DETERMINATION OF THE QUALITY PARAMETER RANGES OF REINFORCING BARS USED IN UGANDA'S CONSTRUCTION INDUSTRY

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A DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH AND GRADUATE TRAINING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN ADVANCED MANUFACTURING SYSTEMS ENGINEERING OF KYAMBOGO UNIVERSITY

OCTOBER, 2024

DECLARATION

This dissertation is my original work and has never been presented for a degree in any other university.

Signature.................................   Date...................................

APPROVAL

We as university supervisors confirm the dissertation has been done by the candidate under our supervision.

Sign…………………………………………… Date. …………………………..

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Dr. Onyutha Charles

DEDICATION

I dedicate this dissertation to my family and friends.

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I express my heartfelt gratitude to the Almighty for granting me the strength and guidance to complete this dissertation within the stipulated timeframe. Without divine mercy, this accomplishment would not have been possible.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Standards for Testing Methods
BRF	Reheating Furnace
BS	British Standards
EAS	East African Standards
GS	Ghana Standards
IS	International Standards
ISO	International Standards Organization
SLS	Sirilanka Standards
SNI	Standard National Indonesia
TMT	Thermo-Mechanically Treated Bars
TS	Tensile Strength
UNBS	Uganda National Bureau of Standards
UNSDGs	United Nations Sustainable Development Goals
US	Uganda Standards
UTM	Universal Testing Machine
UTS	Ultimate Tensile Strength
YS	Yield Stress

LIST OF SYMBOLS

C	Carbon
Cr	Chromium
Cu	Copper
D	Nominal Diameter
E	elongation
Fe	Iron
Lf	Final Length
Lo	Original gauge length
Mn	Manganese
Mo	Molybdenum
Ni	Nickel
P	Phosphorous
S	Sulphur
Si	Silicon
V	Vanadium

ABSTRACT

Uganda's construction industry faces a serious concern with substandard reinforcing bars (rebars), leading to building collapses, fatalities, and financial losses. A study was conducted to determine quality parameter ranges of reinforcing bars by determining mass per unit length, testing mechanical properties, analyzing chemical composition, and evaluating conformity to standards. The goal was to prevent future collapses and safeguard lives and investments. Experiments focused on 10 mm and 12 mm rebars, commonly used in various construction projects, unlike larger rebars typically made from imported billets. Samples from four hardware stores representing different manufacturers were tested, with initial measurements taken using a meter rule and weighing scale to assess length and mass. Later, the mass per unit length was calculated and it was found that the obtained results were within acceptable ranges from 0.567 kg/m to 0.667 kg/m for rebars with diameters of 10 mm and 0.838 kg/m to 0.938 kg/m for rebars with diameters of 12 mm based on US-EAS 412-2-2022. Mechanical properties like yield stress, tensile strength, elongation, and stress ratio were tested on a universal testing machine and they revealed acceptable yield stress values above 500 MPa and elongation above 14 % across all samples. While all rebars exhibited yield stress above the minimum allowable limit of 500 MPa based on US EAS 412-2-2022, some did not meet the stress ratios like A10, B12, C10, C12, and D12, which were below the specified minimum 1.15 outlined in US EAS 412-2-2022. Bending tests indicated no observable cracks in the rebars. On the other hand, Using a spectrometer, the chemical composition of steel rebars was analyzed, and it was revealed that some elements were slightly below allowable limits. The analysis focused on major alloying elements, including C, Mn, Si, P, S, Cr, Mo, Ni, V, and Cu. Rebar A10's manganese content was significantly below the minimum allowable limit of 1.6 % (at 0.75 %). Other elements (C, Si, P, S, Cr, Mo, Ni, V, Cu) were within allowable minimum limits, aligning with US EAS 412-2-2022 standards. The carbon equivalent value (CEV) was then calculated and used to evaluate weldability, which ranged from 0.315 to 0.376, all falling within acceptable established standards. Notably, while three rebars A12, B10, and D10 met the specified quality parameters, the other five rebars A10, B12, C10, C12, and D12 did not conform, primarily due to low-stress ratios below 1.15, a critical factor affecting ductility and load absorption during seismic events. This research could improve the rebar quality and help prevent future building collapses, protect lives, and safeguard investments. The findings emphasized the need for stricter quality control in rebar production and selection to avoid structural failures.

Keywords: Construction industry, Rebars, Stress ratio, Substandard materials, Yield strength

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Reinforcing steel bars, commonly known as rebars, are essential for reinforcing concrete structures (Munyazikwiye, 2010). They will remain the most widely utilized construction materials in terms of volume in the future since this product is constantly in great demand (Delali and Sasu, 2022). Moreover, the construction industry increasingly opts for high-strength Thermo-Mechanically-Treated (TMT) steel bars for projects like flyovers, bridges, and tall buildings due to their optimal mechanical properties (Ssempijja, 2019). If the rebars used in construction fall short of the required properties, structural failures are bound to occur before their expected lifespan (Joshua et al., 2013). Research conducted by Munyazikwiye (2010) highlights the crucial role rebars play in extending the service life of construction buildings and structures. Nevertheless, the utilization of reused metal scraps presents a notable challenge, as pointed out by Tariku (2022), who emphasizes differences in mechanical characteristics caused by inconsistent feed and impurities.

UNBS, on June 18, 2021, emphasized adherence to Ugandan Standards US EAS 412-2:2019 for ribbed bars and warned of rising cases of iron bars flooding the market. The ongoing concern of durability issues with TMT rebars due to corrosion, outlined by Dey et al. (2022), remains unresolved. Despite interventions using TMT bars to enhance durability, uncertainties are about the potential presence of substandard rebars in the market, posing risks to construction projects (Joshua et al., 2013). Senfuka et al. (2011) highlighted a major challenge faced by the Ugandan steel industry: the quality and quantity of appropriate steel scrap, leading to the use of low-quality scrap and resulting in poor-quality steel. The lack of technical awareness in material testing for construction steel may lead to design expectations falling short, affecting site control and compliance (Arinaitwe & Nkubana, 2018).

Building upon the study conducted by Ssempijja (2019) entitled "Investigation of the Mechanical Performance of Carbon-Made Bars of 20mm Diameter" in which findings generally adhered to acceptable standards, three samples failed the bendability test, all originating from a single company. On the other hand, discrepancies in standards referenced were noted, indicating potential oversights in industry practices. Importantly, the investigation neglected the crucial aspect of mass per unit length, critical for determining load-bearing capacity, this study aimed at extending the investigation to 10 mm and 12 mm diameter rebars, focusing on mass per unit length, mechanical properties, chemical composition, and the evaluating the conformity of rebars.

1.2 Statement of the Problem

Uganda has faced significant financial losses, lives, and property due to frequent building collapses. These collapses have been linked to several factors, including inadequate foundations and the use of substandard construction materials, particularly cement and reinforcing bars (rebars). The quality of rebars used in construction varies considerably, with many users neglecting to assess their quality before use, leading to structural failures. The quality of rebars is important in ensuring the safety, durability, and reliability of buildings, as they provide essential structural reinforcement. However, manufacturers often focus only on the grade (yield stress) of rebars, neglecting other important parameters like the stress ratio, which determines ductility. While much research has been done on twisted bars, there is limited research on thermo-mechanically treated bars especially rebars made from recycled recycled scrap. To enhance construction safety, a study was conducted on 10 mm and 12 mm rebars, to determine the mass per unit length, test mechanical and analyze chemical properties to evaluate compliance with US EAS 412-2-2022 standards to build on previous research conducted by Ssempijja (2019), which focused solely on 20 mm rebars.

1.3 General and Specific Objectives

1.3.1 General Objective

To determine the quality parameter ranges of reinforcing bars used in Uganda's construction industry.

1.3.2 Specific Objectives

The specific objectives were:

i. To determine the mass per unit length of reinforcing bars of diameter sizes 10 mm and 12 mm used in Uganda's construction industry.

ii. To test the mechanical properties of reinforcing bars of diameter sizes 10 mm and 12 mm used in Uganda's construction industry.

iii. To analyze the chemical composition of the reinforcing bars of diameter sizes 10 mm and 12 mm used in Uganda's construction industry.

iv. To evaluate the conformity of reinforcing bars of diameter sizes 10 mm and 12 mm used in Uganda's construction industry with established standards US EAS 412-2-2022 by UNBS.

1.4 Research Questions

1. Based on use in Uganda's construction industry, are there variations in the weight per meter of reinforcing bars of 10 mm and 12mm size?

2. What are the mechanical properties of reinforcing bars of size 10 mm and 12 mm used in Uganda's construction industry?
3. What is the chemical composition of reinforcing bars of the selected 10 mm and 12 mm rebars used in Uganda's construction industry?
4. Do the quality parameter ranges of reinforcing bars of size 10 mm and 12 mm conform with the established standards US EAS 412-2-2022.?

1.5 Significance

Determination of ideal quality parameter ranges of reinforcing ribbed bars in Uganda's construction industry was important for guaranteeing the stability, safety, and durability of buildings and ensuring conformity of rebars' quality with established standards. This study aimed not only at testing mechanical and chemical properties but also evaluating the conformity of rebars with established US-EAS-412-2-2022. By upholding high standards of quality, this research would support the industry's expansion, attract investments, and rely on rebars that conform to standards. The results would also provide valuable insights for various stakeholders, such as rolling mills, regulatory bodies, and end-users, and encourage further academic research in the field. Promoting sustainable cities and communities, which is the eleventh United Nations Sustainable Development Goal, would be one way that this research would support both Uganda's Vision 2040 and the UNSDGs.

1.6 Scope of the Study

1.6.1 Time Scope

The study spanned from January 2024 to June 2024, encompassing the procurement and experimentation phase for the selected rebars. During this period, results were tabulated and analyzed, and the final THESIS was submitted for examination.

1.6.2 Content Scope

This research aimed at determining the ideal quality parameter ranges of reinforcing bars used in Uganda's construction industry with minimum yield stress 500 MPa and ductility class C which are ribbed and weldable, specifically focusing on 10 mm and 12 mm diameters to capture the market variety, given their common usage in diverse construction projects. The study explored aspects like mass per unit length, tested the mechanical properties using universal testing equipment, and analyzed chemical composition using the spectrometer, and evaluated the conformity with established standards US-EAS-412-2-2022.

1.6.3 Geographical Scope

The rebars were acquired from four hardware outlets HWA, HWB, HWC, and HWD in the Kampala area since it was an epicenter for many construction projects.

CHAPTER TWO:

LITERATURE REVIEW

2.1 Introduction

This chapter provides an examination of current literature, focusing on important themes or trends that are relevant to this research.

2.2 Manufacture of Rebars

The steel rods that are installed within concrete and brick to assist them preserve their shape and qualities are known as rebar or "reinforcement bars"(Delali & Sasu, 2022).To produce steel rebar, after melting the raw material from either iron ore or steel scrap, the molten steel is delivered into a tundish which feeds into a caster to form billets. Large billets are then reduced continuously into smaller shapes at the rolling mill through specific dies. At this point, the billet begins to take shape into rebars. The bars then undergo finishing which includes coating, twists or ribs, and grooves that give them the ideal reinforcing application appearance (Delali & Sasu, 2022). Nowadays, they are no longer twisted and coated. Instead, they are hardened with chilled water at varying pressures to achieve the desired mechanical and chemical properties. After being quenched, they are left to cool in the air for a few minutes before they are tied to rolls ready for dispatch.

2.3 Determination of Mass Per Unit Length

The oversight of determining the mass per unit length of low-carbon steel rebars during tensile testing in rod mills has been noted by (Musonda et al., 2018). It is explicitly required for TMT rebars, as any mass reduction directly impacts the steel reinforcing bar's capacity (Musonda et al., 2018). Notably, lower weight per meter values don't only affect ultimate tensile strength but also influence the material's microstructure (Musonda et al., 2018). Moreover, a correlation was observed between decreasing weight per meter and reduced %elongation for the Y10 rebar which was attributed to low cooling rates in a study conducted by Musonda et al., (2018).

ASTM A615 specifies the approximate weight for each size of rebar, such as 0.560 kg/m for a 10 mm bar. The standard also states that the minimum weight per unit length of the bar should not be less than 94 % of the nominal weight per unit length. The weight per unit length of all bars tested was measured and the average weight per unit length was calculated. It was found that the weight per unit length of all tested bars fell within the acceptable limits outlined in ASTM A615

Although previous studies have made assumptions about cross-sectional diameters and areas in rebar design (Joshua et al., 2013), the mechanical performance of rebars has been investigated without considering the significance of weight per unit length (Ssempijja, 2019). However, Musonda et al. (2018) emphasized the importance of explicitly measuring weight per unit length during tensile tests in rod mills.

2.4 Testing of Mechanical Properties

On every tensile test carried out on a universal testing machine, the data acquisition system displayed important results of tensile strength, elongation, yield strength, and Ultimate Tensile strength (TS) to Yield strength (YS) Ratio and it was imperative to review each of these important parameters.

2.4.1 Tensile strength

Steel has strength and bonds well with concrete compared with other materials. Laboratory tensile tests on steel rebars should be conducted as one of the quality control procedures in construction.

Rebars with lower tensile strengths exhibit lower hardness and lower yield strengths. Therefore, an increase in tensile strength results in an increase in hardness and yield strength. Failure to control manufacturing operational parameters in steel rebar production like operating temperatures during the reheating of the billets in the reheating furnace could result in the poor grain structure of the billet and ultimately affect the tensile strength and ductility.

The yield strength, ultimate strength, modulus of elasticity, elongation, and impact strength are crucial properties that determine the reliability and durability of a structure These properties are influenced by factors such as chemical composition, heat treatment, and manufacturing processes.

One of the major considerations in determining the quality of reinforced steel bars is the proper yield strength. Both users and manufacturers need to know the correct yield strength to prevent the permanent failure of structures. However, despite meeting the chemical composition requirements, some of the bars failed to meet the specified strength and elongation requirements. This can lead to changes in the failure mode of flexural members, shifting from ductile to brittle behavior The strength and ductility of steel are crucial mechanical properties for structural engineers as they affect the performance and safety of structures.

To reduce costs, steel manufacturers in developing countries, such as Ghana and Uganda, are using recycled steel to produce reinforcing bars. This practice can lead to variations in the chemical composition, crystalline structure, and mechanical properties of the bars

While the literature review provides valuable information on the importance of tensile strength in evaluating reinforcement steel, some gaps need to be addressed. For example, further research could explore the impact of using recycled steel on the mechanical properties and performance of reinforced steel bars. Additionally, studies could be conducted to compare the quality of rebars made from recycled scrap and imported billets to evaluate their conformity with the established standards.

2.4.2 Ultimate Tensile strength (TS) to Yield strength (YS) Ratio

High-strength steels (yield strength, exceeding 450 MPa) hold significant untapped potential, as noted by Anggraini &and Raka (2019). Building codes, including American Concrete Institute (ACI) 318M-14 and Standard National Indonesia (SNI) 2847:2013, mandate a tensile strength (TS) to yield strength (YS) ratio not less than 1.25 (Anggraini & Raka, 2019). Anggraini & Raka's study revealed that Grade 420 exhibited higher TS/YS ratios exceeding 1.25, while High Strength Steel (HSS) bars (Grades 550, 600, and 700 MPa) showed lower TS/YS ratios, falling below 1.25 compared to Grade 420 MPa. In Uganda, the yield strength should be above 500MPa with a stress ratio exceeding 1.15. However, some studies have indicated rebars manufactured to be of substandard quality and factors attributed to the recycling of metal scrap. A research gap exists as there isn't any study highlighting the extent of parameters to which Ugandan-made rebars are falling short of quality. This study aimed to investigate the extent to which the Ugandan-made rebars comply with the established standards.

Maintaining yield strength (YS) and ultimate tensile strength(UTS) values within a narrow band is crucial for member design, preventing brittle shear failure and promoting a more ductile flexure mode of failure. Despite the significance, research findings on high-strength steel reinforcing bars remain limited in the literature, as highlighted by Anggraini &and Raka (2019).

Table 2.1 shows a comparison of the mechanical properties of steel reinforcing bars manufactured in different countries. It included tensile strength, yield strength, and elongation of different countries.

Table 2.1:Mechanical properties of different Grades of Rebars (Source: Anggraini & Raka, (2019))

	Tensile strength, fy		Yield strength		Elongation	
Code	Grade		Grade		Grade	
	420MPa	500 MPa	420MPa	500 MPa	420 MPa	500 MPa
IS 1786	10% More than fy and less than 485MPa	10% More than fy and less than 545 MPa	415	500	14.5	12
ASTM 615M	620	690		520	7-9 depending on the diameter of the rebar	6-7 depending on the diameter of the rebar
Russian	585	600	395	500	14	14

2.4.3 Yield strength

This tensile test, as outlined by Hassan et al. (2021), aids in determining the maximum stress a material can endure while being stretched before significant contraction, known as necking. Despite the high strength observed in the study by Adeleke & Odusote (2013) due to elevated Mn content, the durability of a structure depends not only on rod strength but also on its ductility. Nigerian standards specify a minimum tensile strength of 460 MPa with specific elongation requirements to prevent sudden failures (Joshua et al., 2013).

In contrast, Uganda's US EAS 412-2-2022 sets a minimum yield strength of 500 MPa but lacks a specified maximum yield strength, leading some manufacturers to produce rebars with unreasonably high yield strength, resulting in hardness and eventual failures during construction.This research aims to establish optimal quality parameter ranges for improved rebar.

Musonda et al,. (2018) emphasized the importance of monitoring water flow rate and dwell time during the heat treatment of thermal mechanically treated (TMT) rebar, as these factors impact ultimate tensile strength (UTS), yield strength (YS), elongation, and microstructure. Delali & Sasu (2022) reported TM3's (12mm) lower UTS but considerable necking, indicating higher ductility. Although the rebars met GS 788 standards for yield strength and ultimate tensile strength elongation, they failed to meet BS 4449 requirements, except for TM1 (6mm). Joshua et al. (2013) suggested that if actual yield strength falls below the minimum requirement, reinforced concrete may lose its capacity to resist tensile service loads, leading to reduced structural strength.

Nkem Ede et al. (2014) conducted "an Experimental Investigation of Yield Strengths of Steel Reinforcing Bars Used in Nigerian Concrete Structures." Specimens of 12mm and 16mm exhibited yield strength as low as 233 N/mm^2, highlighting the need to improve steel quality in the Nigerian construction industry. The study recommended similar investigations for other bar diameters commonly used in civil structures, such as 10mm, 20mm, and 25mm, to understand the trend in their yield strengths.

2.4.4 Elongation and Ductility

Elongation, denoting the increase in the gauge length, expressed as a percentage of the original length, is a key indicator of material ductility. According to Nkem Ede et al. (2014), ductility refers to a material's capacity for substantial plastic deformation before failure. It represents the ability of a material to deform plastically without fracturing under tensile stress exceeding its yield strength (Bame et al., 2023). Japanese JIS standards emphasize high elongation, even for bars with maximum tensile strength (Madias et al., 2017).

Adeleke & Odusote (2013) analyzed reinforcing steel bars from collapsed building sites and identified reduced ductility attributed to elevated sulfur and phosphorus content. Excessive Sulphur and Phosphorous presence reduced ductility, rendering the bars unsuitable for reinforcement. In steel, ductility is a crucial property for ensuring occupants' safety in reinforced concrete structures. Ductile steels provide warning signs, such as excessive beam deflection, preceding total structural failure in the event of reinforced concrete failures, particularly under flexural loads.

This allows occupants sufficient time to evacuate before the potential collapse. Ductility assessment often involves determining the stress ratio, by Uganda standards US-EAS 412-2-2022, the specified ductility class is ≥1.15, with a minimum specified characteristic value of elongation set at 14% for rebar B500CWR. This investigation revealed that some selected rebar samples were below the minimum specified stress ratio.

2.4.5 Bendability of Rebars

Bendability refers to the ability of a material to bend or flex without breaking. It is a characteristic that indicates how something can deform under applied force. Most reinforcing bars require to be bent before being placed into concrete; however, they may fracture on bending if the radius of the bend is too tight. The bend and re-bend tests on steel reinforcing bars are two ways of evaluating the ductility of reinforcement. The bend diameter varies with the bar diameter and in some codes varies with grade. The test specimen passes if no cracks appear on the outside of the bent portion of the bar (Bame et al., 2023)

2.5 Analysis of Chemical Composition of the Rebar

Selecting the best composition of ingredients in the melt is one of the huge challenges faced by the scrap recycling industry. For enhanced quality in steel bars, correct metallurgy of the melt is required for good yield (Perera & Guluwita, 2018). In the field of steelmaking, careful selection of scraps is essential, with copper and tin being the most detrimental contaminants causing hot-shortness. Industry standards establish maximum limits for sulfur and phosphorus, known as impurities affecting steel bars' mechanical properties. Small additions of carbon nitride-forming elements like niobium, vanadium, and titanium enhance the strength of low-carbon and low-alloy steels (Perera & Guluwita, 2018).

Residual elements like Cu, Ni, Sn, As, Cr, Mo, Pb, etc., pose challenges as they can't be easily removed. Achieving optimal ingredient composition in the melt is a significant challenge for the scrap recycling industry (Perera & Guluwita, 2018). High silicon content in the material leads to increased strength but reduced ductility (Delali & Sasu, 2022). Alloying elements such as nickel, manganese, molybdenum, and chromium enhance strength, toughness, wear resistance, and corrosion resistance (Delali & Sasu, 2022).

In a study conducted by Delali & Sasu (2022), elevated phosphorus levels in one of the sample materials surpassed the set standards, affecting both strength and ductility. It was noted that maintaining low sulfur content was essential to prevent embrittlement. The study also highlighted that the presence of manganese could result in eutectics, leading to cracking. Additionally, the study found that phosphorus and silicon, although enhancing strength and hardness, could decrease ductility. Furthermore, aluminum and silicon were identified as deoxidizers that help prevent defects in the steel.

Manganese levels in steel affect strength, toughness, and hardness. Manganese and silicon form carbides, strengthening the structure. Consistent yield strength and elongation in TMT bars are achieved with a specific Carbon Equivalent value and a mix of ferrosilicon and ferro-silico-manganese (Perera & Guluwita, 2018; Adeleke & Odusote, 2013).

Despite numerous ribbed steel bar manufacturers engaging in scrap recycling, achieving consistent tensile properties like yield strength and elongation proves challenging due to various constraints(Perera & Guluwita, 2018).

2.5.1 Carbon Equivalent Value

Carbon has a moderate tendency to segregate, and its segregation is often more significant than that of other elements. Carbon, which has a major effect on steel properties, is the principal hardening element in all steel. Tensile strength and hardness value increase as carbon content increases (up to about 0.85% C), while ductility and weldability decrease. Phosphorus segregates but to a lesser degree than carbon and sulfur. The decrease in ductility and toughness is greater in quenched and tempered higher-carbon steels. Increased sulfur content lowers steel ductility and decreases its weldability. This element is very detrimental to surface quality, particularly in low-carbon and low-manganese steels(Adeleke & Odusote, 2013).Carbon Equivalent (CE) value is used to understand how the residuals and different alloying elements affect the strength of steel(Perera & Guluwita, 2018)

Carbon Equivalent (CE) is increasingly drawing the attention of the steel-making industry since it can have an effect on properties like strength and weldability in steel bars (Perera & Guluwita, 2018)CEV is required to set the cooling parameters in the TMT (Thermo mechanically treated) process, and a slight variation in carbon equivalent may alter the physical properties(Hassan et al., 2021). The Carbon Equivalent is calculated using the following formula:

$CEV = C + \frac{Mn}{6} + \frac{V+Mo+Cr}{5} + \frac{Cu+Ni}{15}$ (Source US EAS 412-2-2202)………………..2.1

Table 2.2. Presents the chemical composition of ribbed steel bars based on Srilanka standards SLS 375:2009. The major alloying elements included Carbon, Sulphur, phosphorus, Nitrogen, and Copper and the CE is the Carbon Equivalent used to determine the weldability or joinability of rebars.The maximum allowable limits for these major alloying elements for both cast analysis and product analysis were also presented respectively. The SLS 375:2009 specified maximum allowable limits for these major alloying elements as indicated below.

Table 2.2: Chemical composition of Ribbed Steel Bars (maximum % by mass) (Source: Perera & Guluwita, 2018)

	C	S	P	N	Cu	CE
Cast Analysis	0.22	0.05	0.05	0.012	0.80	0.50
Product Analysis	0.24	0.055	0.055	0.014	0.85	0.52

Carbon Equivalent (CE) value was used to understand how the residuals and different alloying elements affected the strength of steel. Table 2.3. Presents the contribution made by Carbon equivalent value to the weldability of TMT bars. The weldability of TMT bars was determined by using carbon equivalent value. The lower the carbon equivalent value, the easier weldable TMT bars were.

Table 2.3:Weldability of TMT Bars Based on CE Values(Perera & Guluwita, 2018)

Carbon Equivalent (CE)	**Weldability of TMT bars**
Up to 0.35	Excellent
0.36-040	Very good
0.411-0.45	Good
0.46-0.50	Fair
Over 0.50	Poor

2.6 Evaluating the Conformity of Rebars

The challenge lies in identifying optimal alloying elements to ensure consistent rebar quality. According to US EAS 412-2-2022, specific carbon equivalent (CEV) limits are set for various rebar types. However, Perera & Guluwita (2018) emphasize maintaining a narrower CEV range (0.37<CE< 0.4 % by mass) in the melt. BS 4449-2005 specifies CEV limits for cast and product analyses as 0.5% and 0.52 %. The researchers should delve deeper into carbon equivalent values for both analyses to establish ideal ranges for improved rebar material properties.

Table 2.4 Presents the chemical composition (Maximum % by mass)of both cast analysis and product analysis of different major alloying elements which included Carbon, Phosphorous, Nitrogen, Copper, and CE is the carbon equivalentvalue for respective cast analysis and product analysis. Cast analysis is done when the molten liquid is still in the furnace and product analysis is performed directly after casting and on the final rebar product to understand the chemical composition in it. The values indicated in Table 2.4 are the established maximum allowable limits by BS 4449-2005.

Table 2.4: Chemical composition (Maximum percentage by mass) source BS 4449-2005

	Carbon	**Sulfur**	**Phosphorous**	**Nitrogen**	**Copper**	**CE**
Cast analysis	0.22	0.05	0.050	0.012	0.8	0.5
Product analysis	0.24	0.055	0.055	0.14	0.85	0.52

Namara, (2015) notes that steel bars produced from scrap often lack uniformity, exhibiting variations in carbon and manganese content, reduced weldability, and limited machinability. Ssempijja (2019) emphasizes the importance of studying the material's mechanical properties, purity, and surface conditions to enhance bendability since these bars also face challenges in bending to sharp angles without cracking.

According to Ssempijja (2019), attributes like hardness, ultimate tensile strength, and elongation have minimal impact on material bendability. However, higher yield strength, indicative of increased hardness and a lower stress ratio, reduces ductility, posing a higher risk of cracking during bend tests. The bend test conducted followed BS 4449-2005 stating a 90^0 angle for use.

According to ISO 15630-1, the bend test involves bending the test piece to an angle between 160° and 180° over a mandrel specified in Table 2.5, 3d is the maximum mandrel diameter specified for rebars with less than 16mm diameter which is three multiplied by the diameter of the selected sample of less or equal to 16mm diameter.

Table 2.5:Mandrel Diameter Used in Bend Test (Source: US EAS 412-2-2022)

Nominal diameter d (mm)	**Mandrel diameter, max.**
≤ 16	3d
$16 < d \leq 32$	6d
$32 < d \leq 50$	7d

As per BS 4449-2005, the test pieces must undergo a 90^0 bend around a mandrel with diameters specified in Table 2.5. Subsequently, the specimens, after aging and bending back to at least 20^0, should exhibit no visible cracks or fractures detectable by a person of normal vision. This study aimed to explore the use of 165^0 and 180^0 angles in alignment with US EAS 412-2-2022.

Furthermore, both BS 4449-2005 and EAS 412-2-2022 only stipulate the minimum yield strength, lacking specifications for the maximum yield strength in rebar manufacturing. The research soughtto leverage insights from various standards and existing literature to develop optimal quality parameter ranges, contributing to enhanced rebar material.

2.7 Mechanical Performance of Ugandan-made carbon steel bars

In a study conducted by Ssempijja, (2019) discrepancies were found in the standards referenced regarding the mechanical performance of Ugandan-made carbon steel bars, such as citing EAS 412-1-2019 for plain bars instead of EAS 412-2-2019 ribbed bars and referencing BS 4445:2005 instead of BS 4449:2005. The research specifically investigated ribbed bars with a 20mm diameter, using three samples that met specified standards and recommended for further research because of limited resources to select a large sample. However, the evaluation did not consider the mass per unit length, which is essential for determining load-bearing capacity.

The absence of maximum yield stress and stress ratio limits in US EAS 412-2-2022 was noted, indicating a potential oversight by steel manufacturers who may not have had a benchmark to follow. This oversight could lead to the production of rebars with excessive yield stress and stress ratio, Highlighting the need for further research to establish optimal quality parameter ranges. Senfuka et al. in 2013 focused primarily on twisted rebars rather than ribbed bars of 10mm and 12mm sizes currently being manufactured, emphasizing the importance of additional investigation into the quality of rebars. This additional research aimed at determining the mass per unit length, mechanical properties, and chemical composition to ascertain the compliance with the standards outlined in US EAS 412-2-2022 and BS 4449:2005.

2.8 Summary of Literature Review and Research Gaps:

Research gaps identified in the study include the oversight of determining the mass per unit length of low-carbon steel rebars during tensile testing in rod mills, as highlighted by Musonda et al. (2018). This oversight is particularly important for TMT rebars, as any reduction in mass directly impacts the load bearibg capacity of the steel reinforcing bar. The research highlighted the importance of various parameters such as tensile strength, elongation, yield strength, and the Tensile Strength to Yield Strength ratio in steel materials.

Additionally, the study emphasized the strength of steel and its bonding properties with concrete, highlighting the necessity of conducting laboratory tensile tests on steel rebars to ascertain the compliance with set specifications outlined in US EAS 412-2-2-2022 . Furthermore, it discussed the significance of the TS/YS ratio in high-strength steels, with specific requirements outlined in US EAS 412-2-2-2022 and BS 4449:2005.

It highlighted various studies focusing on the effects of different factors such as chemical composition, heat treatment, and manufacturing processes on these properties.On the other hand, research gaps existed and needed for deeper study into ideal Carbon equivalent ranges for improved rebar material properties, investigation into the mechanical performance of Ugandan steel bars, and consideration of factors like mass per unit length for determining load-bearing capacity.

Additionally, there was a need to address oversights in standards regarding maximum yield stress and stress ratio limits to ensure the production of rebars with appropriate mechanical properties. A research conducted by Ssempijja, (2019), inconsistencies were identified in the standards cited. The study focused solely on a 20mm diameter and in most steel manufacturing industries, rebars larger than 12mm are typically produced from imported billets. It was known that these imported billets generally contain fewer impurities compared to rebars made from local scraps.

Therefore, the gap still existed to conduct further research on different rebar sizes to ascertain if they conform to established standards. The absence of maximum yield stress and stress ratio limits in US EAS 412-2-2022 was noted, indicating a potential oversight by steel manufacturers and highlighting the need for further research in this area. It was revealed that bending rebars at sharp angles caused cracks due to substandard rebars and this required further study to establish the causes of such.

The gaps highlighted above were addressed by investigating the quality of reinforcing ribbed bars and focused on aspects like:

- The mass per unit length of the selected rebars to ascertain if rebars manufactured in Uganda possess the established mass per unit range as per US EAS 412-2-2022
- Determined mechanical properties like yield strength, tensile strength, stress ratio to understand trends and discrepancies in quality were identified and recommendedimprove steel quality.
- Involved establishing optimal quality parameter ranges, including,allowable maximumlimits of stress ratio, yield strength, and carbon equivalent values to improve materiality.
- Involved assessing the bendability of rebars, using the bendng machine while following the established standards
- Analyzed the chemical composition of rebars to ascertain if the composition by percentage aligns with US EAS 412-2-2022.
- Highlighted the influence of alloying elements and residuals on steel properties

By addressing these gaps in this study research, it has contributed to enhancing the quality, performance, and understanding manufatured steel reinforcing bars considering the parameters specified in the US EAS 412-2-2022

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter presents the experimental setup and the procedures for determining the mass per unit length, testing the mechanical properties, analysing the chemical composition and evaluating the conformity of rebars with established standards US EAS 412-2-2022.

3.2 Specimen Sampling, Labeling, and Preparation

Table 3-1 shows the various hardware outlets and the sizes of rebars selected from each. The study focused on 10 mm and 12 mm rebars, which are widely used in small to large construction projects. These sizes are primarily made from recycled scrap, unlike larger rebars (16 mm to 32 mm), usually produced from imported billets with fewer impurities. Rebars of 10 mm and 12 mm were selected from each hardware store, representing four steel companies, labeled SC1, SC2, SC3, and SC4, which rank among the top ten steel manufacturers.

These selected rebars were from four different hardware outlets named HWA, HWB, HWC, and HWD not disclosing their names were selected because they sell all brands of steel products manufactured by different steel companies in Uganda. They were marked A10, A12, B10, B12, C10, C12, D10, and D12 totaling to eight specimens. These rebar sizes were chosen randomly to represent a variety in the market since small, medium, and heavy construction sites mostly use them.The rebars were thoroughly cleaned to eliminate surface contaminants, and each of them was cut to the required length ranging from 600 mm to 800 mm for testing, ensuring uniformity across specimens. Cleaning was done using the wire brush to remove the rust and scale that could affect mass measurements and later they were cleaned with cotton waste.

Table 3.1:Coding of the Specimen and their Sources

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

3.3 Different Experimental Set Ups and Procedures

Different equipment was used to determine the mass per unit length, test the mechanical properties, analyze the chemical composition, and ultimately evaluate the conformity of reinforcing ribbed bars used in Uganda's construction industry to ascertain whether they meet the established standards.

3.3.1 Determining the Mass per Unit Length

The mass per unit length of a rebar is a key property that determines its compliance with design specifications. It was important to determine the mass per unit length of each rebar specimen since a reduction in acceptable mass standards affects the load-bearing capacity of the structures. Figure 3.1 shows the weighing scale, meter rule, and rebar specimen. The meter rule was used to directly measure the lengths of the chosen rebars in meters. Subsequently, a weighing scale was also employed to measure the masses of the selected rebars in grams, which were then converted to kilograms.

The mass per unit length in kilograms per meter (kg/m) was then calculated from the ratio of the measured mass to the measured length. A tape measure was used to precisely measure the length of the rebar, while a weighing scale measured its total mass. By dividing the mass by the measured length gives the mass per unit length. This simple yet effective method ensured that the rebar's weight aligns with established standards US EAS 412-2-2022, as the mass-to-length ratio affects both structural integrity and load-bearing capacity

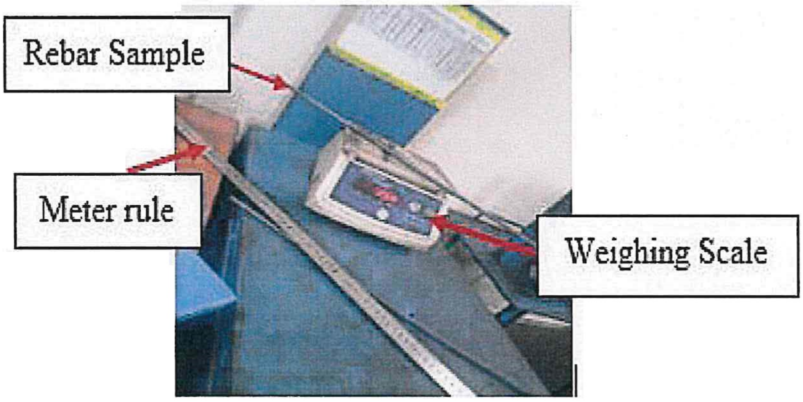

Figure 3.1: Weighing Scale, Meter Rule, and Rebar Specimen

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. Then, the mass of each rebar was measured in grams using a weighing scale and converted to kilograms. Finally, 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 outlined in US EAS 412-2-2022, which is important for maintaining the load-bearing capacity of structures.

3.3.2 Testing the Mechanical Properties

Mechanical properties were determined from the physical laboratory which had the bending machine and universal testing machine that were used for bendability and tensile tests respectively.

(a) Determining Bendability of Rebars on a Bending Machine

Table 3.2 presents the nominal diameters and mandrel diameter standards obtained from US EAS 412-2-2022 standards that were used during the bend test. Given the fact that the bending was carried out on rebar sizes of 10mm and 12 mm, all less than 16mm, the maximum mandrel diameter selected was 3d where d is the diameter of the rebar to be bent.

Table 3.2: Nominal diameter and Diameters Used in Bend Test (Source: US EAS 412-22)

Nominal diameter d (mm)	Mandrel diameter, max.
≤ 16	3d
$16 < d \leq 32$	6d
$32 < d \leq 50$	7d

Figure 3.2 shows a bending machine that was used to bend the selected rebars to check whether rebars could crack or fracture at different angles. The procured rebar specimens were subjected to abending machine at different angles of 160^0 and 180^0 to check the rebar cracking and flexibility.The bend test was done by ISO 15630-1. Bend tests were conducted on 10 mm and 12 mm 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 was 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

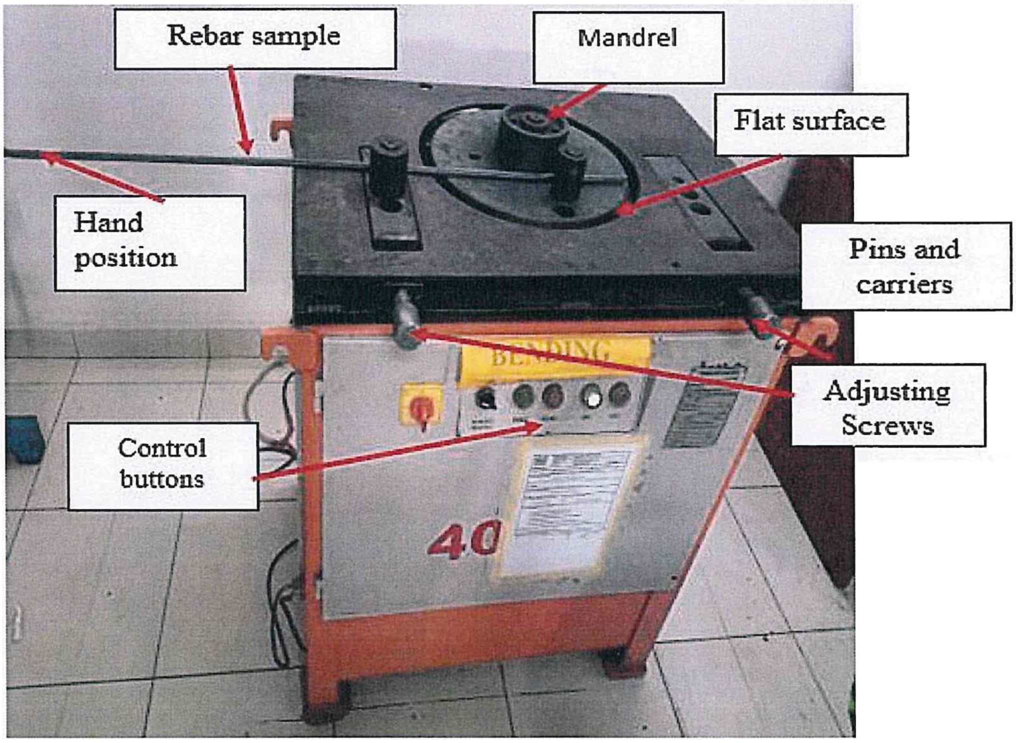

Figure 3. 2: Bending Machine

(b) Tensile Test on Universal Testing Machine

Figure 3.3 shows a data acquisition system and universal testing machine of model UTN/E100, SR.NO 4/2010 with a maximum capacity of 1000 KN that was used during the tensile tests to test the mechanical properties of of the selected rebars like yield strength, elongation, stress ratio, and tensile strength. All these properties were easily obtained once per specimen under test from the displayed results on the computer after the tensile test was completed. The UTM is widely used to test the mechanical properties of materials, including tensile strength, yield strength, and elongation of rebars. By applying controlled force and measuring the resulting deformation, the UTM can determine how the rebar performs under different load conditions. This ensures the rebar's compliance with mechanical strength requirements, which are critical for withstanding various forces in construction applications This universal testing machine was set up according to standard procedures and configured for tensile testing, considering the specific dimensions of each rebar, tensile tests on each 10 mm and 12 mm rebar specimens were conducted.

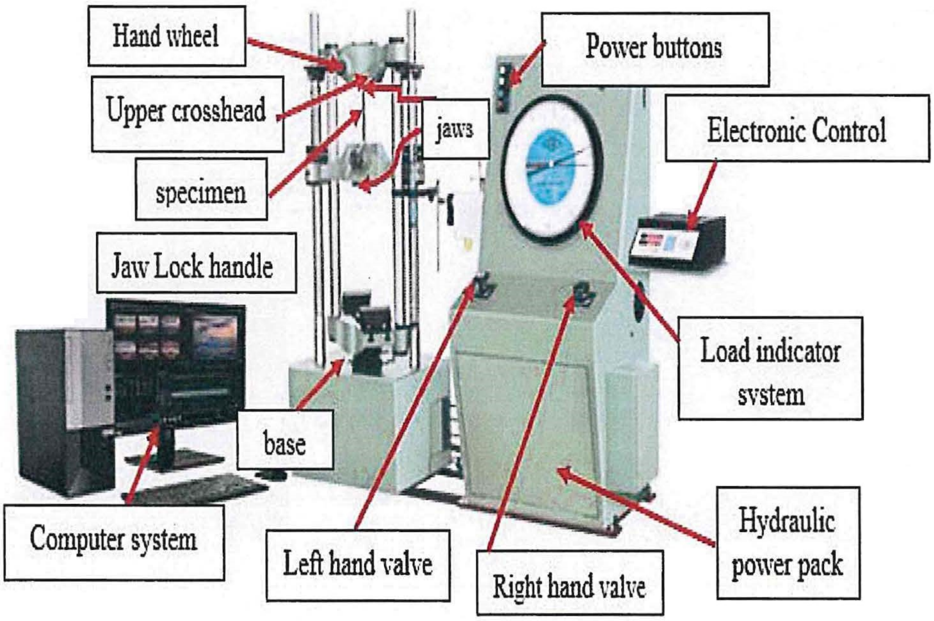

Figure 3.3:UniversalTestingMachine

A universal testing machine (UTN/E-100) was used to perform tensile tests on 10 mm and 12 mm rebar specimens while 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, applyingincremental 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.

3.3.3 Analyzingthe Chemical Composition of Rebars

The chemical composition of a rebar affects its strength, corrosion resistance, and durability. A spectrometer precisely identifies and quantifies the elements within the rebar. By analyzing the metal's composition, you can ensure that it meets the required standards for specific applications (e.g., containing the correct percentages of carbon, manganese, or other alloying elements). This analysis is essential for ensuring the material's performance and longevity in various environments. Figure 3.4 shows a setup of equipment that was used to analyze the chemical composition of the selected rebars. The setup included a cylinder with argon, a data acquisition system, and a spectrometer with a gas purifier.

The procedure below was followed while using the spectrometer to analyze the chemical composition of the chosen rebars, as specified in an International Standard referenced in ISO/TR 9769 beginitemize A setup including a spectrometer, data acquisition system, and argon cylinder was used to analyze the chemical composition of rebars as shown in figure 3.4.

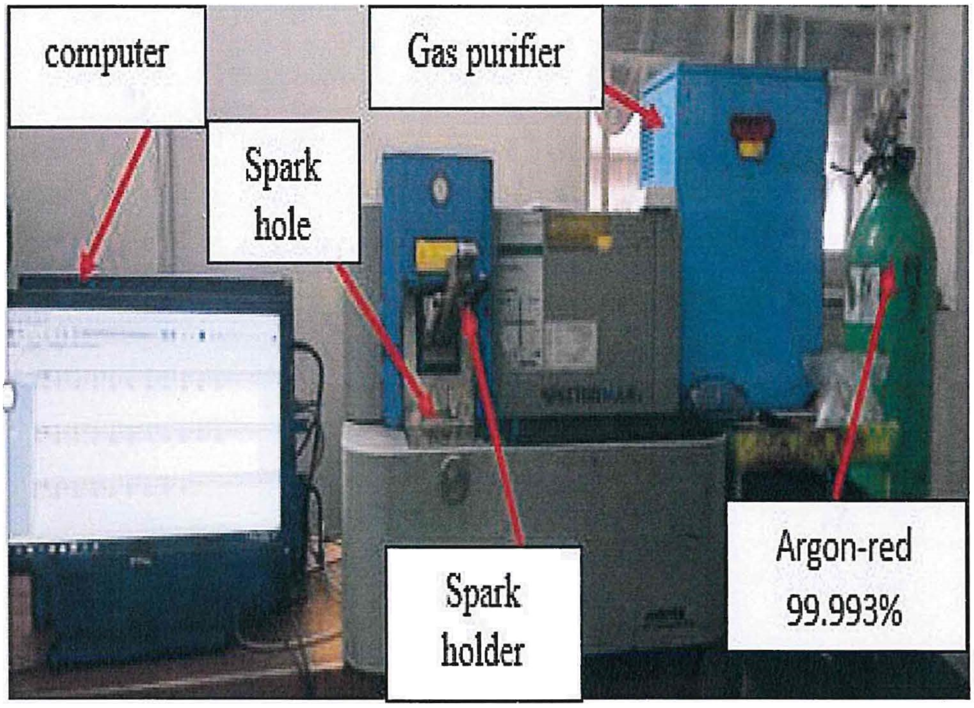

Figure 3.4:Set up of Spectrometer

Rebar samples were prepared by cutting, heating, hammering, and polishing to create a flat surface. The spectrometer was used to analyze the chemical composition of the rebars, following a procedure outlined in ISO/TR 9769.The procedure involved switching on the spectrometer, cleaning the spark rod, and positioning the polished specimen over the spark hole. Spark discharges were initiated to excite atoms and generate characteristic emission lines.

The results were displayed on the screen and printed for record-keeping. The process was repeated for all prepared specimens, and results were tabulated in the results chapter. The Carbon Equivalent Value (CEV) was calculated using a formula from US EAS 412- 2-2022 to express the maximum %age of residue elements present. Carbon equivalent value (CEV) was used to express the maximum %age of the mass of the residue elements present in still scrap and was calculated using the formula obtained from standard US

EAS 412-2-2022.

Figure 3.5 shows some chemically analyzed pieces of rebar samples that were first prepared before subjecting them to chemical analysis to meet the requirements for testing. Small pieces of length 100 mm were cut from each of the selected rebars, heated, and hammered to attain a flat surface that would enable the closing of the spark hole. Then the hammered rebar pieces were taken on the polishing machine to attain a cleaner and finer surface and then later subjected to a spectrometer for analysis.

Figure 3.5:Prepared Pieces for Chemical Analysis

Carbon equivalent value (CEV) was used to express the maximum percentage of the mass of the residue elements present in still scrap and was calculated using the formula obtained from standard US EAS 412-2-2022

3.3.4 Evaluating Conformity of rebars

To evaluate the conformity of rebars after determining the mass per unit length, testing mechanical, and analyzing chemical composition. The results were finally compared against industry standards US EAS 412:2:2022 and BS 4449:2005. These standards specify many parameters but most importantly; tensile strength, yield strength, elongation, chemical composition, stress ratio, and mass per unit length were considered, investigated, tabulated, and later compared with the mentioned standards. Some parameters were also statically evaluated like mass per unit length, tensile test results, and chemical composition by calculating the CEV and then compared with the specified standard in US EAS 412:2:2022.

CHAPTER FOUR

ANALYSIS AND DISCUSSION OF RESULTS

4.1 Introduction

This chapter presents the discussion and analysis of the experimental results obtained from different tests that were conducted to determine the mass per unit length, test mechanical properties (bendability, tensile strength, yield stress, and elongation), and analyze chemical composition. It also presents how the obtained results conformed with the established standards

4.2 Determination of Mass Per Unit Length

Table 4.1 presents the mass per unit length of each selected rebar including their measured lengths using a meter rule, along with their respective masses measured with a weighing scale. Additionally, the table indicates the acceptable minimum and maximum mass per meter values, as well as the standard mass per unit length according to US-EAS-412-2-2022.

Table 4.1: Rebar Mass per Unit Length Analysis

Rebar Size and Outlet	Length , L (m)	Mass, W (Kg)	W/L (Kg/m)	Min. mass per meter (Kg/m)	Standard mass per unit length (Kg/m)	Max. mass per meter(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

Figure 4.1 shows the graphical representation of mass per unit length of rebars on the vertical axis with respective measured rebars on the horizontal axis. The minimum mass of rebar sizes of 10 mm and 12 mm diameter as per standards were 0.567 and 0.838 indicated by green lines respectively while 0.667 and 0.938 indicate the upper mass limits respectively as shown in red lines. The calculated mass per meter (0.592-0.597 kg/m) of 10 mm rebar closely matches the ASTM A615 standard (0.560 kg/m), with a negligible difference.

Figure 4.1 also showed that all the selected rebars were within the designated range as per US EAS 412-2-2022, with D10 exhibiting the highest mass per unit length of 0.624 Kg/m among the rebars of 10mm diameter size, and B12 displaying the highest value of 0.89 Kg/m among all rebars of 12 mm diameter size. Since all the rebars were within acceptable mass per unit length range, it was very necessary to proceed and test the mechanical properties of the rebars to ascertain if they conform to other standards outlined in US EAS 412-2-2022. otherwise, if there were rebars that could not conform to the mass per unit length range, they would be rejected immediately and would not require other tests since mass per unit length affects most of the other obtained results like mechanical properties. On the other hand, the Weight and length obtained were used to create a file for the tenion test while using universal testing machine.

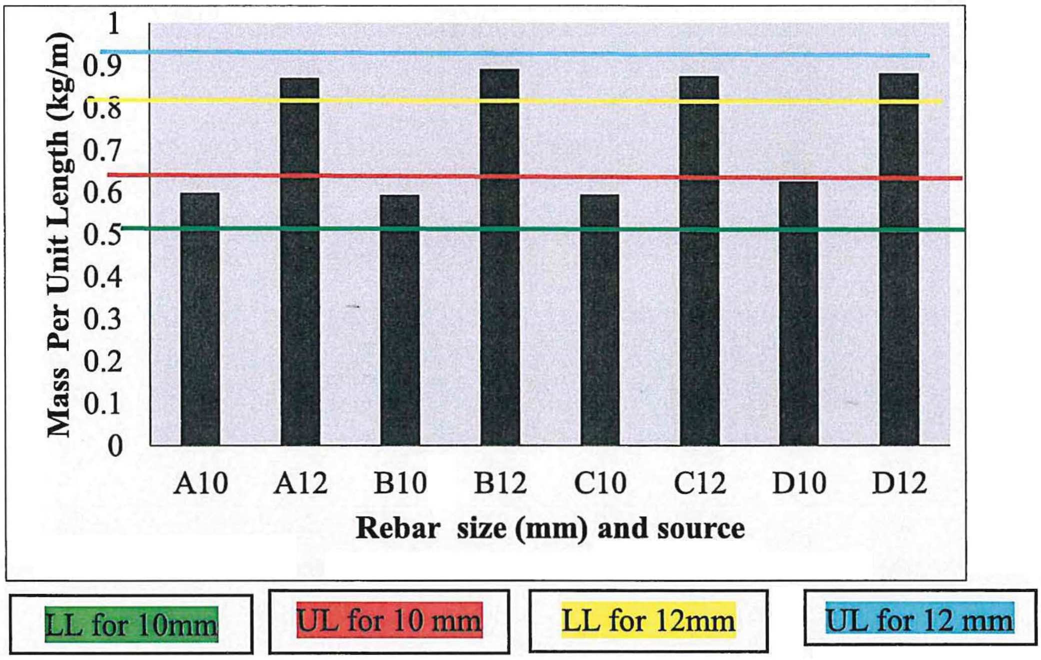

Figure 4.1:A graph of Mass per meter against Rebar sizes

4.3 Testing the Mechanical Properties of Selected Rebar

(a) Bending Test

Rebars crack if they are bent to sharp angles like at 90 degrees if they lack good composition and mechanical properties. In the construction industry and fabrication works, rebars are mostly bent at 90 degrees to suit the design requirements of the project. However, in some cases, these rebars develop cracks as they are bent to some angles. Therefore, it was important to conduct the bend test to ascertain their bendability to avoid eventual failures in real-life applications. It should be noted that all rebars were subjected to a bending machine at different angles of 160 and 180 degrees as per US EAS 412-2-2022 standards as shown in figure 4.2. After a visual inspection of each rebar after the bend tests, there were no cracks observed after bending at those different angles of 160 degrees and 180 degrees.

Table 4.2 shows the summary of the bending test results that were obtained from the bending of the rebars at different angles of 160 degrees and 180 degrees using the bending machine. They were then visually inspected for cracks, all rebars never showed any cracks

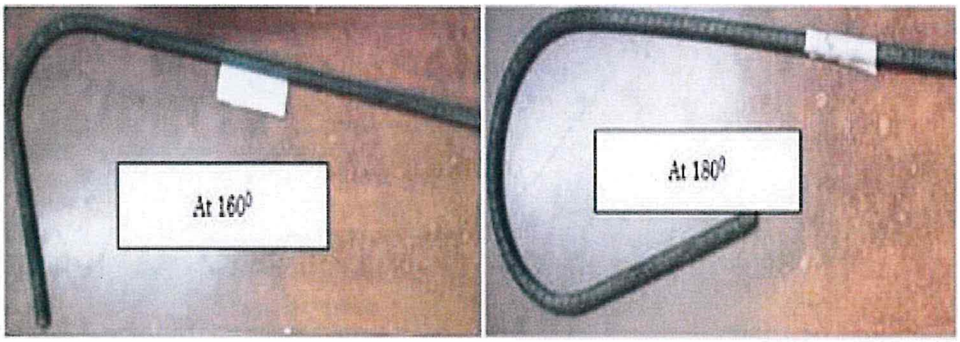

Figure 4.2: Rebars bent at 160^0 and 180^0

Table 4.2: shows the bending test results that were obtained from the bending of the rebars at different angles of 160^0 and 180^0 using the bending machine. They were then visually inspected for cracks, all rebars never showed any cracks and they were considered to have all met the bendability requirement as per US EAS 412-2-2022 standard that states the bar shall show neither rupture nor cracks visible to a person of normal or corrected vision to pass the bendability test. However, this does not mean that rebars have met all the standards specified by US EAS 412-2-2022. These rebars that did not show cracks could only be used on applications determined by the engineer. Otherwise, it is until all parameters conform to standards that qualify rebars standard.

Table 4.2:Bending Test Results

Rebar bent 160^0	Observations	Remarks	Rebar bent at 180^0	Observations	Remarks
A10	No cracks	Satisfactory	A10	No cracks	Satisfactory
A12	No cracks	Satisfactory	A12	No cracks	Satisfactory
B10	No cracks	Satisfactory	B10	No cracks	satisfactory
B12	No cracks	Satisfactory	B12	No cracks	satisfactory
C10	No cracks	Satisfactory	C10	No cracks	satisfactory
C12	No cracks	Satisfactory	C12	No cracks	satisfactory
D10	No cracks	Satisfactory	D10	No cracks	satisfactory
D12	No cracks	satisfactory	D12	No cracks	satisfactory

(b) Tensile Test

Table 4.3 presents the results that were obtained after subjecting the selected rebars to a universal testing machine with a focus on determining the tensile strength, yield stress, elongation, and stress ratio.

Table 4.3:Tensile Test Results

Rebar size and outlet	Tensile Strength (Mpa)	Elongation (%) >14	Yield Stress >500 MPa	Ratio/Stress ratio Required range 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	560	1.118

🟥 Rebars that did not conform to the stress ratio range(Substandard Rebars)
🟩 Rebars that conformed to the stress ratio range (Standard Rebars)

Based on the data in Table 4.3, it was observed that all rebars had yield stress values above 500 MPa and elongation above 14% meeting the standards set by US EAS 412-2-

2022. However, only three specific rebars (A12, B10, and D10, highlighted in green) met the criteria for an acceptable stress ratio above 1.15 as per US EAS 412-2-2022 andbelow 1.35 as per BS 4449-2005. The remaining that were highlighted in red were deemed substandard as they did not fall within the acceptable stress ratio range despite having yield stresses above 500MPa.

This meant that these rebars may lack the necessary ductility to withstand seismic conditions and could potentially fail under stress. The stress ratio is an important parameter for determining rebar ductility, with higher ratios indicating greater ductility. Neglecting stress ratios during design and opting for rebars outside the acceptable stress ratio range can lead to structural failures, especially during events like earthquakes. It's important for project engineers to not only focus on tensile and yield strength but also consider the stress ratio of rebars to enhance structural integrity and resilience against unforeseen events in construction projects.

4.4 Analysis of Chemical Composition of Rebars

Table 4-4 shows the chemical composition of eight samples that were first prepared and then analyzed using the spectrometer.The standards used were US EAS 412-2-2022 and BS 4449:2005 for evaluation with the experimental results.The spectrometer analyzed twenty-eight elements, but the results of major chemical elements by percentagelike C, Si, Mn, P, S, Cr, Mo, Ni, Al, Co, Cu, Nb, Ti, and V in steel manufacture were only considered for this investigation because the rest of the elements were in traceable content.Finally,the Carbon Equivalent Value (CEV) was then calculated using the equation 2.1

Table 4.4: Chemical Composition of the Selected Rebars (%)

Rebars	Fe	C	Si	Mn	p	S	Cr	Mo	Cu	Ni	V	CEV
A10	98.7	0.22	0.2	0.75	0.0282	0.0121	0.0241	0.008	0.008	0.021	0.0012	0.3536
A12	98.7	0.211	0.19	0.703	0.206	0.0214	0.023	0.01	0.01	0.029	0.0018	0.3377
B10	98.7	0.208	0.21	0.703	0.0201	0.0222	0.035	0.01	0.01	0.027	0.0023	0.3371
B12	98.7	0.2	2	0.681	0.0253	0.242	0.048	0.011	0.011	0.029	0.0041	0.3288
C10	98.7	0.225	0.21	0.709	0.0191	0.0252	0.035	0.011	0.011	0.027	0.0021	0.3553
C12	98.7	0.19	0.2	0.674	0.0251	0.0248	0.035	0.011	0.011	0.03	0.0025	0.3147
D10	98.6	0.227	0.19	0.709	0.0288	0.0229	0.067	0.011	0.011	0.029	0.063	0.376
D12	98.7	0.199	0.2	0.704	0.0285	0.0121	0.049	0.011	0.01	0.027	0.0046	0.3317
US EAS 412-2-2022		≤0.25	0.6	1.6	0.05	0.05				0.012		≤0.55
BS 4449:2005		0.24			0.055	0.055			0.85			0.52

Figure 4.3 shows the graphical representation of the chemical composition that indicates chemical composition by the percentage of some elements such as carbon content that ranged from 0.199 to 0.227 across all rebars. Carbon stands as a pivotal element in TMT bar fabrication, influencing their hardenability.

This variation in carbon content improves toughness upon TMT bars. Higher carbon levels result in increased toughness, while lower levels yield more ductility. This diverse chemical composition suggests TMT bars possess high flexibility, ductility, and ease of manipulation. Moreover, optimal fusion during welding, facilitated by carbon content, contributes significantly to achieving a Carbon Equivalent Value (CEV) within the range of 0 to 0.4 for all rebars.

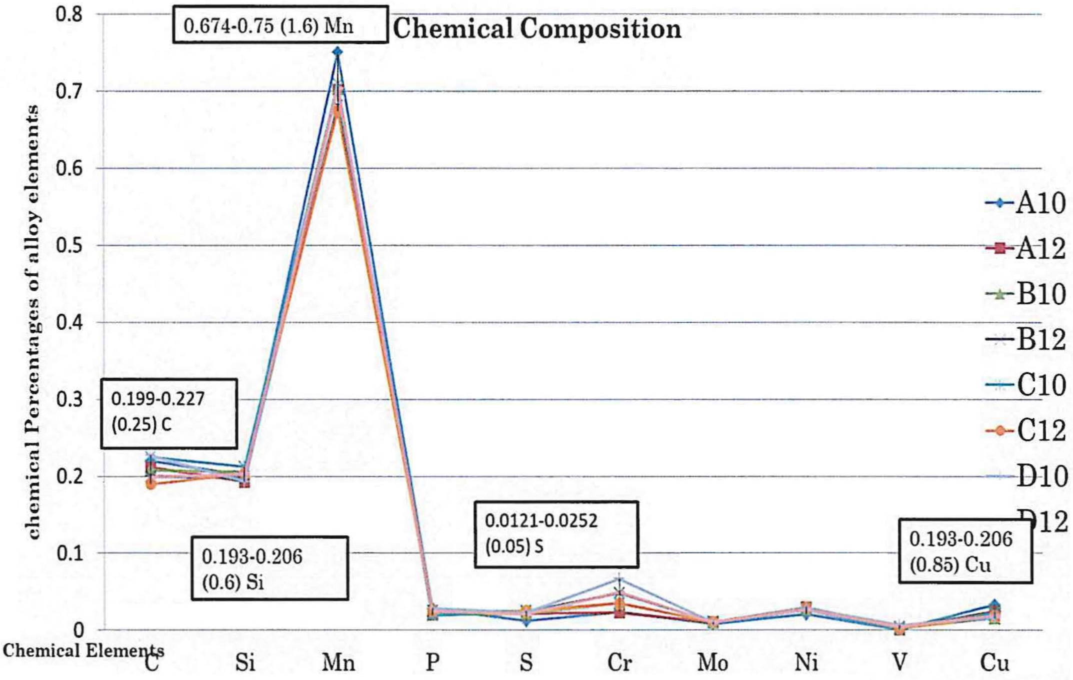

Figure 4.3: A graph of the Chemical Composition of Rebars

Silcon content ranged from 0.193 to 0.206, offering a moderate enhancement to strength and hardness compared to manganese. Acting as a deoxidizing agent, silicon improves rebar quality by minimizing defects. Manganese content ranged from 0greatly0.75, greatly below the maximum allowable limit of 1.6. Lower manganese content correlates with decreased hardness, with an optimal range suggested for improved hardenability, ideally around 0.9 to 1. Manganese also mitigates steel brittleness while imparting strength.

Sulfur content ranges from 0.0121 to 0.0252, with lower levels preferred to prevent hot shortness, just below the maximum limit of 0.05. Minimizing sulfur and phosphorus content is crucial as they can induce surface embrittlement. These impurities must be carefully controlled during manufacturing to avoid exceeding the 0.05±5% threshold. Exceeding 0.055 for phosphorus leads to peeling, while sulfur levels above 0.055 result in embrittlement. Utilizing steel with minimal sulfur and phosphorus content mitigates the risk of cold and hot shortness in rebars.

Chromium, nickel, and molybdenum serve as effective corrosion-resistant elements but should be present in trace amounts, as evident in Table 4-7 data. Copper content within the range of 0.193 to 0.206 for rebars is commendable, well below the maximum limit of 0.85. However, excessive copper and tin, act as contaminants and can adversely affect mechanical properties and should be minimized.

Figure 4.4 shows the Carbon Equivalent Value (CEV) that was used to determine the weldability of join abley of rebars different CEVs affect the weldability of steel differently and it should not be ignored in the investigation of rebars.

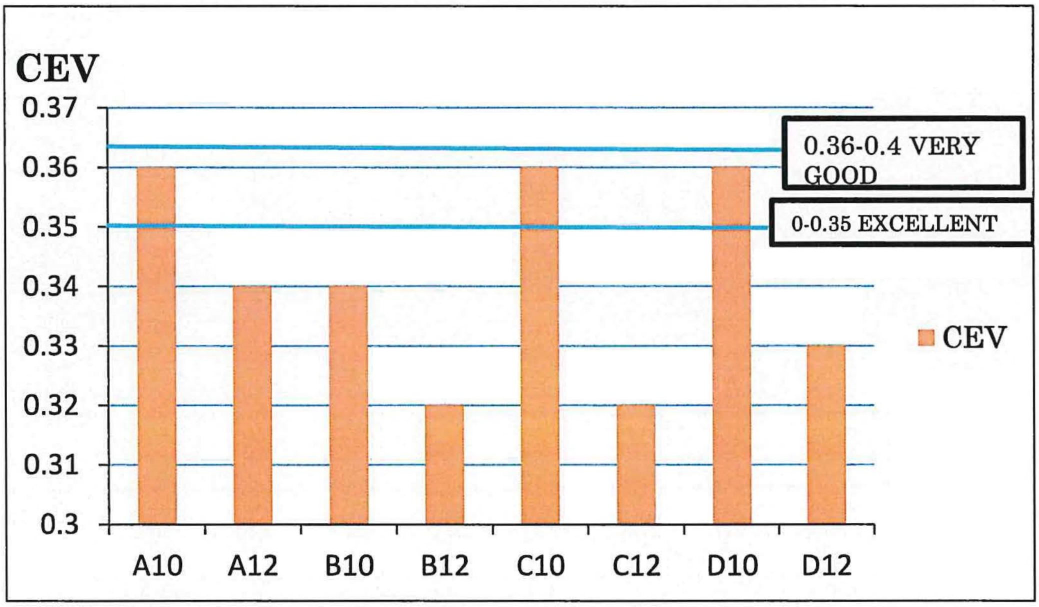

Figure 4.4:Carbon Equivalent Values against Selected Rebars

The carbon equivalent value was determined using the formula $CEV = C + Mn/6 + (V + Mo + Cr)/5 + (Cu + Ni)/15$. CEV serves as a metric in metallurgy to evaluate the weldability of steel, with a lower CEV indicating better weldability.

In the provided data, all chemically analyzed rebars showed that the 12 mm rebar from outlet C (C12) had the lowest CEV of 0.315 which qualifies it to have better weldability characteristics, while the 10 mm rebar from outlet D (D10) had the highest CEV of 0.364 and is very good according to the study conducted by Perera & Guluwita (2018).

Perera & Guluwita (2018) stress the importance of maintaining a narrower CEV range (0.37 < CE < 0.4 % by mass) for consistent rebar quality. It is worth noting that all rebars had a CEV below the lower limit of 0.52 and 0.5 as per the established standards of BS and US-EAS 412-2-2022, respectively.

4.4 Evaluation of Conformity

4.4.1 Determining Mass Per Unit Length

Table 4.5 presents the results of mass per unit length but the average of each of the measured rebars with sizes 10mm and 12 mm was calculated and tabulated respectively as shown.

Table 4.5: Mass Per Unit Length Analysis

Rebar size	Length, L (m)	Mass, W(Kg)	M/L (Kg/m)	Min. M/L (Kg/m)	Standard M/L(Kg/m)	Max. M/L(Kg/m)
A10	0.705	0.421	0.597	0.567	0.617	0.667
B10	0.657	0.389	0.592	0.567	0.617	0.667
C10	0.614	0.364	0.593	0.567	0.617	0.667
D10	0.647	0.404	0.624	0.567	0.617	0.667
AVERAGE	-	-	**0.586**	-	--	
A12	0.609	0.529	0.869	0.838	0.888	0.938
B12	0.61	0.543	0.89	0.838	0.888	0.938
C12	0.648	0.566	0.873	0.838	0.888	0.938
D12	0.637	0.56	0.879	0.838	0.888	0.938
AVERAGE	-	-	**0.878**	-	-	-

Averagely, the mass per unit length of the rebars with size 10mm was 0.586 and this was in the range between 0.567 and 0.667 but slightly below the exact standard value of 0.617

by a value of 0.031Kg/m which is not a big difference as shown in Table 4.6. The average for the rebars of size 12mm was calculated and found to be 0.878 and this was in the range of 0.838 and 0.938. However, 0.878 Kg/m was slightly below the standard of 0.888 Kg/m by o.o1 Kg/m which is surely not a big deviation. Comparably, the mass per unit length of all the samples tested conformed to acceptable limits.

4.4.2 Evaluating the Tensile Tests for Mechanical Properties

Table 4.6 presents tensile test results that were obtained after subjecting the selected samples from the universal testing machine to test their mechanical properties like tensile stress, yield stress, elongation, and stress ratio.

Table 4.6:Tensile Test Results

Rebar size and outlet	Tensile Strength (Mpa)	Elongation (%) >14	Yield Stress >500 MPa	StresRequired range 1.15-1.35s ratio
A10	660	24	582	1.133
B10	648	24	559	1.159
C10	695	22	614	1.131
D10	713	23	617	1.157
AVERAGE	**679**	**24**	**593**	-
A12	657	20	570	1.152
B12	636	19	582	1.09
C12	597	20	536	1.114
D12	626	19	560	1.118
AVERAGE	**629**	**20**	**562**	-

The average was calculated for tensile strength, elongation, and yield strength considering first, the rebars with a size of 10mm and then rebars with a size of 12 mm. It was found that the average yield strengths of the rebars were above 500Mpa as the minimum acceptable yield strength. The stress ratio was calculated as a ratio of tensile strength to yield strength to help one determine the ductility of rebars. The stress ratio should be between 1.15 and 1.35 as per the US EAS 412-2-2022. It was found that only three rebars A10, C10, B12, and C12 did not meet the acceptable stress ratio range of 1.15 to 1.35 and should be regarded as substandard and therefore should be rejected. The cause of rebars failing to meet the acceptable stress ratios could be due to many factors including the operations parameters like reheating and cooling temperatures among others.

4.4.3 Evaluating the Chemical Composition Results

According to Table 4-4, shows the results obtained from the analysis of the selected rebar samples after analyzing them using the spectrometer. The spectrometer used in the analysis was configured to detect twenty-eight elements, but only major elements were considered based on the carbon equivalent value equation. Refering to Table 2-2 which displays the chemical composition obtained from BS 4449-2005 for evaluating conformity, showing five elements and their maximum allowable limits. Carbon equivalent values indicated in the table help determine the weldability of rebars, with higher values indicating better weldability. A comparison between Table 4.4 and Table 4.4 for elements such as carbon, sulfur, phosphorous, nickel, and copper showed minor variations that did not significantly impact the rebar's chemical composition. For example, the allowable maximum carbon limit was 0.22, with results ranging from 0.199 to 0.227 %, all within the allowable minimum limit of 0.22. Additionally, Carbon Equivalent Value (CEV) for all the eight analyzed rebars was calculated and it was found that the rebars denoted by A12, B10, B12, C12, and D12 had the lowest CEV values ranging from 0 to 0.35 indicating excellent weldability compared to rebar denoted by D10 had CEV value ranging from 0.36 to 0.4 indicating very good in terms of weldability as earlier illustrated in figure 4.4

4.5.4 Proposed Quality Parameter Ranges

Table 4.7 presents the proposed ideal quality parameter ranges for good-quality rebars. These maximum parameters were focussed on because they were not specified anywhere in US EAS 412-2-2022. It only specifies the minimum allowable yield strength, stress ratio, and CEV ignoring the respective allowable maximum parameters that are ideal for good-quality rebars The allowable minimum and maximum values for Yield Strength are expected to be 500 MPa and 650 MPa respectively according to US EAS-412-2-2022 and BS 4999:2005 standards. Rebars with Yield strength above 650 MPa crack easily on bending. The Stress ratio should be between 1.15 and 1.35 based on US EAS-412-2-2022 and BS 4999:2005 standards. Rebars outside this range pose poor ductility, a property that should not be ignored when selecting rebars for the construction industry because rebars that are less ductile fail to withstand seismic loadings and result in building collapses. The CEV of rebars should be within the range of 0.5 ±0.05 (US EAS-412-2-2022) and 0.52 (BS 4999:2005) for easy weldability. However, the CEV range of 0.36-0.4 is also good.

Table 4.7:Proposed Quality Parameter Ranges

Performance characteristics	Minimum value	Maximum value
Yield stress	500(USEAS-412-2-2022)	650 (BS 4999-2005)
Stress ratio	1.15 (US EAS-412-2-2022)	1.35(BS 4999-2005)
CEV	0.5 ±0.05(US EAS-412-2-20220 0.52(BS 4999-2005)	

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

All the selected rebars were within the designated range as per US EAS 412-2-2022, with D10 exhibiting the highest mass per unit length of 0.624 Kg/m among the rebars of 10mm diameter size, and B12 displaying the highest value of 0.879 Kg/m among all rebars of 12 mm diameter size.

Mechanically, all rebars had yield stresses exceeding the minimum allowable limit of 500 MPa and elongation exceeding 14 % as per US EAS 412-2022. However, 5 rebars out of 8 did not fall within the acceptable stress ratio ranges of 1.15-1.35 despite having yield stresses above 500 MPa, leading to their classification as substandard. They did not meet established standards specified in US EAS 412-2022, primarily due to manufacturing processes including quenching pressures and reheating furnace temperatures. Additionally, quality checks could not have been adequately done during the production lines.

Any rebar that deviates from the specified range is rejected. Based on the data in Table 4.3, it was observed all rebars had yield stress values above 500 MPa and elongation above 14 % meeting the standards set by US EAS 412-2-2022. However, only three specific rebars (A12, B10, and D10 met the criteria for an acceptable stress ratio above 1.15 as per US EAS 412-2-2022 and below 1.35 as per BS 4449-2005 while A10, B12, C10, C12 and D12 were rebars that were deemed substandard as they did not fall within the acceptable stress ratio range of 1.15 to 1.35 based on US EAS 412-2-2022.

Chemically it was revealed as per CEV, rebars A12, B10, B12, C12, and D12 exhibited excellent weldability, while A10, D10, and C10 had values ranging from 0.36 to 0.40 and these were considered very good in terms of weldability. The determination of ideal quality parameter ranges of reinforcing ribbed bars used in Uganda's construction industry has shown that there is a need to invest in research for better rebar quality focusing on achieving the yield stress that conforms to standards US EAS 412-2-2022.

Additionally, there were slight variations in chemical composition with rebar A10 having the highest 0.75 % Mn far below the allowable 1.6 % as per the standard US EAS 412-2-2022. The rest of the chemical elements for all rebars had close minimum allowable chemical composition % by mass as per established standard US EAS 412-2-2022.

The study finally proposed the quality parameter ranges and these included the maximum yield stress of 650MPa, stress ratio of 1.35, and CEV range of 0.36-0.40. These ranges were benchmarked from the established standards like US EAS 412-2-2022, BS 4449:2005 and compared with the obtained experimental results.

5.2 Recommendations

Recommendations based on the findings of this research include the following:

1. Funding is required to collect a large sample to increase the reliability and generalizability of data
2. Further research into determinants leading to lower stress ratios of rebars with acceptable yield stresses as per US EAS 412-2-2022 is required to have good quality rebars.
3. Microstructural analysis should be conducted using a scanning electron microscope to analyse the internal cracks on bending rebars at different angles.

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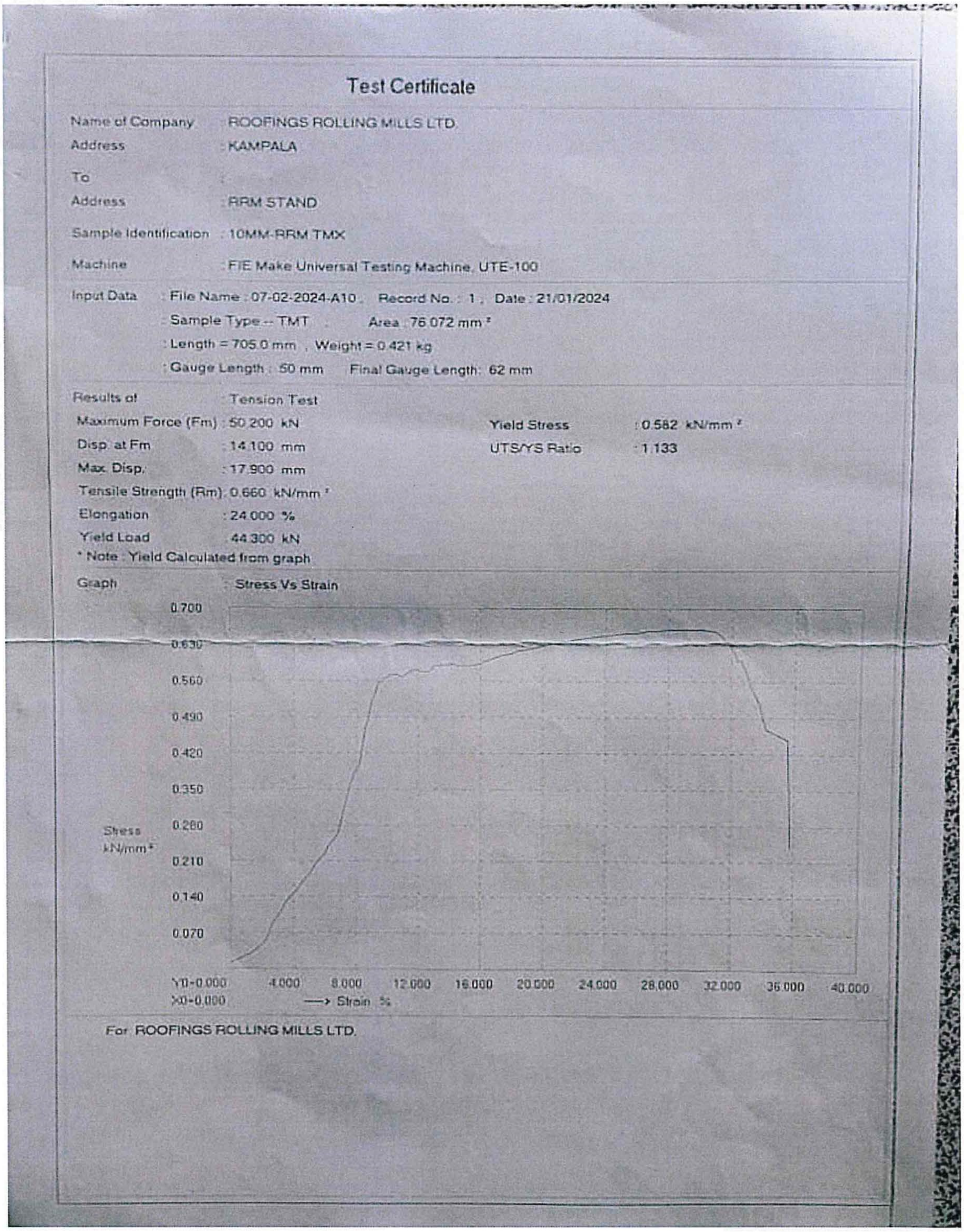
US EAS 412-2-2022 Steel for the reinforcement of concrete — Part 2: Ribbed bars

APPENDICES

Appendix A: Tensile Test Results

Rebar A10



Test Certificate

Name of Company : ROOFINGS ROLLING MILLS LTD.
Address : KAMPALA

To :
Address : RRM STAND

Sample Identification : 10MM-RRM TMX

Machine : FIE Make Universal Testing Machine, UTE-100

Input Data : File Name : 07-02-2024-A10 , Record No. : 1 , Date : 21/01/2024
: Sample Type -- TMT , Area : 76.072 mm²
: Length = 705.0 mm , Weight = 0.421 kg
: Gauge Length : 50 mm Final Gauge Length: 62 mm

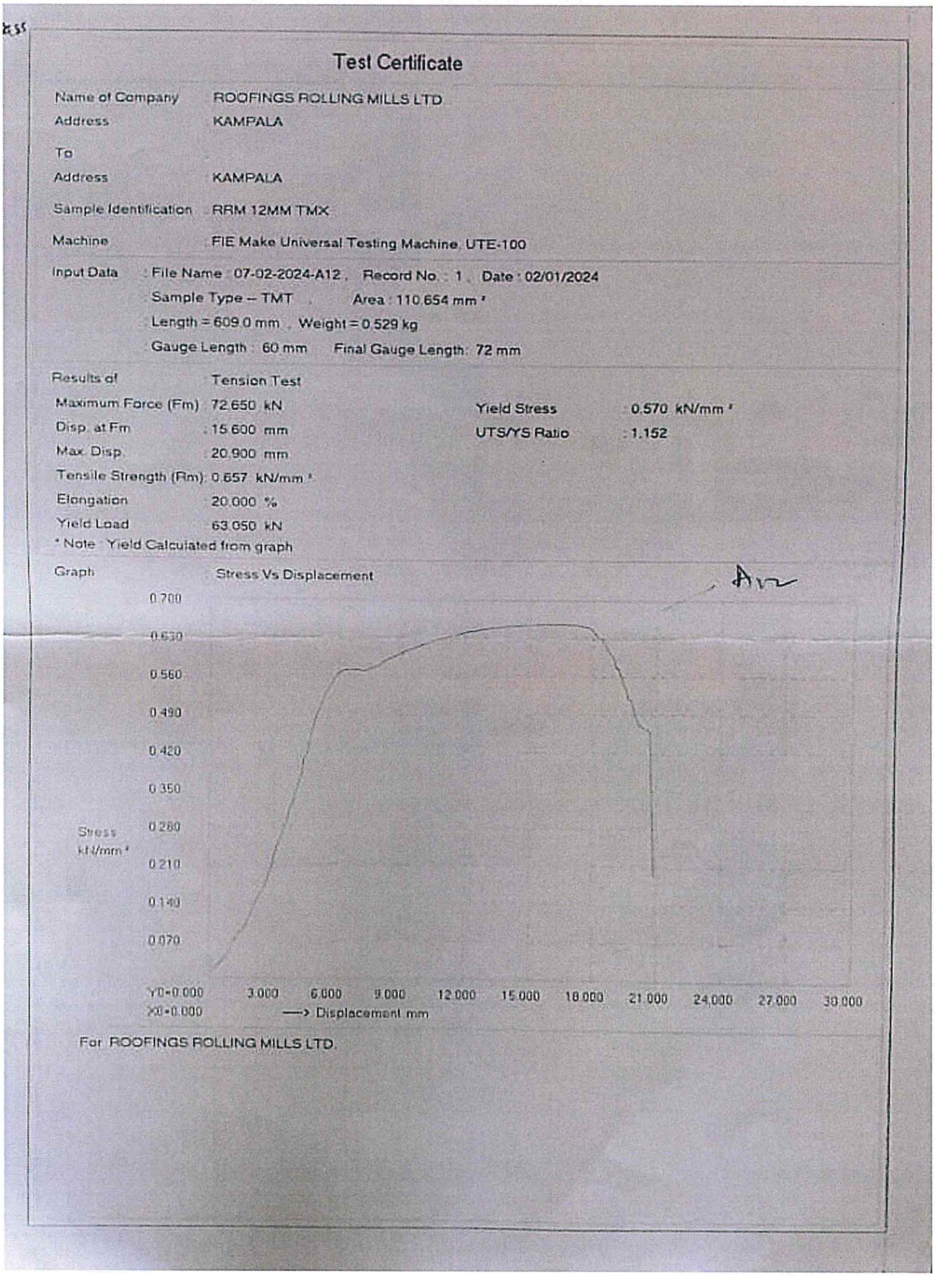
Results of : Tension Test
Maximum Force (Fm) : 50.200 kN
Disp. at Fm : 14.100 mm
Max. Disp. : 17.900 mm
Tensile Strength (Rm): 0.660 kN/mm²
Elongation : 24.000 %
Yield Load : 44.300 kN
* Note : Yield Calculated from graph

Yield Stress : 0.582 kN/mm²
UTS/YS Ratio : 1.133

Graph : Stress Vs Strain

For ROOFINGS ROLLING MILLS LTD.

Rebar A12



Test Certificate

Name of Company ROOFINGS ROLLING MILLS LTD
Address KAMPALA

To
Address KAMPALA

Sample Identification RRM 12MM TMX

Machine FIE Make Universal Testing Machine UTE-100

Input Data File Name 07-02-2024-A12 , Record No. 1 , Date : 02/01/2024
Sample Type – TMT , Area : 110.654 mm ²
Length = 609.0 mm , Weight = 0.529 kg
Gauge Length 60 mm Final Gauge Length: 72 mm

Results of Tension Test

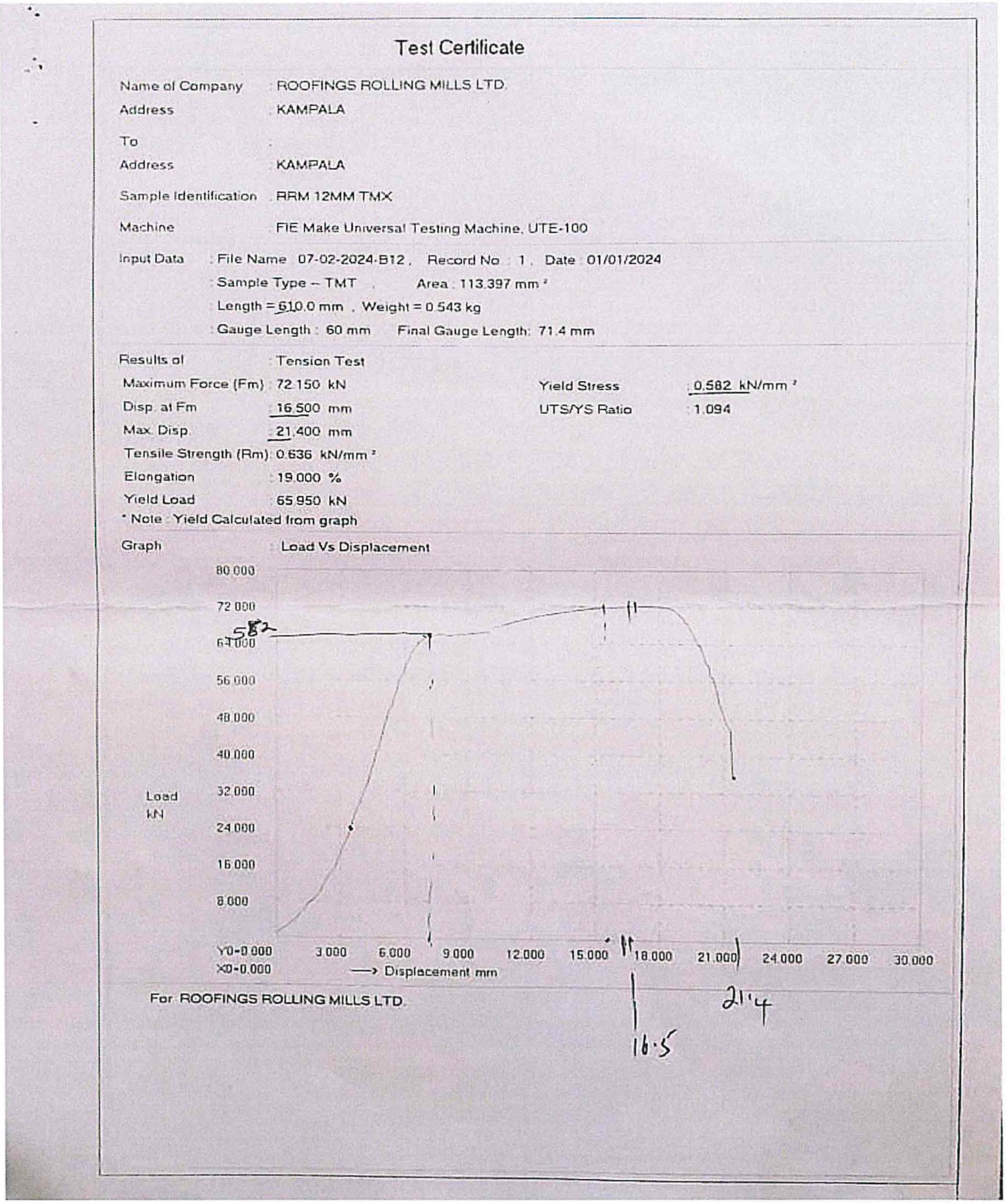
Maximum Force (Fm)	72.650 kN	Yield Stress	0.570 kN/mm ²
Disp. at Fm	15.600 mm	UTS/YS Ratio	1.152
Max. Disp.	20.900 mm		
Tensile Strength (Rm)	0.657 kN/mm ²		
Elongation	20.000 %		
Yield Load	63.050 kN		

* Note Yield Calculated from graph

Graph Stress Vs Displacement

For ROOFINGS ROLLING MILLS LTD.

Rebar B10



Test Certificate

Name of Company : ROOFINGS ROLLING MILLS LTD.
Address : KAMPALA

To :
Address : KAMPALA

Sample Identification : RRM 12MM TMX

Machine : FIE Make Universal Testing Machine, UTE-100

Input Data : File Name : 07-02-2024-B12 , Record No : 1 , Date : 01/01/2024
: Sample Type – TMT , Area : 113.397 mm ²
: Length = 610.0 mm , Weight = 0.543 kg
: Gauge Length : 60 mm Final Gauge Length: 71.4 mm

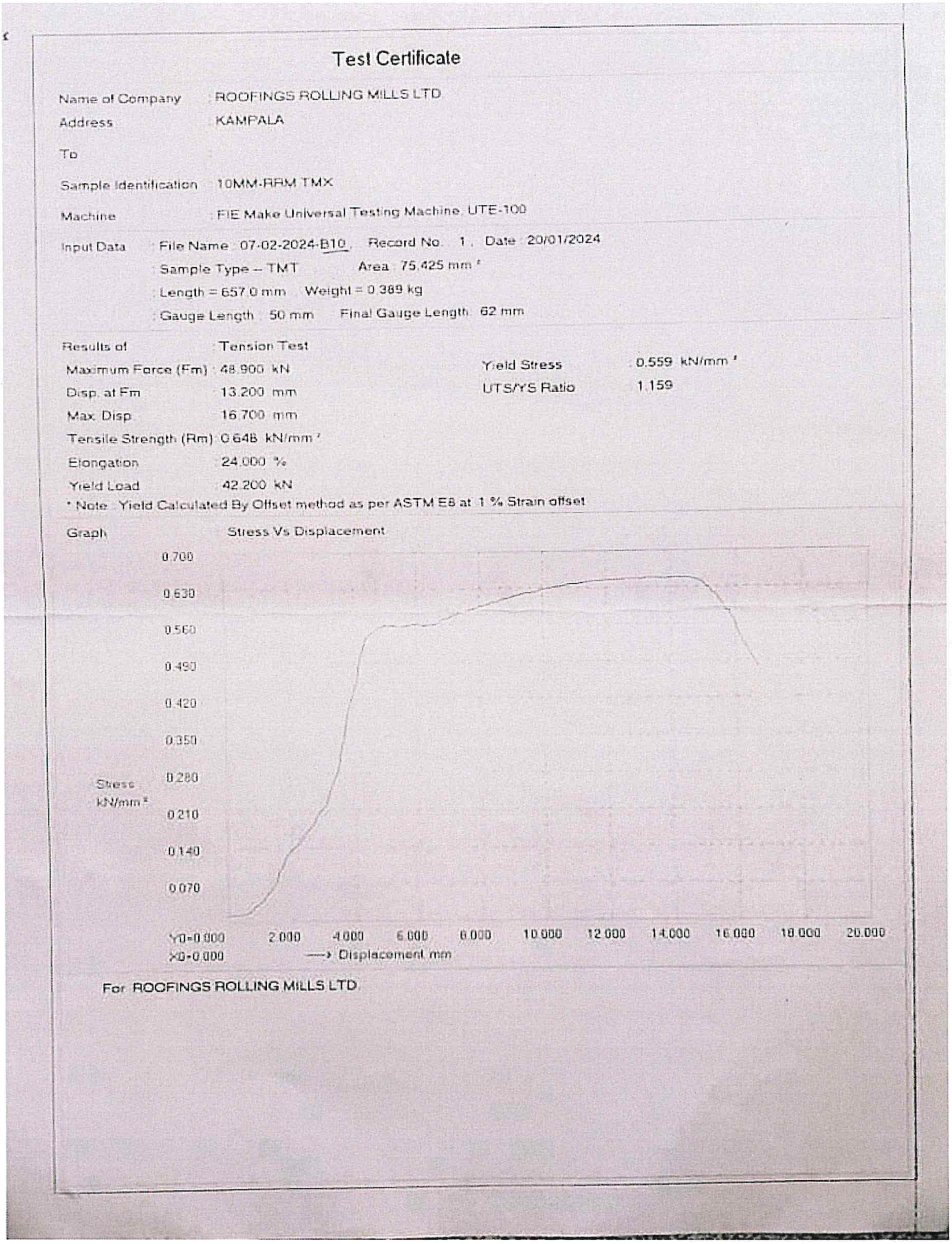
Results of : Tension Test
Maximum Force (Fm) : 72.150 kN
Disp. at Fm : 16.500 mm
Max. Disp. : 21.400 mm
Tensile Strength (Rm) : 0.636 kN/mm ²
Elongation : 19.000 %
Yield Load : 65.950 kN
* Note : Yield Calculated from graph

Yield Stress : 0.582 kN/mm ²
UTS/YS Ratio : 1.094

Graph : Load Vs Displacement

For ROOFINGS ROLLING MILLS LTD.

Rebar B12



Test Certificate

Name of Company : ROOFINGS ROLLING MILLS LTD
Address : KAMPALA
To :
Sample Identification : 10MM-RRM TMX
Machine : FIE Make Universal Testing Machine, UTE-100

Input Data : File Name : 07-02-2024-B10 , Record No. : 1 , Date : 20/01/2024
: Sample Type – TMT Area : 75.425 mm²
: Length = 657.0 mm Weight = 0.389 kg
: Gauge Length : 50 mm Final Gauge Length : 62 mm

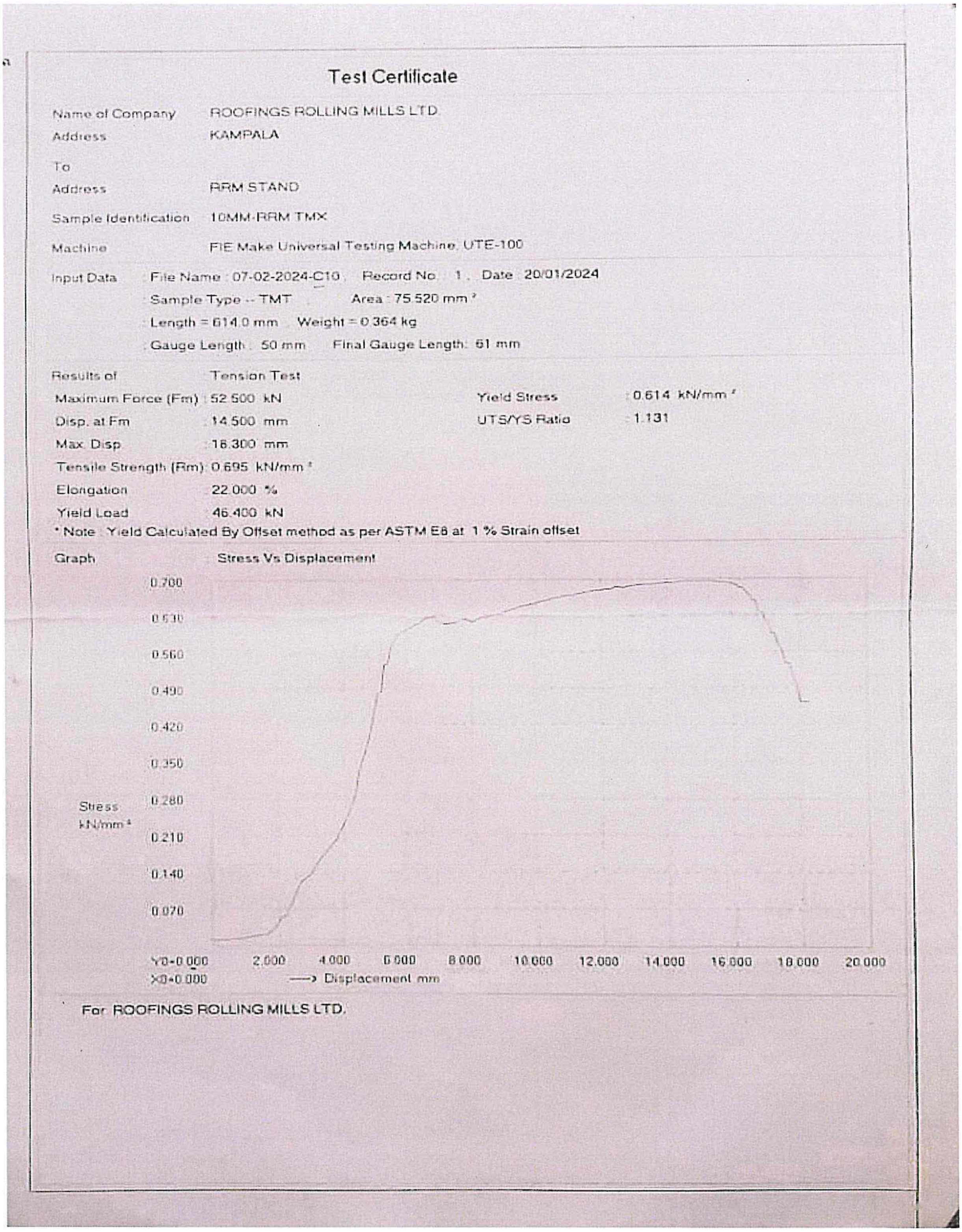
Results of : Tension Test
Maximum Force (Fm) : 48.900 kN
Disp. at Fm : 13.200 mm
Max. Disp : 16.700 mm
Tensile Strength (Rm) : 0.648 kN/mm²
Elongation : 24.000 %
Yield Load : 42.200 kN
Yield Stress : 0.559 kN/mm²
UTS/YS Ratio : 1.159

* Note : Yield Calculated By Offset method as per ASTM E8 at 1 % Strain offset

Graph : Stress Vs Displacement

For ROOFINGS ROLLING MILLS LTD

Rebar C10



Test Certificate

Name of Company ROOFINGS ROLLING MILLS LTD.
Address KAMPALA

To
Address RRM STAND

Sample Identification 10MM-RRM TMX

Machine FIE Make Universal Testing Machine, UTE-100

Input Data : File Name : 07-02-2024-C10 , Record No : 1 , Date : 20/01/2024
: Sample Type -- TMT Area : 75.520 mm^2
: Length = 614.0 mm , Weight = 0.364 kg
: Gauge Length : 50 mm Final Gauge Length: 61 mm

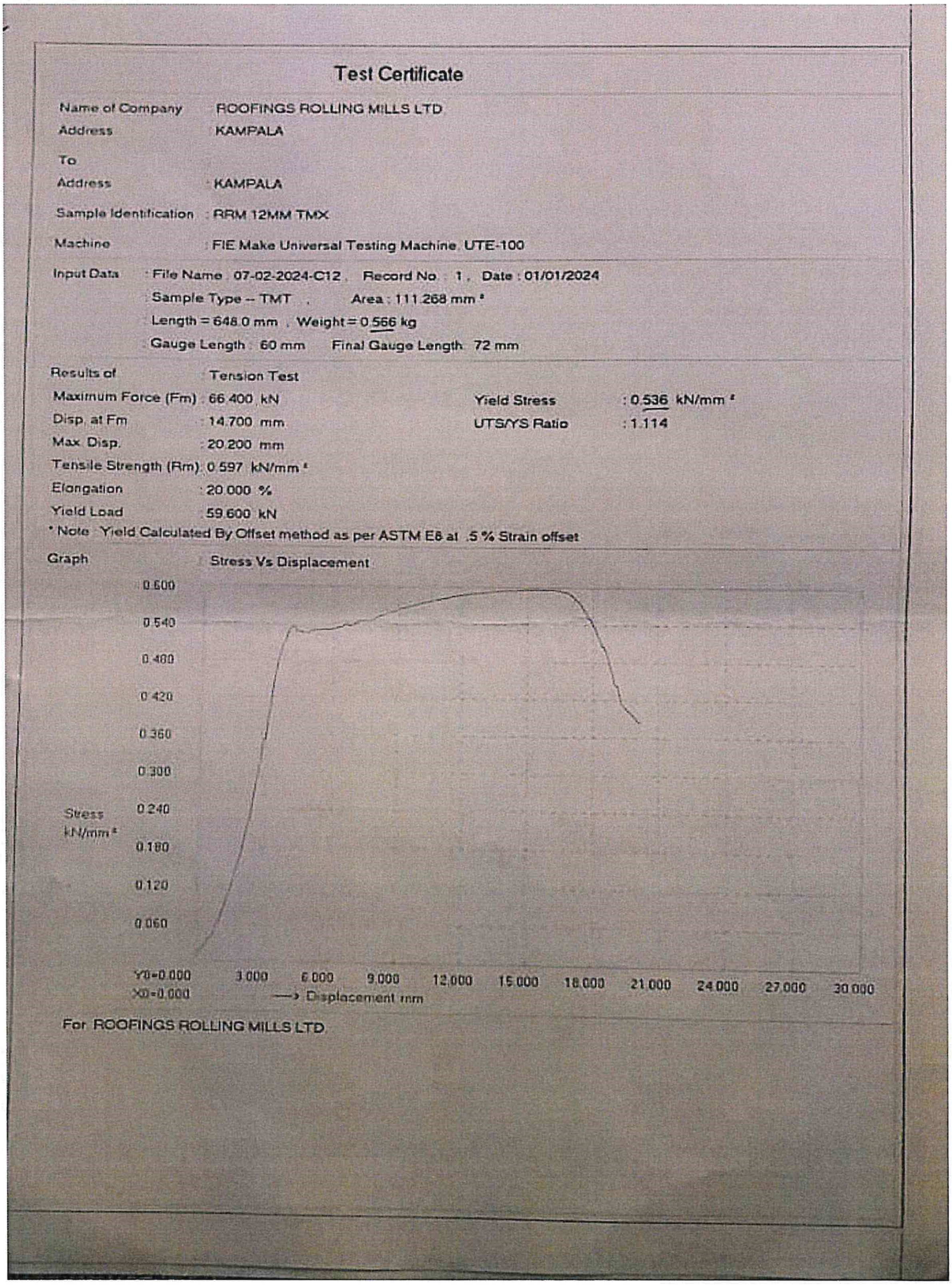
Results of : Tension Test
Maximum Force (Fm) : 52.500 kN
Disp. at Fm : 14.500 mm
Max. Disp. : 18.300 mm
Tensile Strength (Rm): 0.695 kN/mm^2
Elongation : 22.000 %
Yield Load : 46.400 kN
Yield Stress : 0.614 kN/mm^2
UTS/YS Ratio : 1.131

* Note : Yield Calculated By Offset method as per ASTM E8 at 1 % Strain offset

Graph : Stress Vs Displacement

For ROOFINGS ROLLING MILLS LTD.

Rebar C12



Test Certificate

Name of Company : ROOFINGS ROLLING MILLS LTD
Address : KAMPALA

To
Address : KAMPALA

Sample Identification : RRM 12MM TMX

Machine : FIE Make Universal Testing Machine. UTE-100

Input Data : File Name : 07-02-2024-C12 , Record No. : 1 , Date : 01/01/2024
Sample Type -- TMT , Area : 111.268 mm^2
Length = 648.0 mm , Weight = 0.566 kg
Gauge Length : 60 mm Final Gauge Length : 72 mm

Results of : Tension Test
Maximum Force (Fm) : 66.400 kN
Disp. at Fm : 14.700 mm
Max. Disp. : 20.200 mm
Tensile Strength (Rm) : 0.597 kN/mm^2
Elongation : 20.000 %
Yield Load : 59.600 kN

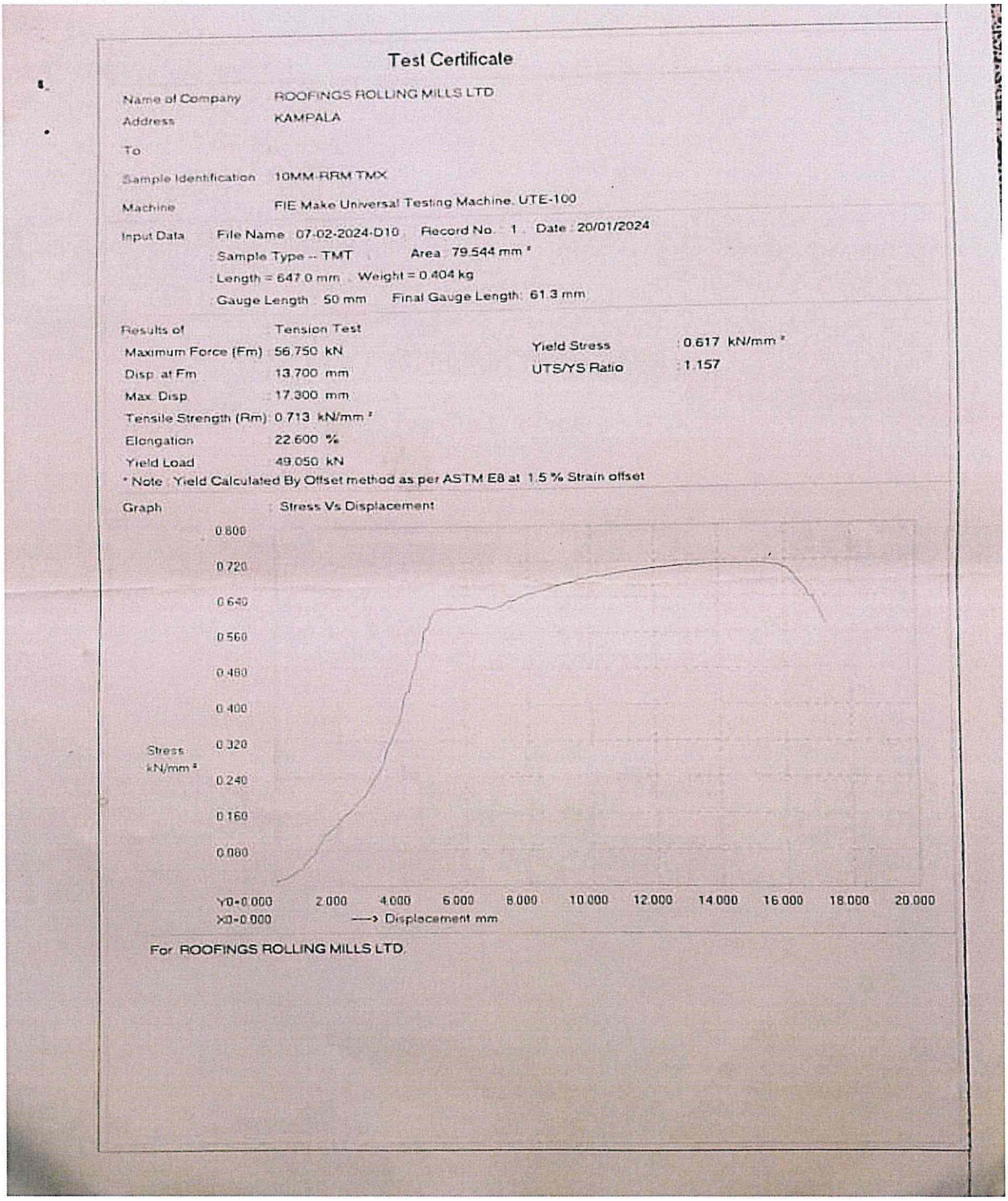
Yield Stress : 0.536 kN/mm^2
UTS/YS Ratio : 1.114

* Note : Yield Calculated By Offset method as per ASTM E8 at .5 % Strain offset

Graph : Stress Vs Displacement

For ROOFINGS ROLLING MILLS LTD

Rebar D10



Test Certificate

Name of Company: ROOFINGS ROLLING MILLS LTD
Address: KAMPALA
To
Sample Identification: 10MM-RRM TMX
Machine: FIE Make Universal Testing Machine. UTE-100

Input Data: File Name: 07-02-2024-D10 Record No.: 1 Date: 20/01/2024
Sample Type -- TMT Area: 79.544 mm^2
Length = 647.0 mm Weight = 0.404 kg
Gauge Length: 50 mm Final Gauge Length: 61.3 mm

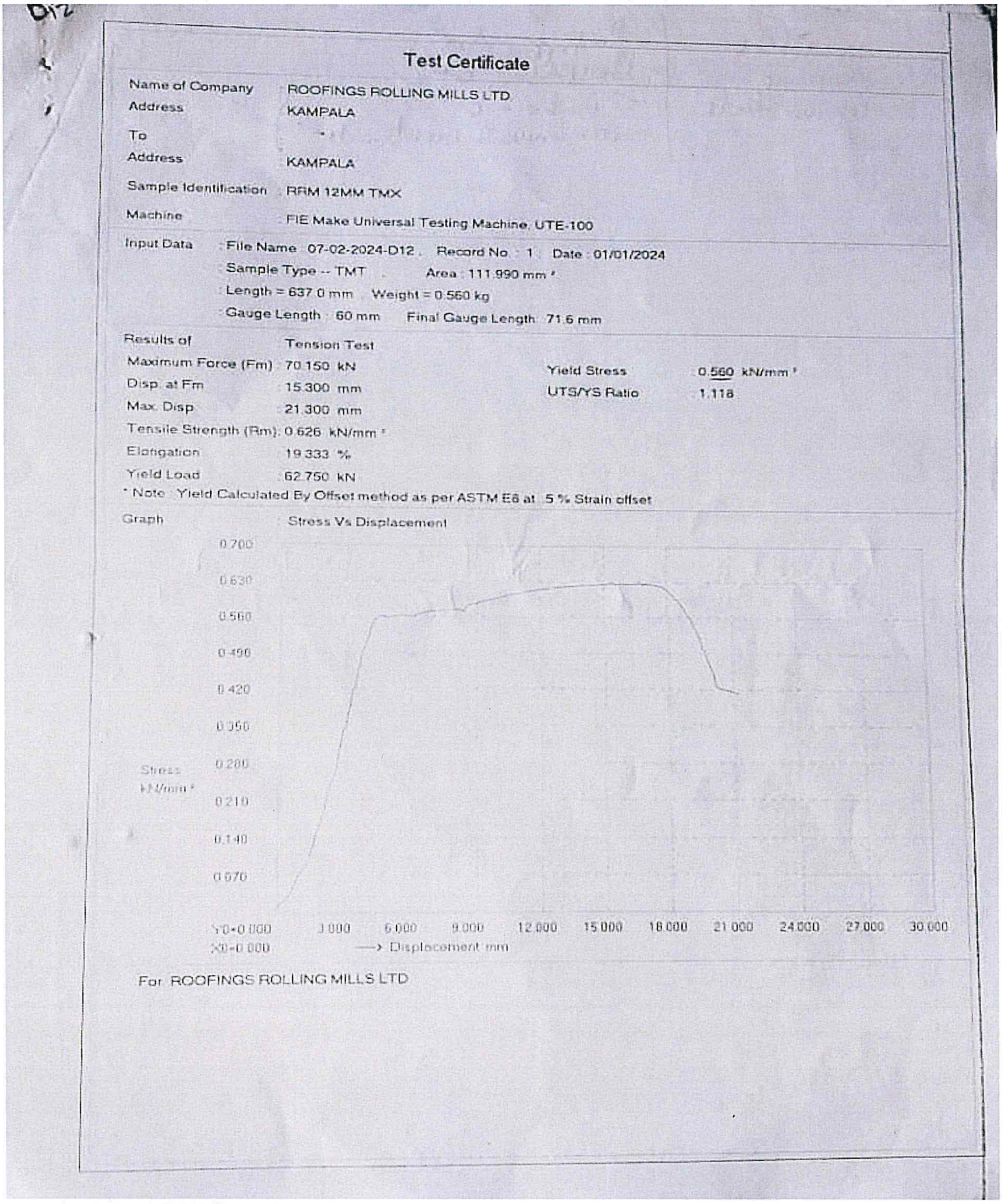
Results of: Tension Test
Maximum Force (Fm): 56.750 kN
Disp. at Fm: 13.700 mm
Max. Disp: 17.300 mm
Tensile Strength (Rm): 0.713 kN/mm^2
Elongation: 22.600 %
Yield Load: 49.050 kN
Yield Stress: 0.617 kN/mm^2
UTS/YS Ratio: 1.157

* Note: Yield Calculated By Offset method as per ASTM E8 at 1.5 % Strain offset

Graph: Stress Vs Displacement

For ROOFINGS ROLLING MILLS LTD.

Rebar D12



Test Certificate

Name of Company : ROOFINGS ROLLING MILLS LTD
Address : KAMPALA
To : ·
Address : KAMPALA
Sample Identification : RRM 12MM TMX
Machine : FIE Make Universal Testing Machine, UTE-100

Input Data : File Name : 07-02-2024-D12 , Record No : 1 Date : 01/01/2024
: Sample Type -- TMT , Area : 111.990 mm^2
: Length = 637.0 mm , Weight = 0.560 kg
: Gauge Length : 60 mm Final Gauge Length : 71.6 mm

Results of : Tension Test
Maximum Force (Fm) : 70.150 kN
Disp. at Fm : 15.300 mm
Max. Disp : 21.300 mm
Tensile Strength (Rm) : 0.626 kN/mm^2
Elongation : 19.333 %
Yield Load : 62.750 kN
Yield Stress : 0.560 kN/mm^2
UTS/YS Ratio : 1.118

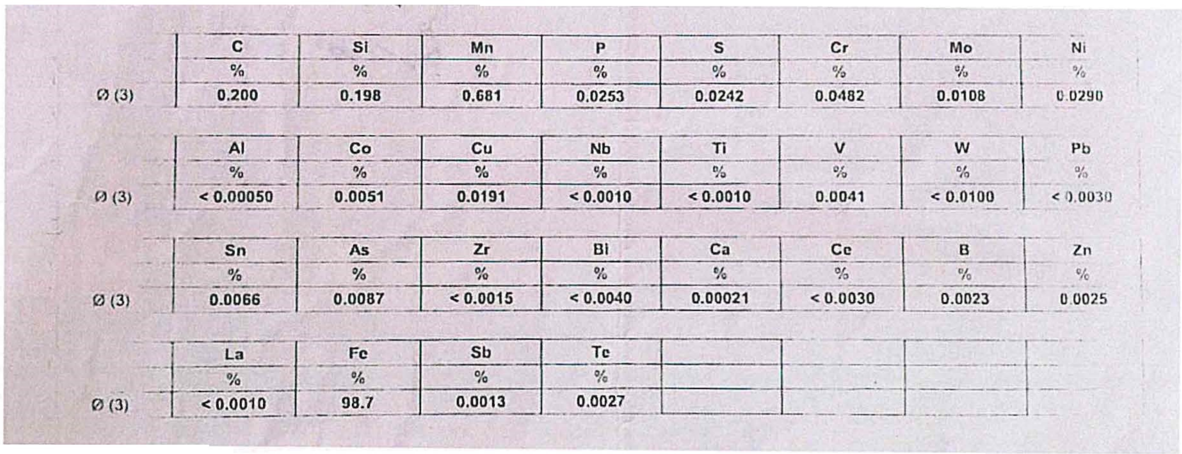
* Note : Yield Calculated By Offset method as per ASTM E8 at .5 % Strain offset

Graph : Stress Vs Displacement

For ROOFINGS ROLLING MILLS LTD

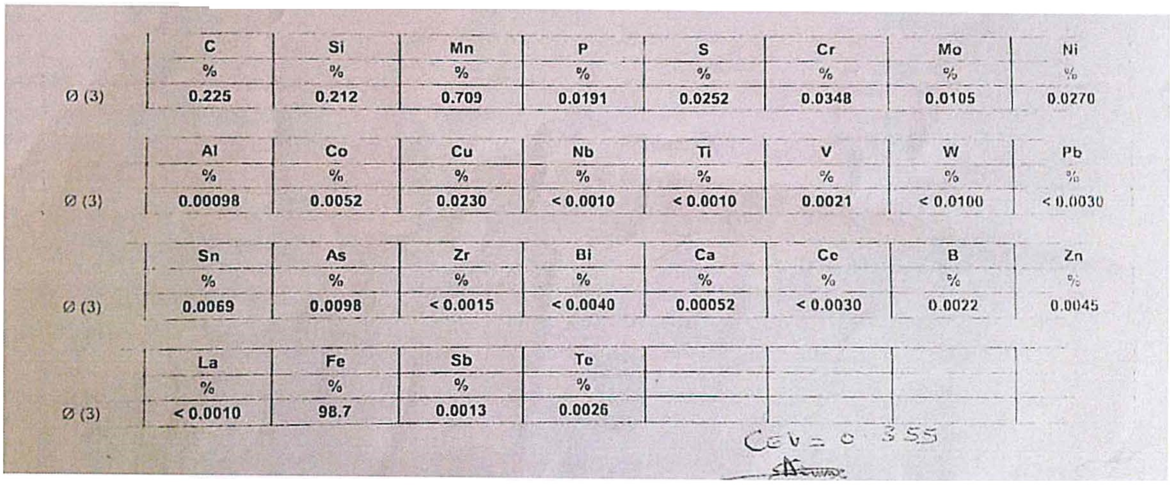
Appendix B: Chemical Composition Results

Rebar A10



	C	Si	Mn	P	S	Cr	Mo	Ni
	%	%	%	%	%	%	%	%
Ø (3)	0.200	0.198	0.681	0.0253	0.0242	0.0482	0.0108	0.0290
	Al	Co	Cu	Nb	Ti	V	W	Pb
	%	%	%	%	%	%	%	%
Ø (3)	< 0.00050	0.0051	0.0191	< 0.0010	< 0.0010	0.0041	< 0.0100	< 0.0030
	Sn	As	Zr	Bi	Ca	Ce	B	Zn
	%	%	%	%	%	%	%	%
Ø (3)	0.0066	0.0087	< 0.0015	< 0.0040	0.00021	< 0.0030	0.0023	0.0025
	La	Fe	Sb	Te				
	%	%	%	%				
Ø (3)	< 0.0010	98.7	0.0013	0.0027				

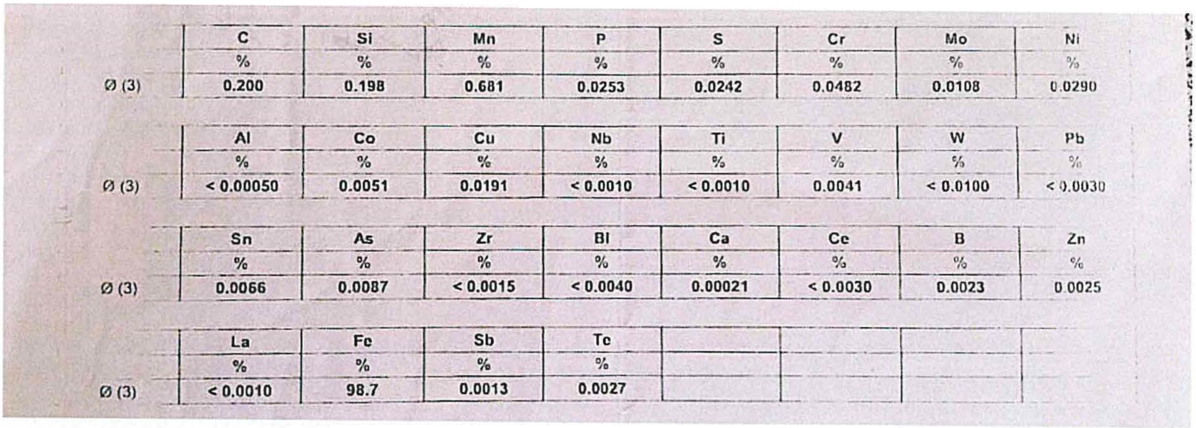
Rebar A12



	C	Si	Mn	P	S	Cr	Mo	Ni
	%	%	%	%	%	%	%	%
Ø (3)	0.225	0.212	0.709	0.0191	0.0252	0.0348	0.0105	0.0270
	Al	Co	Cu	Nb	Ti	V	W	Pb
	%	%	%	%	%	%	%	%
Ø (3)	0.00098	0.0052	0.0230	< 0.0010	< 0.0010	0.0021	< 0.0100	< 0.0030
	Sn	As	Zr	Bi	Ca	Ce	B	Zn
	%	%	%	%	%	%	%	%
Ø (3)	0.0069	0.0098	< 0.0015	< 0.0040	0.00052	< 0.0030	0.0022	0.0045
	La	Fe	Sb	Te				
	%	%	%	%				
Ø (3)	< 0.0010	98.7	0.0013	0.0026				

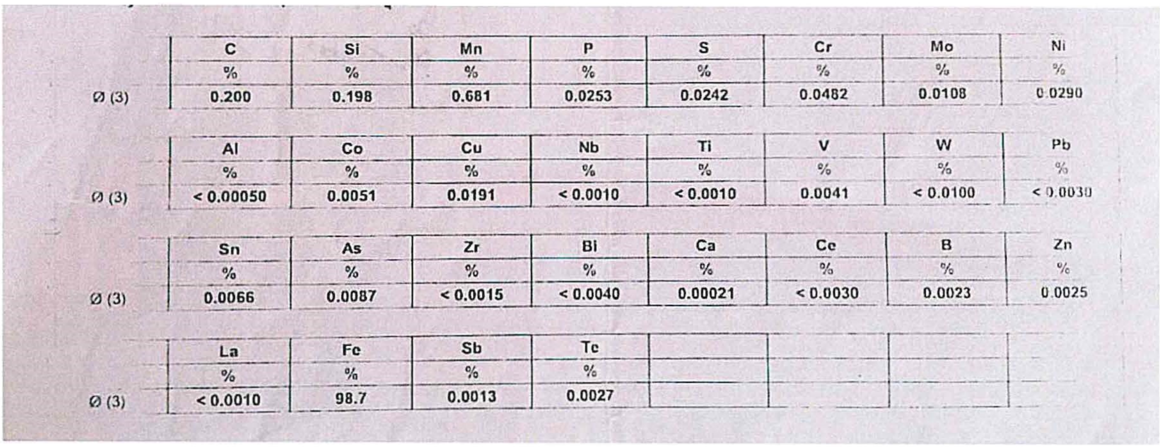
Cev = 0.355

Rebar B10



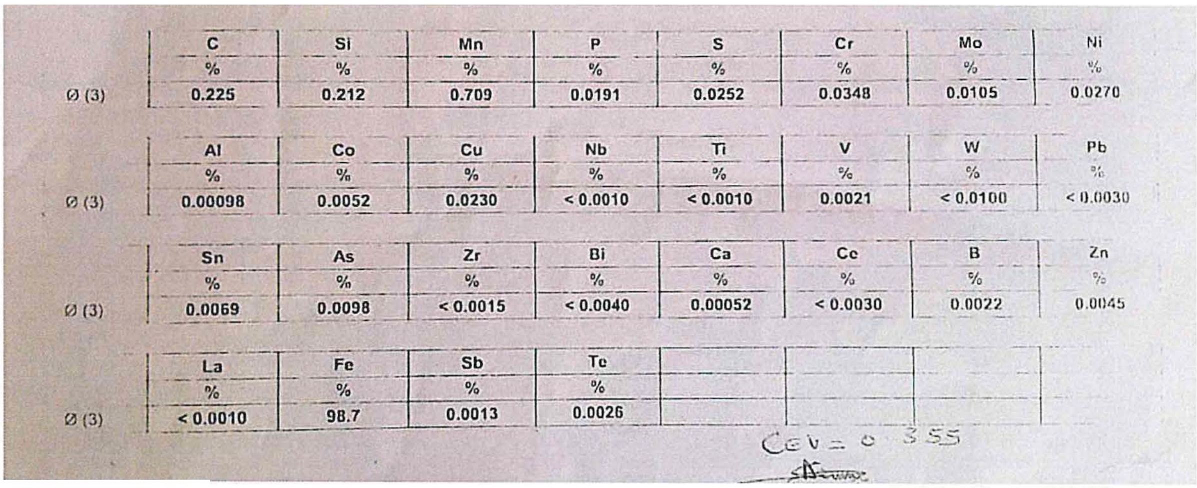
	C	Si	Mn	P	S	Cr	Mo	Ni
	%	%	%	%	%	%	%	%
Ø (3)	0.200	0.198	0.681	0.0253	0.0242	0.0482	0.0108	0.0290
	Al	Co	Cu	Nb	Ti	V	W	Pb
	%	%	%	%	%	%	%	%
Ø (3)	< 0.00050	0.0051	0.0191	< 0.0010	< 0.0010	0.0041	< 0.0100	< 0.0030
	Sn	As	Zr	Bi	Ca	Ce	B	Zn
	%	%	%	%	%	%	%	%
Ø (3)	0.0066	0.0087	< 0.0015	< 0.0040	0.00021	< 0.0030	0.0023	0.0025
	La	Fe	Sb	Te				
	%	%	%	%				
Ø (3)	< 0.0010	98.7	0.0013	0.0027				

Rebar B12



	C	Si	Mn	P	S	Cr	Mo	Ni
	%	%	%	%	%	%	%	%
Ø (3)	0.200	0.198	0.681	0.0253	0.0242	0.0482	0.0108	0.0290
	Al	Co	Cu	Nb	Ti	V	W	Pb
	%	%	%	%	%	%	%	%
Ø (3)	< 0.00050	0.0051	0.0191	< 0.0010	< 0.0010	0.0041	< 0.0100	< 0.0030
	Sn	As	Zr	Bi	Ca	Ce	B	Zn
	%	%	%	%	%	%	%	%
Ø (3)	0.0066	0.0087	< 0.0015	< 0.0040	0.00021	< 0.0030	0.0023	0.0025
	La	Fe	Sb	Te				
	%	%	%	%				
Ø (3)	< 0.0010	98.7	0.0013	0.0027				

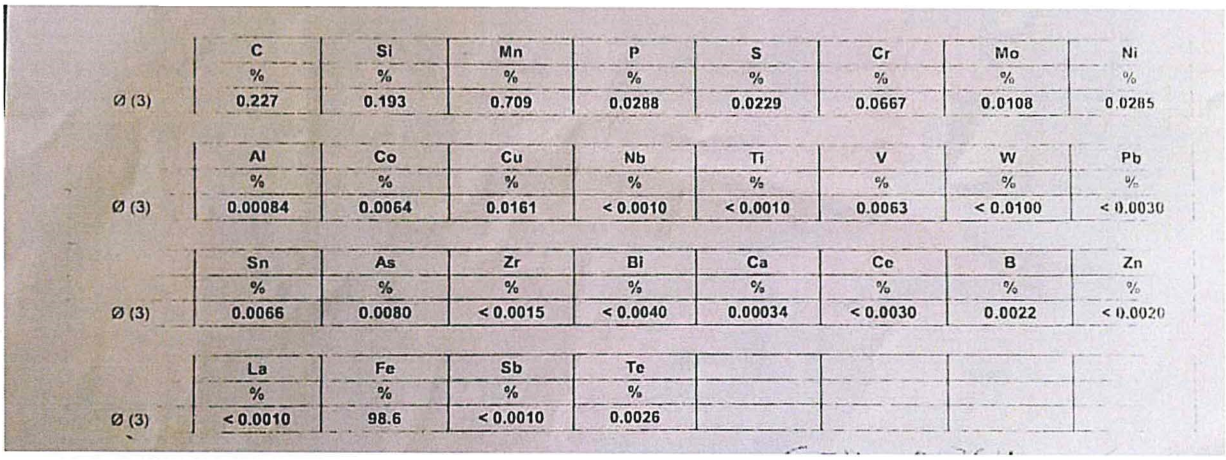
Rebar C10



	C	Si	Mn	P	S	Cr	Mo	Ni
	%	%	%	%	%	%	%	%
Ø (3)	0.225	0.212	0.709	0.0191	0.0252	0.0348	0.0105	0.0270
	Al	Co	Cu	Nb	Ti	V	W	Pb
	%	%	%	%	%	%	%	%
Ø (3)	0.00098	0.0052	0.0230	< 0.0010	< 0.0010	0.0021	< 0.0100	< 0.0030
	Sn	As	Zr	Bi	Ca	Ce	B	Zn
	%	%	%	%	%	%	%	%
Ø (3)	0.0069	0.0098	< 0.0015	< 0.0040	0.00052	< 0.0030	0.0022	0.0045
	La	Fe	Sb	Te				
	%	%	%	%				
Ø (3)	< 0.0010	98.7	0.0013	0.0026				

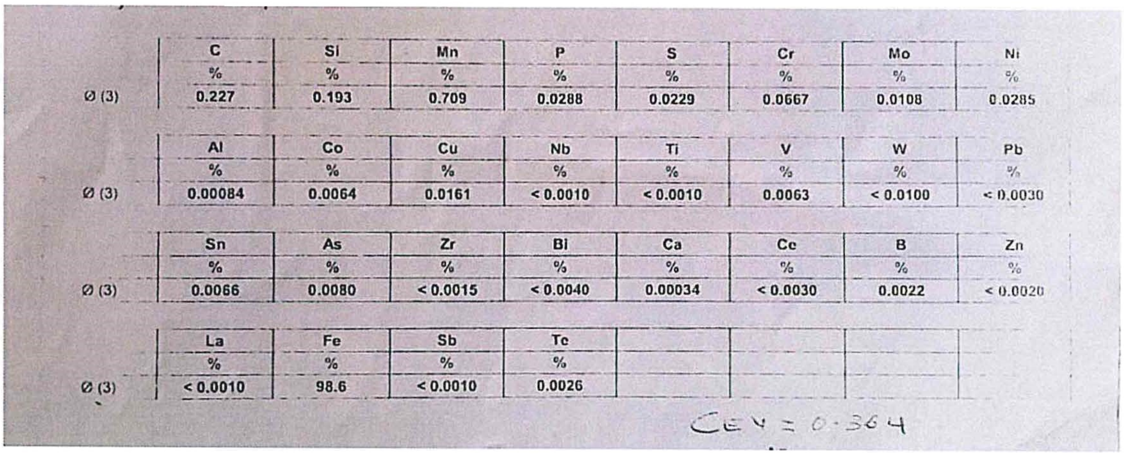
CEV = 0 355

Rebar C12



	C	Si	Mn	P	S	Cr	Mo	Ni
	%	%	%	%	%	%	%	%
Ø (3)	0.227	0.193	0.709	0.0288	0.0229	0.0667	0.0108	0.0285
	Al	Co	Cu	Nb	Ti	V	W	Pb
	%	%	%	%	%	%	%	%
Ø (3)	0.00084	0.0064	0.0161	< 0.0010	< 0.0010	0.0063	< 0.0100	< 0.0030
	Sn	As	Zr	Bi	Ca	Ce	B	Zn
	%	%	%	%	%	%	%	%
Ø (3)	0.0066	0.0080	< 0.0015	< 0.0040	0.00034	< 0.0030	0.0022	< 0.0020
	La	Fe	Sb	Te				
	%	%	%	%				
Ø (3)	< 0.0010	98.6	< 0.0010	0.0026				

Rebar D10



	C	Si	Mn	P	S	Cr	Mo	Ni
	%	%	%	%	%	%	%	%
Ø (3)	0.227	0.193	0.709	0.0288	0.0229	0.0667	0.0108	0.0285

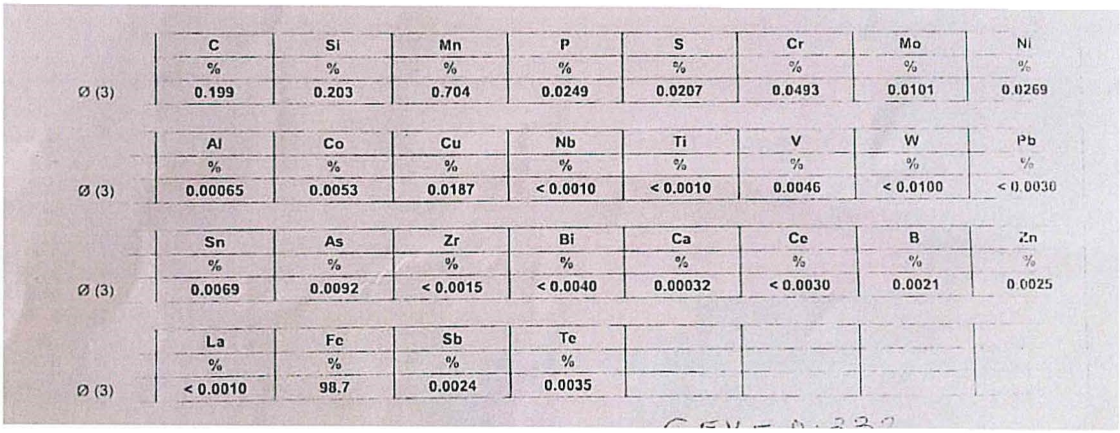
	Al	Co	Cu	Nb	Ti	V	W	Pb
	%	%	%	%	%	%	%	%
Ø (3)	0.00084	0.0064	0.0161	< 0.0010	< 0.0010	0.0063	< 0.0100	< 0.0030

	Sn	As	Zr	Bi	Ca	Ce	B	Zn
	%	%	%	%	%	%	%	%
Ø (3)	0.0066	0.0080	< 0.0015	< 0.0040	0.00034	< 0.0030	0.0022	< 0.0020

	La	Fe	Sb	Te				
	%	%	%	%				
Ø (3)	< 0.0010	98.6	< 0.0010	0.0026				

CEV = 0.364

Rebar D12



	C	Si	Mn	P	S	Cr	Mo	Ni
	%	%	%	%	%	%	%	%
Ø (3)	0.199	0.203	0.704	0.0249	0.0207	0.0493	0.0101	0.0269

	Al	Co	Cu	Nb	Ti	V	W	Pb
	%	%	%	%	%	%	%	%
Ø (3)	0.00065	0.0053	0.0187	< 0.0010	< 0.0010	0.0046	< 0.0100	< 0.0030

	Sn	As	Zr	Bi	Ca	Ce	B	Zn
	%	%	%	%	%	%	%	%
Ø (3)	0.0069	0.0092	< 0.0015	< 0.0040	0.00032	< 0.0030	0.0021	0.0025

	La	Fe	Sb	Te				
	%	%	%	%				
Ø (3)	< 0.0010	98.7	0.0024	0.0035				