AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING AND

ENTREPRENEURIAL DEVELOPMENT

INVESTIGATION INTO STRENGTH PROPERTIES OF RIBBED REINFORCING MILD STEEL BARS PRODUCED BY LOCAL COMPANIES IN GHANA

SUMAILA MOHAMMED

MASTER OF PHILOSOPHY

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A THESIS IN THE DEPARTMENT OF CONSTRUCTION AND WOOD TECHNOLOGY EDUCATION, FACULTY OF TECHNICAL EDUCATION SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

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MAY, 2022

DECLARATION

STUDENT'S DECLARATION

I, Sumaila Mohammed declare that this thesis, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE: …………………………….

DATE: …………………………………….

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of thesis/dissertation/project as laid down by the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development.

PROF. HUMPHREY DANSO

SIGNATURE: …………………………

DATE: ………………………………….

DEDICATION

I dedicate this work to the Almighty God, Allah for taking me through this program successfully. I also appreciate all the effort of my Uncle Prof. Joseph Mbawuni for all his support in my life and to all my friends who contributed to the successful completion of this course especially my course mates.

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GLOSSARY AND ABBREVIATIONS

AAMUSTED	Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development
AC	Category A Chemical Composition
AES	Atomic Emission Spectrometer
AI	Aluminum
AISI	American Iron and Steel Institute
ANOVA	Analysis of Variance
ASME	American Society of Mechanical Engineers
ASTM	American Society of Testing Materials
AT	Category A Tensile Strength
BC	Category B Chemical Composition
BCT	Body Centred Tetragonal
Bo	Boron
BOS	Basic Oxygen Steel Making
BS	British Standard
BT	Category B Tensile
C	Carbon
CBC	Cubic body centered
CC	Category C Chemical Composition
CE	Carbon Equivalent
CEV	Carbon Equivalent Value
Cr	Chromium
CT	Category C Tensile
CTD	Cold twisted deformed
Cu	Copper
EAF	Electric Arc Furnace
ECOWAS	Economic Community of West African State
EL	Elongation
FCC	Face Centred Cubic

Fe	Iron
FFL	Ferro Fabrik Limited
GSA	Ghana Standard Authority
HV	Vickers hardness number
ISO	International Standard Organization
kgf	Kilogram Force
MMD	Mohan Manji Dhrolia
Mn	Manganese
Mo	Molybdenum
MPa	MegaPascals
N	Newton
Ni	Nickel
P	Phosphorus
Rebar	Reinforcing bar
S	Sulphur
Si	Silicon
Sn	Tin
TMT	Thermo-Mechanically Treated steels
USEPA	United State Environmental Protection Agency
UTS	Ultimate tensile strength

ABSTRACT

The construction of high-rise buildings has increased the production of ribbed mild steel bars in Ghana. This was motivated by the fact that, the use of substandard ribbed mild steel bars in construction industry causes collapse of structures in many developing countries. This study aimed at investigating the strength properties of ribbed mild steel bars manufactured in Ghana from scrap metals by subjecting the materials to laboratory tests such as tensile tests, chemical composition analysis, microstructure examination and micro hardness tests. Three (3) steel producing companies were considered for this study. A total of forty-five (45) ribbed mild steel bars of 12mm, 16mm and 20mm diameters of length 500mm were used for the tensile strength experiments. The results of analysis indicated that, tensile strength of ribbed mild steel bars produced in Ghana fulfilled the ASTM E8/E8M-16a with ultimate tensile strength of 460N/mm^2. Angstrom V-950 Spectrometer was used for chemical composition analysis, fifteen (15) pieces of 16mm steel bars of length 50mm were used. Carbon equivalent values (CEV) were calculated from the results of the chemical composition According to ASTM A706/A706M-09b. The findings build on existing evidence of carbon, manganese, Chromium, silicon and copper being the major elements influencing the strength properties. Vickers hardness tests was also conducted on the Vickers hardness testing machine according to ASTM E92-17. The results showed that, all the three companies obtained higher Vickers hardness value between 194 HV to 403 HV which is above the recommended minimum value 150 HV. The study therefore, concludes that the proportion of chemical composition influenced the properties of ribbed mild steel bars. However, it is recommended to producers to control chemical composition contents especially the carbon, magnesium, Sulphur etc., during the production process and maintain its content in the range of the standards.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

This chapter comprises the background of the study, statement of the problem, scope of the study, the significance of the study, the aim of the study, objectives of the study, research questions, limitation of the study and organization of the thesis.

1.2 Background of the study

Kankam and Adom-Asamoah (2002) noted that, the reinforcing low-carbon steel bars used in Ghana are milled from re-cycled scrap ferrous metals by the local producers and the imported rods which are produced from iron ores. In Ghana, steels are used for fabricating burglar proofs for windows and doors and super structures for overhead water reservoirs.

There has been increasing incidents of collapse of reinforced concrete buildings in Ghana. They observed that in Ghana, reinforced concrete (RC) buildings with low-carbon steel constitute about 95% of the building stock in the urban centers.

A study by Alabi and Onyeji (2010) stated that steel is a crystalline alloy of iron, carbon and other elements, which hardens when quenched over its critical temperature. It contains no slag and may be cast, rolled or forged. Carbon is the most important constituent because of its ability to increase the hardness and strength of the steel. More mass of steel is used than all other metals combined in structural applications. Steel can be classified according to the alloying elements. Attributes of reinforcements such as bond with concrete, strength, ductility and resistance against corrosion are important for engineering of sound and durable reinforced concrete (RC) structures.

According to Rolf (2006) low carbon steel is one of the most common types of steel used for general purposes because it is often less expensive than other types of steel. Since it has a low amount of carbon, it is more malleable than other kinds of steels. As a result, it can be rolled thin into products of many shapes.

American Iron and Steel Institute (2002) stated that steel is the backbone of bridges, the skeleton of skyscrapers, the framework for automobiles, the stronger and the more durable frame in building construction.

Ayinuola and Olalusi (2004) identified factors contributing to building failure as including the use of substandard materials and engagement of quacks rather than professional by clients in an attempt to cut down the construction cost.

According to Daodu and Raji (2005) a structure is usually designed to ensure that it does not fail prematurely, whether it is a collapse or service failure. Unfortunately, cases of premature structural failure abound. In Ghana, reported cases of structural failure have recently become frequent, especially for buildings. Several researchers have investigated into the causes of building collapse. One of the most frequently adduced causes is the non-conformance of structural properties of materials used in the actual construction to the properties of materials specified for it. Examples can be found in several research works; Kankam and Adom- Asamoah (2002) took the study to another dimension when they worked on the strength and ductility characteristics of reinforcing steel milled from scrap metals. Their physical and chemical properties were examined and found that the characteristic tensile strength is too high with very little elongation leading to limited ductility compared with standard mild and high yield steel. Ndiaye et al. (2009) working in the same direction investigated the properties of Senegalese steel milled from scrap metals and established that they exhibit poor welding and bending abilities. Chukwudi and Onyeka (2010) examined the role of poor-quality steel rods in building failures in Nigeria but concentrated on a sample size (16mm diameter bars only) obtained from one company. Alabi and Onyeji (2010) working in the same line of thought with Ndiaye et al. (2009) however expanded the frontiers of the study when they examined the chemical and mechanical properties of steel bars from four indigenous companies (with scrap metals as main source of raw material) and a foreign firm.

Ayininuola and Olalusi (2004), when they established that the use of poor quality and substandard steel rods are among the causes of building failure, their use in construction works is specified by relevant codes BS 4449:2005+A2:2009.

Reinforcing steel bars help to resist compressive and tensile stresses in reinforced concrete members and the task of adopting any construction material for use in a project has not been an easy one for the professionals in the built environment. Many factors have to be considered before the final choice is made. The choices are based on strength, cost, accessibility, ease of erection, aesthetics, sustainability and environmental concerns (Ede et al., 2015). Of all these factors, safety remains the most fundamental because the loss of structural integrity could lead to structural failure and the consequent loss of lives, properties, investment and means of economic livelihood. Structural failure is initiated when the material is stressed to its strength limit, thus causing fracture or excessive deformations. The rate of reinforced concrete building and civil infrastructural failures in Nigeria is of great concern and as such demands urgent attention (Ede et al., 2015).

According to Ayininuola and Olalusi (2004), identified factors contributing to building failure as including the use of substandard materials and engagement of quacks rather than professional by clients in an attempt to cut down the construction cost. Ede et al. (2015) analyzed historical data on building collapses within the last 3 decades to identify the trend and the common features of structural collapses in Nigeria. Data on behavior of professionals and the craftsmen were also analyzed to identify how they operate in the sector and how their actions contribute positively or negatively to the collapses.

A study by Abioye and Billihaminu (2016) identified reinforcement as a method of increasing the strength properties of reinforced concrete structural members. Steel rods of different diameters have also been prescribed for use in reinforcing our concrete which up till today has been in use. However, for any reinforcing steel rod to be adequate for its action as reinforcing material, it should satisfy basic characteristics such as yield strength, ultimate strength, percentage elongation and actual diameter. Steel rods are used every day in different construction sites in cites but their suitability is still not confirmed.

The three most popular hardness methods are: Brinell hardness test, Rockwell hardness test and Vickers hardness test (Low and Fink, 2006). Vickers hardness test will be employed for the purpose of this research work, other strength characteristics of ribbed reinforcement mild steel bar such as tensile strength and chemical composition will be investigated in the study.

1.3 Statement of the Problem

There is increase in the population of human settlement globally, hence infrastructural development is also in high demand. This has resulted in high demand of building materials such as cement, aggregate ribbed mild steel bars and ribbed high yield bars. Building materials exhibit different properties when incorporated in the design, ribbed mild steel bars and high yield steel bars are the most widely used material in the construction industry to resist tension in concrete. Therefore, the knowledge and properties of ribbed mild steel bars as potential building materials produced by different companies cannot be compromised since standardization plays major role in selecting appropriate material for construction purposes.

The manufacturing process of ribbed mild steel bars in Ghana largely relies on recycling of scrap metal as a charging material. According to Smith and Hashemi (2006) when iron is smelted from its ore, it contains less carbon than is desirable, to become a steel, it must be reprocessed to increse carbon to the correct amount, at which point other elements such as manganese, phosphorus, silicon etc. can be added. Furthermore, research has shown that due to variation in scrap feeds and impurities present in scraps, the strength properties may vary and contribute to decline in standard ribbed mild steel bars. This affects the quality of the product and service life will be shortened and consequently economical loss will follow (Atsbeha, 2017).

From observation, practical experience and brain storming of large number of contractors and construction workers, it is understood that locally produced ribbed mild steel bars of different companies exhibit different properties while working with, such that some are broken easily, whiles some are bent easily and some are difficult to cut which indicate that the reinforcing bars produced by different companies show different properties which may not comply with standardization and this may affect the functional requirement of the finishing product resulting in collapse of most buildings. A study by Ayininuola and Olalusi (2004), revealed that the use of poor quality and substandard steel bars are among the causes of building failure in the environment. Ayodele (2009) examined the role of reinforcement in the collapse of buildings in Nigeria. The study revealed that the physical, chemical, and mechanical properties of different ribbed mild steel bars produce from different companies were different from one another and the properties of some ribbed mild steel bars did not meet the acceptable standard.

The following studies have explored the properties of reinforcing bars; Alabi and Onyeji, (2010) carried out a comparative assessment of the chemical and mechanical properties of locally produced reinforcing steel bars for structural purposes from four indigenous steel industries that use scraps as their major raw materials. Kareem (2009) worked on the tensile and chemical analysis of selected steel bars produced in Nigeria. Ejeh and Jibrin (2012) examined the tensile behavior of reinforcing steel bars used in the Nigeria construction Industry with a view to ascertaining the level of conformity with relevant standards. Dzogbewu (2010) conducted metallurgical studies of locally produced and imported low carbon steel bars on the Ghanaian market. Arum (2008) investigated the mechanical properties of 12mm steel bars from some parts of Nigeria.

Dzogbewu and Arthur (2013) carried out comparative studies of locally produced and imported low-carbon steels on the Ghanaian Market with two different batches of samples (rebars) from local and foreign producers. The drawback of their studies is that the test samples were limited to 12mm bars only, and no quality comparison among producers of ribbed mild steel bars with standards. There is dearth to research in this area and hence is the focus of this study. There is need for adequate information on the actual behavior of most ribbed mild steel rods used in structural concrete for the construction of all types of buildings, bridges, hydraulic structures, etc. in Ghana. Therefore, this research is aimed at analyzing strength properties of 12mm 16mm and 20mm ribbed mild steel bars produced from recycled scraps by some steel industries in Ghana and to ascertain their conformity with standards such as; Ghana Standard Authority, British Standard, and American Society for Testing and Materials (ASTM) and also to determine their suitability for structural purpose.

1.4 Aim of the Study

The research aims at investigating the strength properties of different diameters of ribbed mild steel bars produced by local companies in Ghana.

1.5 Specific Objectives to the Study

The specific objectives of the study are to:

1. Determine the tensile strength of ribbed mild steel bars produced by local companies in Ghana.
2. Examine the chemical compositions of ribbed mild steel bars produced by local companies in Ghana.
3. Determine the hardness of ribbed mild steel bars produced by local companies in Ghana

1.6 Research Questions

The specific questions the study sought to enquire are:

1. What are the tensile strengths of ribbed mild steel bars produced by local companies?
2. What are the chemical compositions of ribbed mild steel bars produced by local companies?
3. What is the hardness of ribbed mild steel bars produced by local companies?

1.7 Scope of the Study

The study focused on experimental investigation on strength properties of the 12, 16 and 20mm diameters of ribbed mild steel bars produced by local companies because ribbed mild steel bars are used every day in different construction sites in Ghana but their conformity and suitability to standards are still not confirmed. This prompted the researcher in selecting samples of 12mm 16mm and 20mm mild steel bars which are the most used steel sizes in construction for strength properties analysis.

Geographically, the experiments were conducted in the construction laboratory, at the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAM-USTED), material laboratory at the Kwame Nkrumah University of Science and Technology (KNUST) in the Ashanti Region and Tema steel company limited in Greater Accra Region of Ghana.

1.8 Significance of the Study

- The findings of the study provide information to the rolling mills, statutory bodies and end users of ribbed mild steel bars about the strength properties of ribbed mild steel bars and provide alternative ways of improving on the quality of the bars made from scraps.

- The findings of the study contribute to body of knowledge by revealing the potential properties of locally produced ribbed mild steel bars that meet the acceptable performance and international standard to create sustainable construction material in the construction industry.

- The findings of the study also promote the use of locally produced ribbed mild steel bars, which will reduce the high demand of foreign reinforcing steel bars for construction purposes in the country.

1.9 Limitation of the study

Almost every research work encounters challenges in one way or the other and this study is not an exception. This particular study should have been conducted in all steel production companies in the country to ascertain their conformity and standardization of their products but the study was limited to only three. The diameters (sizes) of ribbed mild steel bar should have included all the sizes produced by the steel production companies but the study was limited to only three due to time limitation and financial constraints. Again, samples for the study should have been taken directly from the batches of productions but due to the slow cooling rate and restrictions from producers at the rolling mills that could not happen. Moreover, access to information by the production companies delayed and made it difficult to acquire all relevant information that could have helped to better enhance this study.

1.10 Organization of the thesis

This thesis is organized into six (6) chapters. Chapter one (1) comprises background of the study, statement of the problem, scope of the study, significance of the study, aim of the study, objectives of the study, research questions, limitation of the study and organization of the study. Chapter two (2) comprises comprehensive literature review on the topic under discussion. Chapter three (3) describes the methodology that was used in this research, which focused on experimental investigation on properties of locally produced ribbed mild steel bars in Ghana. Chapter four (4) comprises results from laboratory tests. Chapter fives (5) comprises data analysis, presentation and discussions of test results. Finally, chapter six (6) being the final chapter summarizes the findings, conclusions and recommendations of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Steel has a large field of application ranging from small appliances to big construction industries. Most steels have a crystalline structure and consist of a basic iron-carbon system. Relatively small changes in the carbon content or other alloys result in significant changes in the mechanical behavior of the resultant steel. The mechanical properties of steel that are of interest to the design engineer are the stress –strain curve; the yield strength; the amount of strain at yield, the percentage elongation at failure, or ductility; and the ultimate tensile strength (Ponle et al., 2014). While the mechanical behavior of a particular steel is significantly influenced by its carbon content, other factors that influence its properties are chemical composition and the method applied to shape the billet into the final form as steel bar (Ponle et al., 2014).

Depending upon the carbon content, the steel is designated as low-carbon steel (carbon content 0.10-0.25%), medium- carbon steel (carbon content 0.25-0.60%) and high carbon steel (carbon content 0.60-1.10%). Structural steels normally have a carbon content less than 0.25%. Increasing carbon content increases the hardness, yield and tensile strength of the steel. However, it decreases the ductility and toughness (Ponle et al., 2014). There are also other properties of plain carbon steel that need to be considered and these properties are illustrated as shown in Table 2.1 which indicate Poisson's ratio.

Table 2. 1: Properties of plain carbon steel (Shackelford et al., 2016)

Material	Density $10^3 kgm^3$	Thermal conductivity $Jm^{-1}k^{-1}s^{-1}$	Thermal expansion $10^{-6}k^{-1}$	Young's modulus GNm^{-2}	Tensile strength MNm^{-2}	% Elongation
0.2%C Steel	7.86	50	11.7	210	350	30
o.4%C steel	7.85	48	11.3	210	600	20
0.8%C steel	7.84	46	10.8	210	800	89

Mechanical properties of steel are significantly influenced by the content of its chemical composition; carbon, manganese, phosphorus, Sulphur, silicon, nickel etc. and the method used to shape the ingot into the final form such as cooling rate, annealing, shaping operation etc.

Carbon is the most important element that governs the mechanical properties of steel and most heat treatments of steel are based primarily on controlling the distribution of carbon. Low and medium carbon steels are used extensively for construction of buildings, in most cases as reinforcing bars in concrete. Previous research has been conducted to provide detailed information on the strength and ductility properties of reinforcing bars that are manufactured from scrap metals in developing countries. Typical examples are the cases of Ghana and Nigeria (Kankam & Adom-Asamoah 2002; Balogun et al., 2009)

2.2 Methods of producing concrete reinforcing steel bar

Generally, the methods of producing high quality reinforcing steel bars can be classified into three (3) distinct categories (Hager et al., 2021)

- Reinforcing steel bars produced by micro alloying technique. For these bars, the yield strength can be increased by modifying the chemical composition. These are generally ribbed bars.
- Reinforcing twisted bars subjected to strain hardening after hot-rolling, for instance by cold deformation. This method enables the production of high strength weldable reinforcing bars from low carbon and manganese steels, but it leads to a decrease of ductility and stress-strain diagram with no yield plateau.
- Reinforcing steel bars produced by Thermo-Mechanical Treatment (TMT) technique commonly known as Self Tempered steel bars. These are generally ribbed bars.

Reinforcing steel bars are used for reinforcement of concrete structures, manufacture of anchor bolts, etc. Reinforcing bars (rebars) can be either smooth or deformed. They are produced by hot rolling process with subsequent superficial hardening by heat treatment.

Production of steel is preceded by production of iron through the blast furnace process (Yimer, 2020). The iron produced is then further processed in a steel making furnace to make the steel for the desired product. In a typical process, iron ore, coke and flux (limestone, silica and dolomite) are charged into the top of a large refractory lined fabricated-steel furnace. The common steel making furnaces are: Basic Oxygen Steel making (BOS) and the Electric-Arc Furnace (EAF). In the BOS process, molten iron is first produced by smelting iron ore in a blast furnace. This pig iron is then transferred to a steel making vessel called converter. Some scrap steel up to 30% of the charge may be added. Reinforcing bars are made by rolling steel billets from mills or ingot from scrap metals. The EAF process normally uses 100% scrap metal as the raw process (Yimer, 2020).

Scrap metal is charged into the furnace and heat is applied by means of electrical discharge from carbon electrodes, thus melting the scrap. Table 2.2 shows the typical chemical composition found in a reinforcing steel bar. Reinforcing bars are made by rolling steel billet from mills or ingot from scrap metals.

The rolling processes of steel billet in Figure 2.1 consists of three stages, the first stage is the quenching of surface layer of rebars with water to form martensite on the surface, the core re-maining austenitic. In the second stage, the rebar leaves the cooling zone, the temperature gradient stablished in its cross-section causes heat to flow from center to the surface. The martensite is tempered by the heat left in the core at the end of the quenching stage. The third stage is the isothermal transformation of the remaining austenite in the cooling bed to ferrite and pearlite.

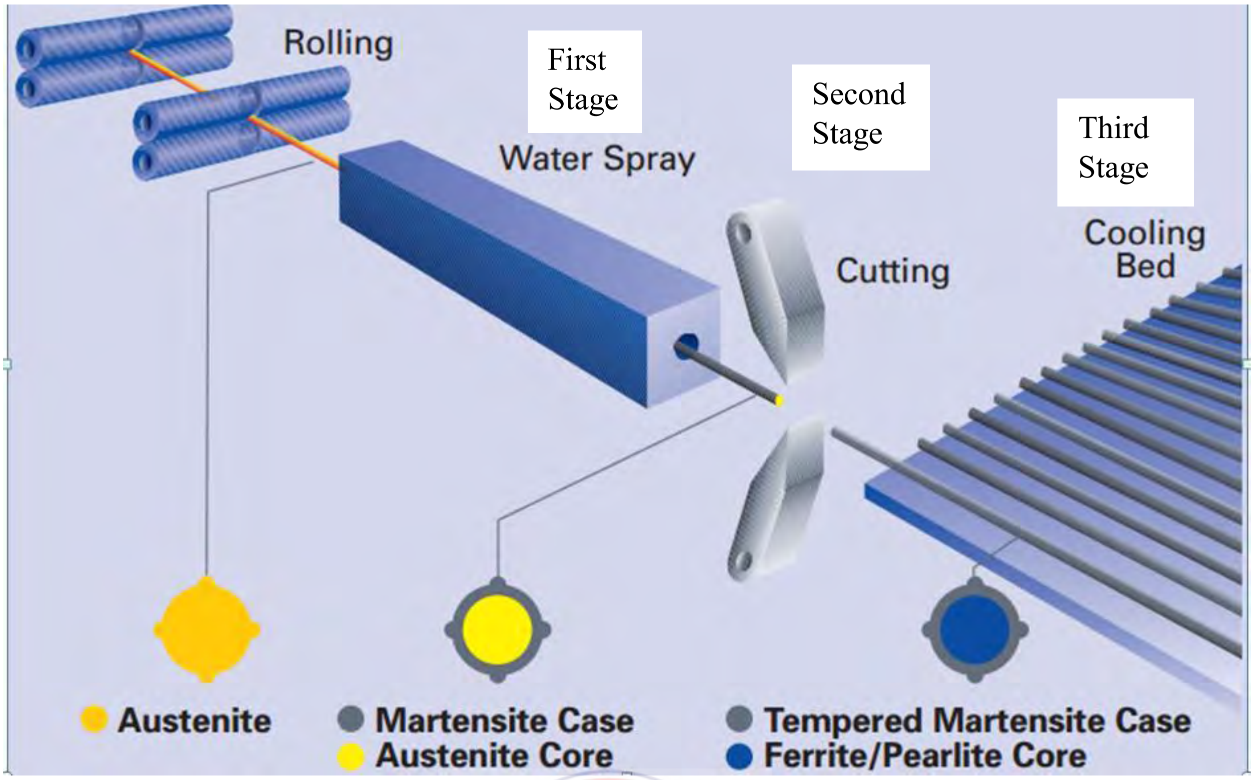


Figure 2. 1: Steel billets reinforcing bar rolling processes (Modi et al., 2014)

Table 2. 2: Typical chemical compositions (% weight) found in a reinforcing steel bar (The CARES Guide to Reinforcing Steels, 2011)

Manufacturing Process	Fe	C	Mn	Si	S	P	Cu	Ni	Cr	Mo	Sn	N
Basic Oxygen Steel making (BOS)	98.69	0.20	0.80	0.15	0.01	0.05	0.03	0.02	0.02	0.01	0.01	0.006
Electric-Arc Furnace (EAF)	98.27	0.20	0.80	0.15	0.15	0.03	0.02	0.15	0.15	0.05	0.025	0.010

Stresses in the reinforcing steel are caused by the loads on the structure. The most common types of reinforcing steel are in the form of bars. These are commonly classified according to the methods of production (hot rolled or cold worked), surface characteristics (plain or deformed), strength grade (medium-tensile strength or high-tensile strength), or weldability.

The most common types of reinforcing steel are in the form of bars. These are commonly classified according to the methods of production (strength grade, surface characteristics, weldability etc.) and commercial name and structure. Figure 2.2 shows the general classification of various metal alloys based on the production from which the reinforcing bars are found in the category of low alloy steel, low-carbon and high strength (Guo et al., 2013) and Figure 2.3 classify ferrous alloys by commercial name and structure (Islam & Rashed, 2019).

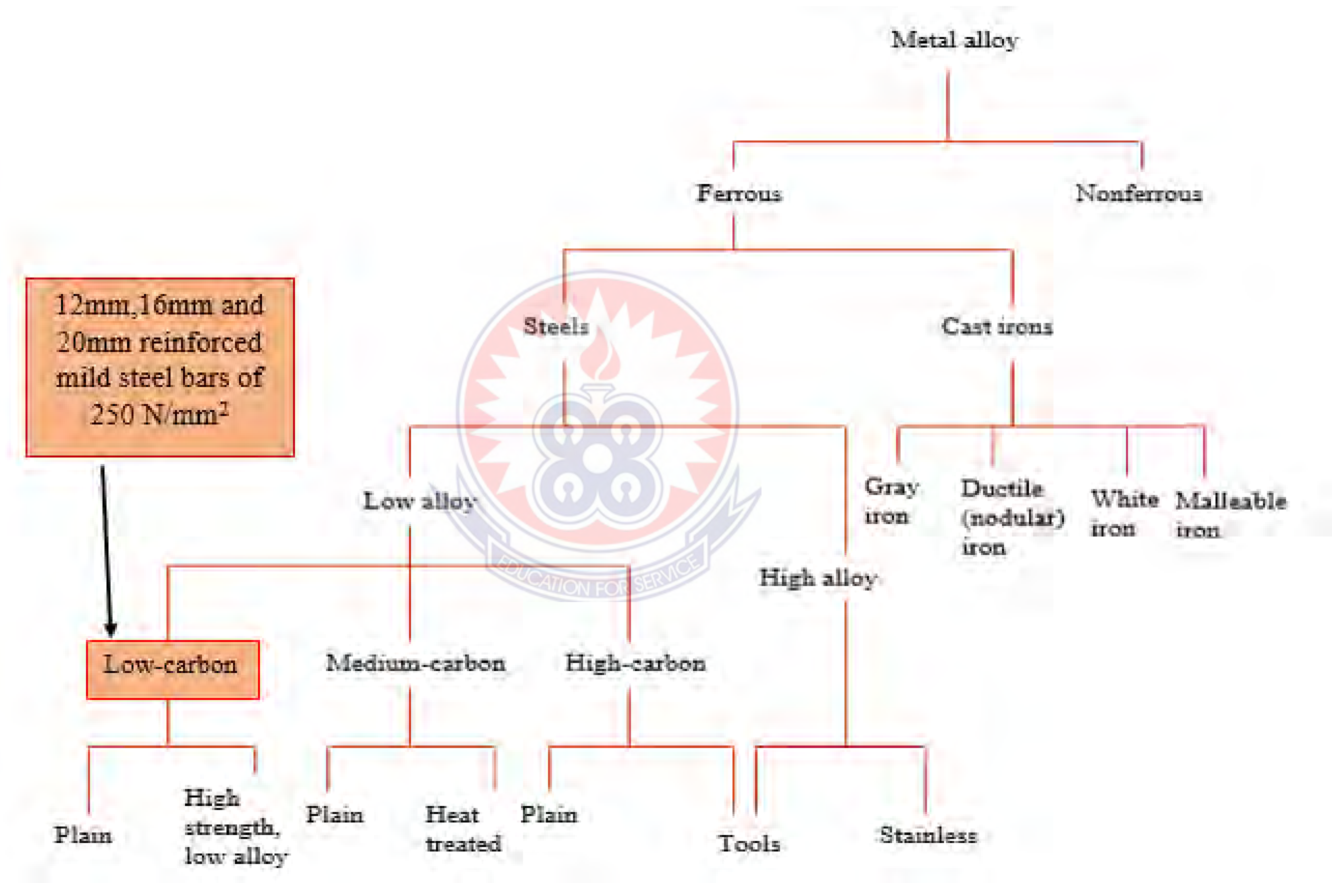


Figure 2. 2: General classification of various metal alloys (Guo et al., 2013).

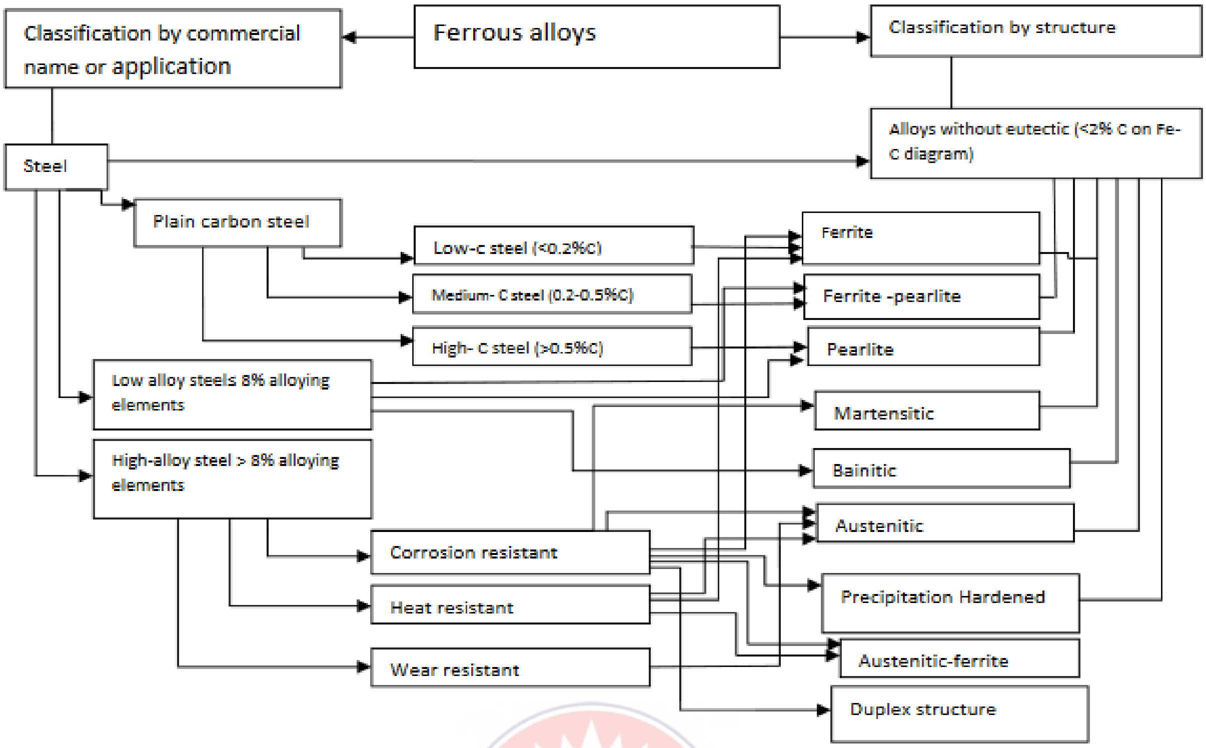


Figure 2. 3: Classification of ferrous alloys by commercial name and structure (Islam & Rashed, 2019)

2.3 Concrete Reinforcing steel bar made from scraps

The production of reinforcing steel bars from scrap metals has raised interest of researchers, who tried to classify the scrap metal commonly used in three categories (home scrap, process scrap and obsolete scrap) according to the place of generation, chemical composition or physical properties (Taszner et al., 2008). Obsolete scrap causes the biggest trouble for steel maker, because its recovery is difficult, and this type of scrap is often mixed or coated with other materials such as copper, glass, plastic, zinc, tin etc. The chemical composition of obsolete scrap fluctuates widely depending on its origin and can affect the mechanical properties of the reinforcing bars.

The bar production process consists of collecting scrap metals as shown in Figure 2.4, sorting them, melting in furnace, mixing with ingredients (additives) and casting the molten metal into molds for making the billet. After the billets solidify, the molds are stripped. Before rolling of each stock, the billet is placed in a soaking pit for heating to ensure that the entire cross section is uniform. The rolled bar is normally cooled in air. To increase the strength of the bar, cold working by twisting is performed and finally the bar is inspected and stored (Taszner et al., 2008).

Figure 2. 4: Collected scrap used for rebar production in Ghana

2.4 Production of ribbed mild steel bars from scraps

The first stage of the production is the segregation of the scrap. The selection of the scrap basically depends on the type of steel which would be produced. For a high carbon steel scraps from engine part are selected while for a low carbon steel scrap from automobile body parts are mainly selected. The scraps are sent to the balling press for compacting so that the bucket can contain a larger volume. After the segregation the bucket is filled and the overhead crane would convey the segregated scrap in the bucket to the Electric Arc Furnace. The roof of the furnace is removed and the bottom of the bucket is open and the scrap drops into the furnace. During the charging of the furnace lime is introduced to prevent early slaging, including oxygen for the oxidation process. The scrap is melted and at a temperature of 1500 ^{O}C the first slag (the scavenger slag) is removed to take away phosphorus, sulfur and other impurities. As the oxidation process continues more of the impurities are moved to the surface of the slag. The furnace is tilted at an angle of 15^{O} and another slag is removed. At a temperature of about 1560 ^{O}C the molten metal should be cleared of slag three times. When the molten metal composition is tested and it agrees with the kind of steel desired to be produced the temperature is raised to the taping temperature of 1640^{O}C Some slag is left at the top of the molten metal in the ladle to minimize temperature loss and the overhead crane is used to transport the ladle to the Ladle Refinery furnace, where the molten metal chemistry is fine-tuned by adding manganese. Nitrogen is then introduced into the molten metal to bring out any non-metallic inclusion to the surface of the molten metal. The molten metal is conveyed to the continuous casting machine before the cast the metal under goes thermo metallurgical treatment (TMT). Thermo metallurgical treatment is the quenching of molten metal as it passes through the casting machined to make it solidified. The molten metal is cast into billet. The billet is preheated and passed through a series of rollers depending on the dimension and surface texture desired (production unit at Tema Steel Company).

2.5 Types of Companies that produce ribbed mild steel bars in Ghana

2.5.1 Ferro Fabrik Limited

"Ferro Fabrik Limited is an 1SO 9001:2015 certified company and one of Ghana's biggest manufactures of steel bars and steel products that champions worker rights as an integral part of its management strategy. It was established to support accelerating growth in Ghana by making the country self-reliant for steel bars and eliminating its dependence on imported steel bars.

FFL core purpose is to maintain the highest standards of manufacturing Finest Quality of steel bars in Ghana. The Company has achieved success on the backdrop of strong Administration, technology, Manufacturing, Supply Chain & Marketing.

FFL is fully committed to assure international quality standards and continues to meet and exceed the customer expectations. The highly qualified management team is constantly upgrading its operating standards to meet ever changing requirements of this industry. Mild Steel is the most affordable form of steel reinforcement specially designed to withstand loads not extending to high-rise buildings. This product is specially designed to provide extensive bendability. These bars are available in 9-meter lengths (30ft) thereby reducing wastages to minimum. It is plain low carbon steel without any alloying elements. It is very ductile and is used as a structural steel for ordinary applications in civil construction. High Tensile Rebar is available from the company in a number of standard rebar sizes in straight lengths. This product is a standard reinforcing steel bar that is used as a tension element in concrete structures to strengthen and hold the concrete together. It is incredibly versatile and very long lasting. By being cast into structures, it effectively counteracts the poor tensile strength of concrete. It is able to be cut to desired size and welded into position. It is for high rise buildings, bridges, Industrial drainages, dams, etc." (Ferro Fabrik Limited, 2021).

2.5.2 B5 Plus Limited.

"B5 Plus Ghana Company Ltd is West African, manufacturing, fabricating, and trading enterprise with the vision to become the world's steel industry benchmark through the excellence of its people, its innovative approach and overall Conduct. With corporate headquarters in Tema Ghana, today the company operates in all the ECOWAS Countries. The company have a significant presence in African steel as an integrated manufacturer of steel and finished steel products. The principal product is steel products which come in seven major categories: Mild Steel, High Tensile and steel bars, Galvanized Products, Stainless Steel, Marine and Mining, Roofing sheets and Nails and Concrete and Fencing. As a producer and a supplier, the company is accessible business partner who ensure quality and security of supply. The company values strong relationships with our customers and believe that commercial relationships are a learnt skill. The integrated supply chain helps the company to ensure high standard of product quality. This reduces the potential need for rework, increases reliability of service and saves the customers time and money. The key to the company success is the ability to deliver upon promises and the skills in responding to the needs of the customers. The strong facilities and market positions allow the company to tailor offers the service to all customers from the smallest to largest." (B5 Plus Limited, 2021)

2.5.3 Fabri Metal Ghana Limited

"Fabri Metal Ghana Ltd is located in Tema, Ghana. The company is working in Steel Products business activities. MMD is a privately-owned company with deep historical and entrepreneurial roots in Africa. It was formed in 2006, MMD is the leading manufacturer of TMT rebars, high-quality thermo mechanically-treated steel reinforcement bars, and merchant bars used to construct residential, commercial, industrial, and civil structures.

Fabrimetal Ghana is part of group MMD (Mohan Manji Dhrolia). MMD has facilities in other parts of Africa. Rwanda, Senegal, Burkina Faso, Angola, DR Congo.

Mohan Manji Dhrolia (MMD) is the founder of the company. His humble beginnings date back to 1961 when he moved to Zaire, Africa, from a small village in India, with a simple dream to build a better Life for his family. His strong work ethics, values and philosophies would become the driving force behind how the family approached life and work. Mr. Dhrolia successfully ventured into the world of commodity trading. His retirement in the mid-1970s paved the way for the family to explore other business ventures including property development, hospitality and then steel manufacturing in Ethiopia in 2005. This was the family's first venture into the steel industry equipped with knowledge and a vision to procure raw materials, localize the commodity and support the native economy.

MMD contributes to the country's rapidly developing infrastructure by eliminating a dependence on imported rebars and merchant bars. Using strategic processes, proven systems, precision tools, and an eager workforce" **(**Fabri Metal Ghana Limited, 2021).

2.5.4 Sentuo Steel Limited

"Sentuo Steel Limited is a Chinese Steel manufacturing company in Ghana, it is located in Tema Plot No. IND/A60/1, Heavy Industrial Area. Sentuo Steel Limited has operated in the Ghanaian market for the past four years after taking over the 300,000-capacity Wahome Steel factory in Tema, 38 km east of the capital. In the face of scarcity of raw materials for the manufacture of iron rods in Ghana, the Managing Director expressed confidence in importing cheaper raw materials.

Sentuo Steel, explained to journalists touring the factory one day, that the importation of steel coils to be straightened and sold as iron rods was one of the major challenges confronting the steel companies. There is a law to that effect, banning the export of ferrous scraps. The ferrous Scrap that the steel Companies use in manufacturing steel bars are supposed to be banned legally. But there have been instances of illegal exports of scraps, some of which have been intercepted by customs at the ports" (Sentuo Steel Limited, 2021).

2.5.5 Rider Steel Company Limited

"In 2012 Rider Steel set up its second production unit in Tema, Ghana to produce and distribute steel products for West Africa and beyond. Rider steel Industry is a privately held global corporation based in Qingdao, China. The business employs over 3,000 workers and operate throughout Europe, Middle East and Africa. Rider Industries is organized into two main business unit: Glass and Steel Production.

Rider Steel is actively engaged in manufacturing of steel for residential and commercial construction industry in West Africa. Rider Steel products include all sizes of high tensile and mils steel from 8mm to 25mm, angle iron and channel beams of different sizes" (Rider Steel Company Limited, 2021).

2.5.6 Sethi Brothers Company Limited

"Sethi Brothers are pioneers in the steel trade and manufacture industry in Ghana. Since the establishment of the company in 1992, It has persistently expanded its market share through the sales of quality steel products and outstanding services.

Sethi Brothers has four decades of trading experience in the steel trade industry. It has operations in Togo and Ghana, with the head office situated in Tema (Steel Works Road Heavy Industrial Area). Sethi Brothers is known for their quality products and exceptional Customer service. Years of dedicated service in the field has seen it expand from retail and wholesale into Manufacturing (Steelco and Sethi Manufacturing) and Real estate development (Sethi Realty) with branches throughout the country of operations. Sethi Brothers are committed to produce correct sizes, correct prices and correct quantities for its clients" (Sethi Brothers Company Limited, 2021).

2.6 Uses of ribbed mild steel bars in Ghana

Ribbed mild steel bars are one of the most common constructional materials in Ghana which are used to increase the tensile strength and compressive strength of concrete. It comes in various diameters and lengths ranging from 6mm to 32mm and 30 feet to 40 feet respectively. The surfaces are provided with ribs or lugs to provide a better bond with concrete as illustrated in Table 2.3.

Table 2. 3: Diameters of ribbed mild steel bars produced by companies in Ghana and their uses.

Uses of ribbed mild steel bars in Ghana		
Diameter	**Surface texture**	**Uses**
6mm	ribbed	Gate design and stirrupts
8mm	ribbed	Stirrups and links
10mm	ribbed	Window design (Burglar proofing), reinforced concrete slab, stirrups
10.5mm	ribbed	Window design (Burglar proofing), floor, mat (stirrups)
11.5	ribbed	Window design (Burglar proofing), reinforced concrete slab,
12mm	ribbed	Window design (Burglar proofing), reinforced concrete slab,
14mm	ribbed	Beam, Column of multi-storey building, bridges
16mm	ribbed	Beam, Column of multi-storey building, bridges
18mm	ribbed	Beam, Column of multi-storey building
20mm	ribbed	Beam, Column of multi-storey building bridges
25mm	ribbed	Multi-storey building (heavy duty), bridges
32mm	ribbed	Story building (heavy duty), bridges

2.7 Major factors influencing mechanical properties of concrete reinforcing bar

2.7.1 Composition of alloying elements of concrete reinforcing bar

Chemical composition variations in producing reinforcing steel bars are unavoidable. Table 2.4 gives the list of chemical ingredients that influence the property of steel rebars (Munyazikwiye, 2013). The alloying elements in steel have effect on the mechanical properties of steel. Shunichi and Morifumi (2013) investigated the effects of micro alloying elements on mechanical properties of reinforcing bars and found that with 0.05% Nb and 0.05 % V addition to 0.25 C 0.5Si 1.2Mn steel (% weight) led to an effective increase in strength. It has been established that with the increase of pearlite phase, tensile strength of steel increases while elongation property, i.e. ductility reduces. The maximum tensile strength is attained at about 100% pearlite phase but the ductility will then be near zero, i.e., the steel would be brittle. Thus, the mechanical properties of steel are related to the carbon content. It has been shown that the hardening capacity of steel depends mainly on its carbon content and to a lesser extent on its content of alloying elements and the grain size of austenite grains .To have a reinforcing steel bar of desirable properties, the carbon content is controlled and is usually found to lie in a narrow range of 0.15% to 0.25%.An index called Carbon equivalent (CE) has been established to convert the amount of these alloying elements into the equivalent percentage of carbon (Abir & Islam, 2014) . Thus, the alloying elements have effect on the mechanical properties of steels. For instance, high –strength steels tend to have a high carbon equivalent. Table 2.4 shows the elements commonly used in manufacture of steels and their effects on the properties of the steel.

Table 2. 4: Effect of alloying elements on the properties of steels (Munyazikwiye, 2013)

Elements	Effect
Carbon(C)	Increases hardness and tensile strength but reduces ductility
Manga-nese(Mn)	Improves hardenablity, ductility and wear resistance. MN eliminate for-mation of harmful iron sulphides, increasing strength at high temperature
Nickel(Ni)	Increases strength, impact strength, toughness, impart corrosion resistance in combination with other elements
Chromium(Cr)	Improves hardenablity, strength and wear resistance, sharply increases corro-sion resistance at high temperature (>12%)
Tungsten(W)	Increases hardness particularly at elevated temperature due to stable carbides, refine grain size
Vanadium(V)	Increases strength, hardness and creep resistance, impact resistance due to formation of hard vanadium carbides limits grain size.
Molyb-denum(Mo)	Increases hardenability and strength particularly at elevated temperature and under dynamic conditions.
Silicon(Si)	Improves strength, elasticity, acid resistance and promotes larger grain size, which causes increasing magnetic permeability
Titanium(Ti)	Improves strength and corrosion resistance limit austenite grain size
Zirconium(Zr)	Increases strength and limit grain size
Boron(Bo)	Highly effective hardenablity agent; improves deformability &machinability
Copper(Cu)	enhances corrosion resistance
Aluminum(A)	Deoxidizer, limit austenite grain size

2.7.2 Carbon equivalence value

The carbon equivalent may be calculated by equation used in most American Society of Mechanical Engineers (ASME) applications shown in equation 2.1. It Increase hardness, tensile strength and weldability of the steel. Carbon is the most important contributor to the hardness and strength of ferrous steels. High carbon content can result in high local hardness. However, other alloying elements also contribute to the overall hardenability of the steel. This effect can be quantified by the determination of the carbon equivalence (CE) of the steel. It is important that any CE determination be calculated using the actual chemical analysis. A major factor in weldability is the carbon equivalent, CEV, of the chemical components in steel. The smaller this value, the better is the weldability of steel.

$$CE = C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Ni+Cu}{15} \qquad \text{……………………Eq. 2.1}$$

In general, the strength of steel increases as the hardenability and the composition related carbon equivalent values increase.

2.7.3 Effect of alloying elements on the mechanical properties of reinforcing steel bar

The alloying elements in steel have been proved to have effect on the mechanical properties of steel. Shunichi and Morifumi (2006) investigated the effects of micro alloying elements on mechanical properties of reinforcing bars and found that with 0.05% Nb and 0.05 % V addition to 0.25 C- 0.5 Si -1.2 Mn steel (% weight) led to an effective increase in strength.

Weiguo et al. (2003) carried a research on production of high strength hot rolled ribbed steel bar BS G460 and found that vanadium addition results in a bar with stable mechanical properties and good uniformity. With increasing carbon content from near 0%, the ferrite phase decreases with a corresponding increase in pearlite phase and about 0.8% carbon, there would be pearlite phase alone. It has been established that with the increase of pearlite phase, tensile strength of steel increases while elongation property, i.e., ductility reduces. The maximum tensile strength is attained at about 100% pearlite phase but the ductility will then be near zero, i.e., the steel would be brittle. Thus, the mechanical properties of steel are related to the carbon content (The Care Guide to Reinforcing Steels, 2008). It has been shown that the hardening capacity of a steel depends mainly on its carbon content and to a lesser extent on its content of alloying elements and the grain size of austenite grains (George, 2007). To have a reinforcing steel bar of desirable properties, the carbon content is controlled and is usually found to lie in a narrow range of 0.15% to 0.25%. The low carbon level is chosen for preventing embrittlement of the bar during strain hardening and the development of undesirable microstructure in the heat-affected zone of such bar during welding (Balogun et al., 2009). However, alloying elements used in the manufacture of steel modify the phase diagram so that the point at which the maximum pearlite phase forms is at a different percentage of carbon. An index called Carbon Equivalent (CE) has been established to convert the amount of these alloying elements into the equivalent percentage of carbon. The alloying elements have effect on the mechanical properties of steels. Table 2.4 shows the elements commonly used in manufacture of steels in general and their effects on the properties of the steel. These include: Manganese (Mn), Silicon (Si), Copper (Cu), Nickel (Ni), Chromium (Cr), Molybdenum (Mo), Vanadium (V), Columbium (Co), Titanium (Ti) and Zirconium (Zi) (Kopeliovich, 2009).

The alloying elements, which increase hardenability, include Carbon (C), Manganese (Mn), Molybdenum (Mo), Chromium (Cr), Silicon (Si) and Nickel (Ni). The BS 4449 international specification limits the Carbon Equivalent (CE) value and Carbon content to 0.51% and 0.25% respectively. The formula used to calculate Carbon Equivalent (CE) in equation 1.

The reinforcing steel bar is considered to be weldable without preheating, if CE is less than 0.51% otherwise the bar is non-weldable BS 4449:2005+A2:2009.

2.7.4 Standard specification of reinforcing steel bars

The common type of reinforcing steel is in the form of bars/wires. These are classified according to the methods of production (hot rolled or cold worked), surface characteristics (plain or deformed), strength grade and weldability. Hot rolled bars are normally deformed with ribs at the surface. Cold worked bars are square twisted. The International Standards Organization ISO 6935-2:2007(E) has defined the required standards for the reinforcing bars used in concrete.

Table 2.5 shows the dimensions, mass/unit length and permissible deviations for different bar sizes, twisted and ribbed bars (ISO 6935-2:2007). The ISO 6935-2:2007(E) and BS 4449:2005+A2:2009 have specified the standards requirement for yield strength for most of the reinforcing bars. The minimum yield strength is 460MPa (BS4449:1997), 500MPa (BS4449:2005) for high tensile deformed bars and 250MPa (BS4449:1997) for mild steel round bars. The tensile strength should exceed the yield strength by 10 to 15% and the minimum % Elongation should be 14% for Grade 460-500 and 22% for Grade 250.

Table 2. 5: Dimensions and mass/unit length of reinforcing steel bars (ISO 6935-2:2007)

Nominal diameter d(mm)	Nominal cross-section A(mm^2)	Mass/ unit length (kg/m)	
		Requirement	Permissible deviation %
6	28.3	0.222	±8
8	50.3	0.395	±8
10	78.5	0.617	±6
12	113	0.888	±6
14	154	1.210	±5
16	201	1.580	±5
20	314	2.470	±5
25	491	3.850	±4
28	616	4.840	±4
32	804	6.310	±4

2.8 Mechanical properties of rebar

Despite stiff competition from other materials, steel remains one of the most important engineering materials. Steel exhibits a wide range of mechanical characteristics of which the strength factor is the dominant property. Engineering strength is however, evaluated in terms of yield strength σy, ultimate tensile strength (UTS), modulus of elasticity (E), percentage elongation, impact strength, bending and hardness strength.

2.8.1 Tensile testing

The tensile test is known as a basic and universal engineering test to achieve material parameters such as ultimate tensile strength, yield strength, % elongation, % area of reduction, Fracture / Breaking Strength (BS) and Young's modulus. These important parameters obtained from the standard tensile testing are useful for the selection of engineering materials.

2.8.1.1 Dimensioning and preparation of tensile test specimen

Munyazikwiye (2010) investigated the characterization and variability of mechanical properties of reinforcing bars made from metal scraps. All bars were cut into length of 600mm each for the preparation of tensile test specimen. Ssempijja (2019) also conducted investigations into the mechanical performance of Ugandan made carbon steel bars with test pieces of length 300mm and obtained from the three steel producers by cutting using a hack saw, the test piece was prepared in accordance to BS 4449:2005. Dzogbewu (2010) researched on metallurgical studies of locally produced and imported low carbon steel rods on the Ghanaian market. The rods of length 40 cm (400mm) were cut into samples with a hacksaw very slowly to avoid heating up the samples due to friction. Arum (2008) worked on Verification of Properties of Concrete Reinforcement Bars in Nigerian for each diameter, the gauge length of which was made 5 times the diameter. That is 12mm rebars were cut to a given gauge length of 60mm, 16mm rebars were cut to a given guage length of 80mm and 20mm rebars had gauge length of 100mm. The gauge length of which was marked on each sample with the aid of ruler, scriber, hammer and center punch prior to testing. This study considered length of 500mm each for the preparation of tensile test specimen.

2.8.1.2 Description of Equipment

The equipment used for tensile testing ranges from simple devices to complicated controlled systems. The universal testing machines are commonly used, which are driven by mechanical screw relatively simple screw-driven machine using large two screws to apply the load whereas hydraulic testing machine using the pressure of oil in a piston for load supply. That type of machine can be used not only for tension, but also for compression tests. And it is linked to a computer-controlled system in which the load and extension data can be graphically displayed together with the calculations of stress and strain. The universal testing machine with model WAW-1000H as shown in Figure 3.1 was used to carry out the tensile strength test of the ribbed mild steel bars used in the study

2.8.1.3 Stress and strain relationship

Figure 2.5 shows that, when the stress is applied to the ribbed mild steel bar; the strain gradually increases represent point O to A which is called proportional limit. From point A, there is increase of stress to point B, the strain also increases proportionally which is called the elastic limit. The stress increases beyond the elastic limit the material undergo deformation. This is expressed as point C to D which is known as the yield point (at point C, the maximum stress required the bar to undergo deformation is called upper yield point and at point D the minimum stress required for the rebar to undergo deformation is called lower yield point). The continuous increase of stress beyond this limit, the stain also increases gradually to point E which is called the ultimate stress or ultimate strength point. Further increase of stress beyond the ultimate stress reduces the cross sectional area. This is the weakest point of the material called necking that means a breaking stage. At this stage, the mild steel bar breaks, thus the curve drops to point F

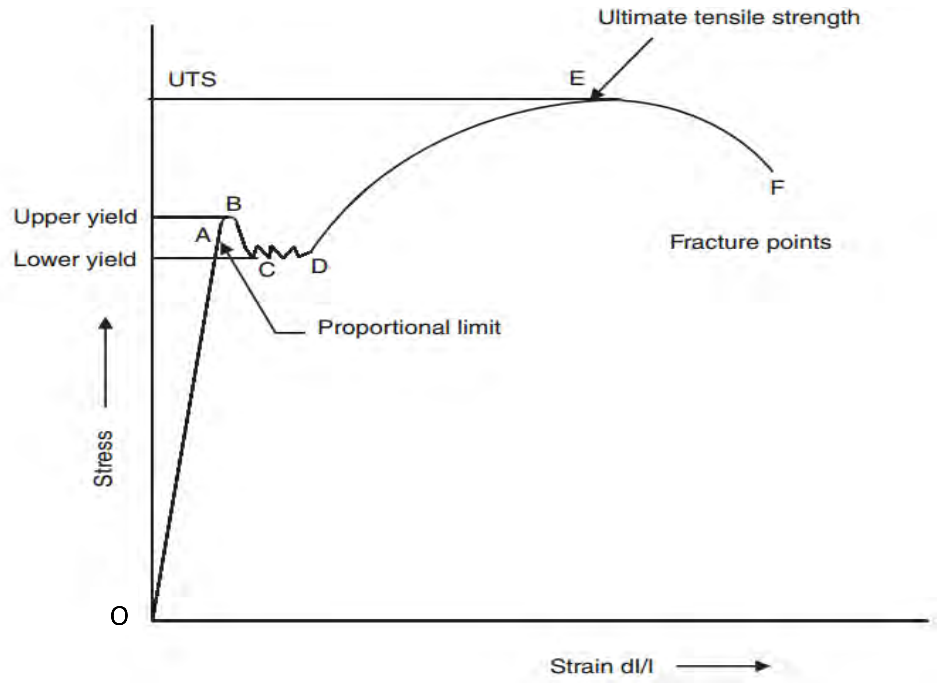


Figure 2. 5: Stress-strain curve for mild steel curve

$\varepsilon = (L_f - Lo) / Lo$

Where σ = is the engineering stress

- ε = is the engineering strain
- P = is the external axial load
- Ao = the original cross-sectional area of the specimen
- Lo = the original length of the specimen
- Lf = the final length of the specimen

Yield strength

By considering the stress-strain curve beyond the elastic portion, if the tensile loading Y continues, yielding occurs at the beginning of plastic deformation. The yield stress can be obtained by dividing the load at yielding (Py) by the original cross-sectional area of the specimen (Ao) as shown in equation.

$O_Y = P_Y / A_O$ ……………………………………………….……..Eq. 2.2

Arum (2008) conducted a research on Verification of Properties of Concrete Reinforcement Bars, by considering ribbed local and foreign bars of nominal diameters 10, 12, and 14mm from recognized ISO origins for his investigations. He chose Lagos, Ibadan, Akure and Ife in Nigeria to represent the general market situation in the country, with 15 specimens each from the 12mm and 16 mm representing Lagos, while the 10, 20 and 25mm representing the remaining. The investigation showed that steel from recognizable origin satisfied both local and ISO requirements for strength and ductility. But, those from non-recognizable origin failed to satisfy the same requirements for high tensile bars, but satisfied the local specifications for mild steel.

An earlier study conducted by Kankam and Adom-Asamoah (2002) on Strength and Ductility Characteristics of Reinforcing Bars milled from Scrap Metals, the physical properties of reinforcing steel produced from scrap metals such as vehicle parts and obsolete machinery in some developing countries as these products were already in use in structural works. Their primary observation was on the mild steel produced in Ghana from recycled steel. The sample steel bars were obtained from three local manufacturing companies in Ghana and their yield strength values were 190, 230 & 260 N/mm^2 and 560, 500 & 550 N/mm^2 for ultimate tensile strength respectively. These gave corresponding elongation values of 9.6, 11.8 & 10.6 for the three samples. All the specimens showed failure mode with little or no necking. Obviously, these showed very high values for characteristic strength with very little elongation leading to limited ductility compared with standard mild and high tensile steel.

Kankam and Adom-Asamoah (2002) concluded that the bars were characterized by inconsistencies in characteristic strength and ductility.

2.8.2 Microstructure of Steel Bars

All thermomechanical treated (TMT) rebars, regardless of chemistry and strength level, exhibit a composite microstructure consisting of ferrite-pearlite at the core and tempered martensite at the rim. Mechanical properties of steel depend 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; Ray et al., 1997). The stages for microstructure from austenite to ferrite – pearlite is illustrated in Figure 2.6.

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 0.6% carbon in plain carbon steels, a thermal treatment called an anneal is used to modify the microstructure and reduce the steel's hardness (Chen et al., 2017)

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^{0}C to 1700^{0}C. Billets come from furnace at temperature between 900^{0}C to 1100^{0}C. 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 thermomechanical treated reinforcement bar since the strength of steel is proportional to the grain size.

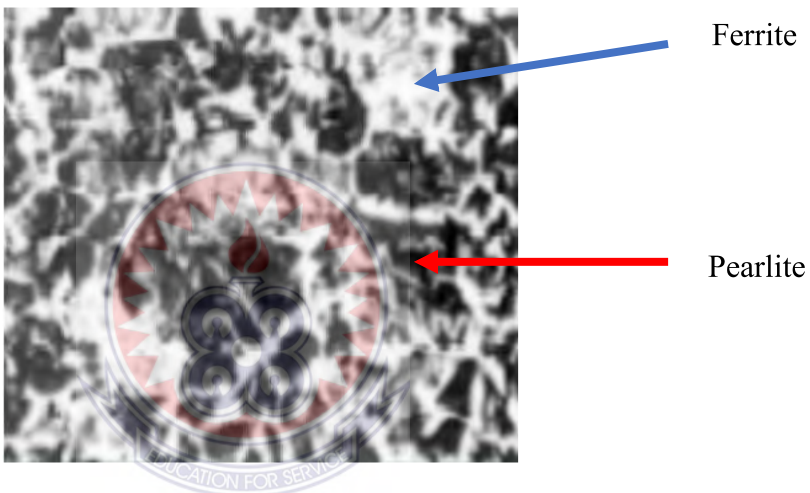


Figure 2.6: Ferrite-Pearlite Core in TMT bar (Islam, 2012)

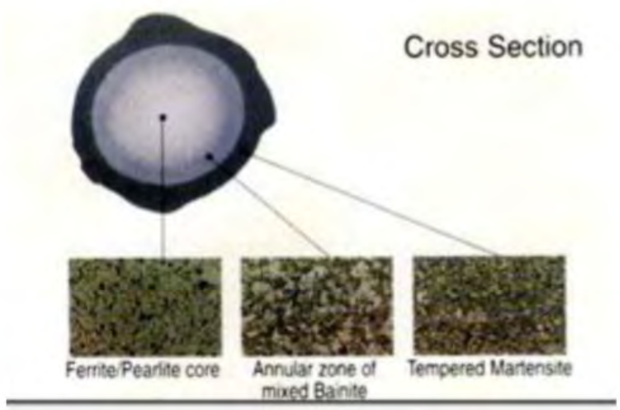


Figure 2. 7: **TMT bar microstructure showing ferrite/pearlite core, intermediate annular zone of mixed bainite, and the outer tempered martensite (Rajuri steel, 2011).**

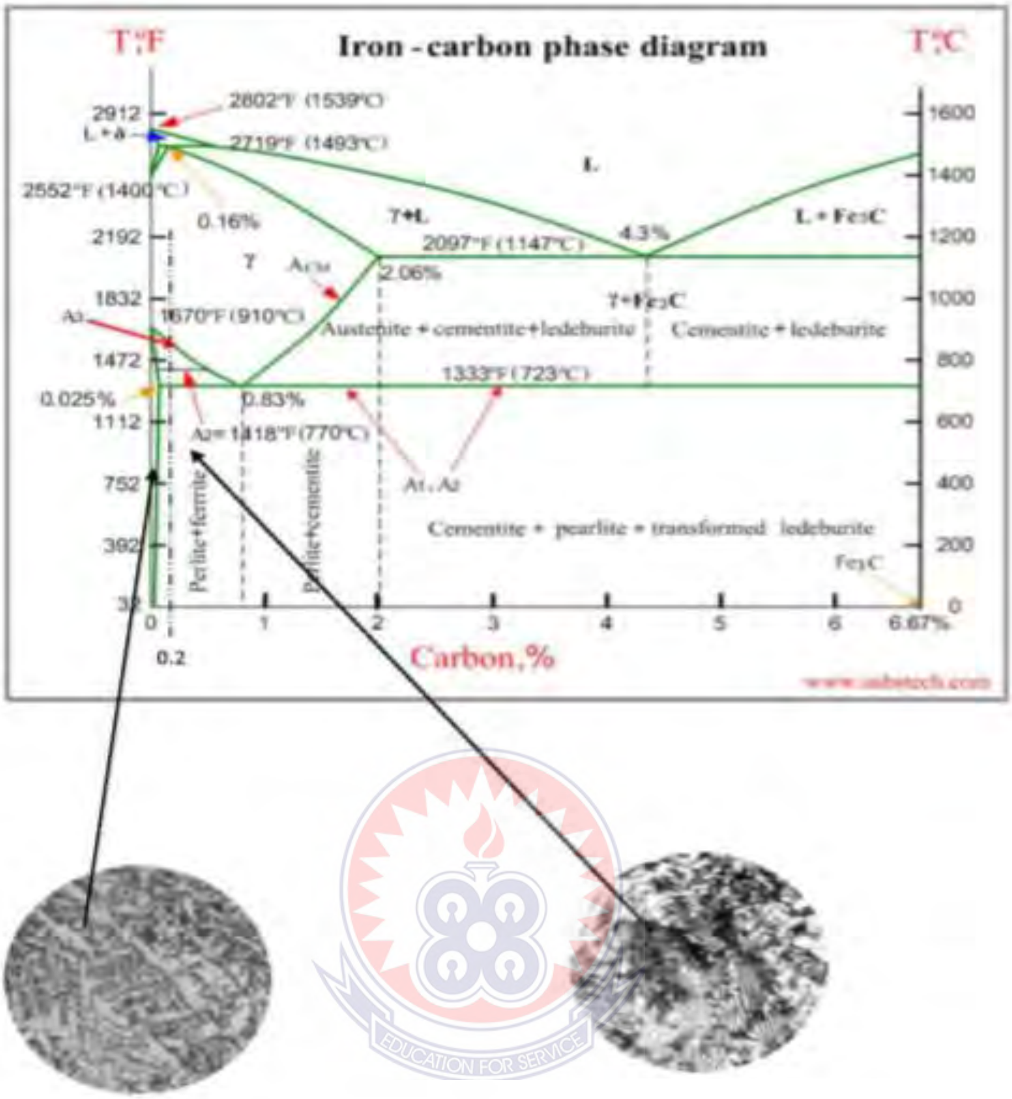
The micro structure depends on the phases present and their proportions. Some possible phases that can occur as the steel cools are Austenite, Face Centred Cubic (FCC-γ); Ferrite, Body Centred Cubic (BCC-α); Cementite, Pearlite and Martensite, Body Centred Tetragonal (BCT). The phases present, and the amounts, are governed by diffusional transformation: the decomposition of austenite into ferrite, pearlite and bainite; itself dependent on the original chemical composition and rate of cooling. Alloying elements can refine the grain (thermal mechanical hot form), lower the austenite to ferrite transition temperature (reduce grain growth), and precipitation harden (impede dislocation movement) (Matthew, 2011). The microstructure of a material can strongly influence physical properties such as strength, toughness, ductility, hardness, corrosion resistance, high/low temperature behavior and wear resistance. These properties, in turn govern the application of the material in industrial practice.

2.8.2.1 Categorization of Carbon Steel

Steels are alloys of iron-carbon and may contain other alloying elements. Low alloy (< 0.10%C), low carbon (< 0.25% C), medium carbon (between 0.25 and 0.60 % C) and high carbon (between0.6 and 1.4 % C), Callister and Rethwisch, (2020) and Raghavan et al, (2014) investigated low carbon steels especially TMT ribbed steel bars used in reinforcement.

2.8.2.2 Iron – carbon phase diagram

A "Phase" is a form of material having characteristic structure and properties. It is a form of the material which has identifiable composition, structure and boundaries separating it from other phases in the material volume. The iron-carbon equilibrium phase diagram is a plot of transformation of iron with respect to carbon content and temperature. Figure.2.8 shows the iron-carbon system of alloys containing up to 6.67% of carbon, which discloses the phase's compositions and their transformations occurring with the alloys during their cooling or heating. Carbon content 6.67% corresponds to the fixed composition of the iron carbide Fe_3C. A study of the microstructure of all steels usually starts with the metastable iron-carbon (Fe-C) binary phase diagram.



Acicular Ferrite

Pearlite
Ferrite = Light Areas
Cementite = Dark Areas

Figure 2. 8: The Iron-Carbon phase diagram (Davydov, 2020)

The following phases are involved in the transformation, occurring with the iron-carbon phase diagram in Figure 2.8.

- L - Liquid solution of carbon in iron;
- δ-ferrite – Solid solution of carbon in iron.

Maximum concentration of carbon in δ-ferrite is 0.09% at 1493°C – temperature of the peritectic transformation. The crystal structure of δ-ferrite is CBC (cubic body centered).

2.8.2.3 Ferrite – solid solution of carbon in iron.

Ferrite: Virtually pure iron with body centered cubic crystal structure (bcc) with low solubility of carbon – up to 0.025% at 723ºC). It is stable at all temperatures. The carbon solubility in ferrite depends upon the temperature (Dzogbewu, 2010).

2.8.2.4 Austenite – interstitial solid solution of carbon in iron.

Austenite has FCC (face cubic centered) crystal structure, permitting high solubility of carbon – up to 2.06% at 1147 ºC. Austenite as showed in Figure 2.9 does not exist below 733ºC and maximum carbon concentration at this temperature is 0.83%. The maximum solubility of carbon in the form of Fe_3C in iron is 6.67%. Addition of carbon to iron beyond this percentage would result in formation of free carbon or graphite in iron. At 6.67% of carbon, iron transforms completely into cementite or Fe_3C (Iron Carbide).

Generally, carbon content in structural steels is in the range of 0.12-0.25%. Up to 2% carbon, we get a structure of ferrite + pearlite or pearlite + cementite depending upon whether carbon content is less than 0.8% or beyond 0.8%. Beyond 2% carbon in iron, brittle cast iron is formed (Dzogbewu, 2010)

2.8.2.5 Cementite

Unlike ferrite and austenite, cementite is a very hard intermetallic compound consisting of 6.7% carbon and the remainder iron. Its chemical symbol is Fe_3C. Cementite is very hard, but when mixed with soft ferrite layers as shown in Figure 2.8 its average hardness is reduced considerably. Slow cooling gives course perlite; soft easy to machine but poor toughness. Faster cooling gives very fine layers of ferrite and cementite; harder and tougher.

2.8.2.6 Pearlite

A mixture of alternate strips of ferrite and cementite in a single grain. The pearlitic microstructure is characterized by the joint arrangement of thin layers of ferrite and cementite, formed by eutectoid reaction from austenite. The distance between the plates and their thickness is dependant on the cooling rate of the material; fast cooling creates thin plates that are close together and slow cooling creates a much coarser structure possessing less toughness. The name for this structure is derived from its mother of pearl appearance under a microscope. A fully pearlitic structure occurs at 0.8% Carbon. Further increases in carbon will create cementite at the grain boundaries, which will start to weaken the steel. It is stable at all temperatures below 723°C. The latter decomposes by eutectic mechanism to a fine mixture of austenite and cementite, called ledeburite (Dzogbewu, 2010).

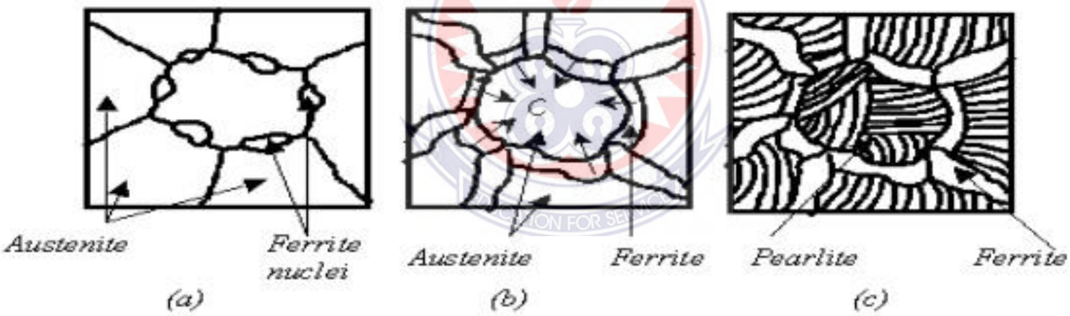


Figure 2. 9: Different stages of formation of pearlite

2.8.3 Hardness strength test

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting. Hardness of materials has probably long been assessed by resistance to scratching or cutting. An example would be material B scratches material C, but not material A. Alternatively, material A scratches material B slightly and scratches material C heavily. Relative hardness of minerals can be assessed by reference to the Mohs scale that ranks the ability of materials to resist scratching by another material. Similar methods of relative hardness assessment are still commonly used today. An example is the file test where a file tempered to a desired hardness is rubbed on the test material surface. If the file slides without biting or marking the surface, the test material would be considered harder than the file. If the file bites or marks the surface, the test material would be considered softer than the file (Atsbeha, 2017).

The above relative hardness tests are limited in practical use and do not provide accurate numeric data or scales particularly for modern day metals and materials. The usual method to achieve a hardness value is to measure the depth or area of an indentation left by an indenter of a specific shape, with a specific force applied for a specific time. There are three principal standard test methods for expressing the relationship between hardness and the size of the impression, these being Brinell, Vickers, and Rockwell. For practical and calibration reasons, each of these methods is divided into a range of scales, defined by a combination of applied load and indenter geometry.

The Brinell and Rockwell hardness tests were developed at a time when metals were the principal engineering materials. A significant amount of data has been collected using these tests on metals. For most metals, hardness is closely related to strength. Because the method of testing for hardness is usually based on resistance to indentation, which is a form of compression, one would expect a good correlation between hardness and strength properties determined in a compression test. However, strength properties in a compression test are nearly the same as those from a tension test, after allowances for changes in cross-sectional area of the respective test specimens; the correlation with tensile properties should also be good. Brinell hardness (HB) exhibits a close correlation with the ultimate tensile strength of steels, leading to the relationship (Kopeliovich, 2009)

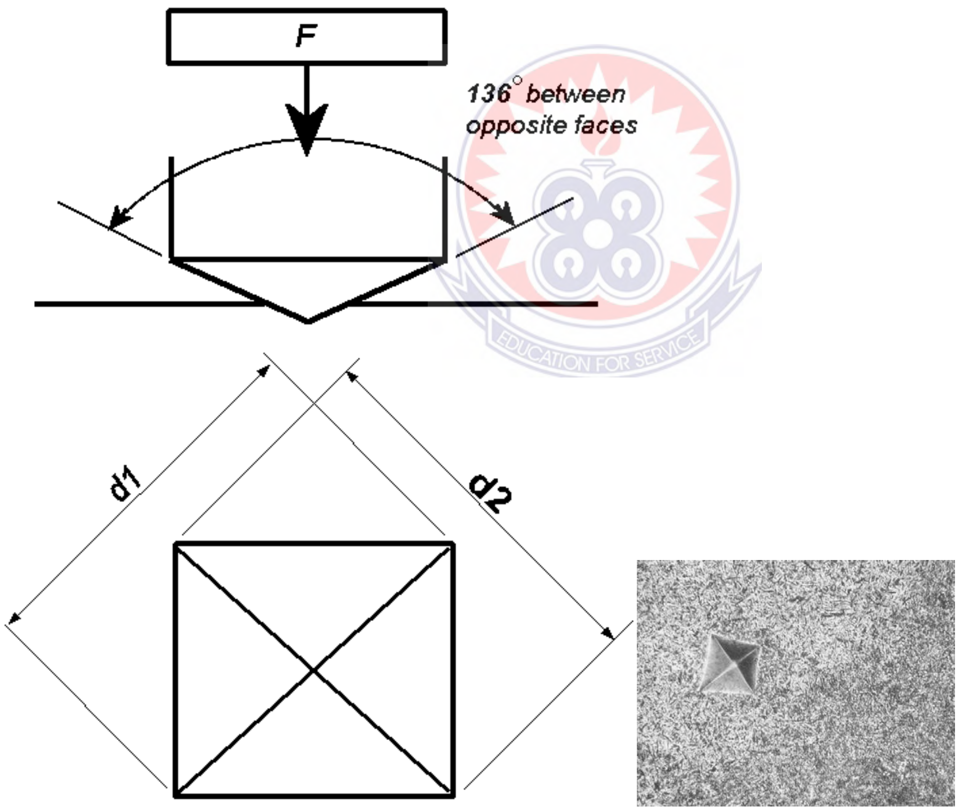
2.8.3.1 Vickers hardness test

This method was introduced in England in 1925 as an alternative to the Brinell method to measure the hardness of materials (Smith and Sandland, 1992).

Vickers hardness test method has been illustrated in Figure 2.10. The test consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. After the removal of load, the two diagonals of the indentation (d1 and d2) left on the surface of the specimen are measured and their arithmetic mean L is calculated. In the present study, the load is considered as P = 100 N and Vickers hardness number is calculated using the following equation:

Vickers Hardness Number (VHN) = $(1.854P)/L^2$

Where P= applied load, L= diagonal distance of indented pyramid



Vickers test scheme

Figure 2. 10: Indentation left after a Vickers hardness test (Flow pattern during Vickers indentation of a material, 2021)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This section describes the materials, equipment and methods that were used in the research work. The research work focuses on experimental investigation on tensile strength, chemical composition and hardness of ribbed mild steel bars produced by local companies which will aid in sustaining building material in Ghana. The main activities here; obtaining test samples, testing the tensile strength to obtain the parameters such as ultimate tensile strength, yield strength, % elongation, % area of reduction, Fracture / Breaking Strength (BS) and Young's modulus, testing the chemical composition to reveal the percentage of elements such as Carbon (C), Manganese (Mn), Molybdenum (Mo), Chromium (Cr), Silicon (Si) and Nickel (Ni) etc. and testing the hardness of ribbed mild steel bars with a diamond indentor and categorizing standards and sub-standards of ribbed mild steel bars produce in Ghana.

3.2 Materials

Ribbed mild steel bars of 12mm, 16mm and 20mm diameter were used for the study. These samples were obtained from three major local factories categorized as Company A, B and C. Five specimens of 500mm length for each diameter were collected. The samples of ribbed mild steel bars were obtained from local producers. A total of seventy-five (75) specimens used for the study included forty-five (45) for tensile strength, fifteen (15) for chemical composition test and fifteen (15) for micro hardness.

3.3 Equipment

The various types of equipment that were used to carry out the tests in the study were the universal testing machine, Angstrom V-950 Spectrometer, Optical Metallurgical Microscope and Surface Grinder.

1. The universal testing machine (UTM) is commonly used for tensile test of ribbed mild steel bars. This type of machine is designed to be used for wide range of tests such as tensile test, compression test, bend test, flexural test etc. by changing the grips and fixtures. It was linked to a computer-controlled system in which the load and extension data can be graphically displayed together with the calculations for stress and strain curve. Universal testing machine with a maximum capacity of 1000kg at the construction and wood laboratory of Akenten Appiah Menka University of Skills Training and Entrepreneurial development was used for the tensile strength test.
2. Angstrom V-950 Spectrometer from Tema Steel Company Limited were used for the chemical composition examination
3. Optical Metallurgical Microscope (x10 magnification), from Kwame Nkrumah University of Science and Technology (KNUST) was used for the microstructure
4. Universal Surface Grinder was used to grind or smoothen the surface of ribbed mild steel bars

3.4 Labeling of Selected Steel production companies

For the purposes of not disclosing the steel production companies investigated in this study, the three sampled steel production companies were labeled to identify their specimen in the investigations that were undertaken in this study. The three steel production companies chosen were labeled with letters A, B and C. The order of identification does not mean the hierarchy of the production capacities, the labeling are only for identification purposes.

3.5 Labeling of Test Specimen for the Experiments

The specimens were labeled using two (2) capital letters and a number where the first letter represented the steel production company, the second letter represented the particular experiment performed, and the number represented the number assigned to the test specimen from each respective company. For example, label AT1, means test specimen is from company A, T represents tensile strength and 1 represents the first steel bar from company A. Table 3.1 shows the labeling of all test specimen for experiments.

Table 3. 1: Labeling of test specimen for the experiment.

Category/ Company	Test Specimen Labeling			
	Tensile Strength	Chemical Composition	Microstructure	Micro hardness
A	AT1	AC1	AM1	AH1
	AT2	AC2	AM2	AH2
	AT3	AC3	AM3	AH3
	AT4	AC4	AM4	AH4
	AT5	AC5	AM5	AH5
B	BT1	BC1	BM1	BH1
	BT2	BC2	BM2	BH2
	BT3	BC3	BM3	BH3
	BT4	BC4	BM4	BH4
	BT5	BC5	BM5	BH5
C	CT1	CC1	CM1	CH1
	CT2	CC2	CM2	CH2
	CT3	CC3	CM3	CH3
	CT4	CC4	CM4	CH4
	CT5	CC5	CM5	CH5

3.6 Sampling Details

In the preparation of the samples for strength properties (tensile, chemical composition and hardness), purposive sampling method was used in the selection from the three producing companies in Ghana. It is a sampling technique whereby the elements selected from the population to participate in the study is done by the judgement of the researcher. A total of seventy-five (75) piece were considered.

3.6.1 Sampling Details for Tensile strength test

Three local steel production companies were used in the collection of the test samples for the tensile strength test experiment. Total of forty-five (45) pieces of ribbed mild steel bars were used in this particular experiment. Five (5) pieces of 12mm from each company (A, B and C), Five (5) pieces of 16mm from each company (A, B and C) and Five (5) pieces of 20mm from each company (A, B and C). The category of company, grade, bar size, length and quantity of ribbed mild steel bars obtained from company A, B and C per test for the tensile strength are summarized in Table 3.2.

Table 3. 2: Sampling details for tensile strength test.

Category of company	Grade	bar Size			Length	Quantity		
		Ø12mm	Ø16mm	Ø20mm	Ø 12,16 and 20mm	Ø12mm	Ø16mm	Ø20mm
A	250N/mm^2	12mm	16mm	20mm	500mm	5	5	5
B	250N/mm^2	12mm	16mm	20mm	500mm	5	5	5
C	250N/mm^2	12mm	16mm	20mm	500mm	5	5	5
TOTAL						45		

3.6.2 Sampling details for chemical composition test

Three local steel production companies were used in the collection of the test samples for the chemical composition test experiment. Five (5) pieces of 16mm of ribbed mild steel bar were collected from each company. A total of fifteen (15) pieces of ribbed mild steel bars of length 50mm each were used in this experiment (Appendix A).

The category of company, grade, bar size, length and quantity of ribbed mild steel bars that were required from company A, B and C per test for the chemical composition is summarized in Table 3.3.

Table 3. 3: Sampling details for chemical composition test.

No	Category of Company	Grades	Bar size	Length	Quantities
1	A	250N/mm^2	16mm	50mm	5
2	B	250N/mm^2	16mm	50mm	5
3	C	250N/mm^2	16mm	50mm	5
TOTAL					15

3.6.3 Sampling details for hardness strength test

Three local steel production companies were used in the collection of the test samples for the hardness strength test experiment. Five (5) pieces of 20mm ribbed mild steel bars were collected from each company. A total of fifteen (15) pieces of ribbed mild steel bars of length 20mm each were used in the experiment as showed in Table 3.4.

Table 3. 4: Sampling details for hardness strength test.

No	Category of Company	Grades	Bar Size	Length	Quantities
1	A	250N/mm^2	20mm	20mm	5
2	B	250N/mm^2	20mm	20mm	5
3	C	250N/mm^2	20mm	20mm	5
TOTAL					15

3.7 Tensile strength test

The universal testing machine with model WAW-1000H as shown in Figure 3.1 was used to carry out the tensile strength test of the ribbed mild steel bars used in the study.

Figure 3. 1: Universal Testing Machine (model WAW-1000H).

3.8 Tensile Test

The tensile test of ribbed mild steel bars sample was performed in accordance with ASTM A706/A706M-09b test standard. Tensile test is a standard test which is conducted using a universal testing machine shown in Figure 3.2 with the lower and upper jaws gripping the ribbed mild steel bar ready to stretch. It was linked to a computer-controlled system in which the load and extension data can be graphically displayed together with the calculations of stress and strain. A total of forty-five (45) test specimens comprising fifteen (15) specimen of 12mm, fifteen (15) specimen of 16mm and fifteen (15) specimen of 20mm from the local steel producers were prepared for the test. Uniaxial load was applied through both the ends at the rate of 5mm/min. The prepared test specimen was positioned in the jaw of the universal testing machine, the machine started to stretch the bar, readings of loads against extensions were recorded. At the yield point the extensometer was removed to prevent damage. The loading continued until the specimen fractured and the necking diameter was recorded. From the test data, the ultimate tensile strength, Young's Modulus, percentage elongation, fracture stress, toughness and the percentage reduction in area were determined. The tensile strength was calculated using the following formulas. Other properties were calculated from these fundamental parameters.

$UTS = P_{max} / A_o$

Where UTS= ultimate tensile strength

P_{max} = is the maximum load applied

A_o = is the Original Cross-sectional area.

The percentage elongation after fracture is given as

$\% \varepsilon = (\ell_u - \ell_o) \times 100 / \ell_o$

Where ℓ_o = is the original gauge length

ℓ_u = is the final gauge length.

The percentage reduction in area is also given as

$\% A = (A_o - A_u) \times 100 / A_o$

Where A_o = is the original cross-section area

A_u = is the minimum cross-sectional area after fracture.

3.7.1 Test procedure

Sample of mild steel bars were cut from the full length of the steel bar, a length of 500mm were cut. The actual diameter, weight etc. were measured. The specimen is mounted on the universal testing machine between the lower jaw and upper jaws. The load range in the machine was adjusted to its maximum capacity. The machine was switched on and the tensile load was applied gradually. For every 5 KN of load, the readings of dial gauge were noted and tabulated. The results were automatically displayed on the computed connected to the universal testing machine. The specimen is removed and final dimensions are measured. Then finally the results are tabulated.

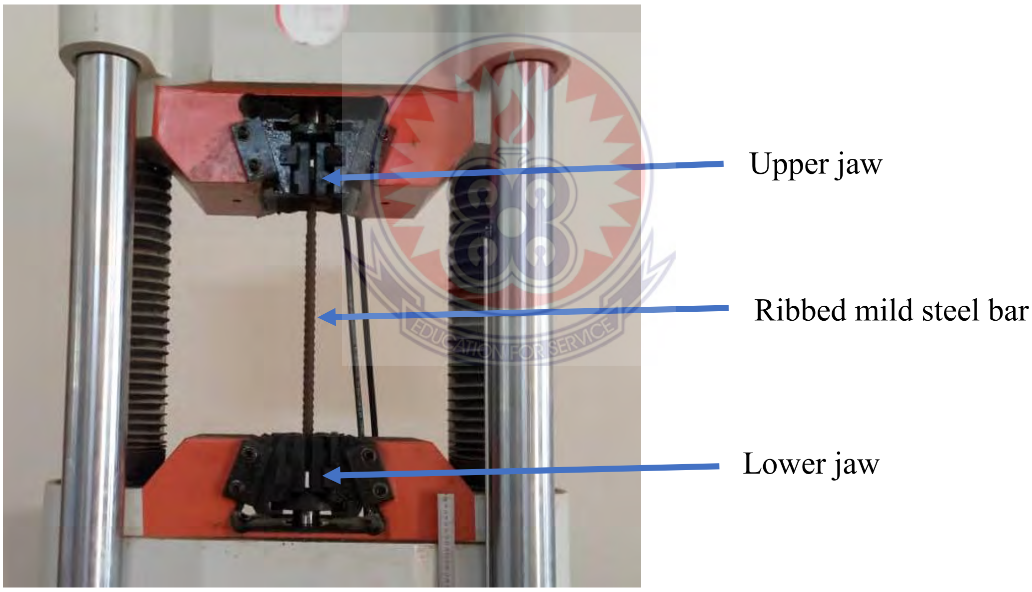


Figure 3. 2: Tensile strength experiment setup.

3.8 Determination of Chemical Composition

The chemical composition from each of the steel bars was determined by Angstrom V-950 Spectrometer apparatus shown in the Figure 3.3. From each steel bar, a test piece of 50mm length was cut and ground flat for spectrometry. Each test piece was marked with a label like BC2 for identification purposes. The test piece was placed in 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.

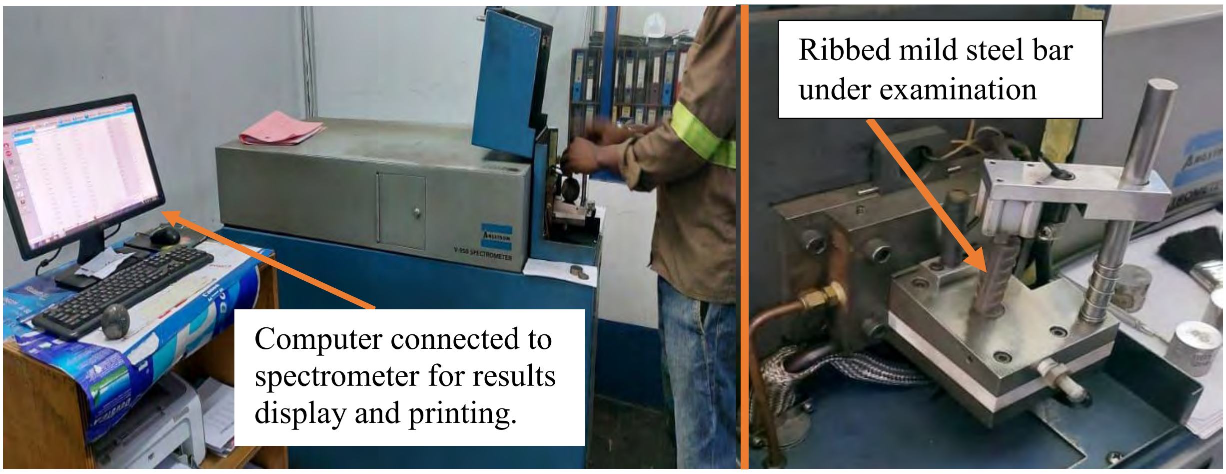


Figure 3. 3: Angstrom V-950 Spectrometer for Chemical Composition

3.9 Microstructure examination

From each steel bar obtained from the steel manufacturing companies, test pieces of lengths of 20mm were cut from the steel specimens. The surface of the test pieces was grinded 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 (Appendix C).

Micrographs of the etched surfaces were obtained using Photo Microscope shown in Figure 3.4 using magnification of 10x and the micrographs were used to analyze the microstructure of the test pieces.

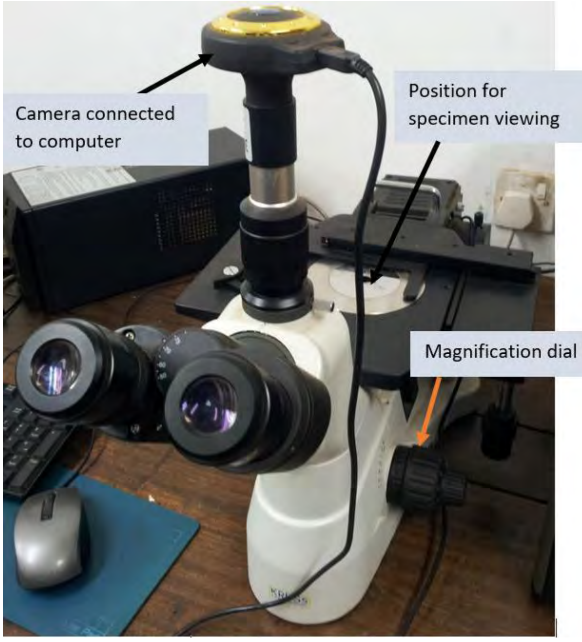


Figure 3. 4: Photo Microscope for Microstructure Test

3.10 Hardness Test

The hardness test of ribbed mild steel bars sample was performed according the ASTM E92-17 test standard. Three most popular hardness methods are: Brinell hardness test, Rockwell hardness test and Vickers hardness test (Low and Fink, 2006).

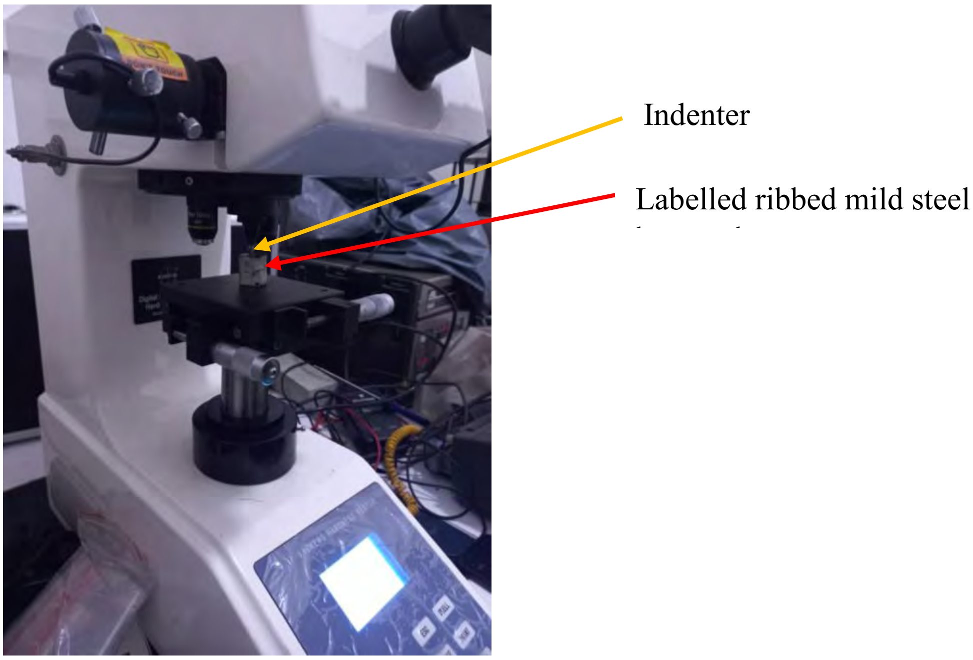


Figure 3. 5: Vickers Hardness experiment set up

The hardness test measured the metal's hardness by determining the metal's resistance to the penetration of a non-deformable ball or cone. The test determined either the width or depth of indentation the indenter made on or into the metal, under a given load, within a specific period of time. According to Low and Fink, (2006) comparing the methods with each other, the Vickers hardness test makes the deepest and widest indentation, so the test averages the hardness over a wider amount of material, which accurately accounts for multiple grain structures and any irregularities in the uniformity of the material. Samuel (2007) also stated that the Brinell hardness test method is the best for achieving the bulk or macro-hardness of a material but the researcher employed Vickers hardness test.

The Vickers hardness tester is used to measure the scratch hardness of reinforcement steel bar specimens. Figure 3.5 shows the experimental set up for micro-hardness test. The Vickers hardness tests method is made to utilize test forces ranging from 9.807 x 10^{-13} N to 1176.80 N (1gf to 120 kgf). A diamond indenter in the form of a right pyramid of a square base of an angle 136° between opposite faces under a load P is forced into the specimen. After the removal of load, the two diagonals of the indentation (X and Y) left on the surface of the specimen are measured and their arithmetic mean L is calculated as shown in Figure 3.6.

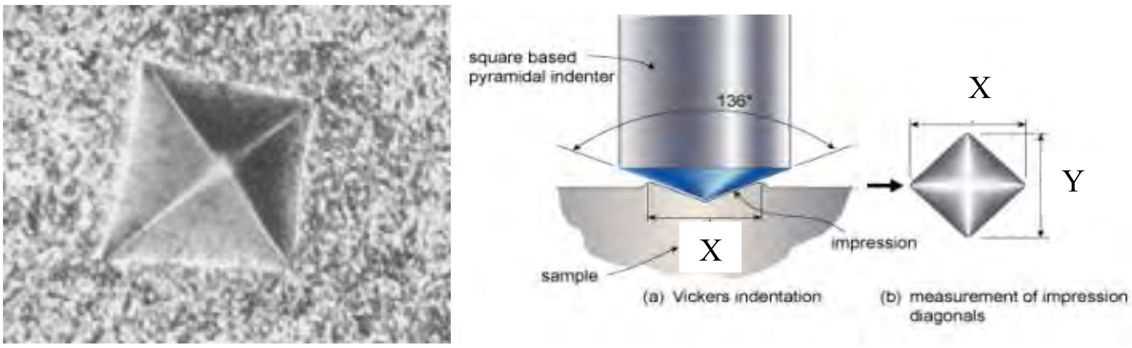


Figure 3.6: Indentation of Vicker hardness test

In the present study, the load is considered as P = 100 N and Vickers hardness number is calculated using the following equation: Vickers Hardness Number (VHN) = (1.854P)/L2

Where

P= applied load

L= diagonal distance of indented pyramid

3.10.1 Procedure

The surfaces of the specimen were cleaned, the indenter of the hardness tester was fixed and switched on the power supply, as the machine gets started, the specimen was placed with the cleaned surface facing the indenter on the anvil at work table. Focused the work piece surface for clean visibility by rotating the hand wheel at the work table upwards and downwards. Selected the load specified (P) push button available on the right side at the hardness tester. Actuated the electric push button (Green Button) at the front for loading, the loading lever started moving up-wards and reached the study position. released the loading lever slowly and brought it to the downward position. For major reading adjusted the display at the indentation made by the indenter to co-inside with the micrometer on the display screen. For major (minor) reading adjusted the movable side at the micrometer and noted down the total reading. The measurement is to be made for two opposite corners of the diagonal indentation. The process was repeated for all the speci-men.

3.11 Data Analysis, Presentation and Discussion

Tables and charts were used to present and discuss results obtained from the test data, using sta-tistical analysis tools; ANOVA, Excel and Max Test.

3.11.1 Analysis of variance (ANOVA)

Analysis of variance (ANOVA) can be defined as a statistical technique used to determine the mean difference between or within groups by conducting one-factor ANOVA test at a significance level of 0.05. Since the strength properties, namely ultimate tensile strength and hardness of a particular reinforcing steel bar are functions of chemical compositions in the ribbed mild steel bar, the analysis of variance (ANOVA) was used to determine the mean difference between ultimate tensile strength and hardness of the ribbed mild steel bars.

CHAPTER FOUR

PRESENTATION OF TEST RESULTS.

4.1 Introduction

This chapter presents the results obtained from the experiments that were carried out on the materials selected from different steel producers in Ghana. The results are presented in the order of the specific objectives, tensile strength, chemical composition, and micro hardness strength.

4.2 Tensile strength

The average results of the tensile strength tests of 12mm, 16mm and 20mm ribbed mild steel bars. The maximum tensile strength, upper yield strength, Lower yield strength, Modulus of Elasticity and Elongation percentage (%) were the parameters obtained from the tensile strength test as presented in Table 4.1. The results were generated by the use of computer connected to the universal testing machine as showed in Figure 3.1 from construction and wood laboratory of Akenten Appiah Menka University of Skills Training and Entrepreneurial development. The detailed results are presented in appendix D.

The results in table 4.1 indicates that, the tensile strength of company A, B and C were obtained for each size of ribbed mild steel bars and the highest average tensile strength, median tensile strength and least tensile strength among the 12mm, 16mm and 20mm ribbed mild steel bars were obtained.

The average modulus of elasticity of company A, B and C were also obtained for each size of ribbed mild steel bars and the highest average modulus of elasticity, median average modulus of elasticity and least average modulus of elasticity among the 12mm, 16mm and 20mm mild steel bars were obtained.

Table 4. 1: Average tensile test results of 12mm, 16mm and 20mm of ribbed mild steel bars.

Sample Brand	Sample No	Actual Diameter mm	Nominal Diameter mm	Area mm^2	Maximum Load kN	Maximum Tensile Strength N/mm^2	Upper yield Load kN	Upper yield strength N/mm^2	Lower yield load kN	Lower yield strength N/mm^2	Modulus of Elasticity GPa	Displacement	Elongation %
Average AT	1	18.00	20	254.47	146.58	576.00	122.03	479.67	121.77	478.67	244.25	59.14	11.83
	2	14.00	16	153.94	109.90	713.80	87.08	566.00	86.23	560.33	232.96	50.17	10.03
	3	10.00	12	78.54	60.36	768.40	52.51	668.75	39.60	504.25	255.97	56.19	11.24
Average BT	1	18.00	20	254.47	151.74	596.20	100.70	395.67	99.87	392.67	202.24	90.71	18.14
	2	14.00	16	153.94	89.61	582.20	61.88	401.75	61.19	397.50	237.46	90.65	18.13
	3	10.50	12	86.59	50.72	585.60	36.35	419.80	36.09	416.80	222.77	88.25	17.65
Average CT	1	19.50	20	298.65	182.30	610.40	141.66	474.20	140.88	471.60	238.16	85.45	17.08
	2	14.00	16	153.94	96.16	624.60	76.98	500.00	75.78	492.50	206.59	65.12	13.02
	3	10.00	12	78.54	50.61	644.40	46.48	591.50	45.90	584.50	246.78	52.80	10.56

Moreover, the average elongation percentage of company A, B and C were obtained for each size of ribbed mild steel bars and the highest average elongation percentage, median average elongation percentage and least average elongation percentage among the 12mm, 16mm and 20mm ribbed mild steel bars were obtained.

4.3 Chemical composition

The results of chemical composition test of 16mm ribbed mild steel bars carried out on an Angstrom V-950 Spectrometer at Tema Steel Company Limited are presented in Table 4.2. From this table, the chemical compositions of the steel bars are slightly different from each other. In order to know the combined effect of the alloying elements of the steel bars, their carbon equivalent (CE) values are calculated using standard formula as follows (Guo et al., 2013): CE $= C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Ni+Cu}{15}$ where C = carbon(%), Mn = manganese(%), Cr = chromium(%), Mo = moleydedum(%), V = vanadium(%), Ni = nickel(%) and Cu = copper(%)

Table 4. 2: Results of chemical compositions of 16mm ribbed mild steel bars.

Category of company	Specimen Code	Chemical composition (%)										CEV
		Fe	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	
A	AC1	98.802	0.101	0.469	0.056	0.025	0.086	0.169	0.100	0.202	0.099	0.257
	AC2	98.629	0.185	0.525	0.048	0.034	0.117	0.216	0.082	0.215	0.065	0.348
	AC3	98.449	0.107	0.607	0.047	0.039	0.259	0.208	0.113	0.226	0.066	0.288
	AC4	98.854	0.059	0.471	0.063	0.024	0.085	0.174	0.096	0.204	0.085	0.213
	AC5	98.860	0.071	0.464	0.061	0.026	0.083	0.175	0.094	0.204	0.077	0.222
Average	AC	98.719	0.126	0.507	0.055	0.030	0.126	0.188	0.097	0.210	0.078	0.287
B	BC1	98.814	0.191	0.268	0.027	0.023	0.107	0.197	0.106	0.253	0.093	0.325
	BC2	98.772	0.181	0.279	0.037	0.027	0.124	0.228	0.105	0.256	0.084	0.319
	BC3	98.854	0.220	0.263	0.044	0.028	0.110	0.176	0.101	0.209	0.078	0.340
	BC4	98.776	0.194	0.282	0.044	0.028	0.128	0.203	0.107	0.252	0.083	0.329
	BC5	98.825	0.176	0.295	0.028	0.019	0.113	0.229	0.093	0.229	0.072	0.307
Average	BC	98.808	0.192	0.277	0.036	0.025	0.116	0.207	0.102	0.240	0.082	0.323
C	CC1	98.559	0.188	0.477	0.043	0.027	0.162	0.270	0.105	0.178	0.092	0.347
	CC2	98.696	0.128	0.449	0.029	0.025	0.141	0.264	0.102	0.171	0.088	0.279
	CC3	98.525	0.163	0.516	0.037	0.028	0.212	0.259	0.099	0.173	0.090	0.325
	CC4	98.672	0.211	0.437	0.033	0.019	0.134	0.251	0.099	0.166	0.089	0.358
	CC5	98.524	0.191	0.511	0.041	0.021	0.190	0.248	0.105	0.178	0.104	0.356
Average	CC	98.595	0.176	0.478	0.037	0.024	0.168	0.258	0.102	0.173	0.093	0.333

4.4 Microstructure

The microstructure has a direct impact on the properties of ribbed mild steel bars. The core zone of the microstructure was viewed from the photo microscope using 10x magnification lens as shown in Figure 3.2. Formation of phases was used to describe the characteristics of the micrographs of the three group of companies. All the steel bars exhibited a composite micro-structure consisting of ferrite and pearlite phases in the core. The micrographs in Figure 4.1 show that most test pieces exhibited different characteristics.

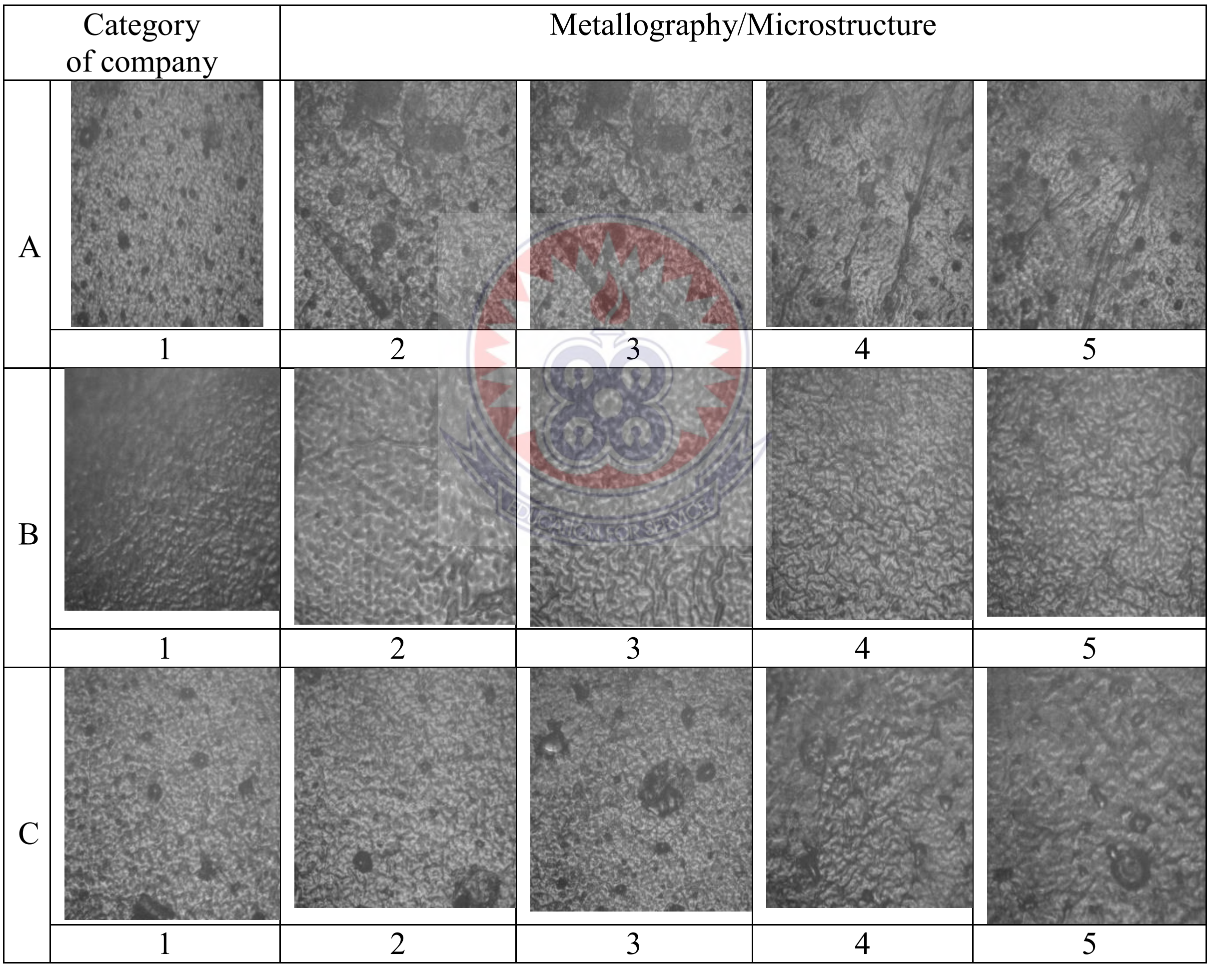


Figure 4. 1: Micrographs of ribbed mild Steel bars of 20mm at 10x magnification for Company A, B and C

4.5 Micro hardness strength

Micro hardness test results are showed in table 4.3. The test was performed by Vickers hardness testing machine on fifteen pieces of ribbed mild steel bars from three production companies at Kwame Nkrumah University of Science and Technology. The hardness test was done to identify the hardness strength of each of the steel bars.

Table 4. 3: Results of Vickers hardness tests of 20mm ribbed mild steel bars.

Category of Company	Sample Number	HV	Maximum	Minimum	Reminder
A	1	194.0	403.3	194.0	209.3
	2	246.4			
	3	254.8			
	4	378.4			
	5	403.3			
Average AHV		**295.38**			
B	1	227.4	363.0	194.0	135.6
	2	268.5			
	3	336.0			
	4	363.0			
	5	260.9			
Average BHV		**291.16**			
C	1	228.6	295.0	228.6	66.42
	2	250.4			
	3	234.5			
	4	295.0			
	5	270.3			
Average CHV		**255.76**			

CHAPTER FIVE

DISCUSSION OF TEST RESULTS

5.1 Introduction

This chapter presents the data analysis and discussion of results obtained from the laboratory experiments that were carried out on the materials selected from different steel producers in Ghana. Bar graphs and tables were used to illustrate the results. Discussion of test results is presented in the order of the specific objectives, that is, tensile strength, chemical composition, microstructure and micro hardness strength.

5.2 Tensile strength

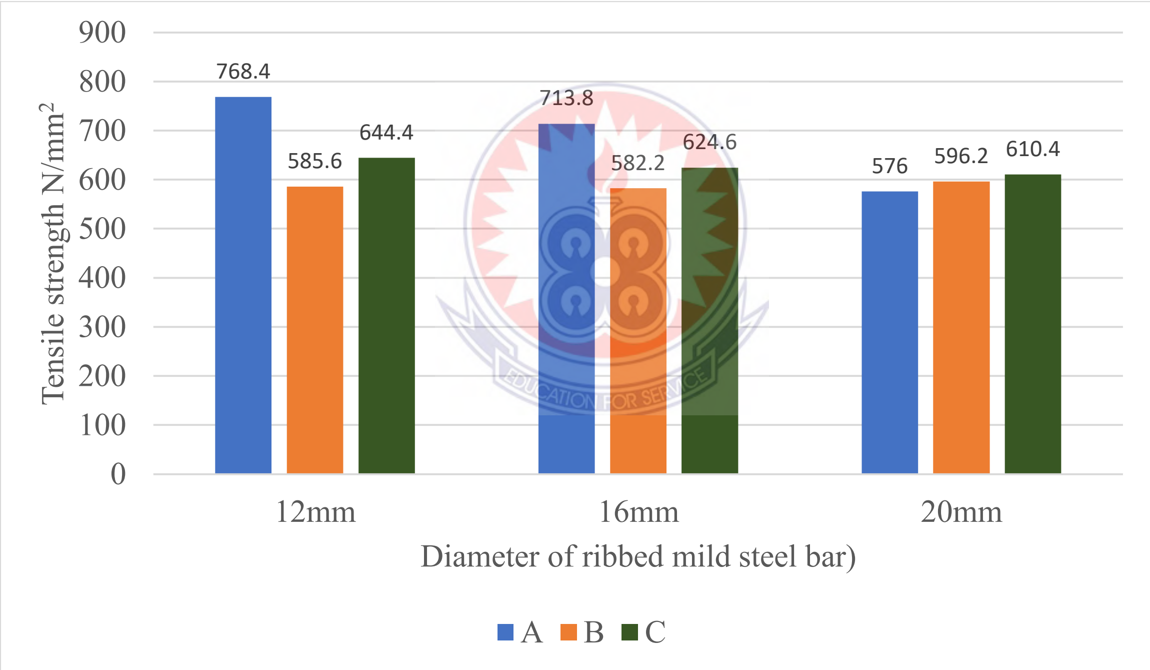


Figure 5. 1: Bar chart of average tensile strength of 12mm, 16mm and 20mm for three steel production companies (A, B and C).

Figure 5.1 indicates the bar graph of average tensile strength of 12mm, 16mm and 20mm for the three production companies (A, B and C). The results indicate that, among the 12mm mild steel bars, the tensile strength of company A obtained the highest average tensile strength of 768.4 N/mm^2, company C obtained median average tensile strength of 644.4 N/ and the least average tensile strength of 585.6 N/mm^2 was obtained from company B.

Among the 16mm mild steel bars, the results indicate that, the tensile strength of company A obtained the highest average tensile strength of 713.8 N/mm^2, company C obtained the median average tensile strength of 624.6 N/mm^2 and the least average tensile strength of 582.2 N/mm^2 was obtained from company B.

Among the 20mm mild steel bars, the results indicate that, the tensile strength of company C obtained the highest average tensile strength of 610.4 N/mm^2, the median average tensile strength of 596.2 N/mm^2 was obtained from company B and the least average tensile strength of 576 N/mm^2 was obtained from company A. The results indicate that, the tensile strength of company A obtaining the highest average tensile strength among the 12mm and 16mm mild steel bars and company C obtained the highest among the 20mm which gave the corresponding elongation values of 11.24, 10.03 and 17.08 (Table 4.1) for 12mm, 16mm and 20mm respectively. However, based on the findings of Kankam and Adom-Asamoah (2002) on Strength and Ductility Characteristics of Reinforcing Bars milled from Scrap Metals, 560, 500 and 550 N/mm^2 for ultimate tensile strength were found. These gave corresponding elongation values of 9.6, 11.8 and 10.6 for the three samples. All their specimen showed failure mode with little or necking (Kankam & Adom-Asamoah, 2002). These showed very high values for characteristic strength with very little elongation leading to limited ductility compared with standard mild and high tensile steel. Shunichi and Morifumi (2006) investigated the effects of micro alloying elements on mechanical properties of reinforcing bars and found that with 0.05% Nb and 0.05 % V addition to 0.25 C, 0.5 Si, 1.2 Mn steel (% weight) led to an effective increase in strength.

5.2.1 Analysis of variance (ANOVA) for tensile strength of 12mm.

Table 5. 1: Single factor summary and ANOVA of tensile strength of 12mm ribbed mild steel bars from company A, B and C.

SUMMARY

Groups	Count	Sum	Average	Variance
A	5	3842	768.4	1055.3
B	5	2928	585.6	416.3
C	5	3222	644.4	460.3

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	87082.13	2	43541.07	67.61385	0.000000293	3.885294
Within Groups	7727.6	12	643.9667			
Total	94809.73	14				

The tensile strength obtained for 12mm ribbed mild steel bars from companies A, B and C were analyzed using one factor ANOVA test at a significance level of 0.05 as presented in Table 5.1. Ribbed mild steel bars of company A recorded the highest mean strength of 768.4 N/mm^2, followed by company C which recorded 644.4 N/mm^2 mean strength while company B recorded the least mean strength of 585.6 N/mm^2. From the ANOVA table shown in Table 5.1, the p-value of 0.000000293 is less than the specified significant level of 0.05 and therefore the difference in the strengths of the steel bars for the companies (ABC) is statistically significant.

5.2.2 ANOVA for tensile strength of 16mm.

Table 5. 2: Single factor summary and ANOVA of tensile strength of 16mm ribbed mild steel bars from company A, B and C.

SUMMARY

Groups	Count	Sum	Average	Variance
A	5	3569	713.8	3718.2
B	5	2911	582.2	798.7
C	5	3123	624.6	58.3

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	45121.6	2	22560.8	14.79332	0.000577	3.885294
Within Groups	18300.8	12	1525.067			
Total	63422.4	14				

The tensile strength obtained after tensile strength test of 16mm ribbed mild steel bars from companies A, B and C were analyzed using one factor ANOVA test at a significance level of 0.05 as presented in table 5.2. Ribbed mild steel bars of company A recorded the highest mean strength of 713.80 N/mm^2, followed by company C which recorded 624.6 N/mm^2 mean strength whiles company B recorded the least mean strength of 582.2 N/mm^2. From the ANOVA table shown in Table 5.2, the p-value of 0.000577 is less than the specified significant level of 0.05 and therefore the difference in the strengths of the steel bars for the companies (ABC) is statistically significant.

5.2.3 ANOVA for tensile strength of 20mm.

Table 5. 3: Single factor summary and ANOVA of tensile strength of 20mm ribbed mild steel bars from company A B and C.

SUMMARY

Groups	Count	Sum	Average	Variance
A	5	2880	576	1200.5
B	5	2981	596.2	496.7
C	5	3052	610.4	214.3

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2988.4	2	1494.2	2.345069	0.138143	3.885294
Within Groups	7646	12	637.1667			
Total	10634.4	14				

The tensile strength obtained after tensile strength test of 20mm ribbed mild steel bars from company A, B and C were analyzed using one factor ANOVA test at a significance level of 0.05 as presented in Table 5.3. Ribbed mild steel bars of company C recorded the highest mean strength of 610.4 N/mm^2, followed by company B which recorded 596.2 N/mm^2 mean strength whiles company A recorded the least mean strength of 576 N/mm^2. From the ANOVA table shown in Table 5.3, the p-value of 0.138143 is greater than the specified significant level of 0.05 and therefore difference in strength between the three companies (ABC) produced is statistically insignificant.

5.3 Chemical Composition

Table 5. 4: Chemical compositions of ribbed mild steel bars

Company	Chemical compositions				CE	VHN
	C	Mn	P	Si		
A	0.126	0.507	0.055	0.126	0.287	255.76
B	0.192	0.277	0.036	0.116	0.323	291.16
C	0.176	0.478	0.037	0.168	0.333	295.38
ASTM (GRADE 250)	0.25	0.60-0.90	0.040	0.060	0.3 0.55	
BS 4449 (GRADE 250)	0.060		0.012	0.055	0.52	
GSA	0.25	1.65	0.05	0.60		

C=Carbon, Mn=Magnesium, P=Phosphorus, S=Silicon, CE=Carbon Equivalent and VHN=Vickers Hardness Number

Sources: actual data from experiments, ASTM A706/A706M-09b, BS 4449:2005 and GS A 573/A 573M: 2014.

5.3.1 Carbon Equivalent Value (CEV)

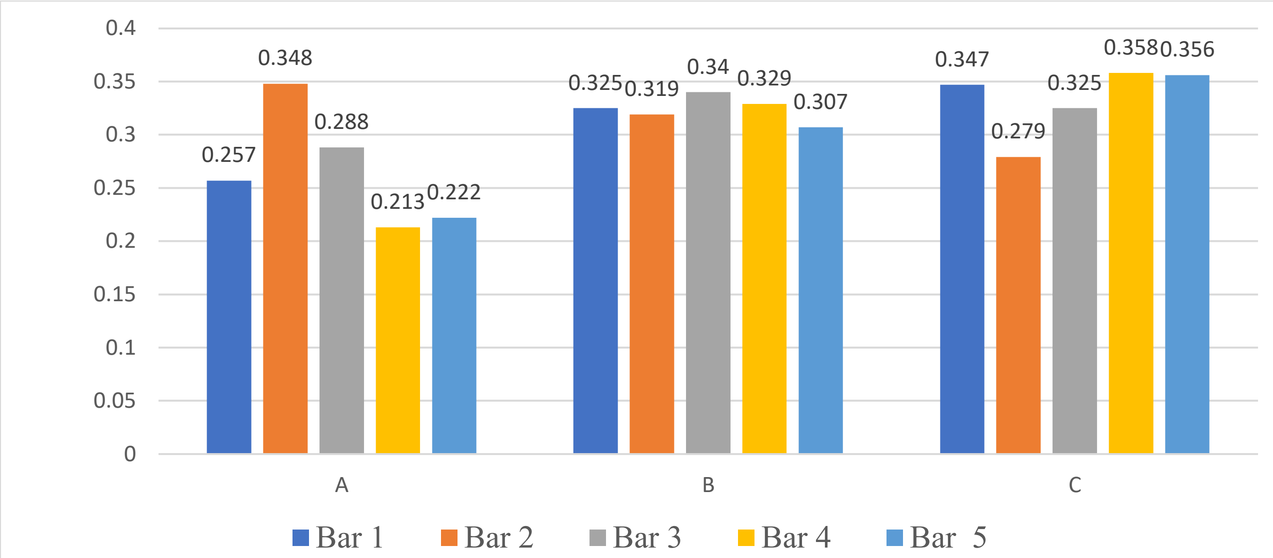


Figure 5. 2: Bar chart of carbon equivalent value (CEV) for chemical composition of 16mm for the three categories of steel production companies (A, B and C).

ASTM A706/A706M-09b specifies maximum contents as 0.25% for carbon, 0.90% for manganese and 0.04 for phosphorus as shown in Table 5.4. The Table also shows specified Maximum contents for BS 4449:2005 and Ghana Standard Authority (GSA). Some of the steel bars obtained acceptable results. The difference in the mechanical strength properties of samples from the two companies' B and C were more significant when the chemical composition was analyzed using carbon equivalent value (CEV). Carbon equivalent value combines seven chemical elements (Carbon, Manganese, Chromium, Molybdenum, Vanadium, Nickel and copper) in a relationship that can be used to draw conclusion based on their percentage.

Based on the companies, (A, B and C) steel bars produced CEV of 0.3% (0.287%), 0.323% and 0.333% respectively which are within the excellent range. The carbon equivalent values obtained from company A, B and C were within the acceptable range of ASTM A706/A706M-09b as shown in Table 5.4. These results build on existing evidence of carbon, manganese, Chromium, silicon and copper being the major elements in their right percentage that influence the toughness of the steel. The results of Ponle et al., (2014) on mechanical properties of reinforcing steel bars produced from recycled scraps, highlighted on the mechanical behavior of a particular steel were significantly influenced by its carbon content. According to Degarmo (2003), Phosphorus and Sulphur are unwanted elements in steels, because they eventually form phosphides and sulphides which do not contribute to the toughness of steel. The study supports Ssempijja (2019) who obtained CEV of 0.3 to 0.55%.

The comparison of the chemical composition of the fifteen (15) ribbed mild steel bars in terms of carbon equivalent value (CEV) is shown as a bar graph in Figure 5.2. According to ASTM A706/A706M-09b, the CEV in the range of 0.3 to 0.55% shows much better mechanical performance of a steel bar better than the CEV above that range. Company B and C had all the ten samples within the excellent range. Only two samples (CEV 4 and CEV 5) from company A are below the excellent range. Company B and C exhibited acceptable percentage because the carbon and phosphorus content in the material met the minimum percentage as specified by ASTM A706/A706M-09b which stated its content of 0.25 and 0.040 respectively. Each category of production company generated almost the same carbon equivalent value with small variations in chemical composition tests across all the materials.

5.3.2 ANOVA for Carbon Equivalent Value (CEV) for 16mm

Table 5. 5: Single factor summary and ANOVA of carbon equivalent value of 16mm ribbed mild steel bars from company A, B and C.

SUMMARY

Groups	Count	Sum	Average	Variance
A	5	1.328	0.2656	0.003008
B	5	1.62	0.324	0.000149
C	5	1.665	0.333	0.001083

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.013391	2	0.006695	4.73744	0.030444	3.885294
Within Groups	0.016959	12	0.001413			
Total	0.03035	14				

The carbon equivalent values of the various 16mm ribbed mild steel bars used in the study were analyzed by conducting one-factor ANOVA test at a significance level of 0.05 as shown in Table 5.5. The mean values of carbon equivalent of 16mm ribbed mild steel bars were used for the ANOVA. There was statistically significant difference between group means as determined by ANOVA (F=4.74, P=0.03). From the ANOVA table shown in Table 5.5 above. Since p-value of 0.030444 is less than the specified significant level of 0.05 and therefore difference to be statistically significant.

5.4 Microstructure

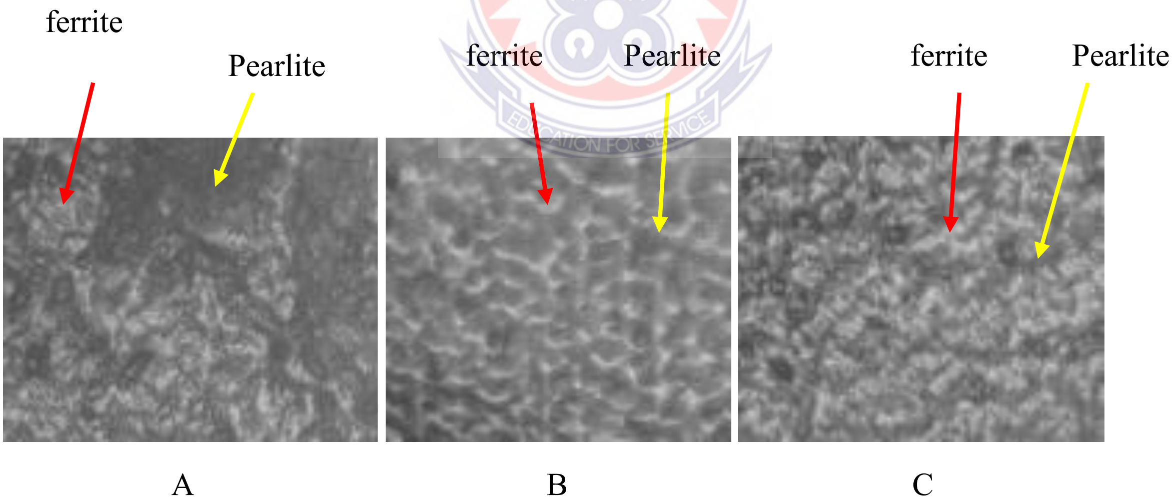


Figure 5. 3: Micrographs of 16mm ribbed mild steel bars for companies (A, B and C).

The core zone microstructure was viewed from Photo Microscope for using 10x magnification lens as shown in Figure 5.3. All the ribbed mild steel bars, regardless of chemical composition and strength level, exhibited a composite microstructure consisting of ferrite and pearlite phases in the core. The micrographs of ribbed mild steel bars do not have any distinct grain boundaries as indicated in Figure 5.3. The micrographs showed ferrites are the white patches which are not clearly visualized and the fine pearlites (ferrites and cementite) are the dark patches that are more visualized. The relatively uneven distribution of phases is visible around some areas in the core for company A. Company B and C had a good distribution of the pearlite and ferrite of the core. This could be the reason why ribbed mild steel bar from company A obtained higher tensile strength than company B and C. The results of the experiment have provided new insight into the relationship between ferrite and perlite. Findings of similar studies from Chen et al. (2017) state that for all steel bars having carbon content above 0.60 carbon in plain carbon steels, a thermal treatment called an anneal is used to modify the microstructure in order to reduce the steel's hardness to prevent from being brittle. Balogun et al. (2009) also worked on Challenges of Producing Quality Construction Steel Bars in West Africa: They found out that the low carbon level is chosen to prevent embrittlement of the steel bar during strain hardening and the development of undesirable microstructure in the heat-affected zone of such steel bars during welding.

5.5 Vickers hardness test

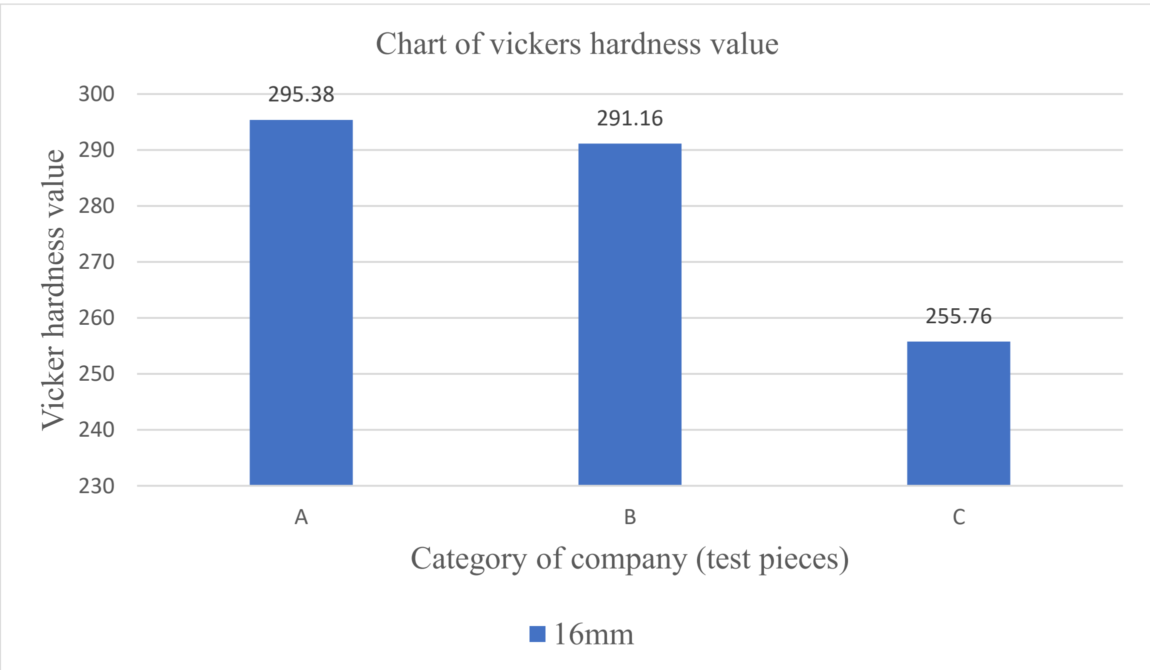


Figure 5. 4: Bar chart of Vickers hardness value of 16mm for the three categories of steel production companies (A, B and C).

Hardness test was performed with Vickers hardness tester on 20mm ribbed mild steel bars produced from companies A, B and C to determine their hardness strength. From Figure 5.4 it can be seen that, the higher the hardness number the lower the carbon equivalent value (Table 4.2) of the ribbed mild steel bars. Company A steel factory has the lowest carbon equivalent CE 0.287 having highest average hardness of 295.38HV, Company B steel factory has higher carbon equivalent CE 0.323 having higher average hardness of 291.16HV and Company C steel factory having the highest carbon equivalent CE 0.333 having the lowest hardness value of 255.76HV. The results show that, the hardness strength for all the companies (A, B and C) obtained is higher than the international standard requirements of Vickers hardness value of 150 HV. The increase in the carbon content leads to the decrease in the hardness of the material. The study supports the findings of George (2007) stating that, the hardening capacity of a steel depends mainly on its carbon content and to a lesser extent on its content of alloying elements and the grain size of austenite grains. To have a reinforcing steel bar of desirable properties, the carbon content is controlled and is usually found to lie in a narrow range of 0.15% to 0.25% as recommended by America Society of Testing Materials and Ghana Standard Authority. The findings of this study supports Ponle et al. (2014) stating that, the higher the carbon content the higher the hardness. This confirms that, percentage elongation decreases as carbon content increases.

5.5.1 ANOVA for Vickers hardness

Table 5. 6: Single factor summary and ANOVA of micro hardness values of 20mm ribbed mild steel bars from company A, B and C.

SUMMARY

Groups	Count	Sum	Average	Variance
A	5	1278.8	295.38	742.393
B	5	1455.8	291.16	3166.523
C	5	1476.9	255.76	8215.682

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4734.521	2	2367.261	0.585733	0.571851	3.885294
Within Groups	48498.39	12	4041.533			
Total	53232.91	14				

The micro hardness obtained after Vickers hardness strength test of 20mm ribbed mild steel bars for company A, B and C were analyzed using one factor ANOVA test at a significance level of 0.05 as presented in Table 5.6. Ribbed mild steel bars of company A recorded the highest mean hardness of 295.38 VHN, followed by company B which recorded 291.16 VHN while company C recorded the least mean hardness of 255.76. From the ANOVA analysis in Table 5.6, the p-value of 0.571851 is greater than the specified significant level of 0.05 and therefore the difference between the hardness values of the steel bars from the three companies (ABC) is not statistically significant.

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS.

6.1 Introduction

This chapter presents the summary of findings, conclusions and recommendations based on the results of investigation into the strength properties of ribbed mild steel bars produced by local companies in Ghana using scraps as their major raw material. The study considered the following objectives; to determine the tensile strength of the ribbed mild steel bars, to examine the chemical compositions of ribbed mild steel bars and to determine the hardness of mild steel bars.

6.2 Summary of Findings

The results of analysis indicated that, the tensile strength of ribbed mild steel bars produced in Ghana fulfilled the ASTM E8/E8M-16a with ultimate tensile strength of 460N/mm^2**.** The highest average tensile strength of 12mm ribbed mild steel bar of 768.4 N/mm^2 was obtained from company A, the highest average tensile strength of 16mm of 713.8m^2 was obtained from Company A and the highest average tensile strength of 20mm of 610.4 N/mm^2 was obtained from Company C. The variation in tensile strength was influenced by the right proportion of the chemical elements which gave the corresponding elongation values of 11.24, 10.03 and 17.08 respectively.

According to the findings for the chemical composition, the carbon equivalent value was examined by using the formula (CE $= C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Ni+Cu}{15}$). Carbon equivalent value combines seven chemical elements (Carbon, Manganese, Chromium, Molybdenum, Vanadium, Nickel and copper) in a relationship that can be used to draw conclusion based on their percentage. all carbon equivalent values (CEV) obtained from company B and C were within the acceptable range of 0.3 to 0.55% as specified by ASTM A706/A706M-09b. Company B and C had all average results of 0.323% and 0.333% respectively which were within the excellent range of the standards, while company A had the lowest CEV of 0.287% which was not within the acceptable range. These findings build on existing evidence of carbon, manganese, Chromium, silicon and copper being the major elements influencing the strength properties of ribbed mild steel bars produced in Ghana.

The study revealed that, in determining the hardness of ribbed mild steel bars it was shown that, the lower the carbon equivalent value the higher the hardness of the ribbed mild steel bars. Company A steel had the lowest carbon equivalent CE 0.287 having highest hardness of 295.38HV, Company B had median carbon equivalent CE 0.323 and a hardness value of 291.16HV while Company C steel had the highest carbon equivalent CE 0.333 and therefore the lowest hardness value of 255.76HV. The results show that, the hardness strength for all the companies (A, B and C) is higher than the international standard requirements of Vickers hardness value of 150 HV. The increase in carbon content leads to increase in the hardness of the ribbed mild steel bars.

6.3 Conclusions

Using scraps as the major raw material for the production of ribbed mild steel bars in Ghana, variation arises owing to grouping of scraps, state of sturdy or shaky machine tool, skill of the operators, perfect tools (improperly profiled, worn out tools), use of coolant, rate of machining all which affect the output of the product etc. With the present available technology, to manufacture several items that are perfectly similar is practically difficult, where ribbed mild steel bars are concerned, the mechanical properties are affected by the impurities contained in the scraps, the particular steel making procedure adopted, as well as the skills of the attendant manpower, the final chemical composition of the resulting steel, rolling procedure, heat treatment adopted etc. Based on the experimental observations and data analysis presented in this research work, the following conclusions can be drawn:

1. It was found out that, the chemical composition of tested ribbed mild steel bars conformed very largely to standards and where values marginally exceeded (in the case of silicon %) the corresponding values of magnesium fall below the maximum specified in the code of ASTM A706/A706M-09b.
2. About 11% of the tested ribbed mild steel samples have their measured diameter equal to the nominal diameter and 89% were smaller than the nominal diameter, which may indicate the high level of diameter inconsistency leading to low level of quality control of the ribbed mild steel bars manufactured.
3. The impurities level (Cu, Ni, Sn and Cr) present in scraps, tramp element content contributed to higher strength and lower ductility of ribbed mild steel bars due to lower bainite fraction, a smaller effective grain size and the precipitation of Cu-rich particle.
4. Generally, there is the need for proper time to time assessment of manufactured ribbed mild steel bars for mechanical properties before any product is used for construction purposes to avoid the problem that may arise due to inconsistency.
5. It would be impossible to produce very good ribbed mild steel bars with good tensile properties like ductility and toughness without manganese as demonstrated in this study.
6. Only about seventy-eight (78%) of the samples have percentage elongation which complies with code values with minimum elongation percentage of 12%.
7. This experimental work on mechanical properties of reinforcing steel bars produced from recycled scraps show characteristic tensile strength of the companies (A, B and C) are higher than the standard of 250N/mm^2 for mild steel.
8. The study therefore, concludes that the proportion of chemical composition influenced the properties of ribbed mild steel bars such as ultimate tensile strength and micro hardness strength of 250 N/mm^2 and 150 HV respectively being the minimum strengths recommended for construction application.

6.4 Recommendations

From the analysis of the results obtained, it can be recommended that:

1. Ghana Standard Board should give more specific values of the mechanical properties such as tensile strength, modulus of elasticity, percentage elongation etc. which are good for each type of constructional work in the country.
2. To manufacturers, it is recommended to control chemical composition contents especially the carbon, magnesium, Sulphur etc. during the production process and maintain its content in the range of the standards.
3. To the end users of ribbed mild steel bars, care must be taken when selecting or using ribbed mild steel bars for construction purposes. It is recommended that before selecting or using ribbed mild steel bars, tensile tests should be carried out on sample of the bars regardless of the mill certificate. This will contribute to the integrity of building structures and prevent any incident that may occur due to the access of sub-standard ribbed mild steel bars in the construction market.
4. A large data should be collected from the same producers over a period of time example every six months to observe the consistency in the production process.
5. Ghana Standard Authority should make sure, acceptable value range stated in the standards are strictly comply by local production companies in Ghana.

6.5 Suggestions for future researcher

In this study, an initial attempt has been taken to investigate the strength properties of ribbed mild steel bars produced by local companies in Ghana. The main motive behind this work was to clearly identify strength properties of the ribbed mild steel bars to enhance quality productions in the country. Future research works from this study can be conducted on the following topics highlighted below:

1. The study of tensile strength values of obtained in the study suggests the ribbed bars are not mild steel and for that matter comparative assessment of mechanical properties of foreign and local mild steel bars.
2. Comparative analysis of microstructure examination on ribbed mild steel bars and ribbed high yield bar produced in Ghana.
3. Examining the deficiency in the bar size and its effect in the design in the construction industry
4. The effect of bending and restraighten of ribbed mild steel bar on tensile strength.
5. Further microstructure examination on ribbed mild steel bars using image technique.

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APPENDICES

APPENDIX A

Average results for chemical composition test of 16mm ribbed mild steel bars.

Cate-gory of com-pany	Speci-men Code	Chemical composition (%)										CEV
		Fe	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	
A	AC1	98.802	0.101	0.469	0.056	0.025	0.086	0.169	0.100	0.202	0.099	0.257
	AC2	98.629	0.185	0.525	0.048	0.034	0.117	0.216	0.082	0.215	0.065	0.348
	AC3	98.449	0.107	0.607	0.047	0.039	0.259	0.208	0.113	0.226	0.066	0.288
	AC4	98.854	0.059	0.471	0.063	0.024	0.085	0.174	0.096	0.204	0.085	0.213
	AC5	98.860	0.071	0.464	0.061	0.026	0.083	0.175	0.094	0.204	0.077	0.222
Aver-age	AC	98.719	0.126	0.507	0.055	0.030	0.126	0.188	0.097	0.210	0.078	0.287
B	BC1	98.814	0.191	0.268	0.027	0.023	0.107	0.197	0.106	0.253	0.093	0.325
	BC2	98.772	0.181	0.279	0.037	0.027	0.124	0.228	0.105	0.256	0.084	0.319
	BC3	98.854	0.220	0.263	0.044	0.028	0.110	0.176	0.101	0.209	0.078	0.340
	BC4	98.776	0.194	0.282	0.044	0.028	0.128	0.203	0.107	0.252	0.083	0.329
	BC5	98.825	0.176	0.295	0.028	0.019	0.113	0.229	0.093	0.229	0.072	0.307
Aver-age	BC	98.808	0.192	0.277	0.036	0.025	0.116	0.207	0.102	0.240	0.082	0.323
C	CC1	98.559	0.188	0.477	0.043	0.027	0.162	0.270	0.105	0.178	0.092	0.347
	CC2	98.696	0.128	0.449	0.029	0.025	0.141	0.264	0.102	0.171	0.088	0.279
	CC3	98.525	0.163	0.516	0.037	0.028	0.212	0.259	0.099	0.173	0.090	0.325
	CC4	98.672	0.211	0.437	0.033	0.019	0.134	0.251	0.099	0.166	0.089	0.358
	CC5	98.524	0.191	0.511	0.041	0.021	0.190	0.248	0.105	0.178	0.104	0.356
Aver-age	CC	98.595	0.176	0.478	0.037	0.024	0.168	0.258	0.102	0.173	0.093	0.333

APPENDIX B

Pieces of ribbed mild steel bars ready for Vickers hardness test.

APPENDIX C

A mixture of 2% nitric acid with 98% ethanol used to etched pieces of ribbed mild steel bars for microstructure examination.

APPENDIX D

Detailed tensile test parameters of 12mm, 16mm and 20mm of ribbed mild steel bars.

Sample Brand	Sam-ple No	Actual Diameter mm	Nominal Diameter mm	Area mm^2	Maxi-mum Load kN	Maxi-mum Tensile Strength N/mm^2	Upper yield Load kN	Upper yield strength N/mm^2	Lower yield load kN	Lower yield strength N/mm^2	Modulus of Elasticity GPa	Displace ment	Elongat ion %
AT	1	18	20	254.47	144.6	568	117.2	461	116.8	459	271.34	68.74	13.76
AT	2	18	20	254.47	161.2	633	135.1	531	134.8	530	/	54.33	10.84
AT	3	18	20	254.47	137.8	542	/	/	/	/	186.32	54.17	10.83
AT	4	18	20	254.47	147.3	579	/	/	/	/	/	55.31	11.06
AT	5	18	20	254.47	142	558	113.8	447	113.7	447	275.08	63.12	12.62
Average AT		**18.00**	**20.00**	**254.47**	**146.6**	**576.00**	**122.0**	**479.67**	**121.77**	**478.67**	**244.25**	**59.14**	**11.83**
AT	1	14	16	153.94	107.1	696	88.8	577	88.6	576	302.21	50.93	10.19
AT	2	14	16	153.94	108.6	705	/	/	/	/	197.59	55.63	11.13
AT	3	14	16	153.94	104.4	678	86.45	562	85.9	558	221.95	57.75	11.55
AT	4	14	16	153.94	126.2	820	/	/	/	/	/	41.43	8.29
AT	5	14	16	153.94	103.2	670	86	559	84.2	547	210.1	45.13	9.03

Average AT		**14.00**	**16.00**	**153.94**	**109.9**	**713.80**	**87.08**	**566.00**	**86.23**	**560.33**	**232.96**	**50.17**	**10.03**
AT	1	10	12	78.54	61.9	788	52.7	671	52.1	663	211.63	59.77	11.95
AT	2	10	12	78.54	56	713	/	/	/	/	282.66	57.70	11.54
AT	3	10	12	78.54	62.4	794	52.8	672	52.75	672	301.17	56.61	11.32
AT	4	10	12	78.54	61.15	779	52.9	674	2.3	29	/	56.06	11.21
AT	5	10	12	78.54	60.35	768	51.65	658	51.25	653	228.43	50.81	10.16
Average AT		**10.00**	**12.00**	**78.54**	**60.36**	**768.40**	**52.51**	**668.75**	**39.60**	**504.25**	**255.97**	**56.19**	**11.24**
BT	1	18	20	254.47	144.6	568	/	/	/	/	225.57	88.59	17.72
BT	2	18	20	254.47	155.9	613	100.8	396	100.4	395	192.8	83.56	16.71
BT	3	18	20	254.47	146.6	576	99	389	97.5	383	181.14	94.21	18.84
BT	4	18	20	254.47	156.1	613	102.3	402	101.7	400	175.15	92.49	18.50
BT	5	18	20	254.47	155.5	611	/	/	/	/	236.54	94.70	18.94
Average BT		**18.00**	**20.00**	**254.47**	**151.7**	**596.20**	**100.7**	**395.67**	**99.87**	**392.67**	**202.24**	**90.71**	**18.14**
BT	1	14	16	153.94	85.15	553	58.25	378	58.2	378	212.37	84.57	16.91

BT	2	14	16	153.94	96.5	627	68.3	444	67.15	436	259.84	85.35	17.01
BT	3	14	16	153.94	89.95	584	/	/	/	/	224.86	91.41	18.28
BT	4	14	16	153.94	86.75	564	58.55	380	57.5	374	282.58	98.04	19.61
BT	5	14	16	153.94	89.7	583	62.4	405	61.9	402	207.64	93.87	18.77
Average BT		**14.00**	**16.00**	**153.94**	**89.61**	**582.20**	**61.88**	**401.75**	**61.19**	**397.50**	**237.46**	**90.65**	**18.13**
BT	1	10.5	12	86.59	51.85	599	36.9	426	36.5	422	/	89.75	17.95
BT	2	10.5	12	86.59	51.65	596	36.5	422	36.45	421	235.59	82.75	16.55
BT	3	10.5	12	86.59	50.85	587	36.9	426	36.4	420	233.28	94.69	18.94
BT	4	10.5	12	86.59	47.6	550	34.8	402	34.7	401	217.12	92.62	18.52
BT	5	10.5	12	86.59	51.65	596	36.65	423	36.4	420	205.09	81.46	16.29
Average BT		**10.50**	**12.00**	**86.59**	**50.72**	**585.60**	**36.35**	**419.80**	**36.09**	**416.80**	**222.77**	**88.25**	**17.65**
CT	1	19.5	20	298.65	180.4	604	139.6	467	139.2	466	206.68	94.16	18.83
CT	2	19.5	20	298.65	181.3	607	142.4	477	141.6	474	275.48	82.03	16.41
CT	3	19.5	20	298.65	180.9	606	141.1	472	140.9	472	/	78.91	15.78

CT	4	19.5	20	298.65	178.9	599	139.9	468	138.7	464	258.41	104.4	20.88
CT	5	19.5	20	298.65	190	636	145.3	487	144	482	212.07	67.58	13.52
Average CT		**19.50**	**20.00**	**298.65**	**182.3**	**610.40**	**141.7**	**474.20**	**140.88**	**471.60**	**238.16**	**85.42**	**17.08**
CT	1	14	16	153.94	95.35	619	77.6	504	75.85	493	206.79	59.60	11.92
CT	2	14	16	153.94	96.3	626	76.35	496	75.7	492	192.85	72.99	14.50
CT	3	14	16	153.94	96.8	629	/	/	/	/	213.92	59.91	11.98
CT	4	14	16	153.94	94.7	615	/	/	/	/	212.8	70.93	14.19
CT	5	14	16	153.94	97.65	634	/	/	/	/	/	62.17	12.43
Average CT		**14.00**	**16.00**	**153.94**	**96.16**	**624.60**	**76.98**	**500.00**	**75.78**	**492.50**	**206.59**	**65.12**	**13.02**
CT	1	10	12	78.54	51.25	653	/	/	/	/	211.52	49.85	9.97
CT	2	10	12	78.54	50.3	640	/	/	/	/	/	53.34	10.67
CT	3	10	12	78.54	50.45	642	47	598	46.2	588	258.9	47.83	9.57
CT	4	10	12	78.54	52.85	673	45.95	585	45.6	581	269.93	59.12	11.82
CT	5	10	12	78.54	48.2	614	/	/	/	/	/	53.87	10.77
Average CT		**10.00**	**12.00**	**78.54**	**50.61**	**644.40**	**46.48**	**591.50**	**45.90**	**584.50**	**246.78**	**52.80**	**10.56**

APPENDIX E

Introductory letters to production companies

AM-STED

AKENTEN APPIAH-MENKA
UNIVERSITY OF SKILLS TRAINING AND ENTREPRENEURIAL DEVELOPMENT
DEPARTMENT OF CONSTRUCTION AND WOOD EDUCATION

P.O.Box 1277, Kumasi Ghana
+233 (0)20 2041116/ (0)20 4743348
info@aamusted.edu.gh
+233 (0)20 511906/ (0)20 204 1037

The General Manager
Ferro Fabrik Limited
P. O. Box 303
Heavy Industrial Area, Tema

May 26, 2021

Dear Sir,

LETTER OF INTRODUCTION

I write to introduce **Mr. Sumaila Mohammed,** a student with index No. **200004276** pursuing M.Phil (Construction Technology) Programme at the Akenten-Appiah Menka University of Skills Training and Entrepreneurial Development (AAMUSTED) formerly College of Technology Education, Kumasi Campus of the University of Education, Winneba.

Mr. Sumaila Mohammed is undertaking a research project and wishes to seek assistance from your establishment to enable him work on his Dissertation.

His research project is titled **"Investigating into the Strength Properties of Ribbed Mild Steel Bars Produced in Ghana".**

Please kindly offer him the needed assistance.

Thank you.

Your sincerely,

Dr. Nongiba A. Kheni
Ag. Head, Department of Construction and Wood Technology Education

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The General Manager
Tema Steel Company Limited
P.O. Box PMB KIA 320
Heavy Industrial Area, Tema

May 26, 2021

Dear Sir,

LETTER OF INTRODUCTION

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The General Manager
Sentuo Steel Limited
P. O. Box TM 1518
Heavy Industrial Area, Tema.

May 26, 2021

Dear Sir,

LETTER OF INTRODUCTION

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Dr. Nongiba A. Kheni
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