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**Case Report**

# COMPARATIVE TRACTION RESISTANCE OF 6 MM REBARS FROM NIGERIA AND TOGO USED IN CHAD

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**Abstract**

This study examines the traction mechanical properties of construction steel used in building construction in Chad. Traction tests were conducted on reinforced steel bars with a nominal diameter of 6 mm sourced from two supply chains, Nigeria and Togo, to characterize the modulus of elasticity, elasticity limit, maximum traction resistance, elongation at break, and fracture mode of the types studied [1, 2]. The results show ductile behavior for both origins; Nigerian steels, in particular, show superior performance in terms of maximum strength [3]. These mechanical performance irregularities, caused by variability in manufacturing processes and supply sources, highlight the need for systematic quality control of imported materials [4]. The results obtained provide objective data to guide the selection of reinforcing bars and thus contribute to the safety and durability of reinforced concrete structures in Chad; the study also recommends the creation of a national testing laboratory for construction materials [5].

**Keywords:** Construction steel, Traction test, Mechanical characterization, Reinforced concrete, Chad, Nigeria, Togo

## INTRODUCTION

Reinforcing steel is an essential structural component of buildings in Chad; however, it is commercialised without its mechanical characteristics being systematically characterized in a form accessible to end users, which exposes structures to the risk of under dimensioning or structural failure. This problem illustrates the interdisciplinary nature of mechanical engineering, whose methods for characterizing materials find direct application in civil engineering and materials science [6]. Steel remains a reference material in construction due to its high mechanical properties in traction, compression, torsion, and flexion [7, 8]. Nevertheless, it presents recognised limitations, susceptibility to corrosion, production costs, and environmental impact, which are driving the search for alternative materials and processes [9]. More widely, the construction sector is contributing increasingly to energy consumption, greenhouse gas emissions, and waste production [10]. Much research today is focused on reducing this impact by developing higher-performance materials or by combining multiple materials within structural elements that are durable, eco-designed, and mechanically resistant [11]. The present study is part of a larger issue concerning the traction mechanical characteristics of steels used in construction in Chad. It combines a theoretical approach with an experimental methodology and applies expertise in material selection, mechanical testing, and structural performance analysis, with direct applicable results for the Chadian context [12]. Finally, it is part of a training program in mechanical testing - design, realization, and interpretation - competencies sought in the industrial sector [13].

## LITERATURE REVIEW

In the field of materials mechanics, the knowledge of the characteristics of solids is essential for designing, dimensioning and guaranteeing the safety of structures [14]. Among the most frequently used tests, traction allows us to evaluate a material's behavior when subjected to forces that tend to elongate it along its axis [15]. Steel is one of the most frequently used materials in civil engineering because of its excellent mechanical properties, its availability, and its capacity to be formed, joined, or combined with concrete [16]. The reinforcing steel (reinforcement bars) is specifically designed for reinforced concrete; it compensates for concrete's weakness in traction [17]. It is generally presented in the form of ribbed bars (high adhesion) to improve adhesion to concrete [18].

In Chad, the usual diameters for reinforcing steel bars are normally 6, 8, 10, and 12 mm; however, these normalized values are not systematically respected in the local market.
The theoretical weight per linear meter of these bars is calculated using the following formula:

*Where p is the linear weight of the bar (kg/m), S is its nominal section (mm²), ρ is the volume mass of steel (7,850 kg/m³), and d is its nominal diameter (mm).*

Reinforcing bars commercialized must respond to norms relating to diameter, linear mass, spacing and height of the ribs, minimum elasticity limit and resistance to rupture ($R_m$), as well as non-fragility in the bending test [1, 19]. Table 1 presents the typical characteristics associated with the 6-8 mm diameter class. The main mechanical conformity requirements relate to three parameters: linear mass (kg/m), minimum elasticity limit ($R_e$), and traction resistance ($R_m$).

**Table 1. Reference Mechanical Characteristics for Reinforcing Steel [1, 9]**

| Diameter (mm) | Typical resistance (MPa) | Unit weight (kg/m) | Elastic limit $R_e$ (MPa) | Elongation at failure (%) | Resistance to traction $R_m$ (MPa) |
|---|---|---|---|---|---|
| 6-8 | ≈ 350 | 0,225-4 | 235-500 | 5-10 | 1,08-1,15. Re |

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Traction is a mechanical effort that applies to stretch or elongate a material [15]. When a material is submitted to a traction test, it passes through three great phases that can be seen on the stress-deformation diagram (Figure 1): the elastic phase, the plastic phase, and the fracture phase [20].

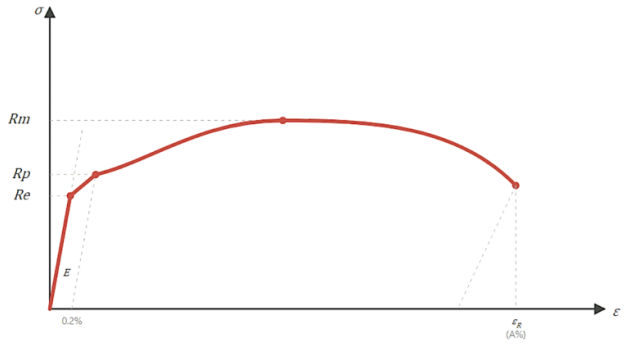



**Figure 1. Conventional traction curve [2, 15]**

*Y-axis: stress σ (MPa); X-axis: deformation ε. The linear elastic region is defined by the elastic limit $R_e$ (or the conventional limit Rp = $Re_{0.2}$), followed by the plastic region up to the maximum resistance $R_m$, and then by the striction up to the failure resistance $R_r$.*

Figure 2 shows a diagram of a cylindrical traction test specimen and its evolution during the test (uniform elongation followed by localized restriction)

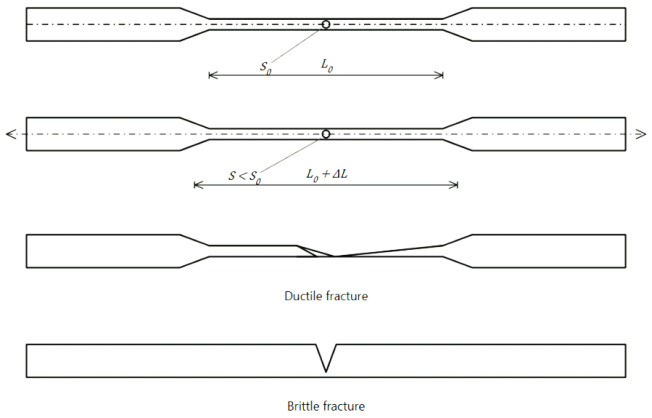



**Figure 2. Schematic of a cylindrical traction test specimen and its behavior during the test [2]**

The characteristic mechanical values are defined as follows:
Normal stress (MPa) :

Deformation :

Young's modulus (MPa) :

Many studies conducted in West Africa, particularly in Nigeria, have highlighted significant variability in the quality of reinforcing bars, both locally produced and imported [3, 4, 21].

## MATERIALS AND METHODS

### Materials Studied

The materials studied are steel bars for reinforced concrete with a nominal diameter of 6 mm, commonly called “6-mm rebar,” imported from Nigeria and Togo [12].

The bars were cut and prepared as test specimens for traction tests. Before the mechanical tests, a geometric characterization was performed to determine the real dimensions of the specimens.

### Measuring the Initial Dimensions

The dimensions of the specimens were measured using a caliper. The initial length ($L_0$), initial diameter ($d_0$), initial section ($S_0$), and linear mass were determined for each provenance. The measurement results are grouped in Table 2.

**Table 2. Geometric characteristics of the test specimens studied**

| Provenance | $L_0$ (mm) | $d_0$ (mm) | $S_0$ (mm²) | Linear mass (kg/m) |
|---|---|---|---|---|
| Nigeria | 30 | 4,55 | 16,26 | 0,127 |
| Togo | 30 | 4,10 | 13,20 | 0,103 |

The initial sections were calculated based on the measured diameters, utilizing the following equation: $S_0 = \pi \cdot d_0^2/4$. The values obtained were 16.26 mm² for the specimens from Nigeria and 13.20 mm² for those from Togo. It should be noted that the actual measured diameters (4.10–4.55 mm) are significantly less than the nominal diameter of 6 mm specified for these bars; this variance is discussed in Section 4.3.

### Preparation of Test Specimens

The test specimens were cut from bars (Figure 3). After that, threaded heads were attached to the ends of the test specimens by electric arc welding using the 111 process, with coated electrodes (Figures 4 and 5). After welding, the assemblies were cooled with water [22]. The objective of this preparation is to assemble and secure the test specimens in the testing equipment.

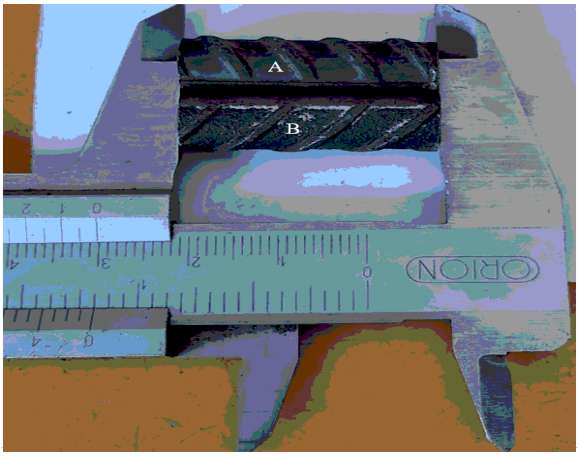
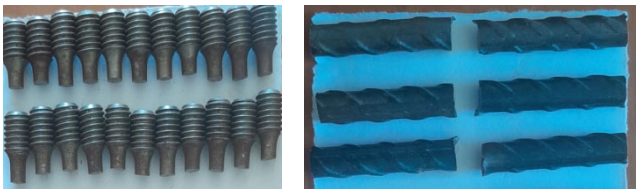
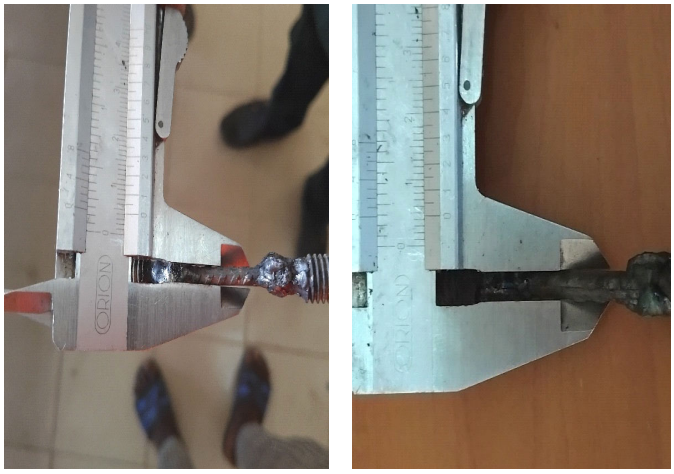



**Figure 3. Measuring the length of test specimens with a caliper: (A) Nigeria; (B) Togo**



A B

**Figure 4. Preparation of test specimens before welding: (A) Threaded steel studs (B) 30-mm pieces of rebar**



A B

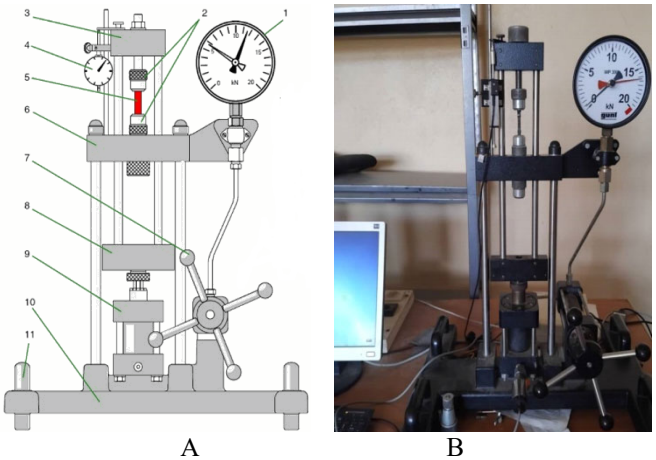
**Figure 5. Mesure du diamètre des barres au pied à coulisse : (A) Togo ; (B) Nigeria**

### Traction testing equipment

The traction tests were conducted using a machine equipped with a frame, a movable traverse, a force cell and an elongation measurement system [23]. The equipment shown in Figure 6 (A and B) includes, in particular :

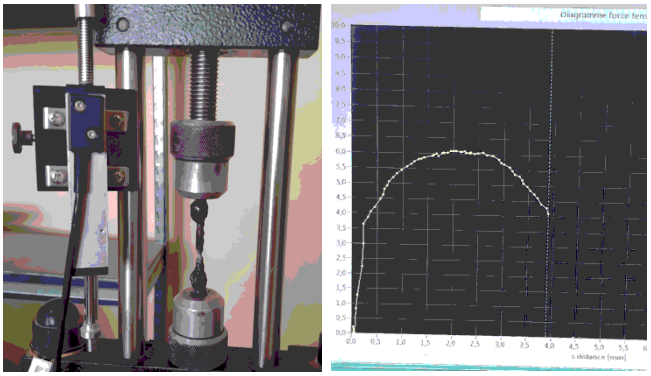
- A force indicator system;
- Clamping heads;
- An upper traverse;
- An elongation sensor;
- The test specimen;
- A protective device;
- A system associated with the force sensor;
- A Lower transverse;
- A main hydraulic cylinder;
- A mount ;
- Handling equipment.

Figure 7 presents: (A) the broken test specimen after the traction test, photographed on the test bench; (B) the traction curve for TEST-N1 of Nigerian-origin reinforcing steel, visualised on a computer.



A B

**Figure 6. Experimental traction testing equipment: (A) description of the test stand; (B) specimen mounting**



A B

**Figure 7. (A) A broken test specimen after a traction test, photographed on the test bench; (B) Traction curve for the Nigerian-origin reinforcing steel, visualized on a computer.**

### Test Procedure

Each test specimen was positioned between the machine's clamping heads. A gradually increasing traction force was then applied until the test specimen ruptured. During the test, the force (F) and elongation (ΔL) were recorded simultaneously at one-second intervals, in accordance with the adopted experimental protocol [15, 24]. The experimental data obtained were then used to plot the force-elongation and stress-deformation curves.

## RESULTS AND DISCUSSION

Uniaxial traction tests were conducted on six concrete reinforcing bar specimens with a nominal diameter of 6 mm, divided into two lots of three specimens each based on their country of origin (Togo and Nigeria). For each test, continuous recording of the applied force and elongation made it possible to plot the raw force-elongation curves (Figures 8 and 10), which were then converted into nominal stress-deformation curves $\sigma = F/S_0$ and $\varepsilon = \Delta L/L_0$ (Figures 9 and 11). The curves obtained present the four classic phases of the traction behaviour of ductile steel: a quasi-linear elastic region up to the elasticity limit, a plastic region with work hardening up to the maximum stress (traction resistance Rm), localized necking accompanied by a decline in load, and finally fracture [15, 20]. This qualitative similarity, common to both provenances, is an initial indication that the two steel grades generally belong to the same metallurgical family (mild to semi-hard reinforced concrete steel), with differences manifesting primarily at the quantitative level, as detailed in the following sections.

### Traction behaviour of 6-mm rebar imports from Togo

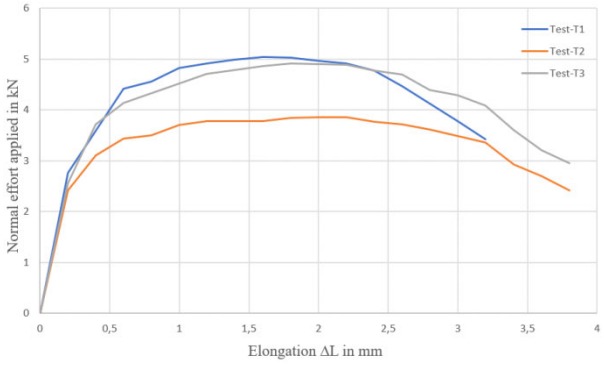



**Figure 8. Force-elongation curves for the three tests of 6 mm reinforcing bars from Togo**

**Table 3. Mechanical characteristics of 6-mm reinforcing bars from Togo**

| Mechanical Characteristics | Test-T1 | Test-T2 | Test-T3 | Average ± Standard deviation | Conformity |
|---|---|---|---|---|---|
| Elongation at rupture (mm) | 3,2 | 3,8 | 3,8 | 3,6 ± 0,35 | No |
| Maximum force $F_m$ (kN) | 5,04 | 3,86 | 4,91 | 4,6 ± 0,65 | - |
| Maximum stress $\sigma_m$ (N/mm²) | 381,82 | 292,42 | 371,97 | 348,74 ± 49,02 | Test2 No |
| Elastic deformation ε (%) | 0,63 | 0,73 | 0,73 | 0,70 ± 0,06 | - |
| Elastic limit Re (N/mm$^2$) | 209,1 | 182,58 | 193,94 | 195,21 ± 13,31 | No |
| Elasticity module E (N/mm²) | 33190,47 | 25010,96 | 26567,12 | 28256,18 ± 4343,48 | No |

**Table 4. Mechanical characteristics of 6-mm reinforcing bars imported from Nigeria**

| Mechanical Characteristics | Test-N1 | Test-N2 | Test-N3 | Average ± Standard deviation | Conformity |
|---|---|---|---|---|---|
| Elongation at rupture (mm) | 3,8 | 4,6 | 4,8 | 4,4 ± 0,53 | No |
| Maximum force Fm (kN) | 6,08 | 6,23 | 5,9 | 6,07 ± 0,17 | - |
| Maximum stress σm (N/mm²) | 373,92 | 383,14 | 362,83 | 373,30 ± 10,17 | Yes |
| Elastic deformation ε (%) | 0,86 | 0,93 | 1,23 | 1,01 ± 0,20 | - |
| Elastic limit Re (N/mm2) | 224,48 | 236,16 | 228,78 | 229,81 ± 5,91 | E1 et E3 No |
| Elasticity module E (N/mm²) | 26102,32 | 25393,55 | 18600 | 23365,29 ± 4142,05 | No |

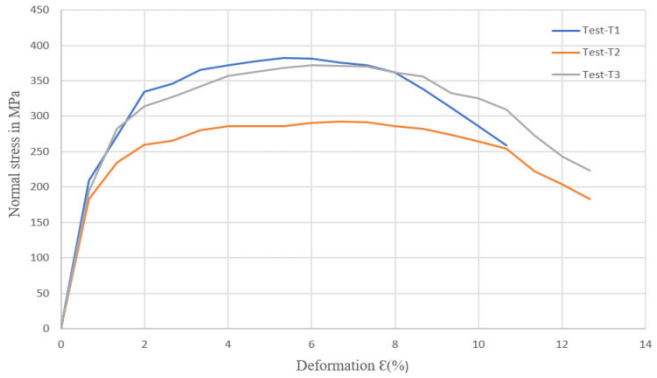



**Figure 9. Stress-deformation curves for the three tests on 6 mm reinforcing bars from Togo**

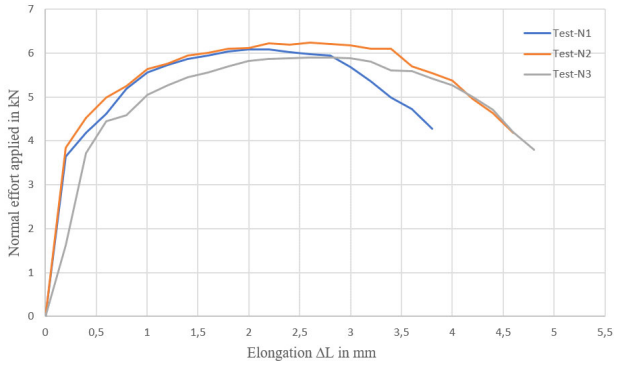



**Figure 10. Force-elongation curves for the three tests of 6 mm reinforcing bars from Nigeria**

The three Togolese test specimens (T1, T2, T3) presented an average maximum stress of 348.74 ± 49.02 N/mm² (Table 3), with marked inter-specimen variation (coefficient of variation ≈ 14%): Test T2 stands out clearly from T1 and T3 (292.42 N/mm² versus 381.82 and 371.97 N/mm², Figure 9), a difference also visible on the force-elongation curve (Figure 8), where T2 reached approximately 3.86 kN compared to 5.04 and 4.91 kN for T1 and T3, respectively. This dispersion suggests either section heterogeneity along the length of the tested bar or a localized defect (inclusion, surface decarburization) specific to this test specimen. In terms of standard values, none of the three test specimens attained the expected conventional elastic limit (average Re = 195.21 ± 13.31 N/mm²), and the apparent modulus of elasticity, which shows significant variation (28,256 ± 4,343 N/mm²), remains well below the ≈ 200,000 N/mm² required for steel. A module that is also variable is the result of an initial slippage in the grips of the traction assembly rather than an intrinsic property of the material, which raises more concerns about the rigidity of the experimental protocol than about the steel quality itself [16]. The elongation at rupture, ranging from 3.2 to 3.8 mm (average 3.6 ± 0.35 mm), indicates ductile behavior but with an overall modest capacity for plastic deformation compared to the values expected for a high-ductility reinforcing steel.

### Traction behaviour of 6-mm reinforcing bars from Nigeria

The three Nigerian test specimens (N1, N2, N3) show significantly more consistent resistance to traction (373.30 ± 10.17 N/mm², coefficient of variation ≈ 2.7%, which is one order of greatness lower than that of Togo), indicating better control of the manufacturing process or greater homogeneity of the primary material for this lot.

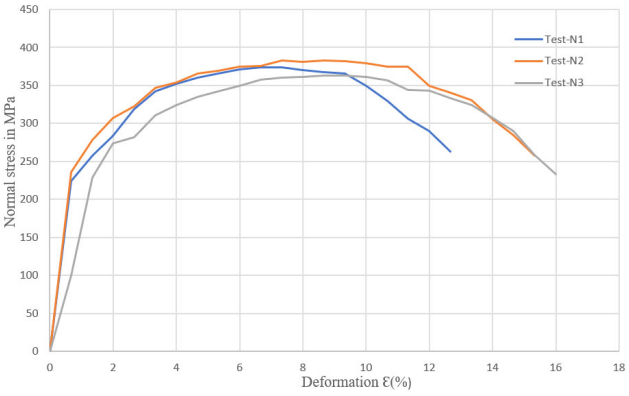



**Figure 11. Stress-deformation curves for the three tests of 6 mm reinforcing bars from Nigeria**

The average maximum stress satisfies the expected standard value (Table 4, compliance "Yes"), contrary to the Togolese lot. However, the elastic limit (229.81 ± 5.91 N/mm²) remains noncompliant for two of the three tests (E1 and E3), indicating that the point of vigilance for this origin is more related to behavior at the beginning of plastic deformation than to ultimate resistance. The stress-deformation curves (Figure 11) also reveal an elongation at rupture that is significantly higher than that of the Togo steel, reaching ≈ 16% of nominal deformation for specimen N3 compared to a maximum of ≈ 12.7% for the Togo steel (Figure 9), indicating significantly higher ductility for the Nigerian steels. The apparent elasticity module (23,365 ± 4,142 N/mm²) also remains lower than the theoretical value for steel, for the methodological reasons mentioned previously.

**Comparative Analysis of Mechanical Properties: Togo and Nigeria**

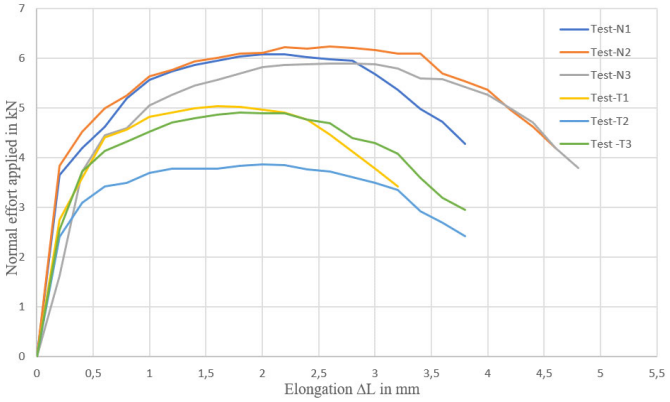



**Figure 12. Comparison of the F-ΔL curves from the three tests of 6 mm reinforcing bars imported from Nigeria and Togo**

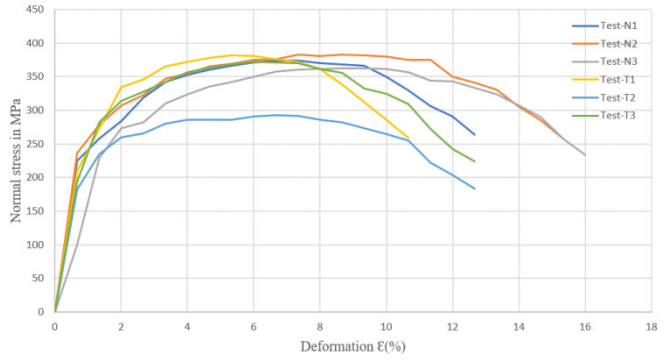



**Figure 13. Comparison of the σ-ε curves for the three 6 mm reinforcing bar specimens imported from Nigeria and Togo**

The superimposition of the six curves (Figures 12 and 13) highlights two systematic differences between the two sources. First, in terms of resistance: the Nigerian curves are globally above the Togolese curves across practically the entire plastics domain, both in terms of force and stress, with an average difference in resistance of approximately 25 N/mm² (373.30 versus 348.74 N/mm², or about +7%). Secondly, and more significantly, in terms of ductility: the Nigerian test specimens can support a deformation before fracture that is approximately 30 to 40 percent greater than that of the Togolese test specimens. This dual advantage simultaneously superior resistance and ductility is particularly noteworthy, as these two properties are generally antagonistic in steels; a strengthening of the metal matrix is most often accompanied by a reduction in ductility [3, 21]. Several metallurgical factors-which should be confirmed by complementary tests-may explain this discrepancy: (i) a different chemical composition, particularly the carbon equivalent content and the alloying elements (Mn, Si), which together govern the elastic limit and ductility of construction steels [25]; (ii) different hot-rolling conditions (final rolling temperature, speed of cooling) that influence the ferritic grain size and, consequently, the resistance/ductility ratio according to the Hall-Petch relationship; (iii) a thermomechanical treatment such as Tempcore or its equivalent, more or less mastered depending on the manufacturer, which confers on modern bars a martensitic surface layer that has been tempered, enclosed by a ductile ferritic-pearlitic heart. In terms of conformity with standards, neither lot fully meets the dimensional requirements (diameter) or the required yield strength; only the Nigerian lot satisfies the maximum resistance criterion. This double nonconformity, for steels that are commonly used on construction sites, constitutes a warning signal for the quality control system for construction materials imported into Chad, and is reflected in similar findings in other countries in the subregion [4, 5, 26]. These results must, however, be interpreted with the precaution required by a trial size of three test specimens per lot : The observed dispersion, particularly for the Togolese lot, does not allow us to exclude a sampling effect, and a statistical test for comparison of means (Student's t-test or a nonparametric test, given the small sample size), conducted on a larger number of test specimens, would be necessary to confirm with sufficient confidence the significance of the differences in resistance and ductility observed between the two provenance groups. Similarly, mechanical characterization does not allow a decision to be made between the metallurgical hypotheses mentioned above; a supplementary analysis of chemical composition (spectrometry) and micrographic observation of the rupture facies would provide decisive insight into the origin of the observed differences. From a practical viewpoint, awaiting more in-depth characterization, these results recommend prioritizing, for structural applications requiring high ductility (seismic zones, elements subject to cyclic or accidental loads), the Nigerian reinforcement bars tested here, while noting that neither lot fully satisfies the standard requirements for diameter and elasticity limit, which justifies systematic inspection upon receipt at construction sites in Chad, independent of the origin of the reinforcement bars used. In essence, the diameters of the two origins do not conform to the six-millimeter nominal diameter specified, and the ruptures observed are ductile for the two steel grades. Nigerian steels show superior ultimate resistance combined with a better resistence-ductility balance [3, 21], results that are globally similar to those reported in the African literature on imported steels [4, 5, 26].

## Conclusion

This study highlights significant variations in the traction mechanical properties of reinforcing steels sold in Chad, depending on their origin, Nigeria or Togo [3, 12]. Nigerian steels generally show superior performance in terms of resistance and ductility, designating them as the preferred choice for structural elements that are likely to be subjected to high stresses [21]. The precise characterization of these parameters is an indispensable prerequisite for the correct dimensioning of reinforced concrete structures [9, 17]. From an operational standpoint, these results pleads in favor systematic quality control of imported construction materials and the creation of a national materials testing laboratory [5]. This work also opens up several possibilities for research, notably complementary torsion tests as well as chemical and microstructural analyses, and calls for the promotion of local production of better quality steels [11, 25]. The safety and durability of construction in Chad require closer collaboration between engineers, testing laboratories, and regulatory authorities [7, 8].

## Author Contributions

Conceptualization, Djondang Sindang; methodology, Djondang Sindang , Mahamat Nour Chaibou; software, Baïmi Badjoua, Djondang Sindang ; validation, Djondang Sindang , Baïmi Badjoua Mahamat Nour Chaibou; formal analysis, Djondang Sindang ; investigation, Djondang Sindang ; resources, Djondang Sindang.; data curation, Djondang

Sindang.; writing-original draft preparation, Djondang Sindang; writing-review and editing, Djondang Sindang, Baïmi Badjoua, Mahamat Nour Chaibou ; visualization, Djondang Sindang; supervision, Djondang Sindang; project administration, Djondang Sindang; funding acquisition, Djondang Sindang , Mahamat Nour Chaibou. All authors have read and agreed to the published version of the manuscript.

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**Author information**

**Conflicts of Interest**

The authors declare no conflicts of interest regarding the publication of this paper.

Ethics declarations
Ethics approval and consent to participate

Not applicable.
Consent for publication

Not applicable.
Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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