Tensile and Flexural Properties of Common Steel Reinforcing bars in Southwestern Nigeria for Concrete Structures

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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 on the physical, chemical and mechanical properties of construction materials has resulted in structural failures. This paper reports the study conducted on the quality assurance of steel reinforcing bar produced by four major manufacturing industries namely TMT Tiger, EURO Therm, Prism and PSL in the Southwestern Nigeria. The tensile tests were conducted on the steel specimens manufactured by these industries in line with ASTM A370. Yield strength, ultimate strength and the percentage elongation of the specimens were analyzed and compared with relevant international standards. The flexural behaviour of RC beam specimens of concrete grade 20 N/mm^2 reinforced with two 10 mm bars each at the tension zone and two 8 mm rebars as hanger bars was comparatively assessed for each of the four rebar types using three-point loading. The tensile test results showed that PSL has the highest yield strength of 430 N/mm^2, while TMT, Eurotherm and Prism were respectively 96.7%, 81.6% and 80% respectively of PSL strength. The values of the flexural stiffness of the tested RC beams were 20 kN/mm (PSL), 17.75 kN/mm (TMT), 16.34 kN/mm (Eurotherm) and 14.25 kN/mm (Prism). PSL rebars had the best tensile and flexural properties even though it does not fully satisfy ASTM A615 and BS 4449. 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.**

Keywords— Reinforced concrete, tensile test, flexural stiffness, reinforcing steel, yield strength, ductility

I. INTRODUCTION

A structure with sound analysis and design could still fail if the quality of the material used for the construction is substandard [1-4]. The two main materials used for reinforced concrete structures are concrete and steel rebars. Steel reinforcing bar, or rebar, is embedded in concrete to improve the overall strength of concrete that surrounds it. Standardizing material properties is critical to ensuring that rebars produced throughout the world exhibits the same physical, chemical, and mechanical properties regardless of the source. Proper mechanical testing is then essential to determine if investigated rebars meet its standard specifications, thereby ensuring the quality of the product [5-7]. The remarkable gap between the flexural capacities of steel rebars and standard requirements can be traced not only to the tensile strength but also the weak bar-concrete interfacial bonding [1, 7-9].

Industrialized materials, such as Portland or blended hydraulic cement and steel, find applications in all sectors of infrastructure development [10-13]. Aside the environmental and operational conditions, the constituent materials account for the increasing cases of structural deficiency and functional obsolescence recorded in the built environment [3-5]. Achieving an acceptable probability that any designed structure would perform satisfactorily during their intended life is often hampered by non-compliance with structural design specifications and non-conformity of material properties used at the design stage and at the construction stage [14-15]. While so many investigations have been conducted on the worrisome trends of structural collapse in Nigeria and other developing countries from social sciences, environmental and engineering points of view [10-13], statistics have shown that quite a significant number of structural failures can be attributed to substandard materials.

Previous studies by Adewuyi [3-5] revealed that reinforced concrete accounts for over 80% of infrastructure systems in developing countries and not less than three-quarters of constructed facilities in the industrialized nations. In recent times, the incessant structural failure of building and civil infrastructure is of great concern [3-5]. The steels used for construction have been evolving ever since their initial development in the late-1800s. The transfer of stress from concrete to steel is made possible through effective bonding between concrete and the

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reinforcement. Previous studies on the chemical, physical and strength characteristics of steel reinforcing materials revealed the dangers of maximizing profit at the expense of quality, a situation that poses a major challenge to the structural reliability and durability of buildings and civil infrastructure [1, 7-8]. Hence, it is imperative to carefully study the intrinsic and mechanical properties of reinforcing steel bars in order to guarantee safe and durable constructed facilities [14-15]. Moreover, extensive investigations on the mechanical properties of steel reinforcement produced from different manufacturing sources and processes are crucial to ascertaining the suitability and reliability for infrastructure development and compliance with the specifications of relevant local and international standards for building and civil engineering construction works [16-19].

In this study, attention has been focused on the quality of recycled steel rebars locally manufactured and distributed substantially within the southwestern Nigeria's building and construction industries. The four locally manufactured steel rebars investigated namely TMT Tiger, Eurotherm, Prism and PSL were subjected to laboratory investigation to assess their tensile properties and the flexural behavior when embedded in concrete as reinforcements.

II. Experimental Programme

A. *Tensile Strength*

Steel reinforcing bars were cut to the testing length of 450 mm in line with the requirements outlined in ASTM A370. The testing length considered a 200 mm gauge length and also provided for the grip lengths of the universal testing machine (UTM) with additional lengths protruding beyond the grips. Each grip of the UTM was 100 mm long and an allowance of 25 mm was made to protrude beyond each grip of the specimen. Tensile tests were carried out on three samples each of 10 mm to 25 mm bar sizes from the four TMT Tiger, Eurotherm, Prism and PSL steel rebars at the National Centre for Agricultural Mechanization (NCAM), Idofia, Kwara State, Nigeria using a UTM at a test speed of 10 mm per min as shown in Fig. 1.

B. *Flexural Strength of RC Beams*

Ordinary Portland cement of grade 32.5 was utilized for concrete production. The aggregates which comprised river sand and crushed granite of 19 mm maximum nominal size conforming to BS 882 [20] were mixed at a water-cement ratio of 0.45 in accordance with BS 1881 [21]. The mix proportion of concrete of density is summarized in **Table 1**.

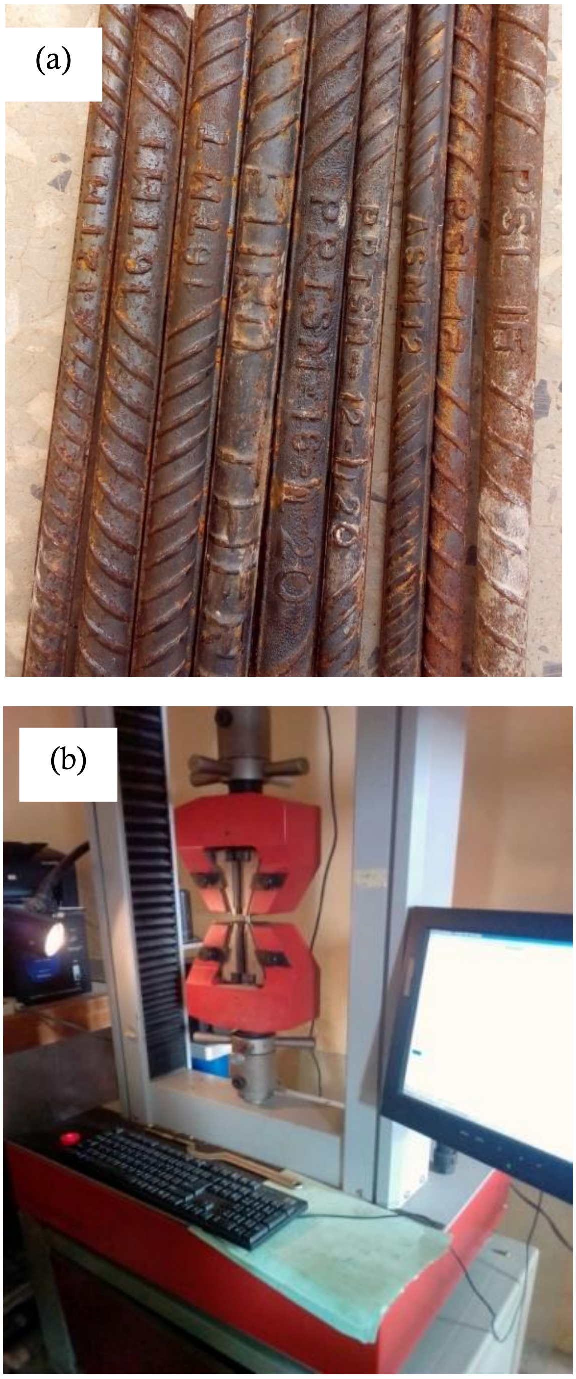

Fig. 1. (a) Steel specimens from different manufacturers, and (b) tensile strength test setup.

TABLE 1: MIX PROPORTIONING OF CONSTITUENTS OF CONCRETE

	Water	Cement	Fine aggregates	Coarse aggregates
Mass (kg)	110	245	485	945
Ratio	0.45	1.00	1.98	3.86

The 7th and 28th day compressive strength values of 150 mm concrete cube were 17.1 and 25.10 N/mm^2 respectively, and the 28th day density was 2404 kg/m^3. Three 100 × 100 × 700 mm RC beams, having an effective span of 600 mm, were each reinforced

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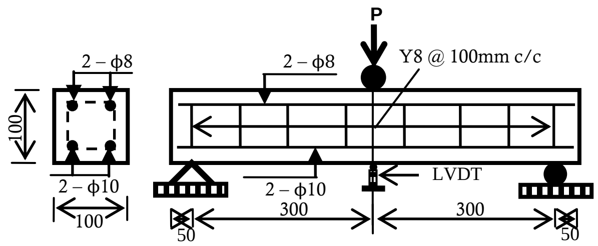
with two 10 mm bars at the tension zone and two bars of 8 mm bars as the hanger bars of each of the four rebar types were subjected to a three point loading flexural test at 28 days. A hydraulic actuator was used to apply a central concentrated load to the RC beam in 0.1 kN increments. A linear variable differential transformer (LVDT) was used for each specimen to measure the vertical displacements at the mid-span under the applied load. A load cell was used to monitor applied load and a data acquisition system was used to record the experimental measures.

The applied force was plotted against elongation (mm) automatically by the data acquisition system connected to the flexural testing machine. The flexural strength determination, also known as modulus of rupture, is essential to estimate the load at which the concrete members may fail. The applied load and the corresponding deflection were recorded, and the bending strength at ultimate collapse was calculated. The schematic test setup of three point loading adopted for flexural strength analysis of the RC beam is shown in Fig. 2. The experimental test setup for the RC beams reinforced with the four selected steel rebar types is shown in Fig. 3.



All dimensions in mm

Fig. 2: Flexural test setup of RC beams

Fig. 3. Experimental setup of RC beam for flexural strength test.

III. Results and Discussion

A. *Tensile behaviour of steel rebar types*

The force-elongation plots for the steel rebars from the four manufacturers are shown in Fig. 4. The tensile strength properties namely, yield strength, ultimate tensile strength, the stress ratio and the percentage elongation were either extracted from the plots or produced directly by the machine. These parameters were subsequently compared with relevant standards such as ASTM A615/A615M [18] and BS 4449 [19].

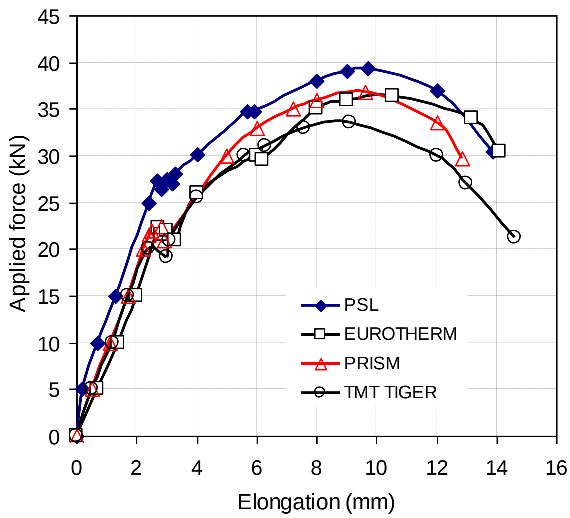


Fig. 4: Load-deflection plot from tensile strength tests

The force-elongation plots from tensile test results revealed that the maximum load attained by PSL, Prism, Eurotherm and TMT were 39.4 kN, 36.9 kN, 36.4 kN and 33.6 kN with a corresponding extension of 9.72 mm, 9.61 mm, 10.55 mm, 9.10 mm respectively. The PSL rebar has the maximum force while Eurotherm rebar has the maximum elongation at the peak while TMT Tiger steel possessed the least ductility. It was found that Eurotherm rebars were 10% more elastic than other rebar types, but of lesser strength. However, PSL and TMT rebars had the maximum and minimum force respectively at the peak.

Of all the steel rebar types considered as shown in Fig. 5, only PSL steel rebar specimens met the minimum requirements for yield strength (YS) and ultimate tensile strength (UTS) as specified by ASTM A706M (420 MPa/ 620 MPa), but did not meet the YS value of BS 4449 (500 MPa/ 540 MPa). This was closely followed by TMT Tiger (415 MPa/598.8 MPa), while Eurotherm (350.7 MPa/ 572.2 MPa) and Prism (345 MPa/ 580.5 MPa) steel rebar specimens are far below the two specifications. Normalizing with the PSL rebars, TMT, Eurotherm and Prism bars were 96.7%, 81.6% and 80.4% respectively of the tensile strength of PSL steel bars.

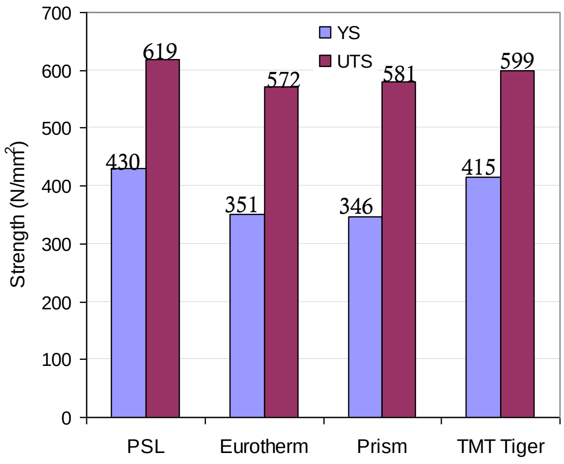


Fig. 5: Yield and ultimate tensile strength of the four rebar types.

On the other hand, the UTS/YS ratios, referred to as stress ratio, for the four reinforcing bar types are plotted in Fig. 6. It is obvious from the test results that all the rebar types satisfied the minimum UTS (550 N/mm^2), stress ratio (1.08) and elongation at fracture (14%) specified by BS 4449 [19]. These were crucial to the ductility, bendability and plasticity of the steel rebars. However, none of the rebars satisfied the minimum yield strength value specifications of BS 4449 [19]. More importantly, in terms of the results obtained from the random tensile test procedure, the degree of randomness both in terms of strength and elongation parameters was highest for Prism, Eurotherm and TMT, while the most reliable manufacturer was PSL steel.

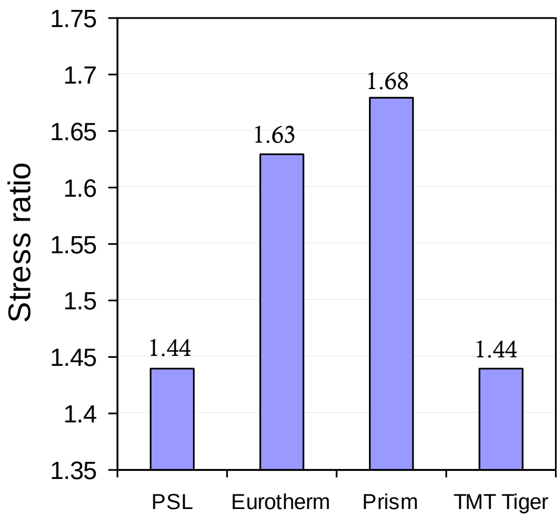


Fig. 6: Stress ratio for the steel rebar specimens from different manufacturers

B. Flexural behaviour of RC beams

The compressive strength of concrete cube specimens at varying curing ages up to 120 days are plotted in Fig. 7. A total of twelve 100 × 100 × 700 mm RC beams, having an effective span of 600 mm, were reinforced with two 10 mm bars at the tension zone and two bars of 8 mm bars as the hanger bars and subjected to a three-point loading flexural testing at 28 days. The test results of the compressive strength of the investigated concrete at 28 days satisfied the target 20 MPa cube strength. The compressive strength of the concrete increased as the curing age increases until 28 days after which it slows down between 28 days to 120 days thus the rate of gain of compressive strength decreased linearly. The latter curing age was considered as a reliable time range when hydration of cement would have been achieved considerably.

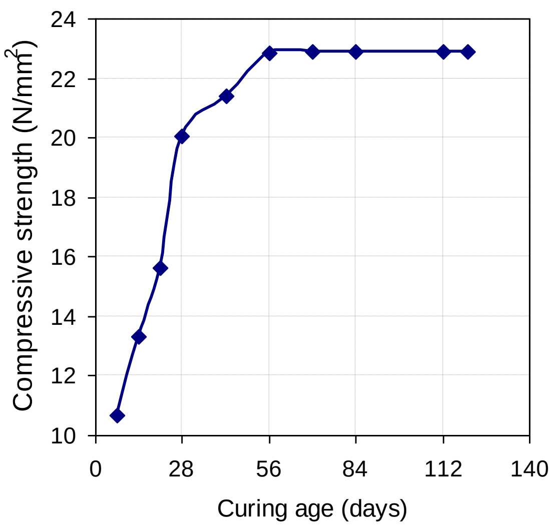


Fig. 7: Compressive strength of concrete cubes at different curing ages

The stiffness of the RC beams from the highest to the least are PSL > TMT > Eurotherm > Prism. For clear comparison of the flexural behaviour of the RC beams reinforced with the four steel rebar types, the mean load – deflection (P-δ) curves of beam samples are plotted in Fig. 8. The maximum loads attained and the corresponding deflections by these beams were PSL (96 kN/5.9 mm), TMT (84 kN/5.6 mm), Eurotherm (87 kN/6.2 mm) and Prism (85 kN/7 mm). The results of the flexural stiffness, measured in terms of the slope of the load-deflection curve from the origin, were 20 kN/mm (PSL), 17.75 kN/mm (TMT), 16.34 kN/mm (Eurotherm) and 14.25 kN/mm (Prism). Benchmarking with the PSL RC beams, the results obtained implied that there were stress losses of 11.25% for TMT, 18.30% for Eurotherm and 28.75% for Prism RC beams. Prism RC beams recorded the maximum deflection of 7 mm, while TMT had the least deflection of 5.6 mm. It is obvious from the study that TMT, though had a higher tensile strength than Eurotherm and Prism steel rebars, exhibited some measure of brittleness when subjected to bending as shown in the rupture of the TMT RC beams at the ultimate flexural load. Additionally, at the ultimate load, Eurotherm and Prism RC beams experienced 5.1% and 18.6% deflection higher than the PSL RC beams.

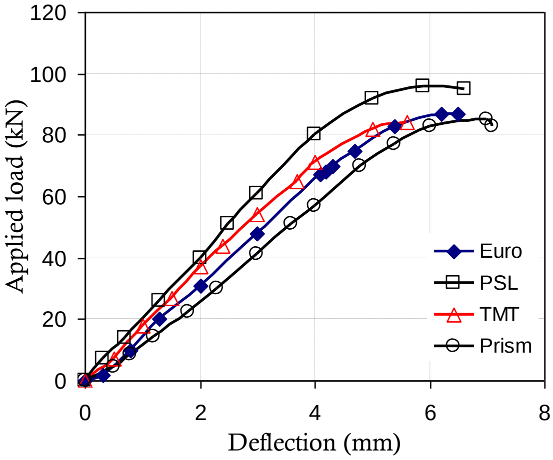


Figure 8: Load-deflection curve from flexural test of RC beams with different rebar types

It is worth emphasizing that flexural strength is directly proportional to the applied load and, by extension, the corresponding bending moment. From the fundamental principle of mechanics of materials, the bending of flexural strength is calculated as presented in Equation 1.

$$f = \frac{My}{I} = \frac{\frac{Mh}{2}}{\frac{bh^3}{12}} = \frac{6\left(\frac{PL}{4}\right)}{bh^2} = \frac{1.5PL}{bh^2} \quad (1)$$

where

f = flexural strength in N/mm^2

M = maximum bending moment

P = applied concentrated load

b, h = width and overall depth of beam

L = effective span of beam

The flexural strength at the bottom fibers of each beam from the highest to the least were 86.4 N/mm^2 (PSL), 78.3 N/mm^2 (Eurotherm), 76.5 N/mm^2 (Prism) and 75.6 N/mm^2 (TMT). In terms of loss of flexural strength with respect to the PSL RC beams, Eurotherm recorded 9.4% loss, Prism lost 11.5% and TMT RC beams lost 12.5%. It is therefore important for the Standards Organization of Nigeria and other stakeholders in Building and Construction Engineering sectors – both the regulators and the practitioners to intervene to standardize the reinforcing bars production. This is crucial to prevent avoidable structural failure of constructed facilities, and unwarranted loss of lives and investments.

IV. Conclusion

The following conclusions can be drawn from the experimental study conducted on the performance of steel bars for reinforced concrete.

1. Only PSL steel rebar specimens met the minimum requirements for yield strength (YS) and ultimate tensile strength (UTS) as specified by ASTM A706M (420 MPa/ 620 MPa), but did not meet the YS value of BS 4449 (500 MPa/ 540 MPa).TMT, Eurotherm and Prism bars were 96.7%, 81.6% and 80.4% respectively of the tensile strength of PSL.
2. The stress ratios of the four steel rebars satisfy the minimum requirement of ASTM and British Standards.
3. The degree of randomness both in terms of strength and elongation parameters was very high for Prism, Eurotherm and TMT, while the most reliable manufacturer was PSL steel.
4. The results of the flexural stiffness, measured in terms of the slope of the load-deflection curve from the origin, were 20 kN/mm (PSL), 17.75 kN/mm (TMT), 16.34 kN/mm (Eurotherm) and 14.25 kN/mm (Prism).
5. With respect to the PSL RC beams, flexural strength losses of 11.25% for TMT, 18.30% for Eurotherm and 28.75% for Prism RC beams.
6. Although TMT Tiger had a higher tensile strength than Eurotherm and Prism steel rebars, it exhibited some degree of brittleness when subjected to bending.

V. Recommendations

(1) Standardization of size and tensile strengths of rebars should be established for different steel manufacturing industries to enhance reliable design of structures. This should be coordinated by the regulatory agency and the relevant professional bodies.

(2) Further studies on the physical and geometric evaluation of the four types of reinforcing bars should be conducted to evaluate the relative rib area and the effect on bonding capability.

(3) For thorough appraisal of structural behaviour of these rebars in flexure, interfacial bond strength of the steel bars should be investigated under varying environmental conditions.

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