MASTERS THESIS

INVESTIGATIONS INTO THE MECHANICAL PERFORMANCE OF UGANDAN MADE CARBON STEEL BARS

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Department of Mechanical and Production Engineering

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A Thesis submitted to Kyambogo University Graduate School in partial fulfilment for a ward of the degree of Master of Science in Advanced Manufacturing Systems Engineering

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DECLARATION

I, Ssempijja Deo, candidate for the Masters of Science in Manufacturing Systems Engineering of Kyambogo University declare that this thesis is my original work and has never been presented for a degree in any other University and no part of this thesis is plagiarized work.

Candidate: Ssempijja Deo

Sign………………………………… Date…………………………………

APPROVAL

This Master's thesis entitled "**Investigation into the Mechanical Performance of Ugandan Made Carbon Steel Bars**" prepared and submitted by Deo Ssempijja in partial fulfillment of the requirements for the Masters of Science in Manufacturing Systems Engineering of Kyambogo University has been supervised and is ready for examination.

Approved by:

Sign:……………………………….. Date:…………………….

Dr Catherine Wandera

Sign:……………………………….. Date:…………………….

Dr Titus Bitek Watmon

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Ssempijja Deo

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Kyambogo

ABSTRACT

Carbon steel bars are one of the most used steel products in structural constructions worldwide. Ugandan steels have been reported to have significant amounts of residual elements due to use of scrap steel in their production. Variations in carbon content have been reported in the Ugandan made reinforcing steel bars made from scrap raw material indicating a lack of chemical composition control. Therefore, to ascertain the compliance with quality standards, this study investigated the mechanical performance of Ugandan made carbon steels bars (20mm TMT ribbed bars) focusing on chemical composition, microstructure, tensile strength, and bendability. A comparison of the results with the requirements of the quality standards BS 4445: 2005 and the East African standard, EAS 412 - 1: 2005, based on ISO 6935 were used to establish the performance of the Ugandan made steel bars. Three (3) steel producing companies were considered based on their annual production capacity. In order not to identify the steel companies chosen, the companies were coded as A, B and C. A total of nine (9) steel bars of 20mm diameter were used in experiments. Three (3) bars were picked from the distributors of each of the steel producers selected. A spark emission spectrometry was used for chemical composition analysis, photo Microscopy of x500 was used for microstructure analysis and a universal tensile testing machine was used for both tensile strength and bendability tests. The carbon equivalent value (CEV) ranged between 0.363% and 0.374% for company *A*, 0.307% to 0.323% for company *B* and company C between 0.347% and 0.397% which are within acceptable range according to BS 4445: 2005 standards ranging 0.3 to 0.55%. There were variations in the microstructures of steel bars. The tensile strength (UTS) alternated between 640N/mm^2 and 714N/mm^2, the yield strength (YS) extended between 538N/mm^2 and 600N/mm^2, UTS/YS ratio was between 1.252 and 1.195 and the percentage elongation 18% to 22%. The values were all within the acceptable range according to BS 4445:2005 standards. The maximum bending force needed to bend to 90^0 was found to be 52235N with a maximum deflection of 74.4mm. The Steel bars exhibited bending stress with a range of 148 N/mm^2 to 166 N/mm^2. The general mechanical performance of the 20mm steel bar had acceptable quality standards basing on BS 4445: 2005 and the East African standard, EAS 412 - 1: 2005, based on ISO 6935 but with variations in carbon equivalent values.

Key words: carbon steel bars, chemical composition, microstructures, tensile strength and bendability

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ACRONYMS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
C	Carbon
CEV	Carbon Equivalent Value
Cr	Chromium
Cu	Copper
DRI	Direct Reduced Iron
HSLA	High-Strength Low-Alloy Steel
Mn	Manganese
Mo	Molybdenum
MPa	MegaPascals
Ni	Nickel
RSA	Random Sampling Analysis
SGR	Standard Gauge Railway
TMT	Thermo-Mechanically Treated steels
UBOS	Uganda Bureau of Statistics
ULC	Ultra Low Carbon steel
UNBS	Uganda National Bureau of Standards
UTM	Universal Testing Machine
UTS	Ultimate Tensile Strength
V	Vanadium
YS	Yield Strength

CHAPTER ONE

INTRODUCTION

This chapter introduces the study through presentation of the status of steel production in Uganda, the quality related problems reported in steel products produced in Uganda and the purpose of this study. The justification of the study, research questions to guide this study, and a conceptual framework for this study are also explained.

1.1 Background of the Study

In the world today, use of high strength TMT steels bars has got a momentum in the construction of flyovers, bridges and high rise buildings because of its good combination of the required mechanical properties. The main reasons for the popularity of steel being it's relatively low cost of making, forming, welding and processing, the abundance of its two raw materials namely; iron ore and scrap, and its unparalleled range of mechanical properties (Anil, 2009). The Steel industry in Uganda has evolved greatly in scale and scope over the years. The development of various mega- infrastructural projects, the emergence of the oil and gas sector, Uganda's high population growth rate, access to regional markets and the rapidly growing urbanization are all opportunities for growth of the steel production sector (Khisa, 2018). Steels have different chemical compositions although up to 90% of the world steel production falls in the plain carbon range (Vogel *et al*., 2006; Kabir, 2014).The Ugandan iron and steel industry has been growing at unprecedented rates averaging from 20% and 30% per annum for imports and exports respectively between 2002 and 2006 due to the booming housing and construction sector in the region (URA, 2010). Steel made from recycled scrap is almost entirely used for building and construction industry in its concrete reinforcement or plain bar form (Oliver *et al*, 2006).

Uganda's development plan as specified in the Vision 2040 and National Development Plan II (2015-2020) highlights growth in the iron and steel industry as essential in the country's industrialization and economic development (National Planning Authority, 2013; NPA 2015). Production and usage of steel is considered to be essential to a country's economic growth.

The total annual production capacities of Ugandan steel rolling mills are tabulated in *table 1.1*. The data was obtained from their respective websites.

Table 1. 1: Production Capacities of Ugandan Steel Industries

No./S	Company Name	Annual Production Capacity (Metric Tonnes, MT)	Source of Data
1.	Tembo Steel Mills (Uganda) Limited - Jinja,	72000 MT	https://www.tembosteels.co.ug/tmt.php
2.	Steel and Tube Industries Uganda Limited - Kampala	130,000MT	http://investmentreviewug.com/2016/09/26/the-steel-tube-industries-ltd-stil
3.	Mayuge Sugar Industries Ltd- Steel Division - Buikwe District - Jinja - Uganda	60,000 MT	https://www.revolvy.com/page/Mayuge-Sugar-Industries-Limited
4.	Roofing Rolling Mills Limited - Namanve Industrial Park, Kira Municipality, Wakiso District	72.000 MT of high tensile TMT bars and twisted bars	https://en.wikipedia.org/wiki/Roofings_Group
5.	Pramukh Steel Limited - Njeru - Buikwe District - Jinja - Uganda	Annual steel production capacity of over 80,000 MT per annum.	http://www.pramukhsteel.com/
6.	MM Integrated Steel Mills (Uganda) Limited - Jinja, Jinja District	50,000 MT	https://www.metalbulletin.com/Article/3182190/MM-Integrated-starts-production-at-47m-steel-plant-in-Uganda.html
7.	China Machine Building International Corporation - Mbarara, Mbarara District	60,000 MT	https://steelguru.com/steel/china-machine-building-international-corporation-to-build-steel-plant-at-mbarara-in-uganda/504545

Uganda has a trade deficit in the iron and steel sector even though there are a number of operational steel manufacturers in the country (Khisa, 2018), including: Roofings Rolling Mills Ltd, Steel and Tube Industries (Uganda) Ltd, MM Integrated Steel Mills (Uganda) Ltd, Tembo Steel Mills (Uganda) Ltd, Uganda Baati Ltd, Pramukh Steel Ltd, Tian Tang Steel Ltd, and Madhvani Steel Limited. Uganda's infrastructure projects with a high steel requirement, such as Karuma dam, often use imported steel due to limitations in Uganda's steel production capacity and quality.

Steel manufacturers in Uganda mainly use scrap steel and imported crude steel (billets, strip steel, hot-rolled coils, wire rods) as raw material. Moreover, about 33% of raw material used in Uganda's annual iron and steel production comes from scrap and raw iron ore while 67% of the raw material used is imported, not taking into account the imported accessory raw materials such as zinc and Aluminium used in galvanizing. Additionally, only 0.0033% of iron ore available in the country is utilized per year showing a potential for iron ore smelting within the country (National Planning Authority, 2018); crude steel production worldwide is steadily growing and reportedly increased by 4.6% in the first six months of 2018 compared to the same period in 2017 (world steel association, 2018). Steel products manufactured in Uganda include: reinforcing bars, corrugated iron sheets, flat bars, angle bars, binding wire, nails, chain link, barbed wire, expanded wire mesh, hollow sections, tubes, and Z-sections. These steel products - *mainly used locally (70%) and some sold to the neighboring East African countries* - are used in construction projects and fabrication of equipment such as agro processing equipment, like hammer mills, threshers (National Planning Authority, 2018).

In a comparison of Uganda's steel production with the worldwide steel production, lack of research and development and quality related issues are some of the factors that have hampered productivity, capacity utilization, and product diversification in Uganda's steel production industry (Ndlovu, 2017),. Additionally, Ugandan steels are reported to have limited weldability and uneven scatter of microelements and non-uniformity of longitudinal mechanical properties. Furthermore, reported a variation in carbon content in the same sample of Ugandan made reinforcing steel bars made from scrap raw material indicating a lack of chemical composition control (Senfuka *et al.*, 2012; Namara, 2015). However, a relationship of the microstructure of a steel to its mechanical properties and manufacturability aspects,

including bendability, machinability and weldability, has not been investigated (William, 2007).
Munyambabazi, (2017) said ‘Most building materials on the Ugandan market are counterfeit, ranging from the cement to steel bars. If the engineer is not cautious then a building will collapse because surely counterfeit cement and other fake materials can never guarantee a building’s strength”. Materials are not strong enough to withhold the load are sometimes used, Hermogene Nsengimana from the African organization for standardization said in 2016, as its organization met in Nairobi to discuss why so many African buildings collapse. Added sometimes scrap metal is used instead of steel (Nakibuuka, 2017; Ssejjoba, 2018).

The focus of this study is to establish the mechanical performance of 20mm TMT ribbed steel bars manufactured by different steel manufacturers in Uganda in line with applicable steel quality standards, that is, the East African standard, EAS 412 - 1: 2005, based on ISO 6935 and BS 4449:2005 quality standard (ISO, 2005). The mechanical aspects to be investigated include: chemical composition, microstructure characterization, tensile strength, and bendability of steel bars made in Uganda.

1.2 Statement of the Problem

There are significant challenges with the quality of steels produced in Uganda. The increased use of scrap material as a source of iron has caused a harsh rise in impurities in steel because the current scrap classification and sorting infrastructure in Uganda is insufficiently advanced to produce a consistent and rich ferrous feed for steelmaking. Steel companies in Uganda mainly use scrap steel and imported crude steel (billets, strip steel, hot-rolled coils, wire rods) as raw material. The steel bars produced from scrap are usually lacking in uniformity, variations in carbon and manganese content, reduced weldability and machinability, and cannot bend to sharp angles (NPA, 2018; Namara, 2015). Senfuka *et al.*, (2012), indicated variations in chemical composition and physical properties of the steels manufactured in Uganda. Ugandan manufactured steels didn’t pass the recommended standard for the Standard Gauge Railway (SGR) project and for construction of Karuma hydro power dam project. Steel manufacturers in Uganda were requested to upgrade their production process and not to use scrap to qualify for supply of steel for big projects like SGR, (Kasingye, 2017). Additionally, there are several new entrants into the steel industry in Uganda. Therefore, there is need to investigate the mechanical performance of carbon steel bars produced in Uganda.

1.3 Research Objectives

1.3.1 Main Objective

The main objective was to investigate the mechanical performance of carbon steel bars made in Uganda.

1.3.2 Specific Objectives

The specific objectives were:

i) to determine the chemical composition of the carbon steel bars
ii) to determine the microstructure of the carbon steel bars
iii) to determine the mechanical properties (Ultimate tensile strength and bendability) of the carbon steel bars
iv) to compare chemical and mechanical properties to both East African standard, EAS 412 - 1: 2005, based on ISO 6935 and BS 4449:2005 quality standard

1.4 Research Questions

i) How does the chemical composition of carbon steel bars made in Uganda conform to quality standard based on EAS 412 - 1: 2005, based on ISO 6935 and BS 4449:2005?
ii) Does the microstructure of carbon steel bars made by different Ugandan steel manufacturers conform to quality standard based on EAS 412 - 1: 2005, based on ISO 6935 and BS 4449:2005?
iii) Does the maximum tensile strength and bendability of carbon steel bars made by different Ugandan steel manufacturers conform to the East African standard, EAS 412 - 1: 2005, based on ISO 6935 and BS 4449:2005 quality standard?
iv) Does the relationship between the chemical and mechanical properties of steel conform to quality standards?

1.5 Justification of the study

Uganda’s development plan as specified in the Vision 2040 and National Development Plan II (2015-2020) highlights growth in the iron and steel industry as essential in the country’s industrialization and economic development (National Planning Authority, 2013; 2015). Production and usage of steel is considered to be essential to a country’s economic growth. There is significant research done on the 10mm, 12mm and 16mm diameter steel bars, but not with 20mm. yet high strength buildings use 20mm diameter steel bars. In Uganda, there is a wide use of scrap for production steel bars and preceding studies indicate variations in chemical composition and physical properties of the steels manufactured in Uganda. (Senfuka, 2014, Musisi, 2019; Namara, 2015). There is need to investigate the quality standards of 20mm steel bar made in Uganda in relation to international standards.

1.6 Significance of the study

This research enhances development of a linkage between academia, construction industries and steel industry by providing the chemical composition, microstructure, tensile strength and bending force that is essential in enhancement of steel functional performance. Additionally, this research plays a vital role in providing information that can be utilized by UNBS and establishes the quality of steel in Ugandan market. The results of this research are closing the missing gap of knowledge about the 20mm TMT ribbed steel bars on Ugandan market.

1.7 Scope of the Study

The research focused on investigation of mechanical performance of steel manufactured in Uganda, particularly concentrating on microstructure, chemical composition, tensile strength and bendability of carbon steel bars. Ribbed TMT bars of diameter 20mm from three (3) different steel producers was used for experiments. The steel producers sampled in this study were selected depending on their annual production capacities in metric tonnes (MT).

1.8 The Conceptual Framework

The conceptual framework is presented in *figure 1.1*. The independent variables included chemical composition and microstructure of the steel bars. The moderating variables relate to the heat treatment that the steel bars are subjected to. The dependent variables include ultimate tensile strength (UTS), yield strength (YS), UTS/YS, percentage elongation, bending force and deflection. The results from dependent variables are compared with international quality standards to determine the mechanical performance of steel in Uganda.

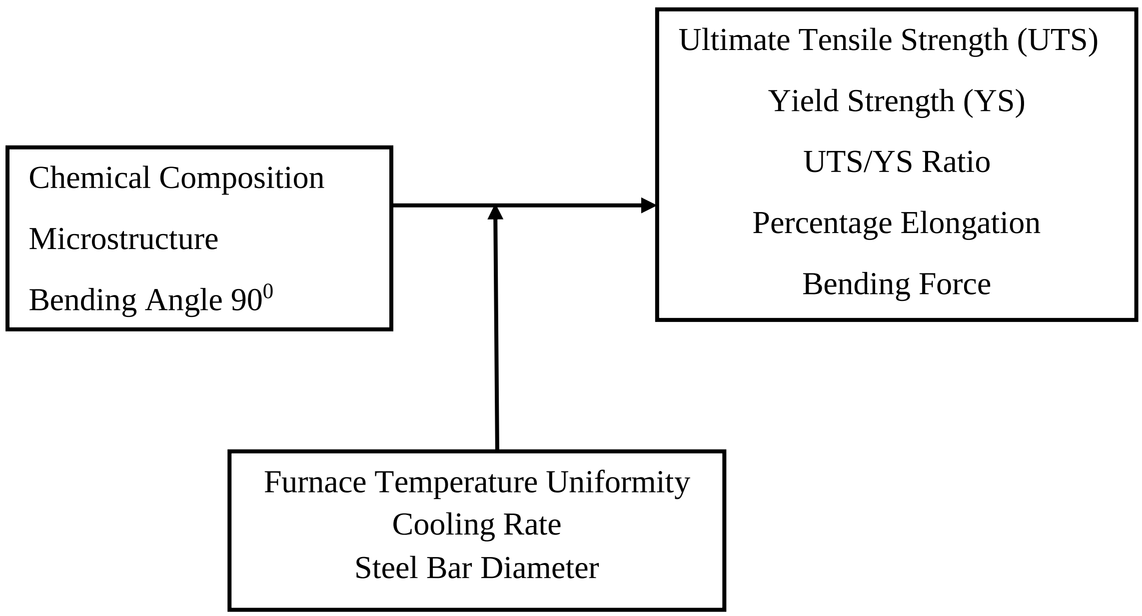

Figure 1. 1: Conceptual Framework

CHAPTER TWO

LITERATURE REVIEW

This chapter highlights the relevant literature to the research. This literature helped develop a deeper understanding of chemical composition, microstructure, tensile strength, and bendability of carbon steels made in Uganda. It also explains the international carbon steel standards compared to locally make carbon steels.

2.1 Steel Production in Uganda

The Ugandan iron and steel industry has been growing at unprecedented rates averaging from 20% to 30% per annum for imports and exports, respectively between 2002 and 2006 due to the booming housing and construction sector in the region (URA, 2010). The industry is donned with a few companies which have been operating steel mills in the country over the years, earlier based on imported billets and currently predominantly using scrap iron. From the 1960s to 1988, the Madhivani group ran East African Steel Corporation in Jinja carried out steel production. Steel Rolling Mills under the Alam Group of companies was also established at Jinja in 1987. BM Technical Services in Mbarara which is run by local entrepreneurship also began operations while more recently in 2002, Tembo Steel Mills was added to the list followed by several others like Roofing Rolling Mills Limited - Namanve Industrial Park. These industries have enabled substantial import substitution, supporting the rapidly expanding building and construction sector and are the major reason why ratio of the imported steel products to the exported ones has generally been reducing (*Figure 2.1)*.

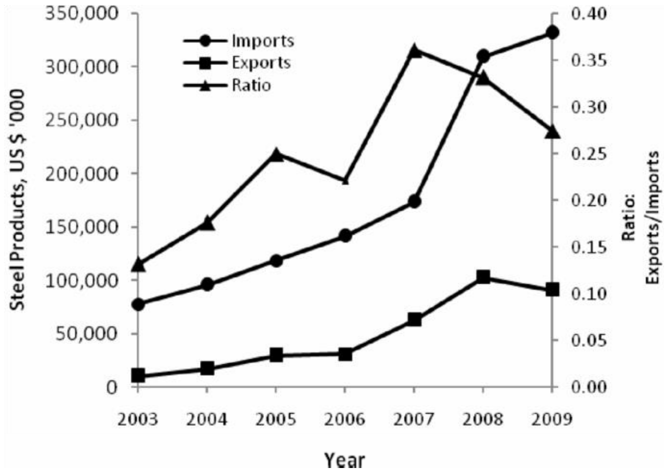

Figure 2. 1: Exports and Imports trends in Ugandan Steel Industry (UBOS, 2009)

The major steel production mode in Uganda, is usually carried out in mini-mills and attains most of its iron from scrap steel recycled from used equipment or byproducts of manufactured product. Direct reduced iron (DRI) is sometimes used with scrap to help maintain the desired chemistry of the steel. The necessary processing of DRI from the mineral ore is still at infant stages in Uganda. The steel processing is done in electric furnaces being either of the arc or induction type. A typical mini-mill in Uganda will have an electric arc or induction furnace for scrap melting, a ladle furnace to administer liquid metal and control its pouring temperature, a billet continuous caster for converting molten steel to solid form, a reheat furnace and a rolling mill. Some of the steel mills however still feature non continuous ingot casting facilities (Ibrahim, 2010).

Senfuka, (2014), in his research concluded that steel in Uganda is mainly made through the recycle products. He also studied the quality of steel through the analysis of its mechanical properties namely; ductility, strength, weldability and hardenability. A high level of tramp element content was found consistent in all sample groups. While the bars were found generally of acceptable ductility, resilience, strength and metallographic properties in spite of relatively high and irregular carbon content, the incidence of fragile samples in each group related to residual element and inclusions content, rolling faults and others were pointed out. The varying composition in individual steel bars was shown to be a factor in the quality of especially the TMT and twisted bars. The wide scatter in yield strength was found to cause unpredictable concrete reinforcement value. The prevalence of Boron in the range 0.0003% and 0.003% was shown to play an outstanding role in raising the yield strength and creating development lengths that often exceed the pre-calculated value. Examination of weldments of the bars showed post weld cracks in up to 13% of the samples both cold and hot cracking. These were also shown to be due to elevated tramp element content rather than carbon content. The incidence uniaxiality of properties also associated to the unpredictable tramp element content was highlighted. On the overall, the use of better sorting methods, more elaborate refining especially at the teeming ladle stage and the exploitation of virgin iron resources to exploit the sponge iron alternative was recommended. Reducing dependence on Boric acid binding for furnace and ladle lining and chemically reducing Boron content from liquid steel was suggested as possible solutions to the unpredictably fluctuating high yield of the steel bars.

In industrialized countries where steel recycling is done, the steel per capita consumption, which is a major indicator of scrap generation, stands at an average 324 kg/year while in Uganda, it is a mere 12-15 kg/year (WSA, 2011 and MOI, 2001). The current overall national shortage of scrap has ultimately caused an inevitable drop in quality of scrap, the major raw material input, and of the final steel product. The bars produced are generally lacking in uniformity, very high in carbon and manganese content, often welding poorly and are unable to be bent to sharp angles, in addition to other deficiencies in as rolled properties. (Senfuka *et al.* 2012).

2.2 Categorization of Carbon Steel

Steels are alloys of iron-carbon and may contain other alloying elements. Low alloy$(< 10wt\%)$, low carbon$(< 0.25wt\%\ C)$, medium carbon $(< 0.25\ to\ 0.60\ wt\%\ C)$ and high carbon$(< 0.6\ to\ 1.4\ wt\%\ C)$, Callister, (2010) and Raghavan, (2014). This research focuses on the low carbon steels especially TMT ribbed steel bars used in reinforcement.

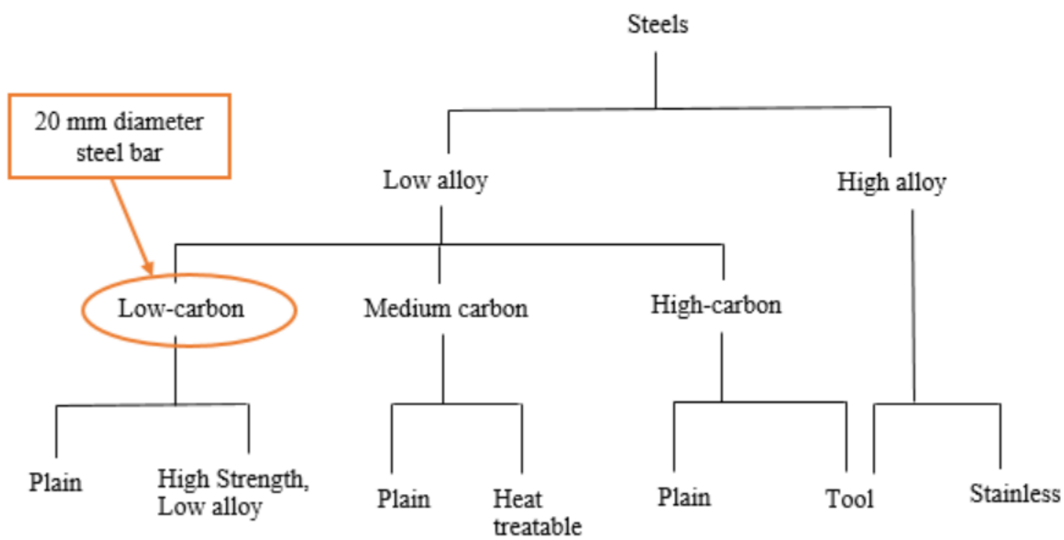

Figure 2. 2: Classification of Steels (Callister, 2009)

2.3 Effects of Alloying Elements in Steel

Srikanth et al., (2008), says that some elements are intentionally added to iron for the purpose of attaining certain specific properties and characteristics. Other elements are present incidentally and cannot be easily removed. Such elements are referred to as "trace" or "residual" elements.

Table 2. 2: Alloy Elements and their Effects on Steel Properties *(Srikanth. et. al, 2008)*

Alloying Elements	**Effects on Steel Properties**
Carbon	Carbon is the principal hardening element in steel. Hardness and strength increase proportionally as Carbon content is increased up to about 0.85%. Carbon has a negative effect on ductility, weldability and toughness. Carbon range in ULC Steel is usually 0.002 – 0.007%. The minimum level of Carbon in Plain Carbon Steel and HSLA is 0.02%. Plain Carbon Steel grades go up to 0.95%, HSLA Steels to 0.13%.
Manganese (Content is 0.20 – 2.00%)	Manganese contributes to steel's strength and hardness in much the same manner but to a lesser degree than carbon. Manganese improves cold temperature impact toughness. Increasing the Manganese content decreases ductility and weldability.
Phosphorus (Residual are less than 0.020%)	Phosphorus is most often a residual but it can be an addition. As an addition it increases hardness and tensile strength. It is detrimental to ductility, weldability and toughness. Phosphorus is also used in re-phosphorized high strength steel for automotive body panels.
Sulphur	Sulphur is present in raw materials used in iron making. The steelmaking process is designed to remove it as it is almost always a detrimental impurity. A typical amount in commercial steel is 0.012%, and 0.005% in formable HSLA.
Silicon	Silicon can be an addition or a residual. As an addition it has the effect of increasing strength but to a lesser extent than Manganese. A typical minimum addition is 0.10%. For post galvanizing applications the desired residual maximum is 0.04%.

Copper, Nickel, Chromium (Chrome), Molybdenum (Moly) and Tin	Copper, Nickel, Chromium (Chrome), Molybdenum (Moly) and Tin are the most commonly found residuals in steel. The amount in which they are present is controlled by scrap management in the steelmaking process. Typically the specified maximum residual quantities are 0.20%, 0.20%, 0.15% and 0.06% respectively but the acceptable limits depend mainly on product requirements.
Vanadium, Columbium and Titanium	Vanadium, Columbium and Titanium are strengthening elements that are added to steel singly or in combination. In very small quantities they can have a very significant effect hence they are termed micro-alloys. Typical amounts are 0.01 to 0.10%. In Ultra Low Carbon Steel Titanium and Columbium are added as "stabilizing" agents (meaning that they combine with the Carbon and Nitrogen remaining in the liquid steel after vacuum degassing). The end result is superior formability and surface quality.
Aluminum	Aluminum is used primarily as a deoxidizing agent in steelmaking, combining with oxygen in the steel to form aluminum oxides which can float out in the slag. Typically 0.01% is considered the minimum required for "Aluminum killed steel". Aluminum acts as a grain refiner during hot rolling by combining with Nitrogen to produce aluminum-nitride precipitates.
Nitrogen	Nitrogen can enter steel as an impurity or as an intentional addition. Typically the residual levels are below 0.0100 (100 ppm).
Boron	Boron is most commonly added to steel to increase its hardenability but in low carbon steels it can be added to tie up Nitrogen and help reduce the Yield Point Elongation thus minimizing coil breaks. At the same time, when processed appropriately, the product will have excellent formability. For this purpose it is added in amounts up to approximately 0.009%. As a residual in steel it is usually less than 0.0005%.
Calcium	Calcium is added to steel for sulphide shape control in order to enhance formability (it combines with Sulphur to form round inclusions). It is commonly used in HSLA steels especially at the higher strength levels. A typical addition is 0.003%.

Salman, (2016), examined the steelmaking process and found out that production variations in chemical composition are unavoidable. The variability of the chemical composition of steel reinforcing bars was evaluated and expressions were developed to represent the probability distribution functions for different chemical. A total of 68 samples were collected and tested using the Spectrometer test to obtain Chemical Compositions. The analysis showed that chemical compositions followed different types of continuous distributions. Results showed that some compositions are above the upper line of the control chart (UCL). Finally, the analyses show that less than 3% of the steel failed to meet minimum ASTM standards for chemical composition. Essadiqi et. al, (2009) in their research on the effects of impurities on steels found out that the Common primary and secondary alloying elements are carbon, manganese, and silicon; and copper, nickel, chromium, and molybdenum, respectively. The two main elements in the tramp category are Sulphur and phosphorous, followed closely by tin and zinc. It should be noted that phosphorous does offer some positive benefits to the steel, but these are heavily outweighed by its negative effects. Therefore the designation of phosphorous as a tramp element is still considered to be valid in the steel industry

2.4 Microstructure of Steel Bars

All the TMT rebars, regardless of chemistry and strength level, exhibited a composite microstructure consisting of ferrite-pearlite at the core and tempered martensite at the rim. Mechanical properties of steel depends on the microstructure, that is, how ferrite and cementite are mixed. Pearlite is a fine mixture of ferrite and cementite arranged in lamellar form. The degree of change is a function of the carbon content of the steel. Pearlite increases the strength of carbon steels (Satyendra, 2014 and Mukerjee et. al, 1997). The stages for microstructure from austenite to ferrite – pearlite are illustrated in *figure 2.3*.

Under a microscope the structure that results from the increasing carbon can be seen. The carbon forms a darker, harder phase called pearlite, which is composed of the ferrite interspersed with layers of iron carbide, a very hard constituent. It is the increase in this pearlite phase, driven by the carbon content, which explains the increase in the steel's mechanical properties, especially the hardness. Above 0.60 carbon in plain carbon steels, a thermal treatment called an anneal is used to modify the microstructure and reduce the steel's hardness (Hall *et.al*, 2017).

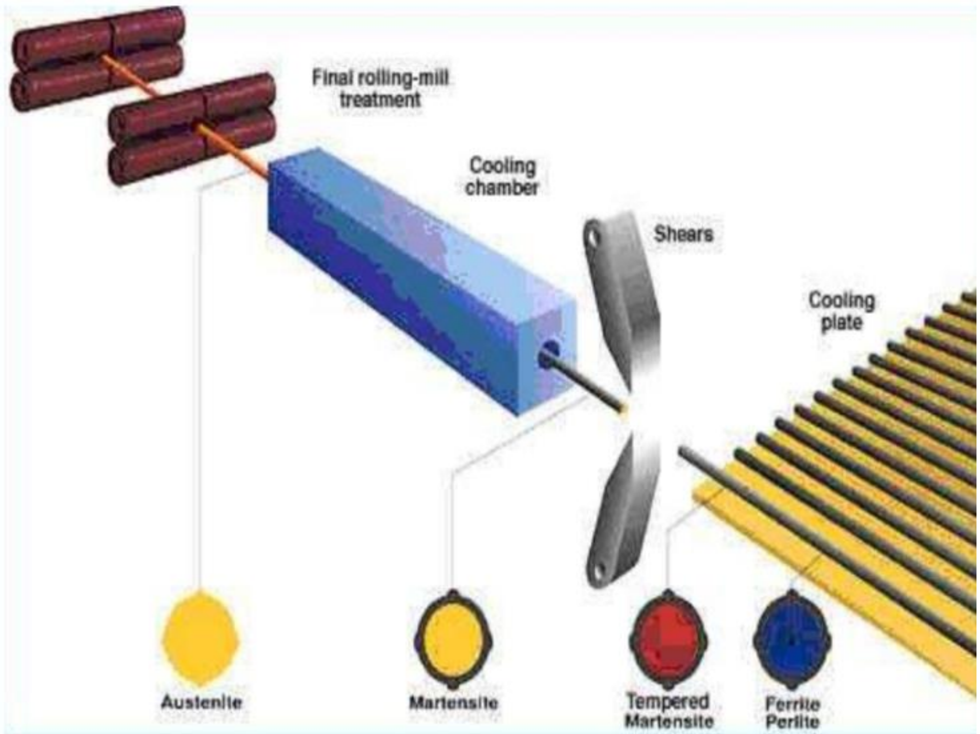

Figure 2. 3: Steel Production Process (Prejem, 2010)

The formation of cracks in steels with a solidification microstructure is connected with either the precipitation or segregation of residual elements during solidification and/or with the accumulation of some residual elements at the scale–metal interface during the soaking of the blocks. Hot-brittleness is connected with the change in the solubility of the trace elements in the solid solution of austenite, with segregations of the surface-active elements to the grain boundaries, with the precipitation of small particles at the grain boundaries during solidification and cooling to the hot working temperature, and with the effect of some elements on the solidification microstructure (Prejem, 2010). The melting temperature in the furnace is between 1500^0C to 1700^0C. Billets come from furnace at temperature between 900^0C to 1100^0C. Temperatures keep reducing as the hot billets are passing through different dies, they enter annealing and quenching sections at temperature slightly below and slightly above 600^0C and come out of quenching section at temperature between 300^0C and 550^0C depending on pressure of water. Finally to the cooling bay (normalizing). These bars therefore exhibit a variation in microstructure in their cross section, having strong, tough, tempered martensite outer ring to constitute the surface layer of the bar, an intermediate semi-tempered middle ring of martensite and bainite, and a refined, tough and ductile ferrite and pearlite circular core. This is the desired micro structure (Markan, 2004). The relatively small grain size is essential for the strong and tough exterior of the TMT reinforcement bar since the strength of steel is proportional to the grain size.

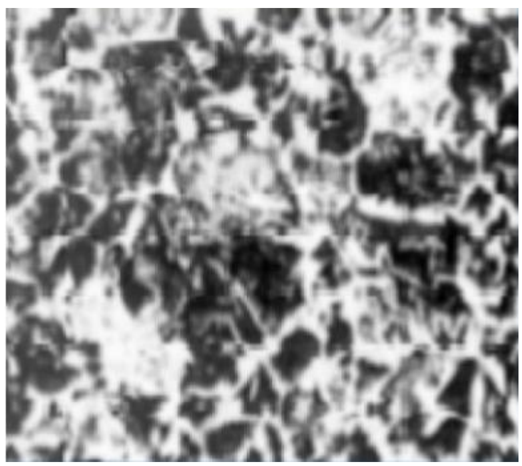

Figure 2. 4: Ferrite-Pearlite Core in TMT bar (Islam, 2012)

2.5 Iron-Carbon Phase Diagram

The iron-carbon phase diagram is used to understand the phases present in steel alloys. Each region, or phase field within a phase diagram indicates the phase or phases present for a particular alloy composition and temperature. For the iron-carbon phase diagram, the phase fields of interest are the ferrite, cementite, austenite, ferrite and cementite phase region, ferrite and austenite phase region, and austenite and cementite phase fields (Callister, 2007).

The phase diagram indicates that an iron-carbon alloy with 0.5% carbon held at 900°C will consist of austenite, and that the same alloy held at 650 °C will consist of ferrite and cementite.

Furthermore, the diagram indicates that as an alloy with 0.78% carbon is slow cooled from 900 °C, it will transform to ferrite and cementite at about 727 °C.

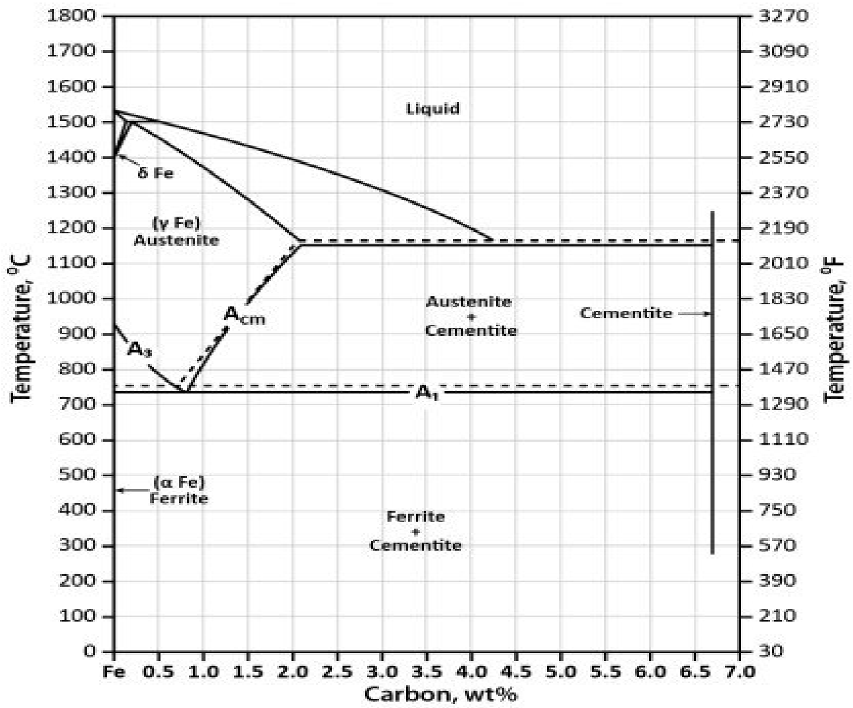

Figure 2. 5: Iron-Carbon Phase Diagram (Satyendra, 2014)

2.6 Bendability of Steel

It is very important to be able to bend the material without the occurrence of cracking. The bendability of the material is controlled by the plate's mechanical properties, its purity and the surface conditions. Therefore, it is important to study these conditions with the intention of improving the bendability. Laschke (2012), conducted research with aim to examining the importance of the material properties for the bendability of the specific steel grade. There are many conditions for various applications such as mobile cranes and vehicles that need to be fulfilled in order for the material to be approved, where one main prerequisite is the bendability. It is very important to be able to bend the material without the occurrence of cracks. The purpose of this work was therefore to investigate and try to find the relationship between the material properties and the critical bending radius. The results showed that the most significant material properties affecting the bendability are the yield strength and the purity close to the plate surface. The results from experiments showed that the toughness of the material can be increased but it does not affect the bendability for these specific steel grades. Other properties such as hardness, ultimate tensile strength and elongation have no major impact on the bendability for this specific composition. The most suitable treatment proved to be tempering at 200°C as the last step in the process chain.

2.7 Failure Modes of High Strength Steel Bars

Failure modes of the high strength steel rebars in tensile loading were studied by observing fracture surfaces after tensile tests. It was found that all TMT steel rebars were low carbon steels having 0.18% of carbon in average. Optical microscopy revealed low carbon martensite in the case and ferrites and pearlites in the core. A transition zone of refined, mixed constituents was also observed in the microstructures. Difference in size, shape and appearance of grains and constituents was observed. Variations in area of hardened case, core and transition zone of the rebars were revealed in the macrostructures. Differentiation in hardness among the TMT rebars was observed due to the variation in microstructures and chemical compositions. It was also found that the hardness of the cases was higher than that of the cores. The dissimilarity in tensile properties of the TMT steel rebars was found too (Kabir, 2014).

2.8 Iron and Steel Industry within the World Economy

González et al., (2011), the iron and steel industry is a very complex sector which is intrinsically linked with the world economy as a whole. Steel products are needed by many industries, such as automotive, construction, and other manufacturing sectors. The steel industry uses significant amounts of raw materials (mainly iron ores, coal and scrap) and energy, and is also a major source of environmental releases such as (among others) emissions of dust, heavy metals, Sulphur dioxide, hydrochloric acid, hydrofluoric acid, polycyclic aromatic hydrocarbons and persistent organic pollutants from sinter plants and coke ovens; waste water from pelletisation; dust and waste water from blast and basic oxygen furnaces; or emissions of filter dust, slag dust, and inorganic and organic compounds from electric arc furnaces (European Commission, 2011). Most raw materials are located remote from the areas of highest steel demand, and so both steel products and inputs are traded internationally and in large quantities.

CHAPTER THREE

METHODOLOGY

This chapter presents the different methods used in the experimental investigation of chemical composition, microstructure, and mechanical properties namely; tensile strength and bending strength, of the steel bars. The specification of tools used to perform different experiments and methods employed in analysis of experimental results obtained are also explained.

3.1 Research Design

The research employed an experimental research design in which four sets of experiments were carried out. The steel bars used were picked enormously from the market from the authentic distributors of the leading steel processors in the country selected according to their annual production capacities. Most of the steel manufacturers are located in Wakiso and Kampala districts of Uganda and their actual names are not stated. The test materials purchased from distributors of the three steel processors considered were subjected to four tests, namely, chemical composition analysis, microstructure investigation, tensile test and bendability test. The results were compared with BS 4445: 2005 and East African standard, EAS 412 - 1: 2005, based on ISO 6935 as a basis to determine the performance of steels manufactured in Uganda. As an experimental research, numerical methods were used to collect data and data analysis.

3.2 Sampling and Coding of Test Specimen

3.2.1 Sampling Techniques and Sample Size Determination

Purposive sampling technique was used with reference to the annual production capacities of steel processors in the country. A sample size of three (3) steel companies was considered out of a total of seven (7) carbon steel bar manufacturers in Uganda. The choice of the sample size of 3 was based on the requirement to have the sample size proportion of at least 30% of the population as indicated in equation 3-1 (Burke et al., 2010). For sample size of three (3) steel manufacturers, the sample size proportion of the population (total number of steel processors) was found to be 43% which is greater than 30%.

$$\frac{sample\ size}{population\ size} \times 100\% \geq 30\% \quad \text{…………}\textit{equation (3-1)}$$

$$\frac{3}{7} \times 100\% = 42.86\%$$

Out of seven (7) main carbon steel bar manufacturers in Uganda, the three steel processors considered had maximum annual production capacity of 130,000MT, 80,000MT and 72,000MT respectively, *table 2.1*.

3.2.2 Coding of Selected Steel Processors

For purposes of not disclosing the steel processors investigated in this study, the three sampled steel processors were assigned identifier codes which were used to identify their specimen in the investigations that were undertaken in this study. The three companies chosen out of seven (7) steel rolling mills were assigned letter codes as *A*, *B* and *C*. The order of identification **does not** mean the hierarchy of the production capacities, the designations are only for identification purposes.

3.2.3 Coding of Test Specimen for Experiments

The specimens were coded using 2 capital letters and a number where the first letter represented the steel processor company, the second letter represented the experiment performed, and the number represented the number assigned to the test specimen from each respective company. For example code AC1, means A from company A, C represents chemical composition and 1 represents the first steel bar from company A. Table 3.1 shows the coding of all test specimen for experiments.

Table 3. 1: Coding of Test Specimen for Experiments

Company ID	Test Specimen Coding			
	Chemical composition	**Microstructure**	**Tensile Strength**	**Bendability**
A	AC1	AM1	AT1	AB1
	AC2	AM2	AT2	AB2
	AC3	AM3	AT3	AB3
B	BC1	BM1	BT1	BB1
	BC2	BM2	BT2	BB2
	BC3	BM3	BT3	BB3
C	CC1	CM1	CT1	CB1
	CC2	CM2	CT2	CB2
	CC3	CM3	CT3	CB3

3.2.4 Description of Test Materials and Test Pieces

Three (3) carbon steel ribbed bars of 20mm diameter, each with an equivalent length of 6m (20ft), were purchased from distributors of each of the three (3) steel processors, a total of nine (9) steel bars were purchased altogether. From each bar (i.e. specimen), four (4) test pieces were cut and prepared for each of the four tests, including: chemical composition, microstructure, tensile strength and bendability experiments. The results for each specimen were tabulated respectively. Ribbed steel bars of diameter 20mm were considered in the study since this size of steel bars are often used for high strength buildings.

3.2.5 Description of Steel International Standards Used

All samples were prepared according to the East African standard, EAS 412 - 1: 2005, based on ISO 6935 standard and BS 4449:2005 which specify the steel bar mechanical, physical, chemical and geometrical properties. The standards were used for benchmarking the mechanical performance of the tested steel bars. *Table 3.2* shows the EAS 412 - 1: 2005, based on ISO 6935 standards and *Table 3.3* shows the British standard *BS 4449:2005* to which plain steel bars are subjected. The tables 3.2 and table 3.3 show the acceptable ranges of these quality aspects according to the standards *BS 4449:2005* and EAS 412 - 1: 2005.

***Table 3. 2*: Steel Standards EAS 412 - 1: 2005, based on ISO 6935 (EAS, 2012)**

Min. Ultimate Strength (N/mm^2)	415 or 500
Min. % Elongation	16
Max. % Carbon	0.27
Max. % Manganese	1.6
Max. % Sulphur	0.07
Max. %Phosphorous	0.07

***Table 3. 3*: Chemical Composition (Maximum % by Mass) (BS, 2005)**

	carbon	**Sulphur**	**phosphorus**	**Nitrogen**	**carbon equivalent**
Cast analysis	0.22	0.05	0.05	0.012	0.50
Product analysis	0.24	0.055	0.055	0.014	0.52

According to BS 4449: 2005, during product analysis, any bar that falls outside the maximum specified limits in *table 3.3* shall be deemed not to conform to this British standard. The mechanical performance of steel bars was based on the minimum percentages of ultimate strength and elongation values based on Steel Standards EAS 412 - 1: 2005, based on ISO 6935, *table 3.2*.

The bending properties after testing in accordance to Steel Standards EAS 412 - 1: 2005, based on ISO 6935, the bar shall show neither rupture nor cracks visible to a person of normal or corrected vision. BS 4449: 2005, recommends the test pieces bend to 90^0 and check for cracks.

3.3 Description of Equipment, Test Specimen and Experimental Procedure

3.3.1 Determination of Chemical Composition

The chemical composition from each of the steel bars was determined by spark emission spectrometry using *SPECTROLAB* apparatus shown in the *figure 3.1*. From each steel bar, a test piece of 20mm length was cut and ground flat for spectrometry done with SPECTROLAB spark Spectrometer as shown in the *figure.3.1*. Each test piece was marked with a code like BC2 for identification purposes. The test piece was placed at the test position and the spark pointer positioned on the grounded surface of the piece. The percentage chemical composition values were tabled automatically by the computer connected to the machine, *Appendix 1*.

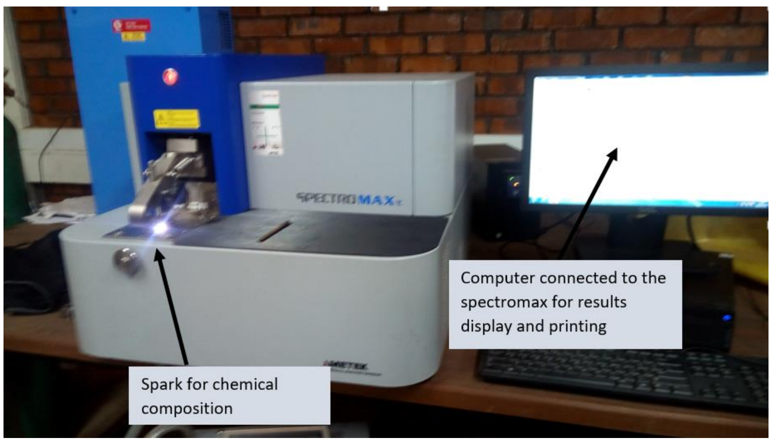

Figure 3. 1: Spectromax Machine for Chemical Composition

3.3.2 Investigation of Microstructure

From each steel bar obtained from steel processor companies, test pieces of lengths of 20mm were cut from the steel specimens. The surface of the test pieces were grounded using rough sand paper as water is poured simultaneously to remove the debris. After grinding off all the roughness, the surface was then micro-polished with Aluminum oxide powder and etched by a mixture of 2% nitric acid with 98% ethanol. Micrographs of the etched surfaces were obtained using an OLYMPUS-412 photomicroscope shown in *figure 3.2* using magnification of x500 and the micrographs were used to analyze the microstructure of the test piece.

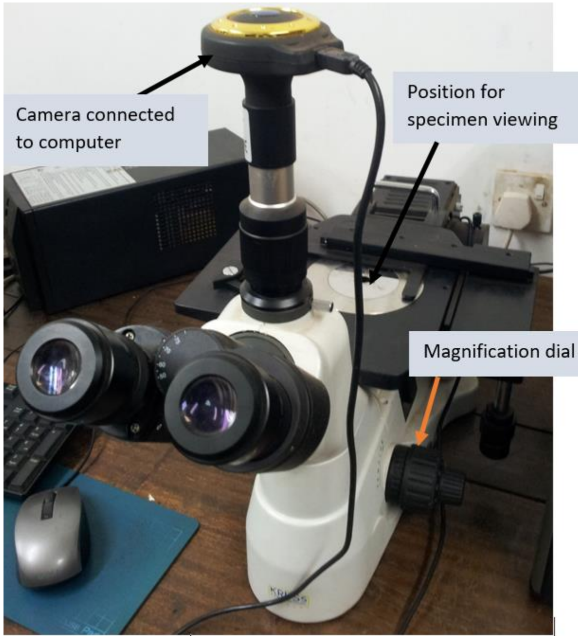

Figure 3. 2: Kruss Optical Microscope for Microstructure Test

3.3.3 Investigation of Tensile Strength

Test pieces of length 300mm shown in *figure 3.3* were extracted from the nine (9) steel bars obtained from the three steel producers by cutting using a hack saw, the test piece was prepared in accordance to BS 4449:2005 and were gripped between the lower and upper jaws of a computerized Testometric hydraulic universal tensile testing machine shown in *figure.3.4*. The test piece was positioned and tightened in the jaws of the machine. The lower jaw is fixed (static) and the upper jaw is movable for tensioning. Each test piece was loaded monotonically on a computerized Testometric hydraulic universal testing machine. The corresponding load-extension graphs were computer plotted. Yield strength, ultimate tensile strength and percentage elongation values were computed using actual cross sections. The force against extension graphs are plotted with the computer connected to the machine automatically.

Figure 3. 3: Steel Bar Prepared for Tensile Test

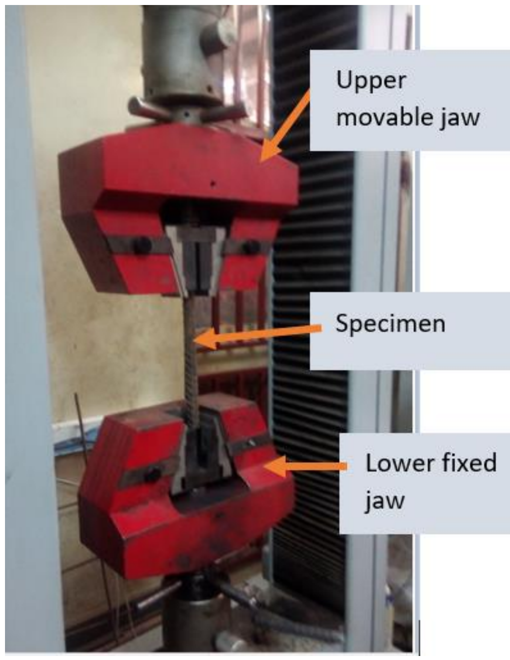

Figure 3. 4: Computerized Hydraulic Universal Tensile Testing Machine

3.3.4 Investigation of Bendability

Test pieces of lengths 250mm shown in *figure 3.5*, were cut using a hack saw and centered on top of the jig in the lower jaw of the UTM as shown in the *figure 3.6*. A jig shown in *figure 3.6* and its upper die were first designed, and fabricated to be used in the bending process. The angle line of 6mm thickness was fabricated at square angle 90^0 for the lower jig. The upper die (male) piece was designed using the 12mm plate of width 50mm and length of 250mm. The bending load was applied at the central position to a bend of 90^0, the peak loads and the deflection of the bar for different specimens were recorded.

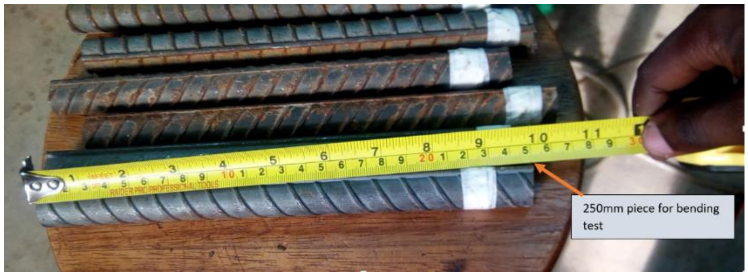

Figure 3. 5: Specimen for Bending Experiment

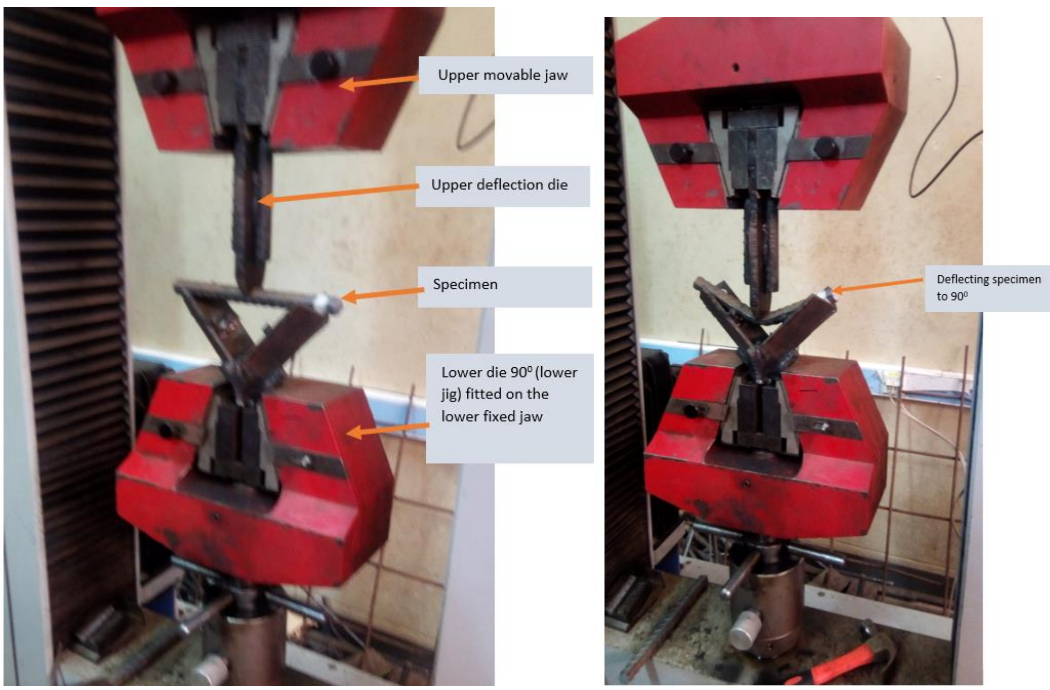

Figure 3. 6: Bending Test

3.4 Data Analysis Techniques and Tools

3.4.1 Analysis of Chemical Composition

The Carbon Equivalent value (**CEV**) was calculated using the equation *(3 – 2), Oelman et al. (1983),* to determine the mechanical performance of steel bars.

$$CEV = C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Ni+Cu}{15} \text{................ (Equation 3 - 2)}$$

Where;

C is the percentage Carbon content

Mn is the percentage manganese content

Cr is the percentage chromium content

V is the percentage vanadium content

Mo is the percentage molybdenum content

Cu is the percentage copper content

Ni is the percentage nickel content

3.4.2 Analysis of Microstructure

The metallographic structure for the core part consists of ferrite and pearlite phases. The relatively coarse-grained crystals and uneven distribution of grain noticeable was compared to the American atlas micrograph for steel bars of carbon 0.18 to 0.26%.

3.4.3 Analysis of Tensile Strength

The MS Excel was used to draw graphs of force against extension for analysis of tensile strength (UTS) and yield strength (YS). Actual measurements were taken from the test piece and compared with the numerical equation (3-3) to determine the gauge length of tensile tests according to BS4449:2005.

$$Gauge\ length\ (test\ length) = 5.65\sqrt{A} \ldots\ldots\ldots\ldots \textit{equation (3 – 3)}$$

3.4.4 Analysis of Bendability

The bending angle 90^0 was used to determine the maximum bending force, bending deflection along the steel bar and the bending stress. Each test piece from the three steel processors was bent to 90^0 and the maximum bending force and deflection was tabled from the computer. After bending to 90^0, each bend was observed for fractures or cracks as both standards recommend.

3.4.5 Determination of significance of Data

The variation of data was done using MS Excel software and Minitab tool for statistical analysis was also used to determination the significance of variation between the chemical composition and the mechanical properties of steel bars. The regression lines were developed

3.5 Summary of the Methodology

The *table 3.4* shows a summary of techniques used to get the data for the respective specific objectives of the study.

Table 3. 4: Summary of Methodology

Specific Objectives	**Data collection Method**	**Materials, Equipment and Tools**	**Test Piece Description**
To determine the chemical composition of the carbon steel bars	experimental	SPECTROLAB spark spectrometer	20mm long piece
To determine the microstructure of the carbon steel bars	experimental	OLYMPUS – 412 Kruss optical microscope, Aluminium oxide, nitric acid as etchant	20mm long piece
To determine the tensile strength of the carbon steel bars	experimental	computerized testometric hydraulic universal tensile testing machine	300mm length
To characterize the bendability of carbon steel bars	experimental	computerized testometric hydraulic universal tensile testing machine, jig fabricated to 90^0	250mm length

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the results obtained from the experiments that were executed on the materials picked from different steel manufacturers in Uganda. It expounds the analysis and discussion of results in relation to standards.

4.1 Results

The results of this investigation are presented in the order of the specific objectives, that is, chemical composition, microstructure, tensile strength and bendability.

4.1.1 Analysis of Chemical Composition

The chemical composition percentages of the alloying elements of the 20mm ribbed steel bar for the nine bars considered are shown in the *table 4.1*. In order to know the combined effects of the alloying elements of steel bars, their carbon equivalent (CEV) values were calculated using *equation (3-1)*. The carbon content for test pieces of company A were between 0.174% and 0.2%, manganese content ranges from 0.722% to 0.833%, Sulphur and phosphorus range was between 0.034% to 0.039%. Test pieces for company B exhibited carbon content of 0.165% to 0.188%, manganese content 0.655% to 0.729%, Sulphur and phosphorus range is 0.042% to 0.045%. And test pieces of company C had carbon content of 0.187% to 0.205%, manganese content 0.667% to 0.869%, Sulphur and phosphorus range is 0.034% to 0.04%. Basing on the BS 4449:2005 and East African steel standards EAS 412 - 1: 2005, which are aligned to ISO 6935, the chemical composition of test pieces obtained from the three companies are within the acceptable limits (C is 0.27%, Mn of 1.6%, S of 0.07%, P of 0.07% and CEV ranging between 0.3 to 0.55%). The second steel bar from company B, coded BC2, had low carbon content of 0.165% which is likely to obtain low strength. The carbon contents of AC1 and CC3, 0.2% and 0.205%, were almost equal to the standard carbon percentage. Table 4.1 shows company A has CEV values ranging between 0.363% to 0.374%. Company B exhibited CEV between 0.307% and 0.323% and Company C exhibited the range 0.347% to 0.397%. All the CEV results of all test pieces were under the acceptable maximum limit of 0.52% (BS 4449:2005).

*T*able 4. 1: Chemical Composition of the Alloying Elements of 20mm Steel Bar

Company ID	Specimen Code	Chemical Composition (%)										CEV
		C	Mn	Si	P	S	Cr	Mo	V	Ni	Cu	
A	AC1	0.200	0.732	0.193	0.039	0.0309	0.169	0.011	0.0043	0.045	0.185	**0.374**
	AC2	0.191	0.722	0.188	0.037	0.0336	0.166	0.011	0.0042	0.046	0.182	**0.363**
	AC3	0.174	0.833	0.276	0.036	0.0355	0.147	0.014	0.0023	0.093	0.252	**0.368**
B	BC1	0.188	0.655	0.313	0.045	0.044	0.05	0.002	0.0067	0.046	0.169	**0.323**
	BC2	0.165	0.684	0.25	0.044	0.044	0.096	0.001	0.0074	0.044	0.064	**0.307**
	BC3	0.175	0.729	0.276	0.042	0.043	0.088	0.002	0.0070	0.031	0.078	**0.323**
C	CC1	0.187	0.667	0.22	0.039	0.0404	0.157	0.008	0.0084	0.047	0.162	**0.347**
	CC2	0.198	0.729	0.239	0.037	0.0384	0.137	0.005	0.0069	0.049	0.193	**0.365**
	CC3	0.205	0.869	0.291	0.034	0.0384	0.139	0.005	0.0075	0.045	0.208	**0.397**

The chemical composition plots in figure 4.1 show that all the three companies generate almost the same composition percentages with small variations in chemical composition across the companies.

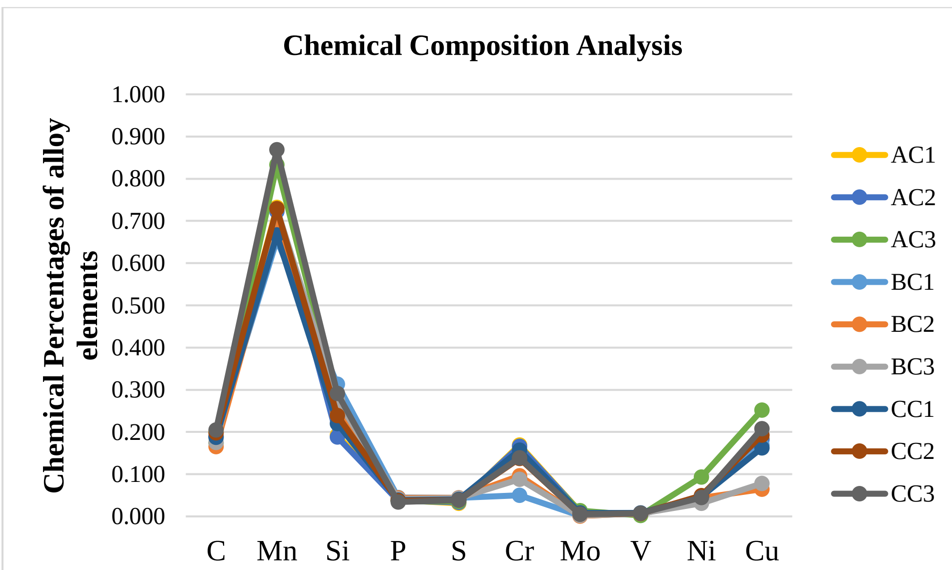

Figure 4. 1: Proportions of Alloy Elements in the Test Pieces

The comparison of the chemical composition of the nine (9) steel bars is clearly depicted using CEV chart *figure 4.2*. The CEV in the range 0.3% and 0.35% shows much better mechanical performance of a steel bar better than the CEV above that range. Company B has all the three bars within the excellent range and only one bar CC1 for company C is within the excellent range while for company A all the three test pieces are outside the excellent range. However, according to BS 4449:2005 standards, all the bars are within the acceptable percentage of 0.5% CEV.

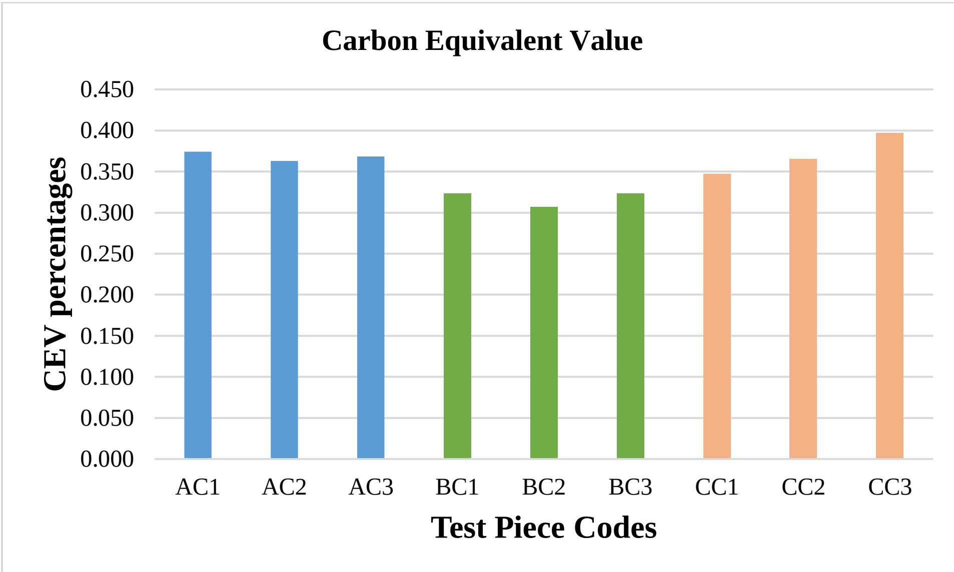

Figure 4. 2: Carbon Equivalent Value of tested steel samples

4.1.2 Analysis of Microstructure

The core zone microstructure was viewed from the photo microscope using x500 magnification lens as shown in *figure 4.3*. All the steel bars, regardless of chemical composition and strength level, exhibited a composite microstructure consisting of ferrite and pearlite phases in the core. The micrographs in *figure 4.3*, show that most test pieces tested exhibited characteristics of hypo eutectoid steel microstructures with ferrite patterns containing the dark part and patches of pearlite. The relatively uneven distribution of phases are visible in AM3, BM2 and CM3 around the core. AM1 and CM1 had a good distribution of the pearlite and ferrite of the core. This could be the reason why steel bar from company *C (CM3)*, cracked during bending to 90^0 test as shown in *figure 4.6*(another author where this was observed). According to the micrograph derived from the American atlas of steels in *figure 4.4* for carbon percentage ranging from 0.18 to 0.26, the distribution of ferrite (dark) and pearlite (white) is even and spread all over the core. This shows uniform properties across the core of the steel bar. Specimen coded AM3 and CM3 had a matrix that was absolutely not matching with the standard microstructure of the low carbon steels. Generally specimens from

Company *B* exhibited a more composite structure close to American Atlas micrograph than that of company *A* and *C*.

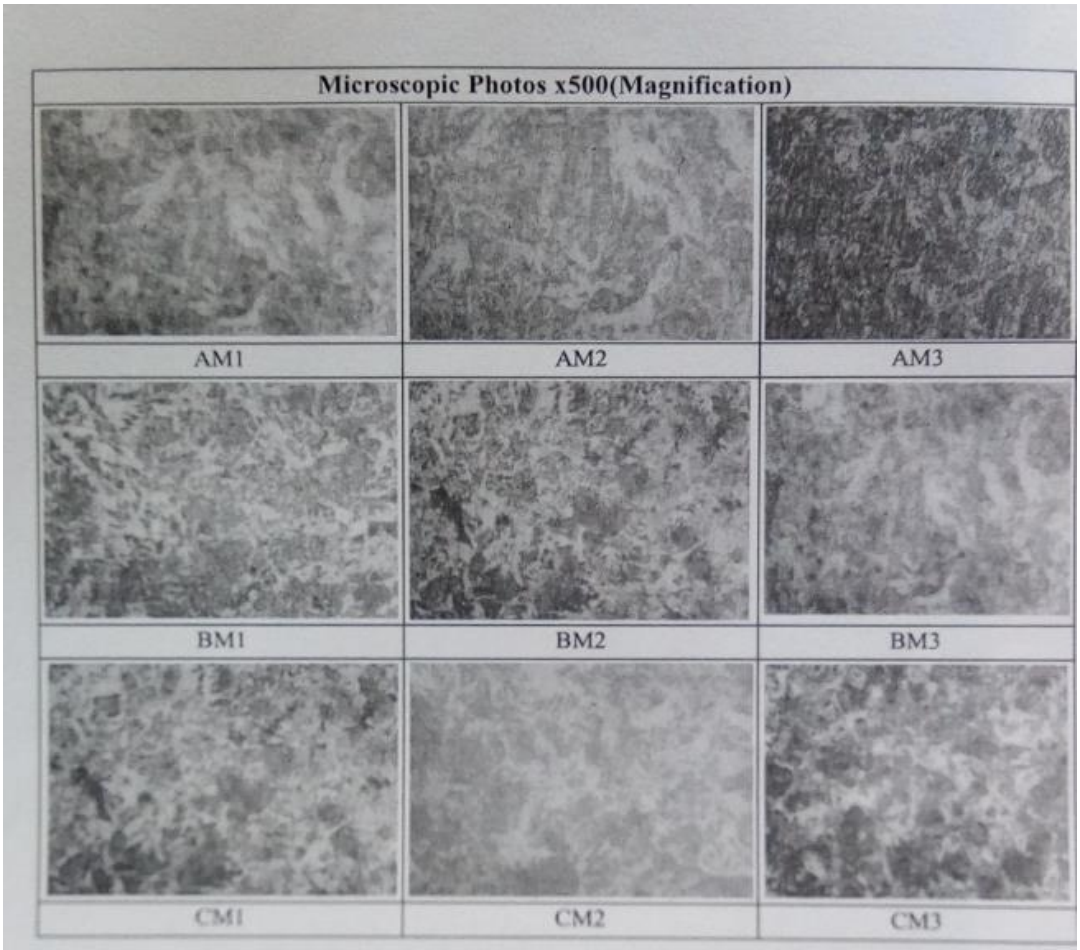

Figure 4. 3: Micrographs of Steel Bars at X500 for Companies A, B and C

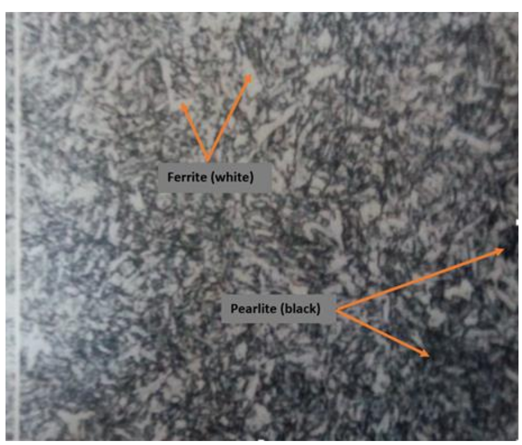

Figure 4. 4: American Atlas micrograph for steel bars of carbon 0.18 - 0.26% (used for comparison with obtained microstructures of steel bars tested)

4.1.3 Tensile Strength

The results of the tensile strength tests indicating the yield strength, UTS/YS ratios and elongation are shown in *table 4.2* and *figure 4.5*.

Table 4. 2: Tensile Properties for 20mm Diameter Steel Bar

Company ID	Specimen Code	Physical Properties			
		Tensile Strength /N/mm^2 (UTS)	Yield Strength N/mm^2 (YS)	UTS/YS	% Elongation
A	AT1	643.00	538.00	1.195	20.30
	AT2	654.00	548.00	1.193	19.50
	AT3	649.20	543.70	1.192	20.60
B	BT1	712.78	569.53	1.252	20.74
	BT2	670.38	570.63	1.175	19.61
	BT3	692.28	570.78	1.191	20.88
C	CT1	659.00	553.00	1.192	22.00
	CT2	686.84	576.49	1.196	20.70
	CT3	713.28	598.59	1.192	18.00

The load (kN) against extension (mm) plots shown on *figure 4.5* indicates that Company *C (CT3),* has the highest ultimate and yield strength but with the lowest percentage elongation of 18%. Company *B (BT1)* is the second with 712.78N/mm^2, 20.74% elongation and company *A* has the lowest ultimate strength. Specimen CT1 obtained the highest percentage elongation, meaning it was the most ductile bar out of the nine tested bars. According to EAS 412 – 2005, based on ISO 6935 and BS 4445: 2005, all the test pieces had acceptable strength and percentage elongation above limits of yield strength 500N/mm^2 and percentage elongation of 16%.

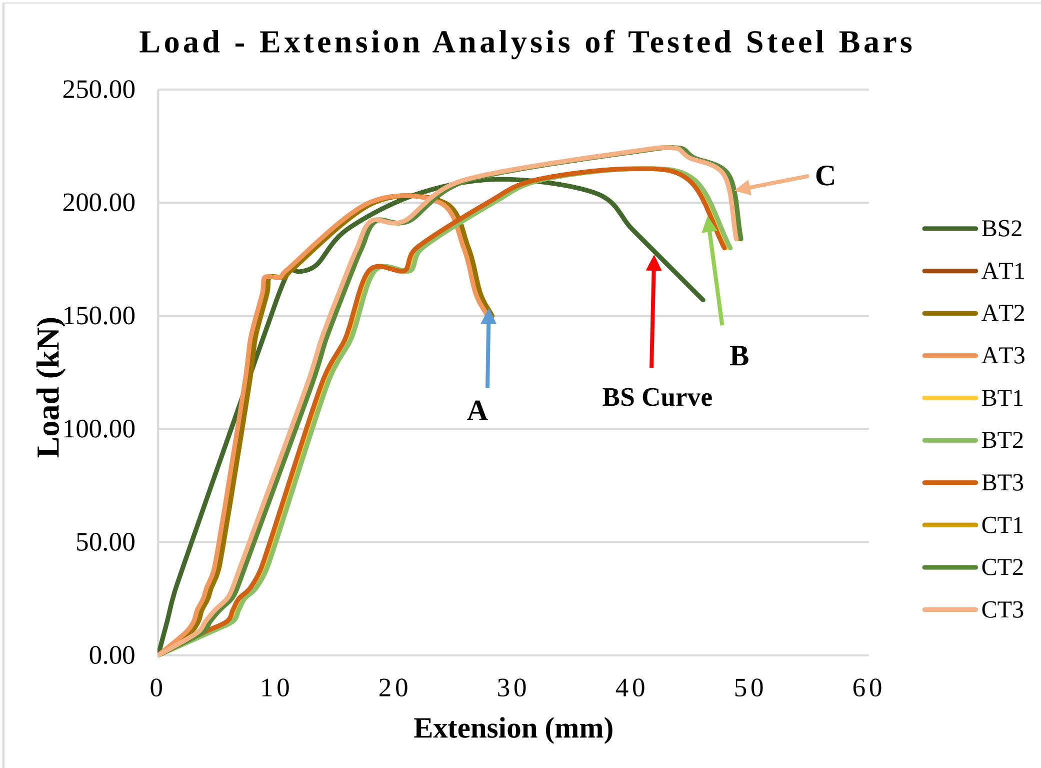

Figure 4. 5: Load (kN) against Extension (mm) for the Three Companies

The load – extension curves of the nine bars are drawn on the *figure 4.5*. The standard load - extension curve of a 20mm ribbed steel bar from British standard was superimposed amidst the nine curves to match standards. The three bars for each company generated the same flow of force against extension. Specimen AT1, AT2 and AT3 had the same curve (curves labelled A). BT1, BT2 and BT3 also generated curves labelled B. CT1, CT2 and CT3 generated curves labeled C. The yield strength of company A is almost the same as the tensile standard curve (BS). However the ultimate tensile strength for A is lower than the standard. Steel bars from B and C obtained both yield strength and ultimate strength above the minimum.

4.1.4 Bending Strength

The peak loads for different specimens were tabulated in *table 4.3*. The bending test results included the force at each peak, young's modulus, deflection at each peak and bend stress.

Table 4. 3: Bending Test Results

Company ID	Specimen Code	Bending Test			
		Force @peak (N)	**Young's Modulus (N/mm^2)**	**Def. @ Peak (mm)**	**Stress (N/mm^2)**
A	AB1	52235	242.6	71.5	166.4
	AB2	50315	249.9	73.7	160.2
	AB3	51283	247.422	73.064	163.3
B	BB1	48097	256.3	70.4	153.2
	BB2	47236	265	71	150.4
	BB3	46336	264.4	70.5	147.6
C	CB1	49265	282	72.7	156.9
	CB2	49071	256.1	74.4	156.3
	CB3	49182.99	284.0625	74.067	156.6

Steel bars from company A obtained the highest bending force and bending stress without failure. Steel bars from company B presented the lowest bending force and bending stress. However, steel bars from company C exhibited the moderate bending force and bending stress with steel bar coded CB3 forming cracks after bending to 90^0 as shown in *figure 4.6*. The bending stress ranging between $148N/mm^2$ and $166N/mm^2$ and deflection 70 to 74mm respectively showed in *table 4.3*.

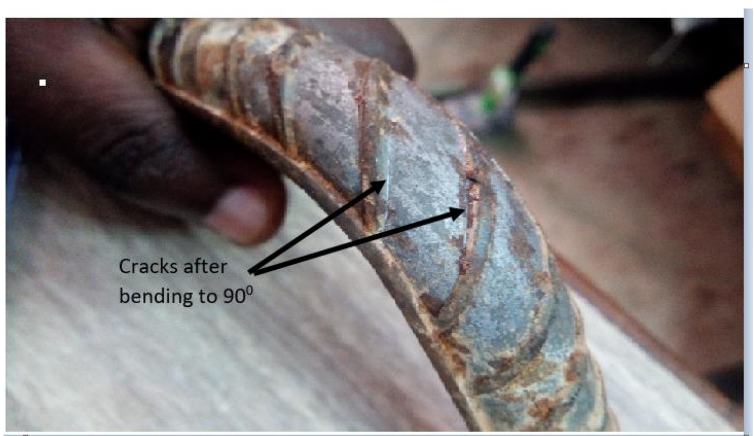

Figure 4. 6: Cracks after Bending the Steel Bar to 90^0

The *figure 4.7* shows the relationship between the applied forces (kN) against the deflection (mm) of the specimen as its bent to 90^0. The three (3) companies exhibited relatively the same bending properties as shown in *figure 4.7*.

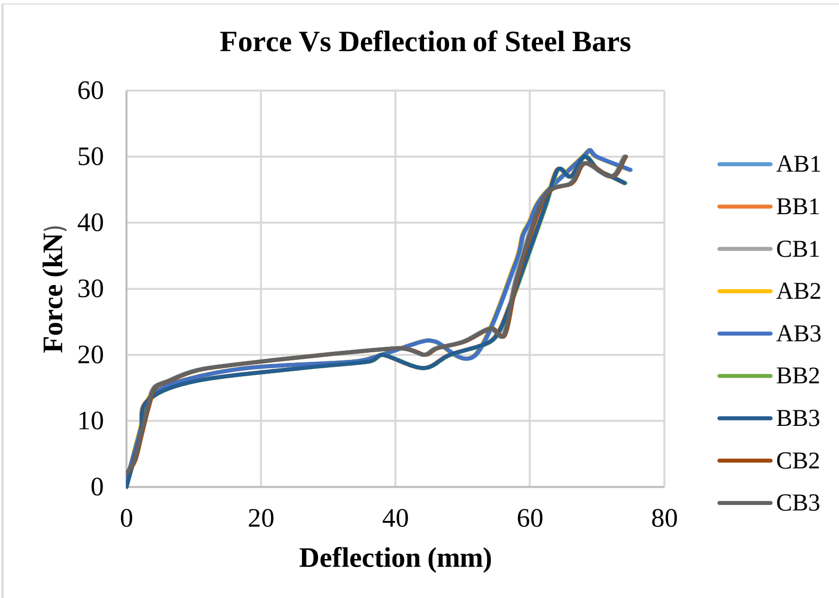

Figure 4. 7: Force (kN) against Deflection (mm) curves

4.2 Discussion of Results

4.2.1 Chemical Composition and Carbon Equivalent Value (CEV)

According to both standards, BS 4449:2005 and the East African standards EAS 412 – 1:2005, based on ISO 6935, carbon content of max 0.27%, manganese max of 1.6%, phosphorus and Sulphur of 0.07%, all the steel bars obtained acceptable results. The CEV of 0.3 to 0.55% according to standards was also achieved from experiments that were done. The difference in the mechanical properties of samples from the three (3) companies were more significant when the chemical composition was analyzed using carbon equivalent value (CEV). This value combines seven chemicals in a relationship that can be used to draw conclusion based on their percentage. Basing on the acceptable excellent value for CEV which is 0.3 to 0.35% according to international standards, company *B* had BC1 and BC3 obtaining the same CEV of 0.323% which was within the excellent acceptable range. Company C had steel bar coded CC1 with

0.347 which is also within the excellent range. The steel bar coded CC3 presented 0.397% which was slightly above 0.35% and this might have been the impact of crack during bending test. However, all carbon equivalent values obtained from all specimen were within the acceptable international standard according to both *BS 4449:2005 and EAC 412-1-2005.*

Steel bar AC1 and CC3 obtaining the best carbon percentage of approximately 0.2%. Company *A* having 0.188% and company *B* 0.176%. Manganese exhibited a range of 0.655 to 0.869%, for phosphorous and Sulphur company B obtained the best percentage which is 0.04% as shown in *table 4.4*. Manganese content of less than 0.30% may promote internal porosity and cracking in the steel bar, Lawrence H, (1980), cracking can also result if the content is over 0.80%. Steel bar CC3 cracked during bending and it presented manganese percentage of 0.869%. The steel bar coded BC2 has CEV 0.307, yield strength of 570.63N/mm^2 and percentage elongation of 19.61% whereas steel bar AC1 had CEV 0.374, yield strength of 538N/mm^2 and elongation of 20.30. The lower CEV, the better mechanical performance of steel bars. *Table 4.4* shows steel bars of CEV between 0.307% and 0.323% had yield strength of 570N/mm^2 and bars of CEV between 0.363 and 0.374% had yield strength of 538N/mm^2 and 548N/mm^2

Table 4. 4: Chemical and Mechanical Properties with Standard Values

Company ID	Specimen code	Chemical Composition (%)				CEV	Ultimate Tensile Strength (UTS)	Yield Strength N/mm^2 (YS)	%Elongation	Bending Stress (N/mm^2)
		C	Mn	P	S					
A	AC1	0.2	0.732	0.039	0.0309	**0.374**	643	538	20	166.4
	AC2	0.191	0.722	0.037	0.034	**0.363**	654	548	20	160.2
	AC3	0.174	0.833	0.036	0.036	**0.368**	649	544	21	163.3
B	BC1	0.188	0.655	0.045	0.044	**0.323**	713	570	21	153.2
	BC2	0.165	0.684	0.044	0.044	**0.307**	670	571	20	150.4
	BC3	0.175	0.729	0.042	0.043	**0.323**	692	571	21	147.6
C	CC1	0.187	0.667	0.039	0.04	**0.347**	659	553	22	156.9
	CC2	0.198	0.729	0.037	0.038	**0.365**	687	576	21	156.3
	CC3	0.205	0.869	0.034	0.038	**0.397**	713	599	18	156.6
BS 4449:2005		**0.24**		**0.055**	**0.055**	**0.52**		**min 500**		
EAS 412-1:2005		**0.27**	**1.6**	**0.07**	**0.07**	**0.3 to 0.55**			**min 16**	

4.2.2 Phases Observed in the Microstructure of Tested Steels

Among the test pieces studied, about seven showed a fairly regular carbon steel microstructure with ferrite forming the pattern in which pearlite spots are distributed. The formation of martensitic related cracks on the CM3, shows a need to preheat to regulate temperature gradient and to control cooling which is unnecessary in typical ferrite-pearlite low carbon steels. For a properly heat treated steel bars, the core microstructures should be fully composed of well-developed ferrite and pearlite phases according to the American Atlas for steel bars and the East African standards EAS 412 – 1:2005, based on ISO 6935. However, the ferrite-pearlite phases in core of *CM3* as shown in *figure 4.3* was significantly deviated from the standard microstructures. The failure to obtain an even distribution of microstructure, affects the properties and performance of the material. The steel bar that cracked had manganese percentage above 0.8%, with CEV 0.397% and the micrograph not well distributed. The microstructure has a direct impact on the properties of steel bar.

4.2.3 Maximum Tensile Strength and UTS/YS Ratio

The standard load - extension curve (*curve labelled BS2*) was plotted together with the tensile curves for the steel bars under consideration. Focusing on the load - extension curve, *figure 4.5*, shows steel bars from company *A* had relatively equal yield strength and ultimate strength to the standard curve while company *B* and *C* obtained higher yield strength, 543 N/mm^2 and ultimate strength, 649 N/mm^2. Company *B* and *C* exhibited higher ultimate strength at longer extensions, meaning, their steel is more ductile than for company *A*.

The British standard (*BS 4449:2005)* which is also used by UNBS, recommends yield strength of 500Mpa and UTS/YS ratio of 1.15 to 1.35. The relationship between the three companies is shown in *figure 4.7*. Ugandan steels obtained acceptable yield strength above 500MPa and the tensile/yield strength ratio is between 1.175 and 1.252.

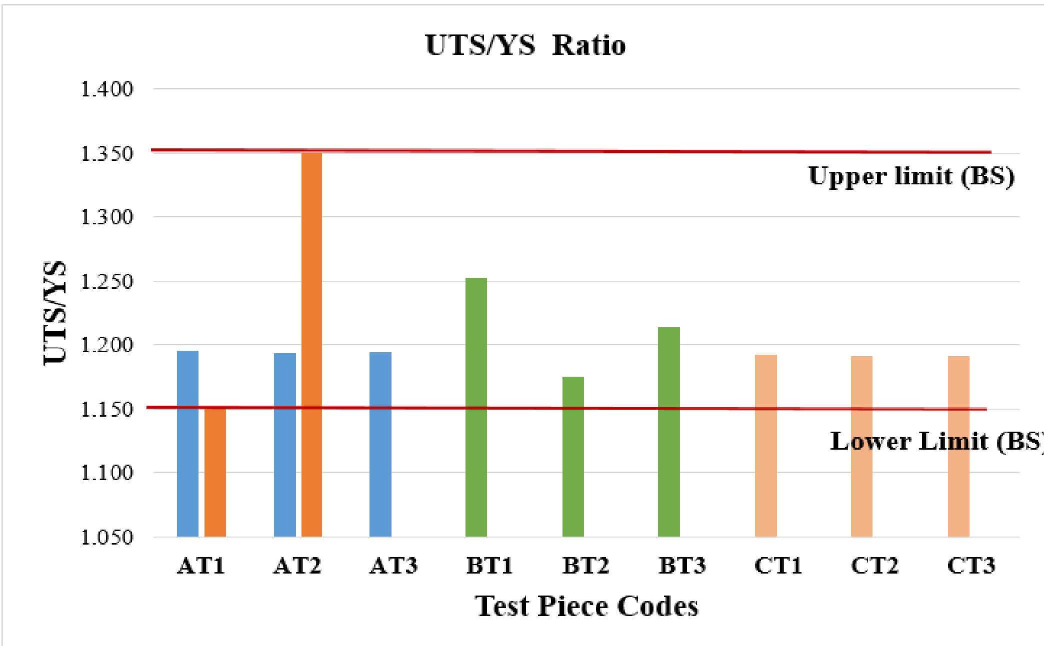

Figure 4. 8: Comparison of UTS/YS Ratio with British Standard (BS)

Company B obtained the best ratio against the British standard, implying, company B exhibits the best tensile properties than company A and C. In f*igure 4.8* shows the maximum value UTS/YS at 1.35 and lowest value of 1.15, company B obtained 1.252. The yield strength of Ugandan steel bar (20mm dia) ranges between 538 MPa and 599 MPa ref. table 4.2, which is above the limit recommended by BS 4449:2005 and East African standards EAS 412 – 1:2005, based on ISO 6935. However, Ugandan steels have better percentage elongation (18% to 22%) which is above 16% according to standards. This means Ugandan steels have better ductility. The CEV of 0.347%, yield strength of 553N/mm^2, UTS/YS of 1.192 resulted the best elongation percentage of 22%.

4.2.4 Maximum Bending Strength

Both BS 4449:2005 and East African standards EAS 412 – 1:2005, based on ISO 6935standards don't have a clear value for bending stress. Standards depicts observations of the bend after bending to 90^0. The bending stress according to Shrabani, (2017), for bars of diameter $> 20mm, \leq 25mm$, is 170 N/mm^2. Steel bars in Uganda exhibited bending stress with a range of 148 N/mm^2 to 166 N/mm^2. *Figure 4.9* shows the upper limit for bending stress and company *A* is obtained 166N/mm^2 without cracking. Company *B* exhibited an average bending stress of 153N/mm^2 without cracking. Company *C* obtained an average of 157N/mm^2 and cracked in the process of bending. Therefore, company *C* didn't pass the bending test. The carbon content 0.205% and manganese of 0.869%, CEV of 0.397% cracked after bending to 90^0. The phases of the same were not evenly distributed according to the micrograph.

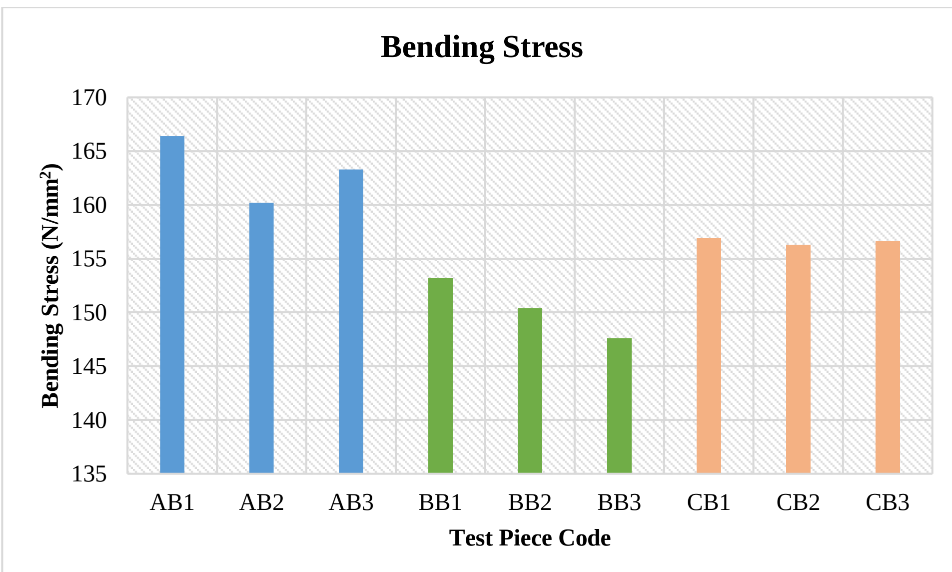

Figure 4. 9: Bending Stress for different test pieces

4.2.5 Comparison of Chemical Properties with Mechanical Properties

The *table 4.5* shows the variance of CEV against ultimate tensile strength, yield strength, percentage elongation and bending stress. There was no statistical significant difference in the values of UTS, YS and percentage elongation considering the P-values. However, the bending stress was below 0.05 implying there was a statistical significant difference in the chemical composition. Thus, the bending properties did not pass the test.

Table 4. 5: CEV versus UTS, YS, %Elongation, Bending Strength

Analysis of Variance (ANOVA)					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Regression	4	0.005913	0.001478	6.77	0.045
Ultimate Tensile Strength (UTS)	1	0.000038	0.000038	0.18	0.697
Yield Strength N/mm^2 (YS)	1	0.000802	0.000802	3.67	0.128
% Elongation	1	0.000018	0.000018	0.08	0.790
Bending Stress (N/mm^2)	1	0.004261	0.004261	19.51	0.012
Error	4	0.000874	0.000218		
Total	8	0.006787			

Coefficients					
Term	**Coef**	**SE Coef**	**T-Value**	**P-Value**	**VIF**
Constant	-1.315	0.547	-2.40	0.045	
Ultimate Tensile Strength (UTS)	-0.000190	0.000454	-0.42	0.697	5.42
Yield Strength N/mm^2 (YS)	0.001469	0.000767	1.92	0.128	7.90
% Elongation	0.00189	0.00663	0.28	0.790	2.02
Bending Stress (N/mm^2)	0.00593	0.00134	4.42	0.012	2.35
Model Summary					
	S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**	
	0.0147777	87.13%	74.26%	0.00%	

The linear regression equation shows the relationship between the ultimate tensile strength, yield strength, percentage elongation and bending stress. The regression lines in the figures below show uniform relationship between carbon, manganese against tensile strength and bending stress. Its only figure 4:12 that shows relative inverse relationship between CEV and Ultimate Tensile Strength (UTS). The comparison between the chemical composition and the mechanical properties of steel gives a negative slope (gradient). This means that the lower the CEV (ranging between 0.3 and 0.5), the better the mechanical properties.

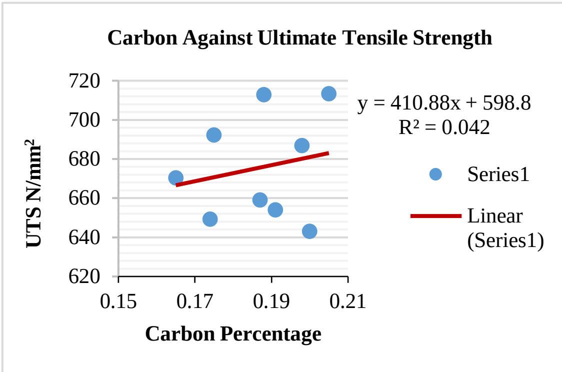

Figure 4. 10: Carbon against UTS

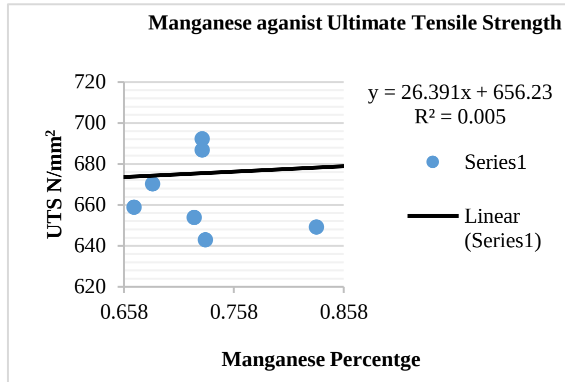

Figure 4. 11: Manganese against UTS

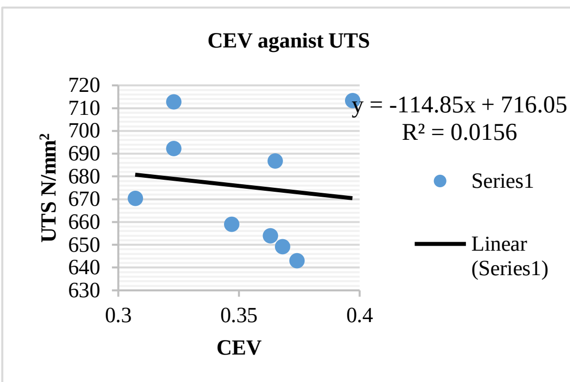

Figure 4. 12: CEV against UTS

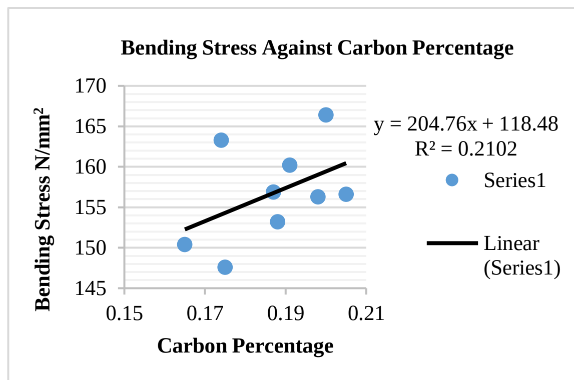

Figure 4. 13: Bending Stress against Carbon

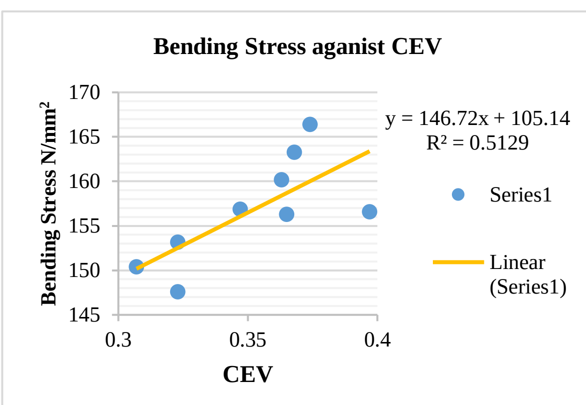

Figure 4. 14: Bending Stress against CEV

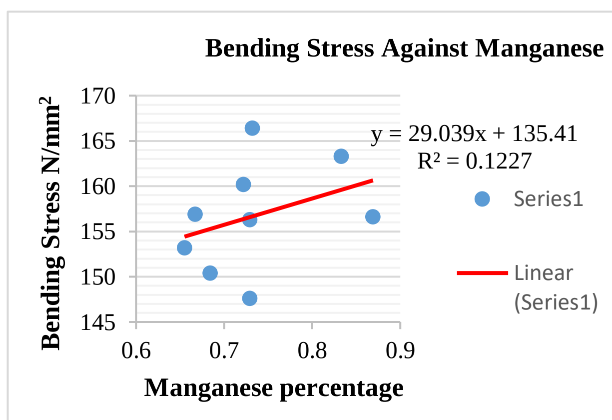

Figure 4. 15: Bending Stress against Manganese

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

From the results of investigation on the mechanical performance of steel made in Uganda, the following conclusions and recommendations were made based on the physical and chemical tests conducted.

5.1 Conclusion

This study investigated the mechanical performance of carbon steels in Uganda and it considered chemical composition, microstructure, tensile strength and bendability. All the 20mm ribbed steel bars purchased from the market met the requirements for the standards that were used. But for carbon composition, one steel bar (BC2) had low carbon percentages as low as 0.165% resulting into the lowest UTS/YS ratio of 1.175. The carbon equivalent values (CEV) for all the tested bars were all within acceptable limits according to standards. However, there were variations in the CEV between the bars considered for this investigation.

In addition, a majority of microstructures observed especially from company *B*, had well distributed phases of pearlite- ferrite phase which is consistent for low carbon steel and also a requirement for the standards considered. Thus, showing uniform properties across the section of steel bars. A few microstructures from Company *A* (material AM3) and company *C* (material CM3) exhibited non uniformity in the distribution of phases resulting into low strength and cracking during bending tests.

Furthermore, all the 20mm ribbed steel bars had acceptable yield strength percentage elongation which was above the minimum requirements for the standards used, that is, 500Mpa and 16% respectively. The 16% elongations represented good ductility of the steel bars tested. Company *A* and company *B* obtained an average percentage elongation of 20% and company *C* exhibiting percentage elongation of 18% and 22%.

Lastly, the maximum bending stress for the 20mm ribbed bar was 166.4N/mm^2 and the minimum was 147.6N/mm^2. One of the bars didn't pass the bending test due cracks observed after bending to 90^0. Company *A* had the highest bending stress of 166.4N/mm^2, followed by company *C* of an average bending stress of 160N/mm^2 and company *B* having the least bending stress of 147.6 N/mm^2 to 153.2N/mm^2

5.2 Recommendations

This study investigated the mechanical performance of carbon steels in Uganda and it considered chemical composition, microstructure, tensile strength and bendability. The chemical composition and microstructure of the steel bar directly affects the quality of the end product. The recommendations are focused on the chemical composition and microstructure of the steel bars.

Regarding specific objective 1, the variation in carbon, manganese and carbon equivalent value percentages can be reduced to a minimum if the quality control department of the respective steel producers monitors the composition from the furnace stage of production. If the steel bar is produced from scrap, then the input scrap materials should be well sorted and monitored. Higher manganese (Mn) content in steel increases the tensile strength and the carbon equivalent properties, this can be reduced by reducing the cooling rate during the heat treatment of steel bars. . The manganese alloy content is reduced due to the presence of silicon by re-smelting silicomanganese with more quartz and coke.

Regarding specific objective 2, the microstructures of the test pieces showed need to control the heat treatment of the steel ribbed bar production process. The microstructure is highly affected by the cooling process of each steel bar. The annealing and quenching sections at temperature should be kept slightly below and slightly above 600^{0}C

Specific objective 3 and 4 depend on the improvement of the above objectives 1 and 2. Once the variations in the carbon, manganese and CEV are matched, tensile and bending stress will be kept significant.

5.3 Action for Further Research

This study required to consider all the steel processing companies in Uganda. The limited financial support reduced the samples to only three (3) companies. Few TMT rebars were picked from the market for experiments. Therefore, there is need to fund research like this.

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APPENDIX

Appendix 1: Results for Chemical Composition of Company A, B and C

Company ID	Specimen Code	Chemical Composition (%)										CEV
		C	Mn	Si	P	S	Cr	Mo	V	Ni	Cu	
A	AC1	0.200	0.732	0.193	0.0389	0.0309	0.169	0.0112	0.0043	0.0454	0.185	0.374
	AC2	0.191	0.722	0.188	0.0368	0.0336	0.166	0.0109	0.0042	0.0457	0.182	0.363
	AC3	0.174	0.833	0.276	0.036	0.0355	0.147	0.0136	0.0023	0.0934	0.252	0.368

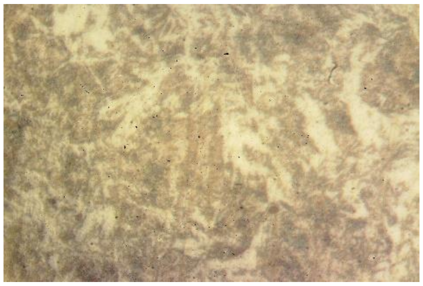
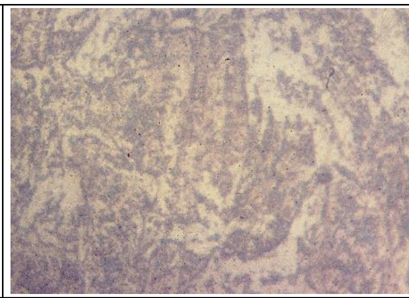
Results for Chemical Composition of B

company ID	Specimen Code	Chemical Composition (%)										CEV
		C	Mn	Si	P	S	Cr	Mo	V	Ni	Cu	
B	BC1	0.188	0.655	0.313	0.045	0.044	0.0503	0.0016	0.0067	0.046	0.169	0.323
	BC2	0.165	0.684	0.25	0.044	0.044	0.096	0.001	0.0074	0.044	0.064	0.307
	BC3	0.175	0.729	0.276	0.042	0.043	0.088	0.0023	0.0070	0.031	0.078	0.323

Results for Chemical Composition of C

company ID	Specimen Code	Chemical Composition (%)										CEV
		C	Mn	Si	P	S	Cr	Mo	V	Ni	Cu	
C	CC1	0.187	0.667	0.22	0.0389	0.0404	0.157	0.008	0.0084	0.0472	0.162	0.347
	CC2	0.198	0.729	0.239	0.0374	0.0384	0.137	0.0051	0.0069	0.0491	0.193	0.365
	CC3	0.205	0.869	0.291	0.0343	0.0384	0.139	0.005	0.0075	0.045	0.208	0.397

Appendix 2: Micrographs for Different Magnifications

Micrographs x500(Magnification)		
		
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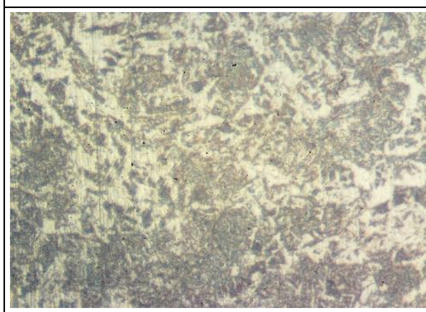
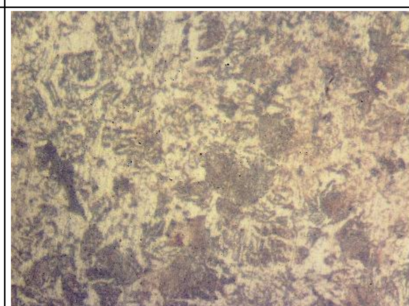
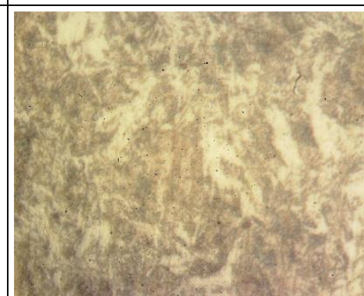
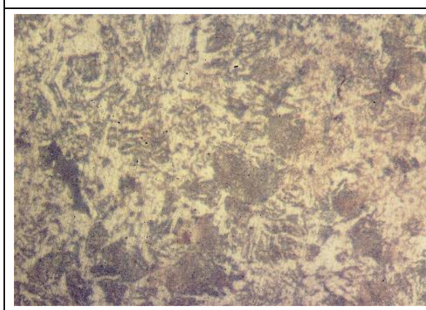
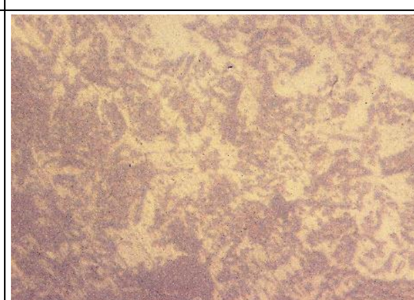
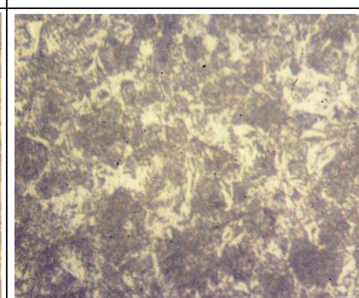
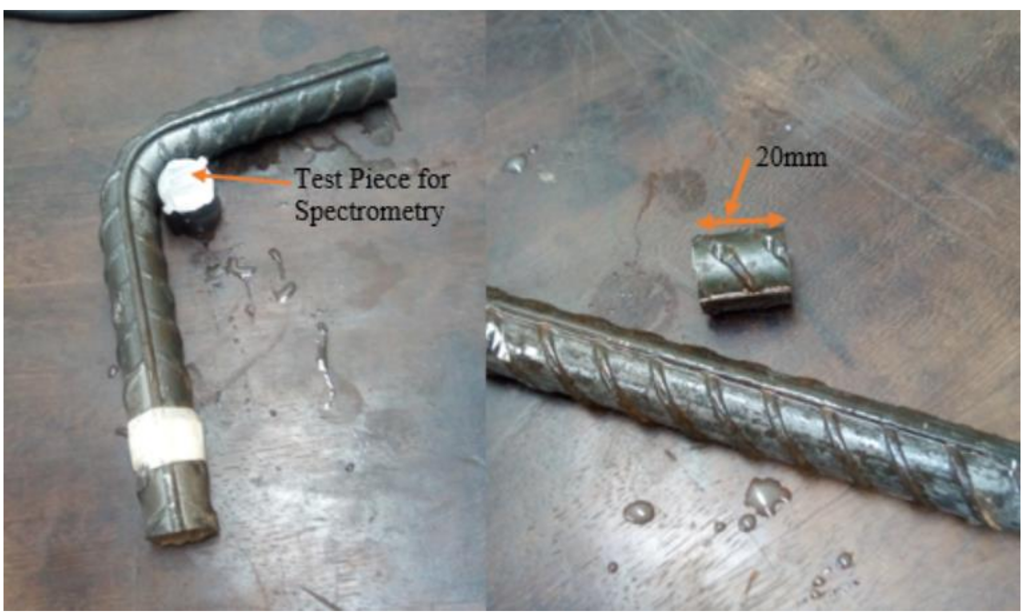
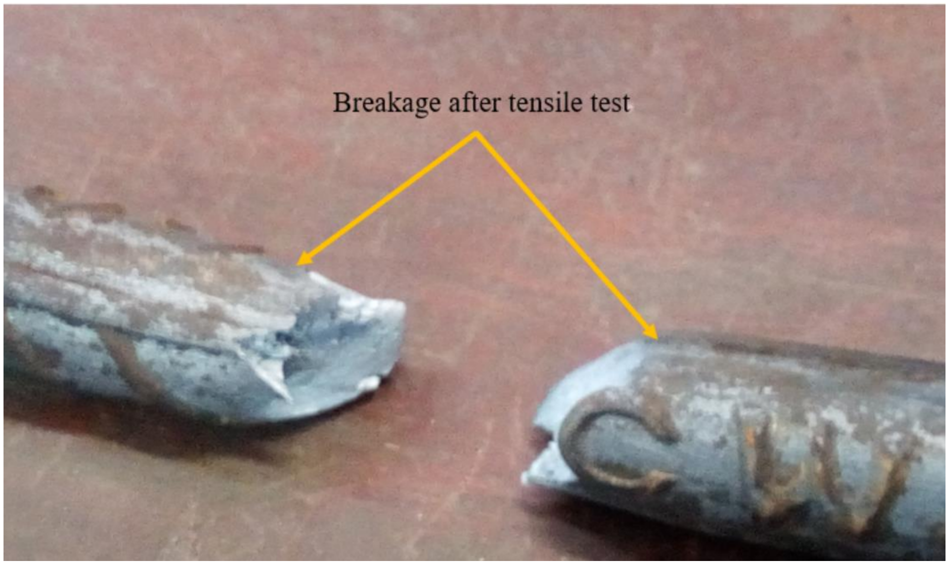
		
BM1	BM2	BM3
		
CM1	CM2	CM3

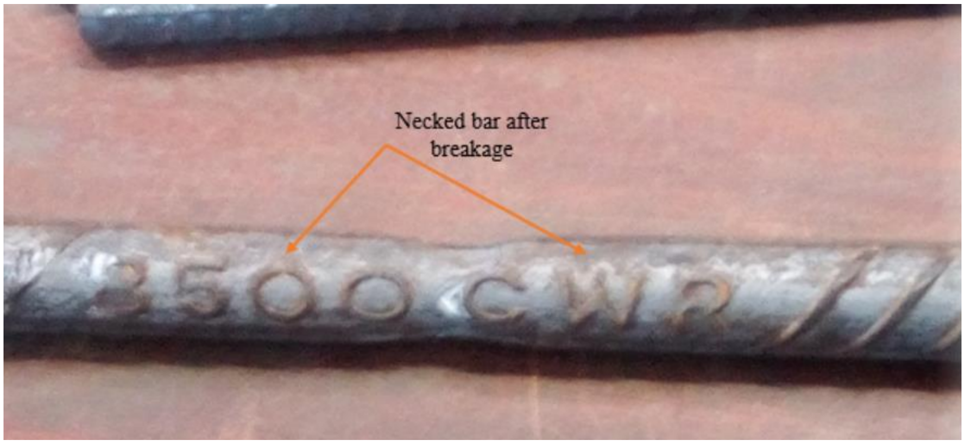
Appendix 3: Micrographs for Different Magnifications

Preparation of specimen for micrograph. Cutting machine for cutting piece of 20mm, grinding aluminum oxide and nitric acid plus ethanol mix for etching

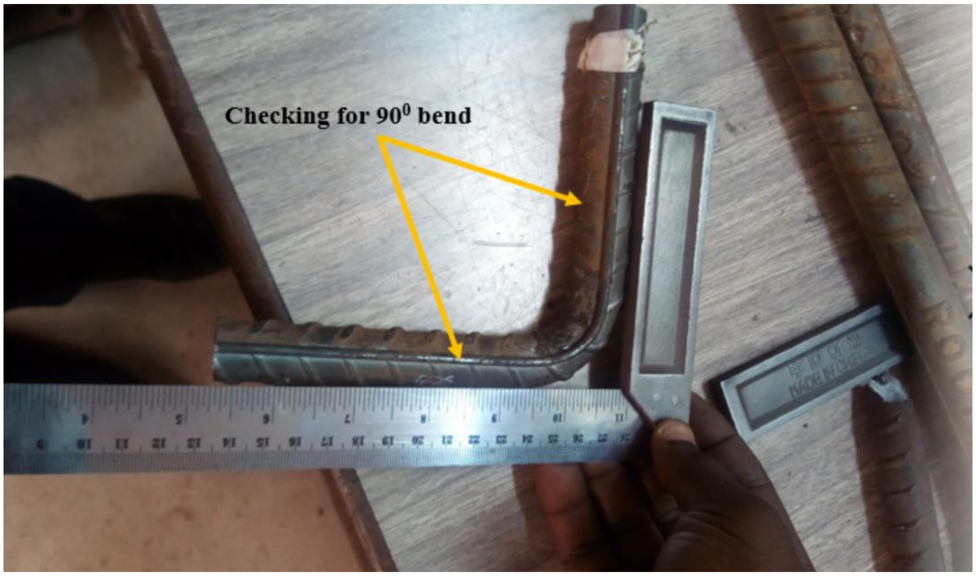


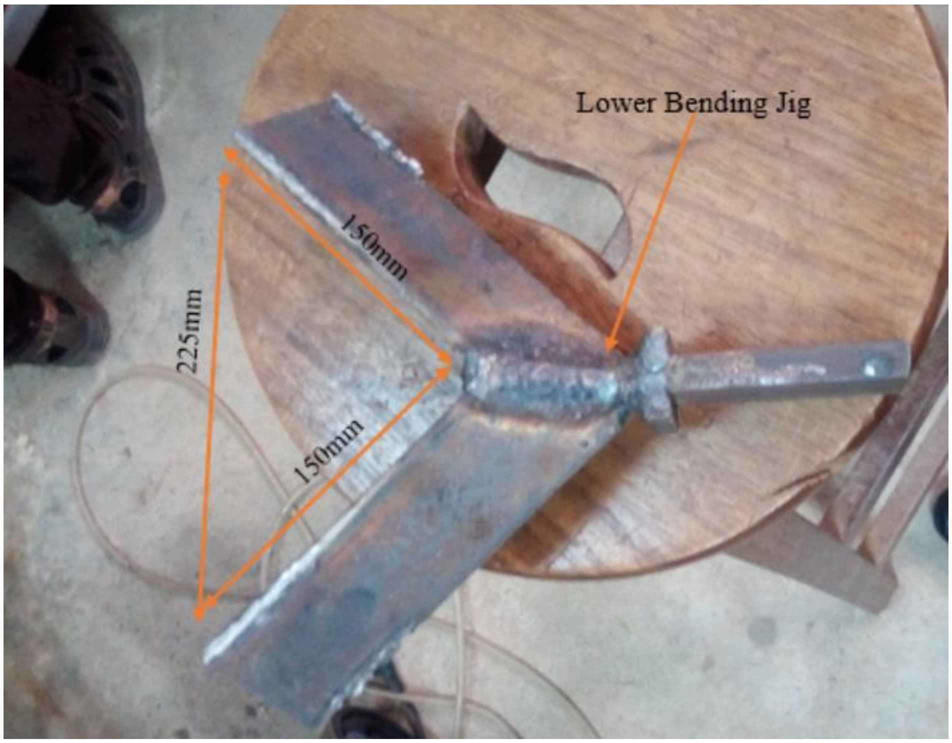
Appendix 3: Tensile Strength Tests Photos





Appendix 4: Bendability Photos





Appendix 5: Some of the Results from the Experimental Tests

Table 1: Average chemical composition for the various materials of the Ribbed Bar samples

Material	Sample Ribbed 20mm A	Sample Ribbed 20mm B	Sample Ribbed 20mm C
Element	%	%	%
Carbon, C	0.184	0.201	0.241
Silicon, Si	0..0787	0.0701	0.0801
Manganese, Mn	0.570	0.563	0.463
Phosphorous, P	0..0332	0.0303	0.0403
Sulphur, S	0.0218	0.0199	0.0178
Aluminum, Al	0.00059	0.00050	0.00060

N:B **a)** The load- extension characteristic graphs of all specimens tested are attached for both tensile and bending.

We hope the results will be of help to your research.

Tests and report done by

Wabwire Andrew
Eng. Materials laboratory

Approved by

Assoc. Prof. J. B. Kirabira
Chair – Mechanical Eng. Dept.

MAKERERE UNIVERSITY
CEDAT
30 JUL 2019
DEPARTMENT OF MECHANICAL ENGINEERING

Testometric
materials testing machines

winTest™ Analysis

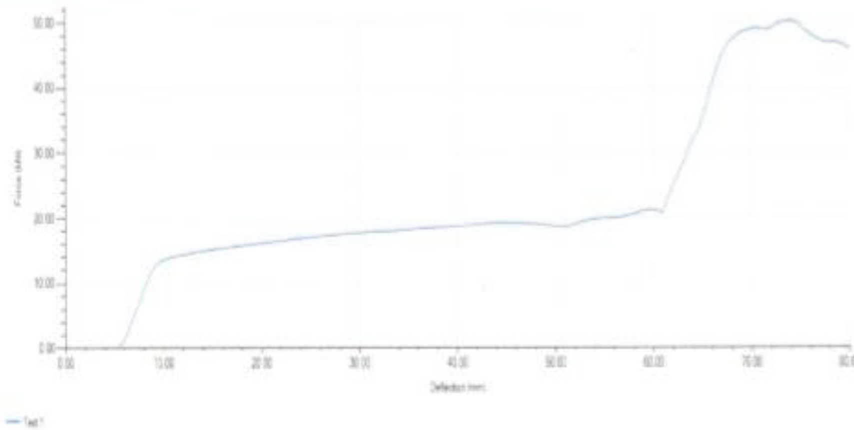
20mm Ribbd Bar

Sample from ~~SH~~ RRM

Sample : 1
Diameter : 20mm
Length : 250

Machine No. : 0300-02032
Test Name : Steel Bending Test
Test Type : Compression
Test Date : 29/07/2019 10:43
Test Speed : 40.000 mm/min
Preload : Off
Diameter : 20.000 mm
Sample Height : 20.000 mm

Test No	Diameter (mm)	Force @ Peak (N)	Youngs Modulus (N/mm²)	Def. @ Peak (mm)
1	20.000	50314.999	249.857	73.663



Page 1 of 1

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winTest™ Analysis

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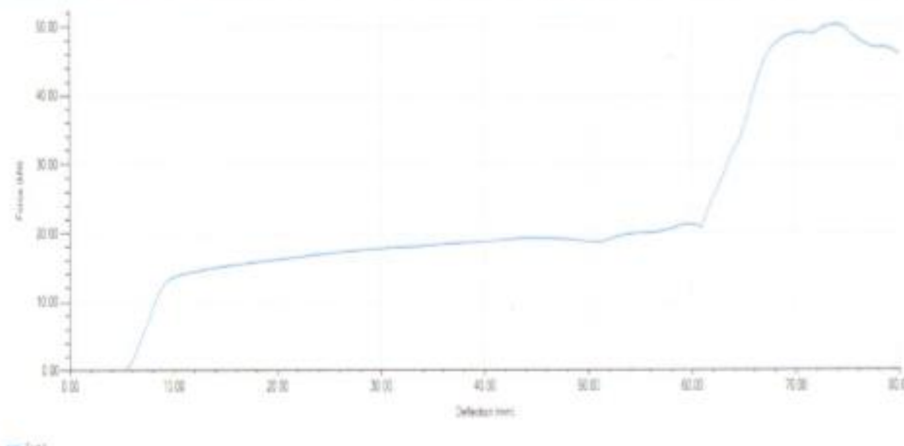
1	20.000	50314.999	249.857	73.663



Page 1 of 1

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winTest™ Analysis

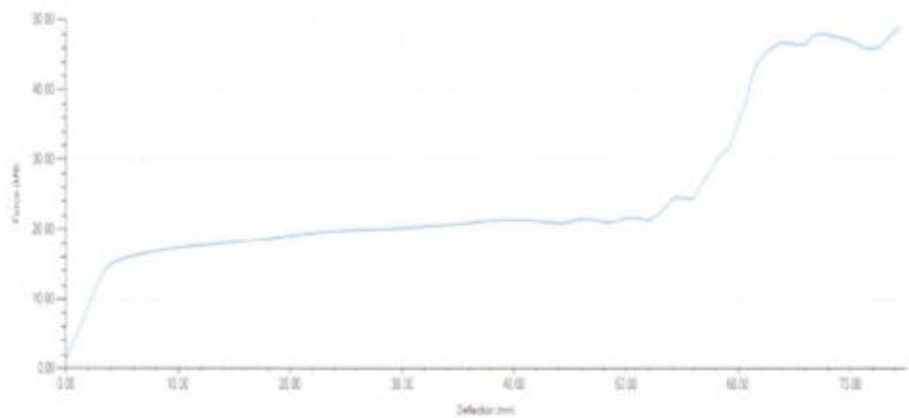
20mm Ribbd Bar

Sample from PMK

Sample : 2
Diameter : 20mm
Length : 250

Machine No. : 0300-02032
Test Name : Steel Bending Test
Test Type : Compression
Test Date : 29/07/2019 10:58
Test Speed : 40.000 mm/min
Preload : Off
Diameter : 20.000 mm
Sample Height : 20.000 mm

Test No	Diameter (mm)	Force @ Peak (N)	Youngs Modulus (N/mm^2)	Def. @ Peak (mm)
1	20.000	49070.999	256.138	74.397



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winTest™ Analysis

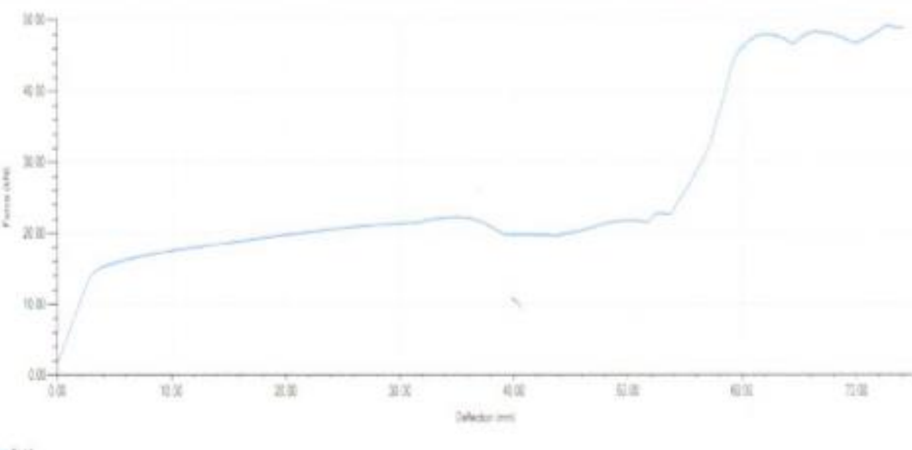
20mm Ribbd Bar

Sample from PMK

Sample : 1
Diameter : 20mm
Length : 250

Machine No. : 0300-02032
Test Name : Steel Bending Test
Test Type : Compression
Test Date : 29/07/2019 10:53
Test Speed : 40.000 mm/min
Preload : Off
Diameter : 20.000 mm
Sample Height : 20.000 mm

Test No	Diameter (mm)	Force @ Peak (N)	Youngs Modulus (N/mm^2)	Def. @ Peak (mm)
1	20.000	49264.999	281.987	72.737



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Testometric
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winTest™
Analysis

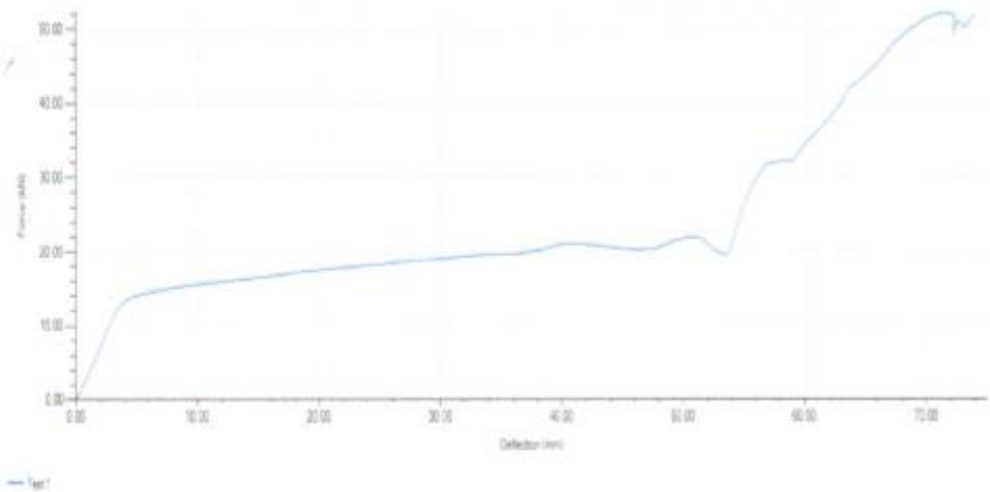
Ribbed BAR

20mm FROM RRM

Sample : 1
Diameter : 20mm
Length : 250

Machine No. : 0300-02032
Test Name : Steel Bending Test
Test Type : Compression
Test Date : 29/07/2019 10:00
Test Speed : 40.000 mm/min
Preload : Off
Diameter : 20.000 mm
Sample Height : 20.000 mm

est No	Diameter (mm)	Force @ Peak (N)	Youngs Modulus (N/mm^2)	Def. @ Peak (mm)
	20.000	52235.001	242.587	71.465



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Analysis

Ribbed BAR

20mm FROM RRM

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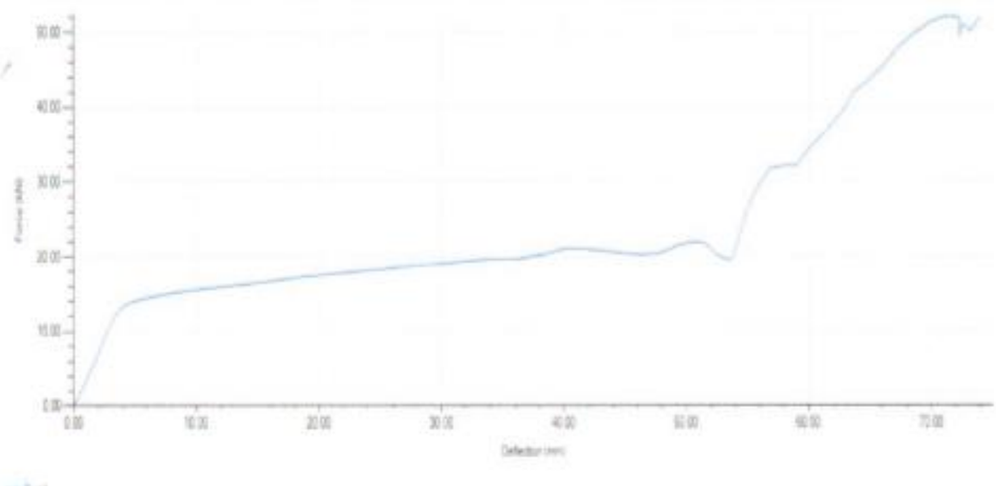
Test Date : 29/07/2019 10:00
Test Speed : 40.000 mm/min
Preload : Off
Diameter : 20.000 mm
Sample Height : 20.000 mm

Test No	Diameter (mm)	Force @ Peak (N)	Youngs Modulus (N/mm^2)	Def. @ Peak (mm)
	20.000	52235.001	242.587	71.466



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