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Mechanical Properties and Microstructural Analysis of Reinforcement Steel Bars in Osun State Construction Industry

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ABSTRACT

Steel bars are crucial components in structural engineering. The frequent incidents of building collapse in Nigeria highlight the importance of carefully analysing the characteristics of reinforcement steel bars available in the local market. A study was conducted in Osun State to evaluate the compliance of locally available steel bars with essential standards. The study examined the mechanical properties of reinforcement steel rods with diameters of 7, 9, 12, and 14 mm, procured from a random selection of four prominent dealers with a moderate customer base in the Osun State market. Using a universal testing machine and Brinell hardness tester, standard procedures were employed to determine hardness values, yield strength, and ultimate tensile strength. Additionally, Scanning Electron Microscopy (SEM) was used to investigate microstructural properties at the metallurgy laboratory of SARD and the Department of Materials Science and Engineering, Obafemi Awolowo University, Ile-Ife, Osun State. The mechanical evaluation of reinforcement steel bar samples (A, B, C and D) from Osun State markets showed that only Sample B met the NIS 117 standard, while Samples A, C, and D failed ASTM A706 and BS 4449 yield strength requirements. None met the UTS standards. SEM analysis revealed that surface roughness reduced strength in Samples A and B, while microvoids and inclusions weakened Samples B and D. Sample C exhibited brittle fracture, indicating low ductility. These defects make the bars unsuitable for high-load applications. These defects make the reinforcement steel bars unsuitable for high-load applications without proper treatment. It is therefore concluded that Rigorous quality control, standardized testing, and proper procurement of steel bars are essential to ensure safety in construction projects.

INTRODUCTION

The construction industry is a cornerstone of national development, providing critical infrastructure that supports economic growth and societal advancement (Julius *et al.*, 2023). Reinforced concrete, a composite material combining concrete and reinforcement steel bars (rebar), is a fundamental element in modern construction, ensuring durability, stability, and structural safety (Aiyedun *et al.*, 2023). Steel bars provide the tensile strength that plain concrete lacks, making them indispensable in diverse applications, from residential buildings to large-scale industrial structures (Idiata *et al.*, 2023).

In Nigeria, the rapid urbanization and infrastructural expansion, particularly in Osun State, have significantly increased the demand for reinforced concrete (Adekunle, 2024; Aluko, 2011). However, this growth has been accompanied by mounting concerns regarding the quality and reliability of locally produced reinforcement steel bars. Empirical studies and anecdotal evidence indicate that substandard steel materials are frequently used in construction projects, contributing to structural failures, economic losses, and safety risks (Rufai, 2023).

The quality of reinforcement steel bars is intrinsically linked to their mechanical properties, such as tensile strength, yield strength, and elongation, as well as their microstructural characteristics, including grain size, phase distribution, and the presence of defects (Rufai, 2023; Shuaib-Babata *et al*., 2019). These properties are vital for assessing the ability of the material to withstand stresses and environmental conditions encountered in structural applications. In Nigeria, the prevalent use of recycled scrap materials in steel production has introduced significant variability in the chemical composition, microstructure and mechanical performance of reinforcing bars (Julius *et al*., 2023; Odusote *et al*., 2019). This practice often deviates from internationally recognized standards, such as Nigerian Industrial Standards (NIS), British Standards (BS), and ASTM International Standards.

Structural failures in Nigerian urban centers remain a pressing challenge, with a significant portion attributed to the use of substandard reinforcement steel bars (Onomivbori and Agbafor, 2022). While Lagos and Abuja have recorded a higher number of structural failure incidents, as reported in the literature in Ogundeji, 2025. Osun State has not been entirely spared, although the state has witnessed fewer cases, only two within the same period (Ogundeji, 2025). The issue remains a concern. One notable incident, documented by Olawale (2015), involved the collapse of a single-story building along University Road, Oke-Baale, Osogbo. Adeosun *et al*. (2020) highlighted several contributing factors to building failures in Osun State, including poor workmanship, the use of substandard materials, faulty design, and non-adherence to construction specifications. Additionally, inadequate supervision and flawed designs have further exacerbated the problem (Olasunkanmi, 2022).

This study assesses the mechanical performance and microstructural properties of reinforcement steel bars sourced from a random selection of four prominent dealers with a moderate customer base in the Osun State market. By correlating these properties with compliance with established standards (AISI, 2024; ASTM, 2009; ISO, 2007; SON, 2004). The study seeks to provide actionable recommendations for improving the quality of construction materials. These findings will contribute to fostering safer and more resilient infrastructure development in the region

METHODOLOGY

In this study, reinforcement rods ranging from 6 mm to 14 mm were procured from four different dealers in the local market in Osun State, Nigeria. These dealers were randomly selected based on their extensive customer networks within the state. The research focused on analysing the mechanical and microstructural properties of steel rods in selected sizes: 14 mm, 12 mm, 10 mm, and 8 mm, sourced from dealers A, B, C, and D. However, measurements of the procured samples revealed actual sizes of 14 mm, 12 mm, 9 mm, and 7 mm, respectively. Notably, the rods obtained from dealers C and D deviated from the standard sizes of 10 mm and 8 mm, which are commonly used in the region for various construction applications. This deviation in reinforcement steel rod sizes may be a deliberate practice by steel producers aimed at cost reduction, often to the detriment of buyers (Bame *et al*., 2023). This phenomenon, sometimes called the

"Nigeria factor," raises concerns regarding material integrity and structural safety. Additionally, factors such as manufacturing defects, material shrinkage and expansion, as well as wear and tear of rolling dies and equipment, could also contribute to these inconsistencies. The steel rod samples A, B, C, and D were washed and cleaned before each sample was cut into four specimens, resulting in 16 specimens for mechanical and microstructural analysis, as detailed in Table 1. This labeling system facilitated a comprehensive comparative analysis of the samples.

To test the mechanical properties of specimens 1, 2 and 3, tensile testing was conducted at the SARD at Obafemi Awolowo University Laboratory, using the Universal Tensile Testing Machine. Throughout the test, the universal machine jaws applied force to pull the specimens apart until fracture.

Table 1: Samples for Each Prominent Dealer

	DEALER A (14 mm)	DEALER B (12 mm)	DEALER C (9 mm)	DEALER D (7 mm)
SPECIMEN 1	A1	B1	C1	D1
SPECIMEN 2	A2	B2	C2	D2
SPECIMEN 3	A3	B3	C3	D3
SPECIMEN 4	A4	B4	C4	D4

The load-to-extension graphs were generated as the load was incrementally applied to the tensile specimens, coupled with tensile stress to tensile strain as shown in Figure 1. The ultimate tensile strength (UTS) and yield strength (YS) were determined, and the percentage elongation was calculated.

Additionally, the hardness of the samples was assessed using a Brinell hardness tester. The obtained Brinell hardness number was reported as a Rockwell value (HRC) to facilitate comparison with commonly referenced hardness scales in engineering applications. For the microstructural analysis, Scanning Electron Microscopy (SEM) was used at the Department of Material Science and Engineering to examine the microstructural properties of specimen 4, which constitutes the four samples sourced from the prominent dealers in the Osun State market.

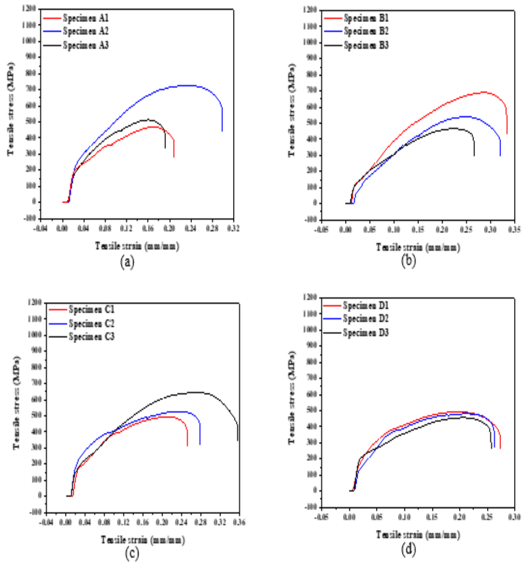

Figure 1: The Tensile Stress-Strain curves of Samples (a) A, (b) B, (c) C and (d) D

RESULTS AND DISCUSSION

Mechanical Properties

The comparative analysis of yield and ultimate tensile strengths among reinforcing steel bars sourced from four prominent dealers in the Osun State market is detailed in Figures 2 and 3 aligning the findings with established standards. The observed variations in both yield strength (ranging from 378.19 to 436.18 MPa) and ultimate tensile strength (ranging from 477.04 to 569.14 MPa) were contingent upon the different diameters of the steel bars examined. The percentage elongation, depicted in Figure 4, exhibited a range of 23.26% to 30.58% across the range of steel bar diameters (14 mm to 7 mm). Figure 5 illustrates the hardness values (24.24 to 43.91 HRC) for a variety of steel bars acquired from four prominent dealers, providing further insights into the mechanical properties essential for structural engineering applications. This comprehensive evaluation underscores the significance of assessing quality attributes such as mechanical properties and compliance with standards in reinforcing steel bars within the context of structural engineering considerations.

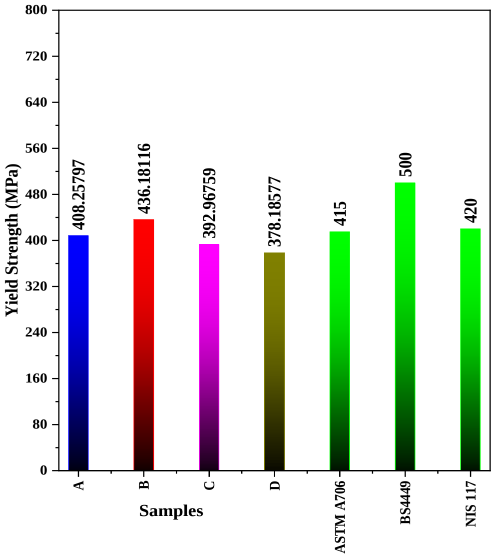

Figure 2: Yield Strength of The Samples

Tensile Strength and Yield Strength:

The transition from elastic to plastic deformation, denoted by the yield point, establishes the yield strength of reinforcing steel bars, crucial for structural and construction applications (Tavio *et al.*, 2018). ASTM A706 (ASTM, 2009), BS4449 (BSI, 2005), and NIS 117 (ISO, 2007) have set the benchmark yield strengths at 415 MPa, 500 MPa, and 420 MPa, respectively. In Figure 2, it is evident that the reinforcing steel bars from samples A, B, C, and D (7, 9, 12, and 14 mm) having 408.26MPa, 436.18 MPa, 392.97 MPa, 378.19 MPa respectively exhibit lower yield strengths compared to these established standards, particularly as per BS4449 (BSI, 2005). While samples B met ASTM A706 and NIS 117 standards, samples A, C and D have 1.65%, 5.61% and 9.73% less yield strength when compared with ASTM A 706, respectively, 2.88%, 6.88%, and 11.06% less yield strength when compared with NIS 117 standard. The underlying trend observed could be caused by the substandard raw materials, improper alloy composition, inadequate heat treatment, rolling process defects, excessive material porosity, and overstretching during cold working. Addressing this issue is imperative for ensuring compliance with reinforcing steel bars with industry standards. Also, the yield strength observed in the current study was compared with the findings from previous research, as outlined in Table 2. Comparative analysis reveals that the yield strength surpasses that of Alabi and Onyeji (2010) for reinforcing steel bars failing to meet required standards. Adequate yield strength in reinforcing steel bars is of paramount importance to effectively resist tensile forces within a concrete structure; without sufficient yield strength, the reinforcement would not be able to properly carry loads and could lead to structural failure (Idiata *et al.*, 2023). Figure 3 presents the variation in Ultimate Tensile Strength (UTS) among the tested reinforcing steel bar samples, representing the maximum load they can endure before reaching the point of fracture. According to the specified standards: NIS 117 (ISO, 2007), BS4449 (BSI, 2005), and ASTM A706 (ASTM, 2009)—the UTS benchmarks stand at 500 MPa, 600 MPa, and 590

MPa, respectively. All steel bar samples procured from the four prominent dealers align with the NIS 117 requirement, except the 14-mm-diameter sample D, registering a UTS of 477.04 MPa, falling short of the stipulated standards by 4.81%. None of the sampled steel bars met the recommended UTS standards outlined by ASTM A706 and BS4449. Also, the UTS observed in the current study was compared with the findings from previous research, as outlined in Table 2.

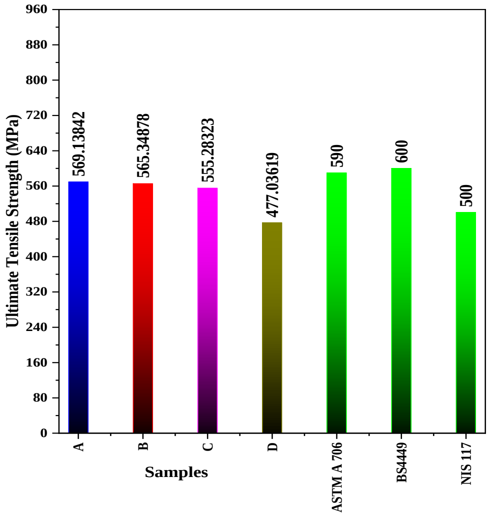

Figure 3: Ultimate Tensile Strength of The Samples

Table 2: Mechanical Properties of Reinforcing Steel Bar Samples Compared with Previous Studies

Samples	Yield Strength (MPa)	UTS (MPa)	Elongation (%)	Hardness (HRC)	References
A	408.26	569.14	23.26	43.91	Present study
B	436.18	565.35	30.58	41.2	Present study
C	392.98	555.28	29.52	36.98	Present study
D	378.19	477.04	26.46	24.24	Present study
EC	460	597	9.0	21.2	Adeleke and Odusote, (2013)
IC	486	586	11.7	20.2	Adeleke and Odusote, (2013)
SC	551	626	9.1	19.6	Adeleke and Odusote, (2013)
SF	400	693	18.0	47.9	Alabi and Onyeji, (2010)
US	450	652	28.0	44.3	Alabi and Onyeji, (2010)
NS	400	611	28.0	47.3	Alabi and Onyeji, (2010)
AS	325	660	25.0	45.5	Alabi and Onyeji, (2010)

Comparative analysis reveals that the UTS of the present study was close to those reported by Adeleke and Odusote, (2013) for reinforcing steel bars failing to meet required standards. Adequate UTS in reinforcing steel bars is of paramount importance to resist tension and maintain the structural integrity of the concrete by preventing cracks. This makes it an important consideration when selecting rebar for construction projects; a higher ultimate tensile strength indicates a stronger steel that can withstand greater stress before failure.

Percentage Elongation:

The different samples of reinforcing steel bars, labeled A, B, C, and D, demonstrate varying percentage elongations of 23.26%, 30.58%, 29.52%, and 26.46%, respectively, as shown in Figure 4. These variations demonstrate differences in their ductility and ability to undergo deformation under applied stress. The percentage elongation observed in the current study was compared with findings from prior research, as outlined in Table 2. Comparative analysis reveals that the elongation percentages surpass those reported by Adeleke and Odusote, (2013) for reinforcing steel bars failing to meet required standards. Adequate ductility in reinforcing steel bars is of paramount importance, as it directly influences the ductility of structural members in reinforced concrete (Abubakar and Abdulmajeed, 2023). Figure 4 provides an affirmation that all examined reinforcing steel bars possess sufficient ductility, are capable of withstanding unfavourable distribution of plastic deformations, and mitigate the risks of premature tensile fracture and buckling during utilization. This inherent ductility is crucial for ensuring the structural resilience and longevity of reinforced concrete components.

Hardness:

Hardness, denoting a material's resistance to abrasion, was assessed for all reinforcement steel bars from samples A, B, C and D. The results reveal that samples A, B, C and D have hardness values of 43.91, 41.2, 36.98, and 24.24 HRC. The hardness values meet the stipulated ASTM (15.46 HRC) and BS4449 (13.48 HRC) standards, as highlighted in Figure 5. A comparison of the hardness values (HRC) in the current study with findings from previous research, as shown in Table 2, reveals that samples A, B, C and D exhibit considerably higher hardness values than those reported by Adeleke and Odusote, (2013) but align closely with the results obtained by Alabi and Onyeji, (2010). The high hardness values are essential for the effectiveness of reinforcing steel bars in construction and structural applications. A deficiency in hardness, below recommended standards, can adversely impact the performance of steel bars in service.

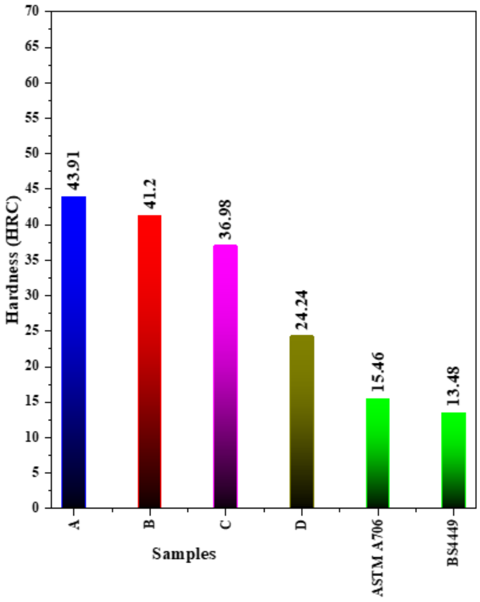

Figure 4: Percentage Elongation of The Samples

Microstructural Analysis

Scanning Electron Microscopy (SEM) was employed to analyse the surface roughness, irregularities, microvoids, inclusions and fracture characteristics of steel samples A, B, C and D, with sizes of 7 mm, 9 mm, 12 mm and 14 mm, respectively and their effects on mechanical properties. The SEM images of samples A, B, C and D, as shown in Figure 6, reveal several defects, including surface roughness, microvoids, inclusions, and brittle fracture patterns, all of which significantly impact the mechanical properties of the material. Surface roughness, as observed in samples A and B as presented in Figure 6a and Figure 6b, introduces stress concentration points that reduce yield strength and ultimate tensile stress (UTS) by facilitating early crack initiation.

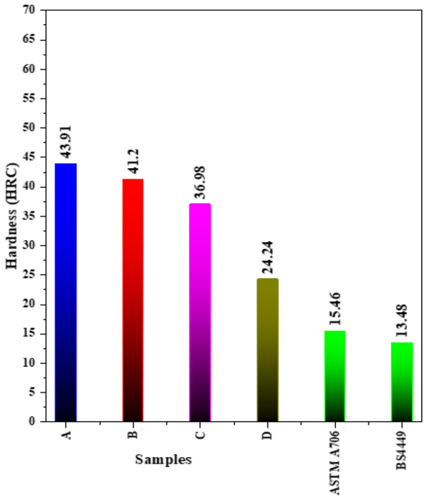

Figure 5: Hardness Value of The Samples

This roughness can also lower hardness due to inconsistent material properties across the surface. Additionally, rough regions may indicate oxidation or wear, which can make the surface brittle and reduce ductility, leading to premature failure under tensile loading. Microvoids and inclusions, evident in samples B and D as presented in Figures 6b and 7d, create weak spots that degrade mechanical integrity. These defects decrease yield strength and UTS by providing sites for crack nucleation and propagation, which reduces overall load-bearing capacity. Furthermore, inclusions may introduce brittle phases into the material, increasing localized hardness while compromising toughness and elongation. The presence of fractured and highly textured surfaces, as seen in sample C and presented in Figure 6c, suggests brittle fracture, indicating that the material has low ductility and fails without significant deformation. Such failure mechanisms are common in materials exposed to improper heat treatment, leading to sudden and catastrophic failure. To improve mechanical properties, techniques such as surface treatments, heat treatments, and grain refinement can be employed to reduce defect severity, enhance strength, and improve toughness. Proper material processing and testing are crucial to mitigating these issues and ensuring long-term reliability.

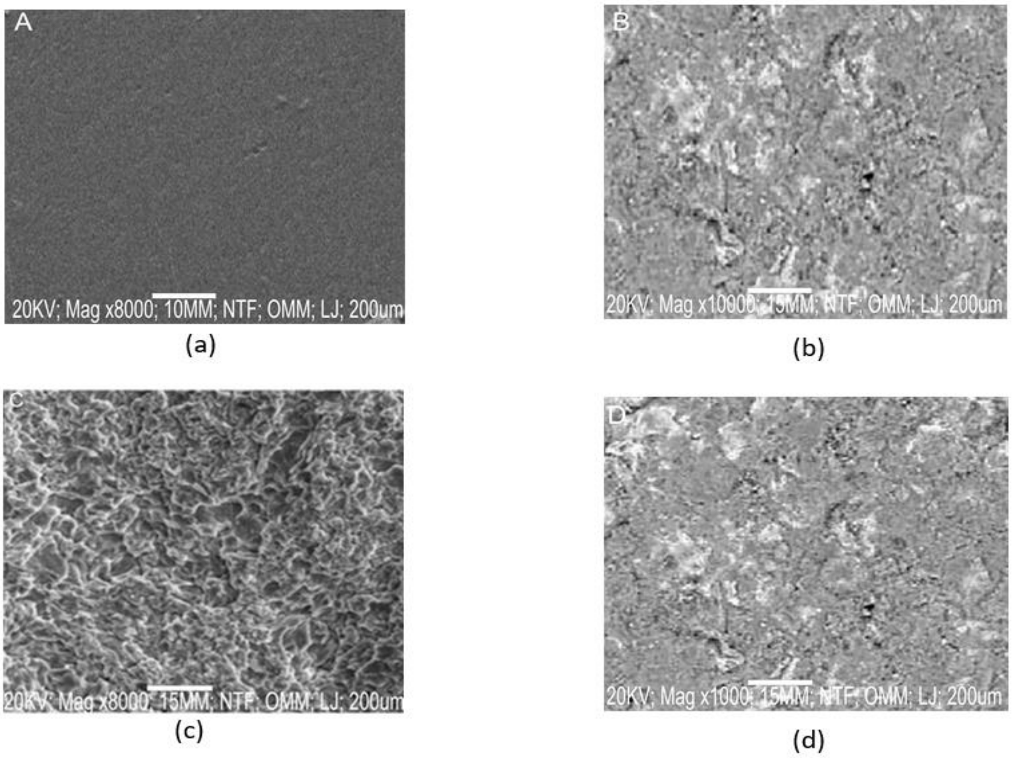

Figure 6: Scanning Electron Microscopy result for the samples (a) A (b) B (c) C and (d) D

CONCLUSION

The investigation on the mechanical and microstructural properties of reinforcing steel bars obtained from four major dealers in the Osun State market has yielded comprehensive insights. The SEM images show defects like surface roughness, microvoids, inclusions, and brittle fracture, all negatively impacting mechanical properties. Surface roughness lowers the yield strength and tensile stress of Samples A and B by creating stress concentrators, while microvoids and inclusions act as crack initiation sites, reducing the strength and ductility of Samples B and D. Brittle fracture of Sample C suggests low ductility, leading to sudden failure under stress. These defects make the reinforcement steel bars unsuitable for high-load applications without proper treatment. In support of the SEM analysis, the mechanical evaluation demonstrated that while Sample B met the NIS 117 standard, Samples A, C, and D failed to satisfy the yield strength requirements of ASTM A706 and BS 4449. Furthermore, none of the samples met the ultimate tensile strength (UTS) standards of ASTM A706 and BS 4449. However, all samples exceeded the minimum requirements for hardness and percentage elongation. Therefore, these steel bars are not suitable for high-load structural applications.

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