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Investigating the Quality Parameter Ranges of Reinforcing Ribbed Bars Used in Uganda's Construction Industry

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Abstract
Using standard reinforcing ribbed bars is important for maintaining the durability and structural integrity of buildings. However, Uganda has faced a concerning rise in building collapses attributed to substandard rebars, resulting in loss of life, financial burdens, and legal repercussions for clients. This problem may worsen if not addressed, leading to additional casualties and economic damage. To address rebar concerns, an investigation was conducted focusing on various quality parameters, such as mass per unit length, mechanical properties, and chemical composition. Tests were performed on 10mm and 12mm rebars from four hardware stores representing four steel manufacturers. Initial measurements indicated that mass per unit length was within acceptable ranges: 0.567-0.667 Kg/m for 10mm and 0.838-0.938 Kg/m for 12mm rebars. Mechanical testing showed yield stress exceeded the minimum requirement of 500 MPa across all samples, with elongation above 14%. However, some rebars (A10, B12, C10, C12, and D12) failed to meet the required stress ratio of 1.15 as per US EAS 412-2-2022. Chemical analysis revealed slight variations in elements but met established standards, with only three rebars (A12, B10, and D10) conforming to quality parameters, highlighting the need for stricter adherence to standards to prevent structural failures.
Keywords: Building Collapses, Durability, Mechanical Properties, Quality Parameters, Reinforcing Bars.

I. Introduction

The increasing use of high-strength Thermo-Mechanically-Treated (TMT) steel bars in the construction of flyovers, bridges, and tall buildings is notable due to their favorable mechanical properties (Ssempijja, 2019). In Uganda, the steel industry has witnessed significant growth, with various steel products, including rebars, being manufactured locally. This shift is important as the construction sector previously relied on imported steel products, which were both costly and inconsistent in quality (Senfuka et al., 2012). The expansion of large-scale infrastructure projects, the developing oil and gas sector, rapid population growth, access to neighboring markets, and urban development have all contributed to opportunities for further development of the domestic steel manufacturing industry (Ssempijja, 2019).

However, the quality of reinforcement steel bars produced in Uganda faces challenges, particularly regarding the use of recycled metal scraps. Research conducted by Munyazikwiye, (2010), highlights the essential role that rebars play in extending the service life of construction buildings and structures. The reliance on recycled materials, as noted by Achamyeleh (2022), introduces variability in mechanical properties, primarily due to impurities, leading to a perception that locally produced rebars are substandard. This has affected consumer behavior significantly, as concerns about quality persist.

Reinforcing steel bars, or rebars, is important for reinforcing concrete structures (Munyazikwiye, 2010), and their demand is expected to continue growing (Delali and Sasu, 2022). The construction industry increasingly favors high-strength TMT steel bars for their optimal mechanical properties, especially when structural integrity is at stake (Ssempijja, 2019). If the rebars do not meet requisite mechanical properties, there is a risk of structural failures occurring before their anticipated lifespan (Joshua et al., 2013). Munyazikwiye, (2010) emphasizes that the role of rebars in construction is critical, as they significantly influence the longevity of buildings and structures.

Nevertheless, the use of recycled metal scraps poses challenges. Tariku, (2022) pointed out that differences in mechanical characteristics stem from inconsistent feed and impurities during steel production. Moreover, the Uganda National Bureau of Standards (UNBS) issued a warning on June 18, 2021, regarding the influx of substandard iron bars in the market and emphasized compliance with Ugandan Standards US EAS 412-2:2019 for ribbed bars. Corrosion remains a significant durability concern for TMT rebars, as noted by Dey et al. (2022), further complicating the market situation. The potential presence of substandard rebars raises concerns over construction project safety and integrity (Joshua et al., 2013).

Senfuka et al. (2012) identified another challenge for the Ugandan steel industry: the quality and quantity of appropriate steel scrap. The reliance on low-quality scrap can lead to poor-quality steel, affecting overall construction quality. Additionally, a lack of technical expertise in material testing for construction steel can result in unmet design expectations, negatively impacting site control and compliance (Arinaitwe and Nkubana, 2018). The emphasis on quality control of reinforcement steel bars, particularly those produced from recycled metal scraps, is important as variations in mechanical properties could compromise construction projects (Munyazikwiye, 2010).

The growing demand for high-strength TMT steel bars highlights the need for stringent quality and reliability measures to prevent structural failures (Joshua et al., 2013). Steel continues to be the preferred material for reinforcing concrete due to its strength and compatibility; however, the presence of substandard rebars in the market remains a significant issue (Rafi and Lodi, 2015; Dey et al., 2022). Building on Ssempijja's (2019) research, which indicated that some carbon-made bars of 20mm diameter did not meet acceptable standards, further investigation is necessary.

This paper aimed at evaluating mass per unit length, mechanical properties, and chemical composition, ultimately assessing conformity to established quality standards, specifically US EAS 412-2-2022. Addressing these issues was important for enhancing the quality and reliability of steel products in Uganda's construction industry.

II. Materials and Methods

2.1 Specimen Sampling, Labeling, and Preparation

Table 1 lists hardware companies and their corresponding rebar sizes. Two sizes (10mm and 12mm) were selected from each company, representing four top steel manufacturers (SC1-SC4). The rebars were sourced from four hardware outlets (HWA-HWD) that sell various steel brands. Eight specimens were marked (A10-D12) to represent common sizes used in small, medium, and heavy construction projects. The rebars were thoroughly cleaned to eliminate surface contaminants, and each of them was cut to the required length ranging from 600mm to 800mm for testing, ensuring uniformity across specimens.

Table 1: Coding of the Specimen and their Sources

Hardware	Companies	Rebars chosen
HWA	SC1	A10 A12
HWB	SC2	B10 B12
HWC	SC3	C10 C12
HWD	SC4	D10 D12

2.2 Procedure of Determining the Mass Per Unit Length

To determine the mass per unit length of each rebar specimen, a four-step process was followed. First, the length of each rebar was measured in meters using a meter rule. Next, the mass of each rebar was measured in grams using a weighing scale and converted to kilograms. The mass per unit length (kg/m) was then calculated by dividing the mass by the length. This process was repeated for all selected specimens to ensure compliance with acceptable mass standards, which is important for maintaining the load-bearing capacity of structures.

2.3 The Procedure of Bendability of Rebars on a Bending Machine

Bend tests were conducted on 10mm and 12mm rebar specimens using a bending machine, following the ISO 15630-1 standards outlined in US EAS 412-2-2022. The tests involved bending the specimens at 160° and 180° angles using a maximum mandrel diameter of 3d, where d is the rebar diameter. The procedure consisted of measuring, cutting, and placing the specimen in the machine, then starting and stopping the machine at the desired angle. The specimens were visually inspected for cracks or deformities, and the observations from both angles were recorded and presented in the results chapter

2.4 The Procedure of Tensile Test on Universal Testing Machine

A universal testing machine (UTN/E-100) was used to perform tensile tests on 10mm and 12mm rebar specimens, adhering to standard procedures. The machine was properly set up and configured for tensile testing, with specimens securely gripped between the upper and lower jaws.

After initializing the machine and verifying parameters, the test commenced, applying incremental loads until the rebar reached its maximum load and fractured. Upon completion, the machine was shut down, and the fractured specimens were removed. The initial measured values of weight and length were then input into the computer, generating mechanical test results. This procedure was repeated for all rebar specimens, with the comprehensive results presented in the subsequent chapter.

2.4 The procedure of Analyzing the Chemical Composition of Rebars

A setup, comprising a spectrometer, data acquisition system, and argon cylinder, was used to analyze the chemical composition of rebar samples. The samples were prepared through cutting, heating, hammering, and polishing to create a flat surface, enabling accurate analysis. The spectrometer was then used to examine the chemical composition, following the procedure outlined in ISO/TR 9769.

This involved initializing the spectrometer, cleaning the spark rod, and positioning the polished specimen over the spark hole. Spark discharges were generated to excite atoms, producing characteristic emission lines, results were displayed on the screen and printed for documentation. This process was repeated for all prepared specimens. Furthermore, the Carbon Equivalent Value (CEV) was calculated using a formula from US EAS 412-2-2022, quantifying the maximum percentage of residual elements present

III. Results

3.1 Determination of Mass Per Unit Length

Table 2: Mass and Length Measurements of Rebar Specimens

Rebar	L (m)	M (Kg)	W/L (Kg/m)	Min. M/L	Std M/L	Max. M/L(Kg/m)
A10	0.705	0.421	0.597	0.567	0.617	0.667
A12	0.609	0.529	0.869	0.838	0.888	0.938
B10	0.657	0.389	0.592	0.567	0.617	0.667
B12	0.61	0.543	0.89	0.838	0.888	0.938
C10	0.614	0.364	0.593	0.567	0.617	0.667
C12	0.648	0.566	0.873	0.838	0.888	0.938
D10	0.647	0.404	0.624	0.567	0.617	0.667
D12	0.637	0.56	0.879	0.838	0.888	0.938

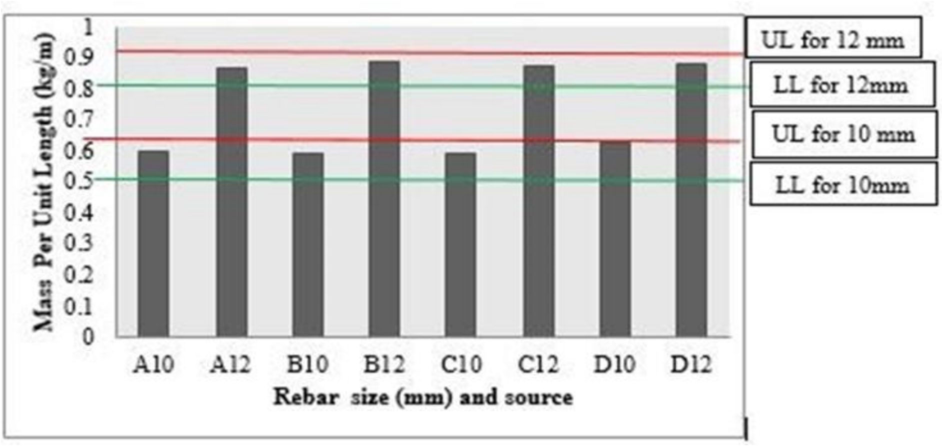

Fig 1: Representation of Mass Per Unit Length

Table 2 shows the mass per unit length of each rebar, including measured lengths and masses, as well as acceptable minimum and maximum values. The standard mass per unit length according to US-EAS-412-2-2022 is also indicated. Fig.1 graphically represents the mass per unit length of rebars showing the upper limit and lower limits of mass per unit length of the measured samples.

3.3Tensile testing of rebars

Table 3: Tensile Test Results

Rebar	TS (MPa)	Elongation greater than 14	YS (MPa)	Stress Ratio 1.15-1.35
A10	660	24	582	1.133
A12	657	20	570	1.152
B10	648	24	559	1.159
B12	636	19	582	1.09
C10	695	22	614	1.131
C12	597	20	536	1.114
D10	713	22.6	617	1.157
D12	626	19	56	1.118

Table 3 shows the results of the universal testing machine, which tested the tensile strength, yield stress, elongation, and stress ratio of the selected rebars.

3.4 Analysis of Chemical Composition

Table 4: Chemical Composition Analysis

Rebars	A10	A12	B10	B12	C10	C12	D10	D12
Fe	98.7	98.7	98.7	98.7	98.7	98.7	98.6	98.7
C	0.22	0.211	0.208	0.2	0.225	0.19	0.227	0.199
Si	0.2	0.19	0.21	0.2	0.21	0.2	0.19	0.2
Mn	0.75	0.703	0.703	0.6	0.70	0.674	0.709	0.704
p	0.0282	0.206	0.0201	0.0253	0.0191	0.0251	0.0288	0.0285
S	0.0121	0.0214	0.0222	0.242	0.0252	0.0248	0.0229	0.0121
Cr	0.0241	0.023	0.035	0.048	0.035	0.035	0.067	0.049
Mo	0.008	0.01	0.01	0.011	0.011	0.011	0.011	0.011
Cu	0.008	0.01	0.01	0.011	0.011	0.011	0.011	0.01
Ni	0.0207	0.0285	0.0269	0.029	0.027	0.0295	0.0285	0.0269
V	0.0012	0.0018	0.0023	0.0041	0.0021	0.0025	0.063	0.0046
CEV	**0.354**	**0.336**	**0.337**	**0.329**	**0.35532**	**0.315**	**0.376**	**0.332**

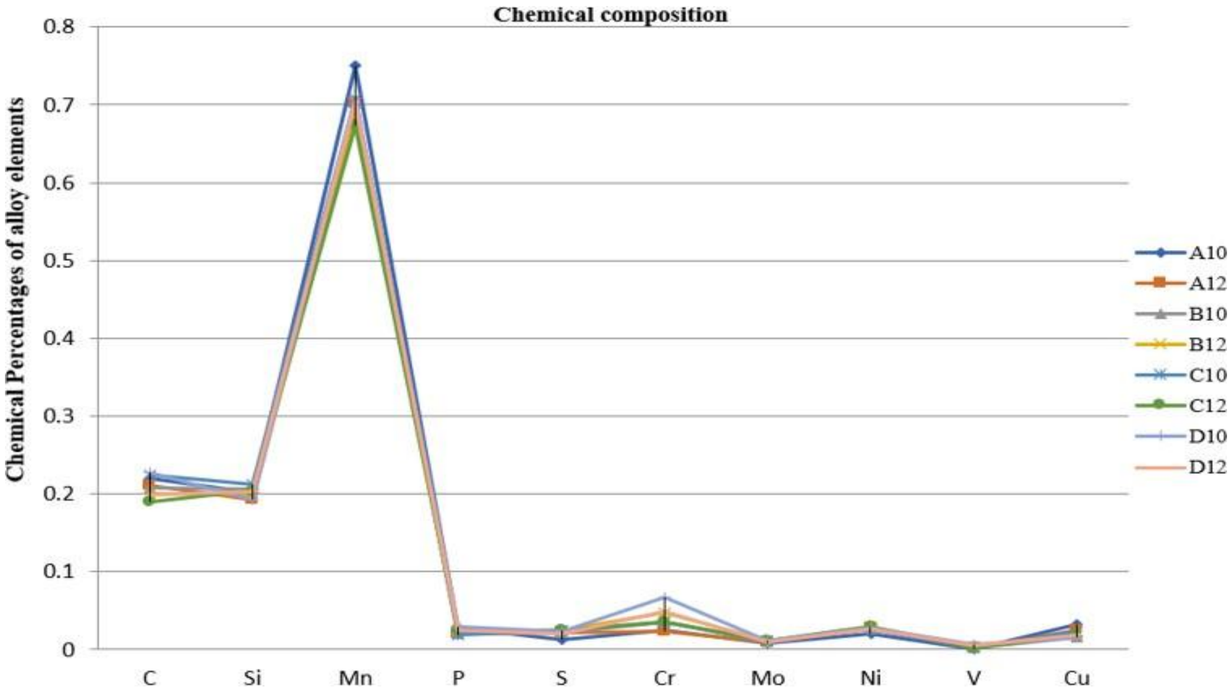

Figure 4: A graph of the Chemical Composition of Rebars

Table 4 shows the chemical composition of eight rebar samples, analyzed using a spectrometer and evaluated against US EAS 412-2-2022 and BS 4449:2005 standards.

3.3.1 Carbon Equivalent Value

Table 4.5 presents the contribution made by carbon equivalent value to the weldability of the rebars. A very good range of CEV is considered to start from 0.36 to 0.4 and an excellent one from 0.0 to 0.35.

The carbon equivalent value was determined using the formula

CEV = C + Mn/6 + (V+ Mo + Cr)/5 + (Cu + Ni)/15.

Table 4.5: Carbon Equivalent Value

Rebars	A10	A12	B10	B12	C10	C12	D10	D12
CEV	0.353	0.338	0.337	0.329	0.355	0.315	0.376	0.332

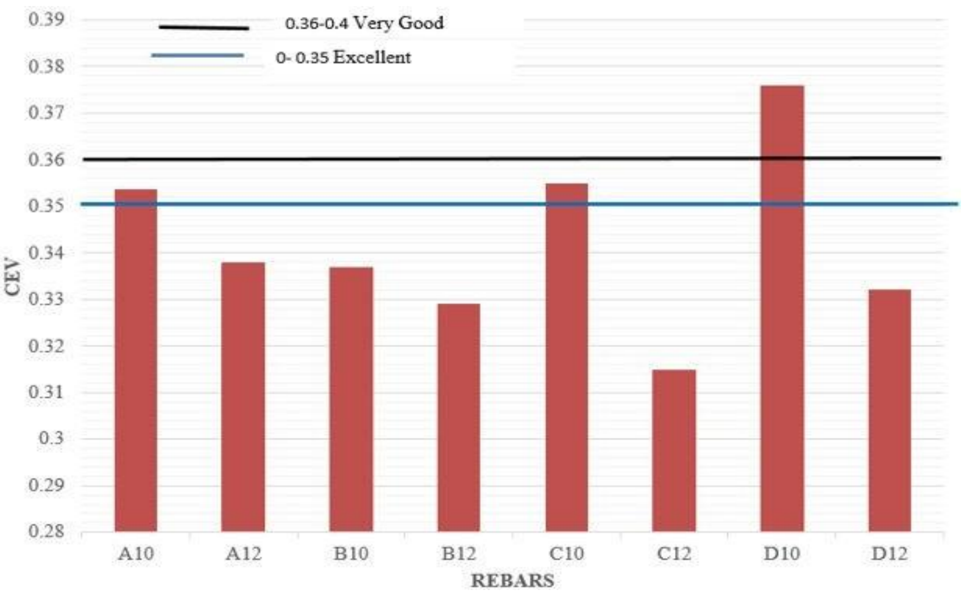

Figure 3: Carbon Equivalent Values against Selected Rebars

The Carbon Equivalent Value (CEV) is a measure of steel weldability, with lower values indicating better weldability. The analyzed rebars showed CEV values ranging from 0.315 (C12) to 0.376 (D10), with all values below the limits set by BS 4999-2005 and US-EAS 412-2-2022. C12 had the lowest CEV, indicating better weldability.

Perera and Guluwita (2018) recommend a narrower CEV range (0.37-0.4%) for consistent rebar quality. All rebars met this criterion, with CEV values below 0.4%. The results suggest that the rebars have good weldability, with C12 being the most suitable for welding applications.

IV. Discussion

All selected rebars after determining mass per unit were within the designated range, with D12 exhibiting the highest mass per unit length among 10mm diameter rebars (0.624Kg/m). B12 displayed the highest value among all 12mm diameter rebars (0.89 kg/m). The minimum and maximum mass limits for 10mm and 12mm diameter rebars are indicated by green and red lines, respectively.

From the tensile tests, all rebars met the standards for yield stress and elongation, but only three (A12, B10, and D10) met the criteria for acceptable stress ratio. The remaining rebars had substandard stress ratios, indicating a potential lack of ductility.

The stress ratio is important for determining rebar ductility, and neglecting it can lead to structural failures, especially during events like earthquakes. Project engineers should consider stress ratio in addition to tensile and yield strength to ensure structural integrity. Rebars with substandard stress ratios may not withstand seismic conditions and could potentially fail under stress.

From the spectro Lab, the paper focused on major chemical elements like carbon, silicon, manganese, and others, which affect the rebars' properties. The Carbon Equivalent Value (CEV) was calculated to determine weldability.

The chemical composition suggests that the rebars have high flexibility, ductility, and ease of manipulation, with optimal fusion during welding. The content of elements like silicon, manganese, and sulfur is within acceptable limits, contributing to improved strength, hardness, and reduced brittleness. The CEV values indicated good weldability, but careful control of impurities like sulfur and phosphorus is necessary to avoid exceeding threshold limits

V. Conclusion

This paper revealed that three out of eight rebar samples failed to meet the required stress ratio, despite exceeding the minimum tensile strength threshold. The reliance on scrap materials in manufacturing and neglect of stress ratio control in imported billets may increase this issue over time. Ignoring stress ratio values, which determine ductility capacity, poses significant risks to the construction sector. This is because unique material strength properties, such as tensile and yield strength, impact structural behavior. Lower-than-specified stress ratio values may lead to sudden collapse without visible warning signs. Therefore, to ensure the structural integrity of buildings, it is important to consider stress ratio values in conjunction with other quality parameters, and implement a comprehensive quality control framework comprising stricter measures, regular inspections, and testing of rebars, as well as educational initiatives to educate construction professionals on the critical role of stress ratio values in maintaining structural safety, thereby guaranteeing the durability and reliability of construction projects.

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