steel Mills, UAE (ST) and PSL Steel Mills, India, (PSL) as shown in figure 1. Steel bars were cut to a testing length of 450 mm in line with ASTM A370 specifications. A gauge length of 200 mm was marked on each specimen using a jig and punch device, as prescribed by the standard. The steel rebars were long enough to fully occupy the grips of the universal testing machine (UTM), with an additional 25 mm allowance protruding beyond each grip. Each grip measured 100 mm in length. A small load was applied initially to remove slack. Tensile tests were performed on three samples each of bar sizes ranging from 10 mm to 25 mm, taken from seven different steel brands: Star, PSL, TMT Tiger, Top, Eurotherm, Prism, and Dust. Testing was carried out using an electromechanical UTM at the National Centre for Agricultural Mechanization (NCAM), Idofia, Kwara State, Nigeria, at a constant test speed of 10 mm per minute.

Figure 1: Steel rebar types from different manufacturers

2.2 Sample Preparation for SEM

Steel samples were cut to a length of 20 mm using cutting saw and the surfaces were smoothened using a file. CitoPress-30 was used to attach the sample to the resin (polyfast). Temperature (180 ^{0}C) and pressure (325 Pa) were applied to melt the resin and the sample was encased. The sample was then cooled for easy handling during testing. The samples were then polished in Tegramin-30 of the 6 batches. Samples were rubbed against diamond polishing disks of different microns (1 micron, 3 microns and 6 microns) and the water was sprinkled as the sample was polished to obtain a very smooth and shiny surface. Samples were polished with a 3µm diamond paste and finished with a 0.1µm diamond paste. Energy-dispersive X-Ray Spectroscopy (EDS) was used in conjunction with SEM to identify the elemental composition near the surface of the steel sample. The prepared sample was mounted to a 30 mm aluminium stopper. The sample was placed in the GeminiSEM 500 (CMS-SEM-EDAX-01-1) where it was placed in a sample holder then in transfer lock which was then pre pumped. The sample got secured with rod transfer in the EDS detector. Through the lancers into the chamber where samples sat on the vacuum, when the electron hits the sample, there was electron sample interaction, an empty space was created in the energy cell. Electron then lost energy in the form of X-ray. The EDS detector then worked with electron microscope to generate the X-ray which the EDS detector picks up. Once the vacuum was ready, the sample was then transferred to the stage. The photographs were taken from backscatter of four quadrant. The EDX detector was then cooled down. The sample was then positioned and the image was taken at 9.8mm working distance. The signal was sent through to the computer and results were saved for analysis. Figure 2 and3 shows series of process in SEM experiments

Figure 2: Steel rebar types samples and CitoPress -30

Figure 3: Prepared Sample in a sample holder

2.3 Vickers hardness Test

Bulk hardness testing (HV) was carried out on the steel samples 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 Steel rebar samples.

The Vickers hardness testing (HV) was determined according to ISO 6507 by pressing the pyramid-shaped indenter (with interfacial angle of 136°) into the steel specimen of length 20 mm from different steel manufacturers with a defined test load of 30 Kgf. 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 were measured, and the hardness number was calculated by dividing the load by the surface area of indentation as stated in equations below. The Vickers hardness value should be between the ranges 150HV to 650HV. The larger the indent left by the indenter at a defined test force in the surface of the steel specimen, the softer the specimen.

$$HV = Constant \times \frac{test\ force\ (F)}{Surface\ of\ indentation} = 0.102 \times \frac{2F\sin(\frac{\theta}{2})}{D^2} \quad (1)$$

$$HV = 0.1891 \times \frac{F}{D^2} \quad (2)$$

$$D = \frac{d_1 + d_2}{2} \quad (3)$$

Where F 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 (136^0).

3.0 RESULTS AND DISCUSSION

3.1 Elongation Tensile behaviour of steel rebars

The force-elongation plots for the steel rebar types from tensile test results as shown in Figure 4 revealed that the maximum load attained by Star, PSL, TOP, Prism, Dust, Eurotherm and TMT Tiger were 40.6 kN, 39.4 kN, 38.2 kN, 36.9 kN, 36.9 kN, 36.4 kN and 33.6 kN with an extension of 9.65 mm, 9.72 mm, 9.84 mm, 9.61 mm, 9.65 mm, 10.55 mm and 9.10 mm respectively. The two imported rebars namely STAR and PSL has the maximum force while Eurotherm rebar has the maximum elongation at the peak and TMT Tiger steel possessed the least ductility. This shows that Eurotherm rebar was more elastic than its counterpart by 10 % and of lesser strength while STAR and TMT rebar has maximum and minimum force respectively at the peak.

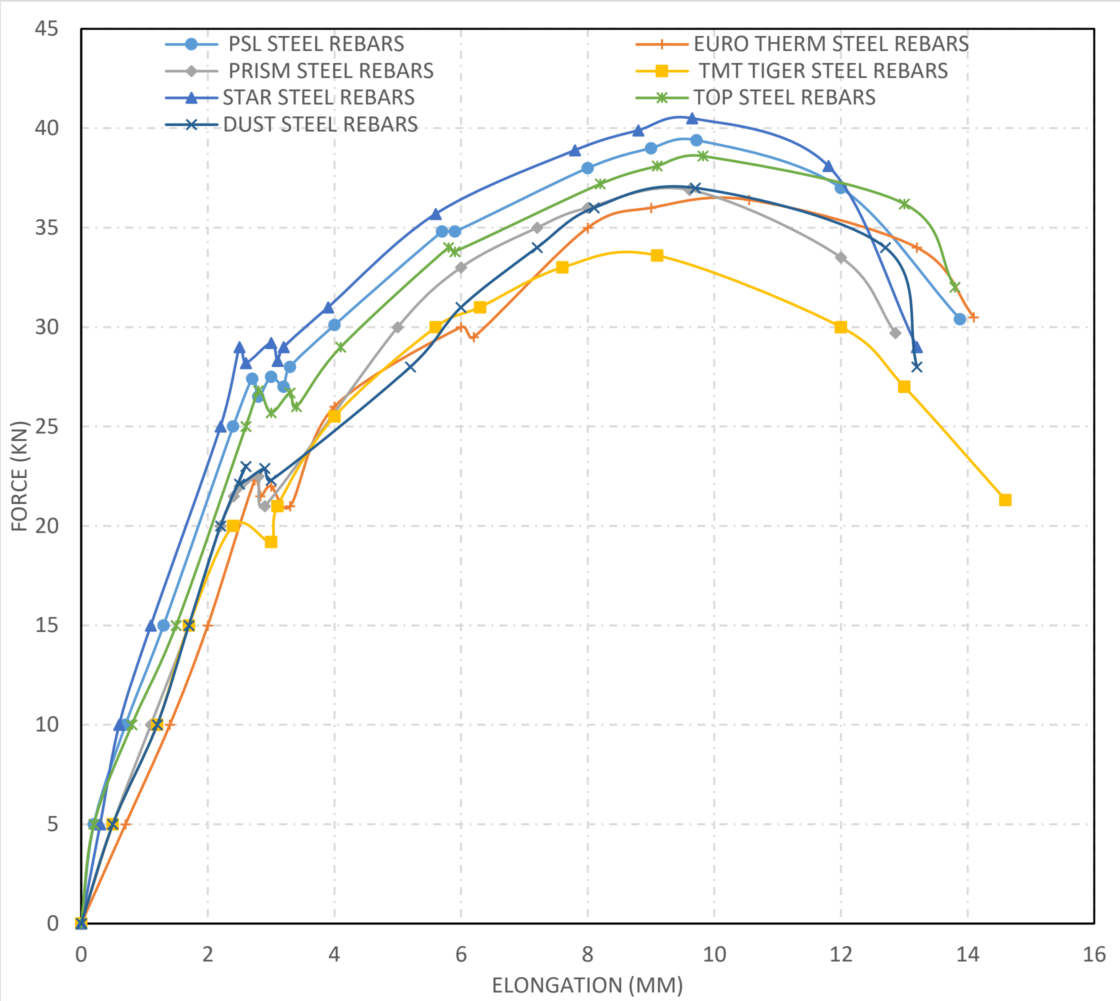


Figure 4: Load-deflection plot from tensile strength tests

3.2 Yield Strength and Ultimate Tensile strength of steel rebars results

The results of the tensile strength properties for the steel rebar types are presented in table 1. Of all the imported steel rebars sampled, STAR steel rebar has the highest Yield Strength (YS) in the range of 432.5 – 495.6 N/mm^2 while PSL Steel rebar has the highest UTS in the range 619.2 – 620.1 N/mm^2. Out of the five local steel rebar types considered, TMT Tiger Steel rebars has the maximum Yield strength in the range of 415.0 – 497.8 N/mm^2 while PRISM Steel rebars has the minimum Yield Strength in the range of 345.8 – 350.9 N/mm^2. TOP Steel rebars has most UTS in the range of 620.5 – 621.2 N/mm^2 while DUST Steel rebars has the least UTS in the range of 575.3 – 585.2 N/mm^2. The Stress Ratio for the imported and local steel rebars is in the range of 1.26 – 1.44 and 1.25 - 1.68 respectively. The percentage elongation for the imported and local steel rebars is in the range of 14.4 – 15.2 and 12.0 – 16.7% respectively.

Table 1: Mechanical Properties for the Reinforcement Steel Types

Steel Rebar Types	**Tensile properties of Steel Rebar Types**				
	Yield Strength (N/mm^2)	**Ultimate Tensile Strength (N/mm^2)**	**Young's Modulus (kN/mm^2)**	**Stress Ratio**	**Elongation (%)**
STAR	432.5 – 495.6	610.8 – 622.4	160-163	1.26 – 1.41	14.4 – 15.2
PSL	429.9 – 493.7	619.2 – 620.1	161-164	1.26 – 1.44	14.4 – 14.9
EUROTHERM	350.7 – 358.6	572.2 – 596.7	120-124	1.63 – 1.66	14.3 – 16.7
TMT TIGER	415.0 – 497.8	598.8 – 623.3	157-162	1.25 – 1.44	14.3 – 16.2

TOP	428.5 – 491.1	620.5 – 621.2	156-159	1.26 – 1.45	14.3 – 15.5
PRISM	345.8 – 350.9	580.5 – 581.7	119-123	1.66 – 1.68	12.0 – 15.1
DUST	347.6 – 353.5	575.3 – 585.2	117-122	1.65 – 1.66	13.3 – 15.7

Additionally, all the steel rebars examined, both locally produced and the imported counterpart met the requirements for the minimum Ultimate Tensile Strength of 550 N/mm^2 as specified by BS 4449 (2001) and ASTM A706M standard as presented in figures 5. Whereas, TMT TIGER Steel rebars possessed higher values of Ultimate Tensile Strength than what is specified in the standard which is 620 N/mm^2.

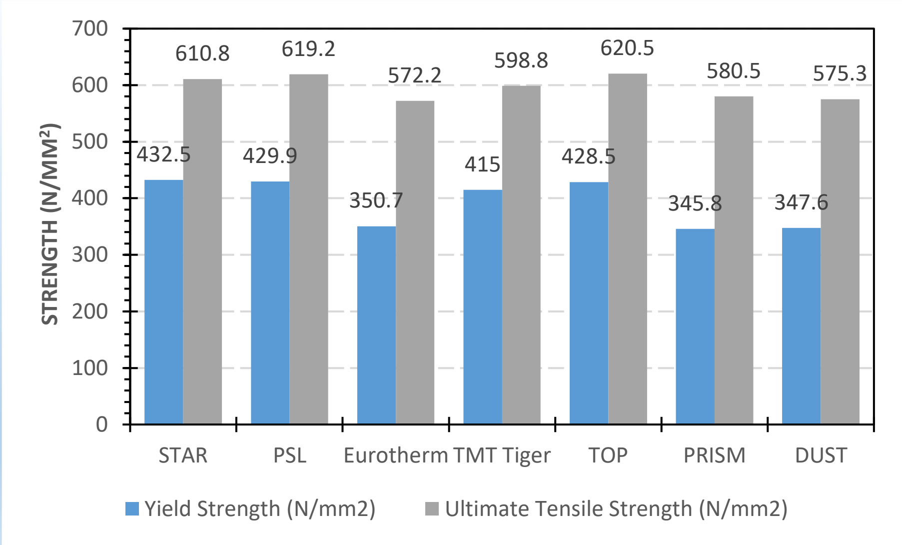
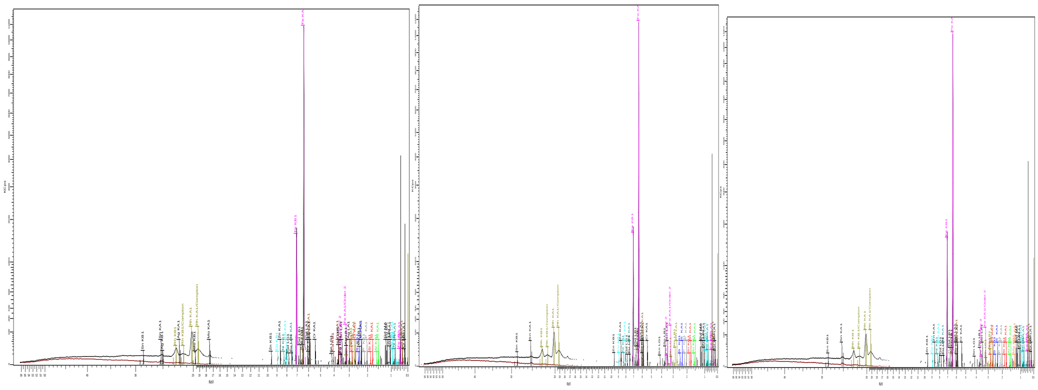


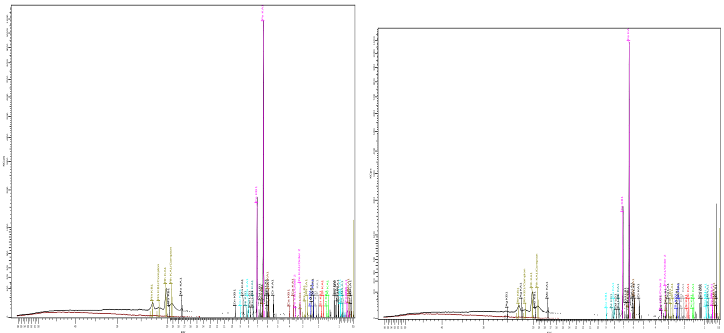
Figure 5: Yield and Ultimate Tensile Strength of the Steel rebar types.

3.3 Energy Dispersive X-ray Spectroscopy (EDS) and Scanning electron microscopy (SEM)

By using high-resolution SEM/EDS analysis system, micro-inclusions in the steel samples were detected on a metallographically prepared surface area. Each result had SEM image and EDS spectra as presented in Figure 6 below. It was possible to determine the position, shape, and composition of each inclusion particle. The results showed that each sample had different phases and the BSE mode was used to locate the area of interest for subsequent EDS analysis. It was noticed that some samples had cracks going inside. These cracks from the edge allowed the scale inside the sample. When magnification increases, more defects were picked including inner cracks which could possibly be there during manufacturing. There were also micro pores which may had cracks running in them which are likely to cause structures to fail when steel reinforcing bars fail to withstand the tension. This showed that manufacturer of STAR and TOP steel rebars can be recommended because of less inclusions in their steel bars unlike PRISM and DUST steel rebars with more inclusions. More inclusions in steel bars could lead to them being weak with low yield strength. This was highlighted by another researcher that inclusions can initiate ductile and brittle facture in steel bars.



(a) (b) (c)



(d) (e)

Figure 6: X-ray diffraction pattern of

(a) STAR (Imported) rebars
(b) Eurotherm rebars
(c) TMT Tiger rebars
(d) Top steel rebars
(e) Prism rebars

3.4 Hardness Test Results

The Vickers Hardness test was carried out on the steel rebar samples and the results is as presented in figure 7 below. The Vickers Hardness value is in the range of 360HV to 662HV for the local rebars and in the range of 352HV to 420HV for the imported rebars. The minimum and maximum required Vickers Hardness values (HV) for carbon steel by ASTM A760 are 150 HV and 650 HV respectively.

PRISM steel rebar had a Vickers Hardness value of 662 HV which is above the standard value of 650HV. This is probably as a result of increase in Carbon content of the steel Rebar composition. However, the hardness values for all other steel samples investigated were found to be more than the estimated minimum standard values of 150HV for reinforcing steel bars. As a result of this, both imported and local steel rebar types investigated were suitable for construction work.

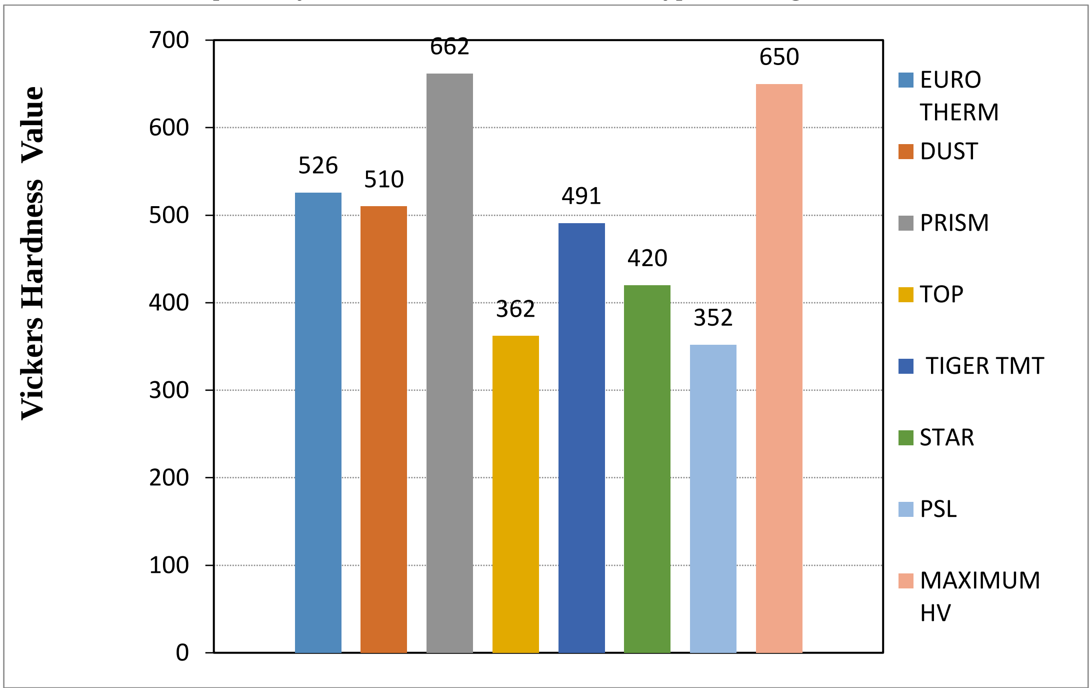


Figure 7: Bar chart of Vickers Hardness value for steel rebar types

CONCLUSIONS

The following conclusions can be drawn from the experimental study conducted on the optimum design of steel reinforcing bars in the performance of concrete structural beams.

(1) Size distribution of steel reinforcement types shows that for the imported bars (STAR and PSL), the degree of uncertainty is in the range of 0.55% to 0.94%. Whereas, the locally produced steel rebars (Eurotherm, TMT Tiger, TOP, Prism and Dust) shows that the degree of uncertainty is in the range of 0.80% to 1.91% with 25

mm steel rebars having the least COV and 10 mm steel rebars having the highest COV.

(2) Hardness test shows that PRISM steel rebar had a higher Vickers Hardness value of 18.5% above the standard value. However, the hardness values for all other steel samples investigated satisfy the standard values of 650HV to 150HV for reinforcing steel bars.

(3) The tensile test results showed that Eurotherm bars were more elastic than other types by 10%, but of lesser strength. PSL and Star has the highest yield strength of 430 N/mm2, while TOP, TMT, Eurotherm, Dust and Prism were respectively 99.8%, 96.7%, 81.6%, 80.5% and 80.5% respectively of PSL and STAR strength. The steel rebar types exhibit a UTS and YM with respect to PSL of 93.9% and 73.9% (Prism), 92.6% and 74.5% (Eurotherm), 93.1% and 72.7% (Dust), 96.8% and 97.5% (TMT Tiger) and 98.7% and 99.4% (Star) respectively. The higher cost of imported steel rebars over the local ones is justifiable in terms of strength and stiffness.

(4) The XRF and SEM showed that STAR and TOP steel rebars have less inclusions in their steel bars unlike PRISM and DUST steel rebars with more inclusions. Inclusions in steel bars could lead to low tensile strength properties, initiate ductile and brittle facture in steel bars.

It is therefore essential for structural engineers and various stakeholders in construction industry to be acquainted with the properties of construction materials and enforce quality assurance prior to design and during construction to avert structural failures. Hence, the relevant standards regulatory bodies and other stakeholders in Building and Civil Infrastructure should intensify efforts towards standardizing the steel reinforcing bars in order to avert structural failures and avoidable loss of lives and properties

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