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Assessment of Suitability of Selected Reinforcing Bars Used for Construction in Nigeria

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***Abstract* — This study is aimed at assessing the suitability of reinforcing bars used for construction in Nigeria. Reinforcing bars were selected at random from the ones produced at different locations within Nigeria and imported into Nigeria. The reinforcing bars samples collected from the study area were subjected to various laboratory tests and inspection (i.e. Ductility, Bar Size and Pattern, Yield Stresses etc).Then the results compared with required standards. The Results showed that all the reinforcing bars tested (both local and imported), except 10 mm from some local sources have their Yield Stresses and % Elongation greater than the required standards. All the imported bars have their measured sizes equal to their nominal sizes, while this was not true for all the locally manufactured bars. The rib deformations of all the bars (local and imported) are in conformity with the required standards and codes, though, manufacturer's names were not engraved on the products as required. The disparity in measured and nominal sizes of some samples, made the quality control of the local bars doubtful. Bar sizes should therefore be taken into consideration and seen to be adequate before products are allowed to be circulated in Nigeria markets.**

Keywords—Reinforcing Bars; Ductility; % Elongation; Nominal Size; Yield Stress.

I. INTRODUCTION

Steel reinforcement is predominantly used in concrete works and most modern structures (e.g. building, bridges etc) are constructed using reinforced concrete. Reinforced concrete is a composite material used for construction all over the world. It comprises mainly concrete and steel as reinforcement. Knowledge concerning the characteristics and behaviour of these materials is vital if safe, reliable and durable structures are to result. Concrete is a material with very high compressive strength, very durable and good resistance to fire whereas, steel will corrode if unprotected and suffer rapid loss of strength at high temperatures but has a very good tensile resistance. The resulting combination of these two materials, known as reinforced concrete, combines many of the advantages of each; the relatively low cost, good weather and fire resistance, good compressive strength, and excellent formability of concrete and the high tensile strength and much greater ductility and toughness of steel. If these properties are combined, it will be seen that the materials play complementary roles in reinforced concrete ([10],[11],[13]).

The steel is able to provide the tensile resistance while the concrete provides the compressive resistance and also protect the steel from corrosion to give adequate durability and fire resistance. The tensile strength of concrete is only about 10 percent of the compressive strength. Because of this, nearly all reinforced concrete structure are designed on the assumption that the concrete does not resist any tensile stress. Reinforcements are designed to resist the tensile stresses, which are transferred by bond between the interfaces of the two materials ([11],[13]).

The most common type of reinforcing steel is in the form of round bars, available in a variety of diameters ranging from 6mm to 32mm. For most effective reinforcing action; it is essential that steel and concrete deforms together, i.e. there must be sufficient bond between the two materials to ensure no movement of the steel bars in the surrounding concrete. This bond is provided by the chemical adhesion that develops at the steel-concrete interface and by the closely spaced rib-shaped surface deformation on reinforcing bars to provide high degree of interlocking of the two materials. Also, for an effective reinforcing action, the thermal expansion coefficient of the two materials must be relatively close to each other. Surrounding concrete must be able to provide excellent corrosion protection and fire resistance to the steel by the provision of adequate cover to the steel bars ([9],[12]).

Design codes emphasized that steel reinforcement must adequately satisfy certain requirement with regards to yield strength, ductility and surface deformations. In Nigeria, reinforcement must satisfy requirements with regards to yield stress, ductility and surface deformations in line with [12]. The code specified that every bundle of bars or each coil shall have a label attached containing the following: NIS mark, Batch reference, Grade Specification, size, cast number, name of manufacturer and Standard Organisation of Nigeria (SON) identification mark. It also emphasized that the manufacturer shall roll a characteristics identification mark on the surface of every ribbed bar produced at intervals not greater than 1.5 metres to indicate the origin of manufacturer.

It has been observed however, that none of the reinforcing bars found in the market has neither batch reference, identification mark nor name of manufacturers. It is even doubtful if laboratory tests were carried out on these bars to ascertain their level of compliance with the NIS strength requirements. It can therefore be summarized that the level of quality control in the manufacture of these reinforcing bars cannot be ascertained. Many authors such as [1], [5], [6], [7], [8], [15], [16] etc have carried out researches on this study and based on experience, some even proposed that yield strength of high yield bars used in Nigeria should be taken as 410 N/mm2 instead of the stipulated 460 N/mm2.

It is therefore necessary to investigate the yield strength of reinforcing bars used in the country to ascertain their level of compliance with the NIS standard. This study is necessitated in view of structural collapses being experienced in the country which may be due to several factors, among which is material failure. This makes it necessary therefore to assess the viability of materials used for construction in the country (which in this project is limited to reinforcing bars). It is expected that the level of compliance of reinforcing bars with [12] with respect to yield stress, ductility and ribs pattern will be established.

STUDY AREA - The study area consist of four locations across Nigeria namely Ajaokuta, Aladja, Ikorodu and Osogbo. Ajaokuta is a town and Local Government Area in Kogi State, Nigeria and situated on Latitude 7.5561ºN and Longitude 6.655ºE. Aladja is a coastal town, one of the largest and highly populated indigenous towns in Delta State situated on Latitude 5.333ºN and Longitude 6.183ºE. Ikorodu is a city and Local Government Area in Lagos State situated on Latitude 6.600ºN and Longitude 3.500ºE, while Osogbo is the capital city of Osun State. It seats the Headquarters of both Osogbo and Olorunda Local Government Areas situated on Latitude 7.767ºN and Longitude 4.567ºE as shown in Fig.1 ([2]).

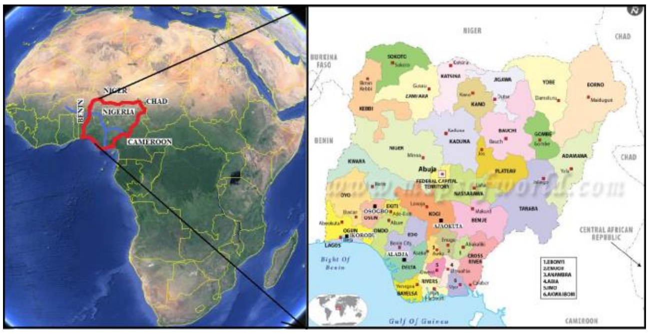


Fig. 1: Location of the Study area – Ajaokuta, Aladja, Ikorodu and Osogbo [4]

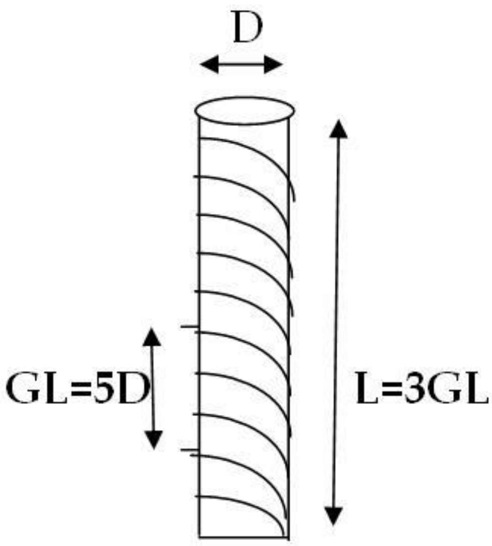
II. MATERIALS AND METHODS

MATERIALS - Locally manufactured bars were procured from four randomly selected rolling mills across the country viz;

- Ajaokuta Steel Rolling Company, Ajaokuta, Kogi State (AJ);
- Primus Steel Rolling Mill, Km 9 Osogbo-Ikirun expressway, Osogbo, Osun State (PS);
- African Steel Rolling Company, Ikorodu, Lagos State (AS) and
- Delta Steel Rolling Company, Aladja Delta State (DT).

Five (5) lengths of 13m each of 10mm, 12mm, 16mm and 20mm diameters (depending on what was available) were procured directly from the companies and at their stock piles. It was also realized that reinforcing bars were imported into the country from two major countries; Germany (GMY) and Ukraine (UKR). The available sizes (high yield) were 10mm, 12mm, 14mm and 16mm diameters. Ten (10) lengths of each size were obtained directly from the importer with identification tags on them showing their country of origin. Mild steel was obtained from the importers, as it is not produced locally, and only 16mm diameter (imported) was available. This confirms the gradual phasing out of mild steel in the construction industry. Ten lengths of the steel were procured.

METHODOLOGY - The specimens were prepared in accordance with clause 11.1.4 of [12] with a gauge length of 5D (where D is the nominal diameter of the bar). Cut length of specimen was taken as 3 x gauge length to ensure that fracture occurs approximately in the middle of the final gauge length. The specimen was cut by shearing cutters and tested as received (not machined). The geometry of the test specimen is as shown in Fig. 2 while the gauge and cut lengths are tabulated in Table 1.



Where GL is the gauge length; D is nominal diameter and L is cut length

Fig. 2: Specimen Configuration

Table 1: Gauge and Cut Length of Specimen

Nominal Diameter(mm)	Gauge Length (mm)	Cut Length (mm)
10	50	150
12	60	180
14	70	210
16	80	240
20	100	300

The machine used for the test is the Instron micro-computer controlled electromechanical universal testing machine shown in Fig 3 with a maximum load capacity of 50 kN, a speed range of 0.005 mm/min to 500 mm/min and speed accuracy of ± 1%. The machine works better under an ambient temperature of 10-35^{o}C and a relative humidity of ≤ 80%.

In line with [12], the diameter of the specimen was measured to ascertain the actual diameter using the vernier calliper. The rib pattern was also observed before the tensile test was carried out. The machine was set to a speed of 100 mm/min; the laboratory environment was regulated to a relative humidity of 50% and temperature of 27^{o}C. The specimen was made free from dust and grease and clamped in the machine using the grips with clevis pin coupling and the machine set ON. At failure, the machine automatically switches OFF and the failed specimen recovered. Strain gauges were not attached to the specimens to monitor the strains because the machine is micro-computer controlled, and processes the test results automatically.

Fig. 3: Instron micro-computer controlled electromechanical universal testing machine

Generally, the tests were conducted for Bar Size, Ductility, Rib pattern and Yield stress of the iron specimen. Yield stress and Elongation were extracted from the Instron electromechanical universal testing machine after the test. Mean Yield Stresses, Standard Deviation, % Elongation etc were determined from the results extracted and correlations established among them for the selected local and imported reinforcing iron bars. The results were compared with [3] and [12].

DUCTILITY - Ductility refers to the extent to which a material can undergo plastic deformation in tension before failure occurs. In plastic or inelastic method of design, it is important that high yield bars are sufficiently ductile for the formation of plastic hinges which eventually leads to a collapse mechanism. If the steel is not ductile enough, there will be no room for sufficient rotation for redistribution of moments to take place and a brittle or catastrophic failure will result. [2] has specified a minimum ductility as percentage elongation for reinforcing bars to make sure that reinforcing bars are ductile enough for the formation of plastic hinges at maximum moment and produce sufficient rotation for redistribution of moment to take place and finally result in a ductile failure ([14]).

YIELD STRESS - The yield stress is a parameter used in the calculation of the area of reinforcement required to reinforce the section. A small area of steel will be required to reinforce a section if the steel has a high yield stress and a small cross section of concrete will be required to accommodate the reinforcement. Unlike when bars of less yield stress (mild steel) are used, large area of reinforcement results and a large cross section will be required to accommodate it. Though reinforced concrete with small cross sections is more economical, sections must not be too small to the extent that instability of the structure/component occurs ([14]).

III. RESULTS AND DISCUSSION

Table 2: Measured Bar sizes and Rib Pattern for the selected Reinforcing Bars

SOURCE	LOCAL													IMPORTED							
	AJ				AS			DT			PS			GMY				UKR			
NOMINAL DIAMETER (mm)	10	12	16	20	10	12	16	12	16	20	10	12	16	10	12	14	16	10	12	14	16
No. of SPECIMEN	5	5	5	5	5	5	5	5	5	5	5	5	5	10	10	10	10	10	10	10	10
AVERAGE MEASURED DIAMETER (mm)	10	12	16	20	10	12	14	12	15	18	9	11	16	10	12	14	16	10	12	14	16
RIB PATTERN	Spiral				Spiral			Spiral			Spiral			Creston/ Spiral				Creston/ Spiral			

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It was noted as shown in Table 2 that the Average measured diameters of all the imported bars are equal to their respective nominal diameters while about 38.5% of the locally made bars have their measured diameters smaller than their nominal diameters, which may be an indication of the level of quality control of the local bar manufacturers. It was also observed that the surface geometry of the bars (local and imported) are such that they have transverse ribs running across the axis of the bars and spaced along the bar at uniform distances as stipulated by clause 8.1.1 of [12]. Ribs of local bars were seen to be in Spiral form over the circumference of the bar while half the circumference was in Spiral and the other half in Creston forms for imported bars. Though, none of the bars (local and imported) were found to have the names of the manufacturer stamped on it - this is against the regulation of [12].

From the Instron electromechanical universal testing machine print out after the tests, the Yield Stress and Elongation were extracted. From these results, analyses for the Mean and Standard Deviation of the Yield Stresses and % Elongation of all the selected reinforcing bars were calculated and shown in Table 3. Graphs were plotted from the Table 3 as shown in Figs. 4 and 5.

Table 3: Mean Yield Stresses and Mean of Elongation for the selected Reinforcing Bars

SOURCE	BAR DIAMETER (mm)	NUMBER OF SAMPLES	MEAN YIELD STRESSES (N/mm^2)	STANDARD DEVIATION (N/mm^2)	MEAN OF ELONGATION (mm)	MEAN OF % ELONGATION ON 5D GAUGE LENGTH (%)
AJ	10	5	358.20	41.54	5.33	10.66
	12	5	635.01	29.63	23.86	39.77
	16	5	580.25	5.48	17.29	21.61
	20	5	552.12	27.89	23 86	23.86
AS	10	5	650.46	29.63	26.25	52.50
	12	5	733.51	22.45	24.21	40.35
	16	5	714.08	14.46	24.33	30.41
DT	12	5	640.04	28.99	24.08	40.13
	16	5	644.41	25.32	18.20	22.75
	20	5	577.11	17.03	20.88	20.88
PS	10	5	405.71	5.48	7.20	14.44
	12	5	567.25	24.36	23.70	39.50
	16	5	656.87	30.26	26.90	33.63
GMY	10	10	568.70	52.11	17.83	34.56
	12	10	596.59	32.03	18.88	31.15
	14	10	597.83	89.34	18.42	25.93
	16	10	616.06	10.42	17.26	21.59
UKR	10	10	535.45	53.70	17.17	32.94
	12	10	587.44	44.97	18.04	30.07
	14	10	596.41	12.68	16.23	23.19
	16	10	656.54	7.94	17.23	21.55

It can be seen from Fig. 4 that the Yield Stresses of PS (Osogbo – Local bars), GMY (Germany – Imported bars) and UKR (Ukraine – Imported bars) increase as the diameters of bars increase. However, AJ (Ajaokuta – Local bars), AS (Ikorodu – Local bars) and DT (Aladja – Local bars) showed erratic behaviours. Initially, the Yield Stresses of AJ (Ajaokuta – Local bars), AS (Ikorodu – Local bars) and DT (Aladja – Local bars) increase as the diameters increase before decrease as the diameter of bars increase. About 8% of the imported bars have Yield Stresses below the NIS stipulated minimum standard while about 15% of the local bars have Yield Stresses below the NIS stipulated minimum standard. [12] stipulated minimum standard of 500 N/mm2 for Yield Stress and 12% for percentage Elongation.

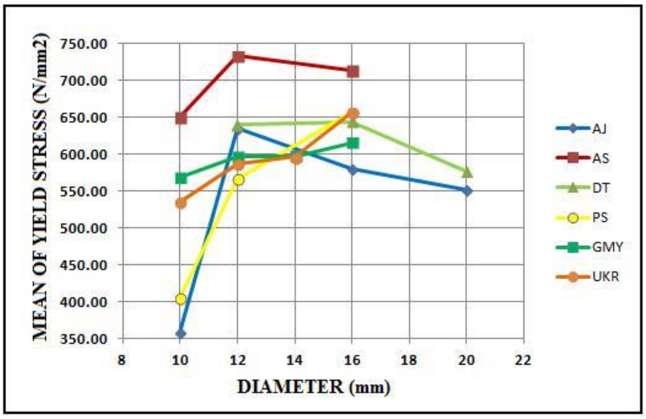

Fig. 2: Graphs for Mean Yield Stresses against Bar Diameters for the selected Reinforcing Bars

It can be seen from Fig. 5 that the % Elongation of AS (Ikorodu – Local bars), DT (Aladja – Local bars), GMY (Germany – Imported bars) and UKR (Ukraine – Imported bars) decrease as the diameters of bars increase. AJ (Ajaokuta – Local bars) and PS (Osogbo – Local bars) also showed erratic behaviours. Initially, their % Elongation increase as the diameters of bars increase before decrease as the diameters of bars increase.

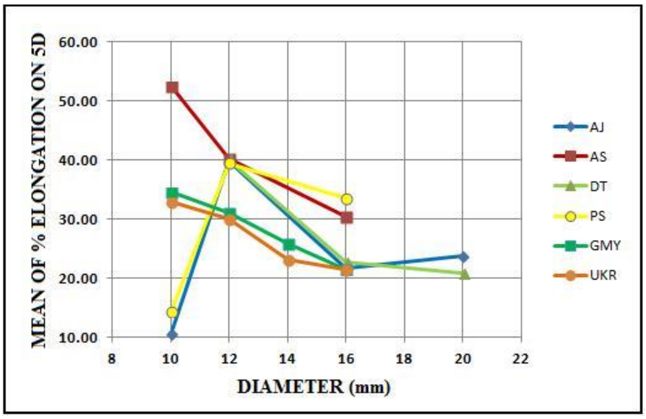

Fig. 3: Graphs for Mean of % Elongation against Bar Diameters for the selected Reinforcing Bars

Fig. 5 also indicated that about 46% of the local bars tested fell short of the NIS stipulated minimum standard of 12% Elongation while about 19% of the imported bars did not met the NIS stipulated minimum standard. Ductility of the Reinforcing bars is measured in terms of their % Elongation.

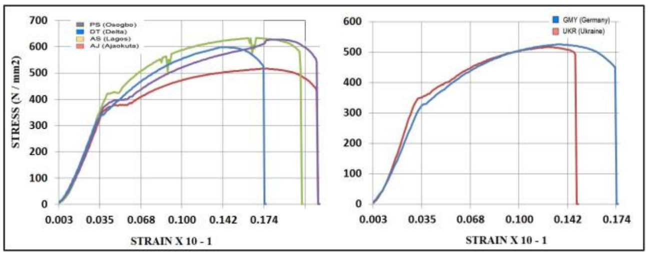

Fig. 4: Stress – Strain Curves for the selected Reinforcing Bars

Fig. 6 showed Stress/Strain curves for the local and imported bars as produced by the test machine. It was observed that graphs of the local bars looks similar, likewise that of the imported bars. Therefore, one of each (local and imported), is used for the description. It can be seen that the graphs rise steeply almost in a straight line (a-b) which is the linear elastic range. Though, the plots for the local bars showed little plateau (b-c), both curves do not show distinct yield points (like mild steel). They rose again as a result of strain hardening (c-d) and gets to the ultimate stress. Deformation continues even with decrease in load until the material breaks (e).

One of the most important properties of steel is the Modulus of Elasticity (E) which was determined from the curves in Fig. 6 for local and imported bars respectively. Using the initial straight portion of the curves, the slope denotes the Modulus of Elasticity and it was found to be 150 kN/mm2 for local and 200 kN/mm2 for imported bars. These values showed that Modulus of Elasticity for the imported bars was equal to the value specified by both [3] and [12] while that of local bars was about 25% less.

Table 4: Coefficient of Variation for the Selected Reinforcing Bars

VARIABLES	YIELD STRESS (N/mm²)		% ELONGATION	
	IMPORTED	LOCAL	IMPORTED	LOCAL
MEAN	594.38	593.5	17.67	20.47
STANDARD	37.9	32.74	1.94	6.91
COEFF. OF VARIATION (%)	6.38	18.13	11.01	33.73

The Coefficient of Variation (COV) of the data for Yield Stress and % Elongation for both local and imported bars were determined to know the consistency of the data collected and summarized as shown in Table 4. From the table, it was observed that the COV of imported bars for both Yield Stress and % Elongation were smaller than that of the local bars, indicating that the imported bars are more consistent in terms of Yield Stress and % Elongation.

IV. CONCLUSION

From the study,

1. It was found that all the reinforcing bars tested (both local and imported), except 10 mm from some local sources have their Yield Stresses greater than 500 N/mm2 and % Elongation greater than 12%. These are the minimum values specified by the code ([12]) for Yield Stress and % Elongation.
2. It was also found out that all the imported bars have their measured sizes equal to their nominal sizes, while this was not true for all the locally manufactured bars. The rib deformations of all the bars (local and imported) are in conformity with the code ([12]) recommendations, though, manufacturer's names were not engraved on the products as required by the code.
3. It is seen that the Yield Stress and % Elongation of local bars are significant to the source. Bars from Lagos are better in terms of both Yield Stress and % Elongation. Those of bars from Delta are better than that of Osogbo but Osogbo bars were better in % Elongation than Delta. Ajaokuta bars take the rear in terms of both Yield Stress and % Elongation. Though, imported bars shows no significance for both Yield Stress and % Elongation, Germany bars still offer higher Yield Stress and % Elongation than Ukraine bars.
4. Though most of the bars tested have Yield Stress and % Elongation higher than [12] specification of 500 N/mm2 and 12% respectively, but out of the local bars, bars from Lagos is seen to be the better and can be recommended for use. While government should intensify effort through its regulatory agencies (like Standard Organisation of Nigeria) to make sure that other local bar manufacturers improve on the quality of their products.
5. It was also discovered that there is disparity in measured and nominal sizes of some samples, making the quality control of the local bars doubtful. Bar sizes should therefore be taken into consideration and seen to be adequate before products are allowed to be circulated in Nigeria markets.

Further research work could be done on this study.

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