CHARACTERISATION OF REINFORCING STEEL BARS IN THE NIGERIAN CONSTRUCTION INDUSTRY

BY

MOHAMMED UMAR JIBRIN

DEPARTMENT OF CIVIL ENGINEERING,
FACULTY OF ENGINEERING,
AHMADU BELLO UNIVERSITY,
ZARIA, NIGERIA.

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MOHAMMED UMAR JIBRIN
Ph.D/Eng/40010/2004-2005

A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY (PhD) DEGREE IN CIVIL ENGINEERING.

DEPARTMENT OF CIVIL ENGINEERING,
FACULTY OF ENGINEERING,
AHMADU BELLO UNIVERSITY, ZARIA – NIGERIA.

AUGUST, 2012

CERTIFICATION

This project dissertation entitled **"CHARACTERIZATION OF REINFORCING STEEL IN THE NIGERIAN CONSTRUCTION INDUSTRY"** by Mohammed Umar Jibrin meets the regulations governing the award of the degree of Doctor of Philosophy (Ph.D) in Civil Engineering, of Ahmadu Bello University, Zaria and is **approved** for its contribution to knowledge and literary presentation.

Professor S. P. Ejeh	----------	----------
Chairman, Supervisory Committee	Signature	Date
Dr. Y. D. Amartey	----------	----------
Member, Supervisory Committee	Signature	Date
Dr. I. Abubakar	----------	----------
Member, Supervisory Committee	Signature	Date
Dr. I. Abubakar	----------	----------
Head of Department	Signature	Date
Professor A. A. Joshua	----------	----------
Dean, School of Post Graduate Studies	Signature	Date

DECLARATION

I hereby declare that this dissertation has been composed by me and that it is a record of my own research. It has not been accepted in any previous application for a higher degree. All quotations and other sources of information are specifically acknowledged by means of references.

_____ _____

Mohammed Umar Jibrin Date

Ph.D/ENG/40010/2004-2005

DEDICATION

This research is dedicated to my beloved Father, Alhaji Jibrin Mohammed of blessed memory who initiated me towards the process of acquiring education from primary school up to Master of Science in Civil Engineering. He gave all encouragements towards furthering my education up to Ph.D. level, but did not wait to see me through for God's best known reasons.

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For errors, omissions and observed infirmities that remain, I of course acknowledge as my own responsibility.

ABSTRACT

This research entitled "Characterization of Reinforcing Steel Bars in The Nigerian Construction Industry" was undertaken to find out the physical and chemical properties of the reinforcing steel bars used in the Nigerian Construction Industry. The study investigated the tensile, bending and chemical composition parameters of the steel bars in relation to their level of conformity with the standards. Samples from 418 pieces of bars from 19 companies were used in the experiment and 1520 test results were obtained. It was found that all the samples tested short of expectations of BS4449:1997 in at least one parameter tested. Eighty five percent (11/13) of the local bars tested did not comply with the characteristic strength provisions while the corresponding ductility figures are satisfactory for eighty five percent (11/13) of the bars. It was further established that the foreign bars, despite complying with the code in characteristic strength, have performed below expectations in ductility implying they can fail without warning. It was also noted that the tested reinforcing steel bars have not reasonably agreed in terms of chemical concentrations and percentage composition. There seems to be a lot of impurities in the samples as evidenced by the uncontrolled presence of sulphur, phosphorus and nitrogen. Although, the Carbon equivalent (C.eqv.) values are within acceptable range, there is a conspicuous absence of some critical elements such as Vanadium and Molybdenum that are supposed to be important determinants of strength and ductility.

LIST OF ABBREVIATIONS

1. Al……..Aluminium
2. ASTM……..…American Standard for Testing & Measurements
3. Ba…….Barium
4. BFM…….Blast Furnace Method
5. Br……..Bromine
6. BS…….British Standard
7. BSI…….British Standard Institution
8. C……Carbon
9. Ca……..……Calcium
10. CARES…….Certification Authority for Reinforcement Steels
11. Cl…….… Chlorine
12. Co……..…Cobalt
13. COREN……Council for the Regulation of Engineering in Nigeria
14. Cd…….Cadmium
15. C.eqv……...Carbon Equivalent Value
16. CERT……..Centre for Energy Research & Training
17. Cr…….Chromium
18. Cu…….Copper
19. DRM……..Direct Reduction Method
20. ERM……..Engineering Regulation & Monitoring
21. Fe…….Iron
22. f_y…….Characteristic strength of steel
23. Ga…….Gallium

24. Ir……Iridium

25. ISO……International Standards Organization

26. MAØ…….Mean Actual Diameter as measure

27. MIT…… Massachusetts Institute of Technology

28. Mn……Manganese

29. Mo…..……Molybdenum

30. µ……..... Mean

31. N…….…... Nitrogen

32. NARICT…….National Research Institute for Chemical Technology

33. Ni……..…..Nickel

34. NCP…….…...Nigerian Code of Practice

35. NIS……..…Nigerian Industrial Standard

36. NSE……Nigerian Society of Engineers

37. Os……Osmium

38. Ø……..Diameter of Sample

39. P……..…..…. ..Phosphorus

40. Pb……..…….. Lead

41. Re……Rhenium

42. Rh……Rhodium

43. Pt…….Platinium

44. ∑…….……Summation

45. S……...……Sulphur

46. SD……..…. Standard Deviation

47. Si…….Silicon

48. SON…….Standards Organisation of Nigeria

49. Sn…….Tin

50. Te ……Tellurium

51. Ti……..Titanium

52. V……..Vanadium

53. Zn…….Zinc

54. Zr…….Zirconium

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CHAPTER ONE

INTRODUCTION

1.1 PREAMBLE

The reported cases of structural collapse in most states of the federation are on the increase. The outcome of the investigations by the Engineering Regulation and Monitoring (ERM) Committee and Council for the Regulation of Engineering in Nigeria are pointing accusing fingers at unqualified personnel as well as substandard materials used in the Nigerian Construction Industry [ERM – Kano Zonal Inspectorate (2011)]. Thus reinforcing steel plays a key role as a construction material whose properties must be known prior to applications in structural design.

According to UK Cerification Authority for Reinforcing Steels (CARES Part 1), for a reinforcing steel bar to be used in any reinforced concrete work, it must satisfy some vital criteria amongst which are:

Bend test.

Possess adequate strength to discharge its load bearing function.

Possess ductility for functionality and sufficient warning prior to failure.

Possess good weldability for site fabrication and to minimize accidental damage.

Possess good bond properties.

All metallurgical processes and controls must be in place to accommodate the requirements by the manufacturer.

Steel reinforcing bars available in the Nigeria's Building Industry are obtained from both internal and external sources. The former comes mainly from the major steel plants in Nigeria such as Delta, Osogbo, Katsina amongst others and the foreign dominated Nigerian based mini mills that started operation in the country since around 1956. Imported steel bars coming into the country are mainly from Russia and Ukraine. Others are those imported for specific uses by multinational companies. Field survey conducted has revealed that most construction companies in Nigeria make

all their reinforcing steel procurements from the open markets and it is a known fact that these products are not sold along with accompanying technical information that will aid design. The Survey also indicated that some of these products have been rebarred. It has also been observed that some of the reinforcing steel from foreign sources does not have any traceable history such as country of origin or specifications.

Thus, there is a need for a complete understanding of the properties of the reinforcing steel bars in the Nigerian Construction Industry so that all associated short comings can be properly taken into cognisance for best structural applications within the building industry.

1.2 STATEMENT OF THE RESEARCH PROBLEM

As we all know, Abuja is one of the biggest construction sites in the world. Many reinforcing steel test results that were conducted in reputable laboratories such as the heavy concrete laboratory of Ahmadu Bello University, Zaria have failed test to meet the BS4449(1997) requirements. This might have accounted for many foundations been blown up. Thus, quality tests on the reinforcing steel in the Nigerian Construction Industry can not be over emphasized.

Thus, information on the strength, deformation characteristics and chemical composition of the reinforcing steel bars used in the Nigerian Construction Industry in relation to codes such as BS4449(1997) provisions need to be known.

1.3 AIM AND OBJECTIVES OF THE STUDY

1.3.1 AIM OF THE STUDY

The aim of the research was to determine the properties of reinforcing steel bars in the Nigerian Construction Industry.

1.3.2 OBJECTIVES OF THE STUDY

The objective of the study is to examine the properties and quality of reinforcing steel bars in the Nigerian Construction Industry. This involves determination of the strength and deformation characteristics of the reinforcing steel bars with respect to properties known to have adverse effect on fitness for use in design and construction. The specific objectives of this study are to determine:

The tensile characteristics of the reinforcing steel bars used in the Nigerian Construction Industry.

The bending behaviour of the steel bars used in the Nigerian Construction Industry.

The chemical composition of the reinforcing steel bars used in the Nigerian Construction Industry.

The effect of the elemental composition on the strength of the reinforcing steel bars used in the Nigerian Construction Industry.

1.4 SIGNIFICANCE OF THE STUDY

This study is a reawakening of the consciousness of all key players in the Nigerian Construction Industry on the need to properly examine the properties of building materials especially reinforcing steel in the Nigeria market beyond the index of physical properties to the measure of chemical, textural and structure composition before putting into use.

The relevance of this study to particularly practising engineering personnel cannot be overemphasized. Apart from igniting curiosity and further research into steel manufacturing processes, relevance and use, this study will assist them to further appreciate the place of steel in civil engineering works and their specific use, raw material composition, and how a blend of them could be used to produce the best properties steel products.

This study also draws the attention of the government as well as regulatory bodies to critically examine the properties of steel used in the Nigerian Construction Industry with a view to

making efficient laws to properly control the steel industry in Nigeria and the importation of reinforcing steel bars from foreign countries so as to put a lasting solution to the incidence of collapse of buildings which the country frequently experiences. Thus, this study will agitate the government to tackle smuggling of steel bars into Nigeria especially those without relevant agencies approval and registration.

The study will also educate the public to stop patronizing reinforcing steel bars with unknown history even as it arouse buyers curiosity to demand for a strength compliance certificate before procurement so that only confirmatory test will be conducted before commencement of construction works.

1.5 SCOPE AND LIMITATION

This study is limited to the tensile strength, bending test and chemical properties of reinforcing steel bars.

1.6 RESEARCH OUTCOME

It was found that most steel bars produced in Nigeria fall short of code requirements in terms of characteristic strength, bending and chemical composition. On the other hand, the foreign bars despite their compliance with the code provisions in tensile properties fall below the code specifications in respect of elongation requirements. Notably, all the bars tested showed significant deviation in terms of chemical composition, as there is no point of convergence amongst all the samples considered.

CHAPTER TWO

LITERATURE REVIEW

2.1 PREAMBLE

The literature review comprises an overview of some selected scholarly related works on tensile tests, bend tests and chemical composition of reinforcing steel bars that have been undertaken by researchers from recognised institutions. The chapter also discusses provisions made by some British Standards (BS4449: 1966 & 1997), American Standards for Testing and Measurement (ASTM A38/A38M).It also discussed the steel industry in some selected countries across the world – Inuwa (2011) and the standard manufacturing processes for reinforcing steel – Omoweh (2005).

Steel is an alloy consisting mostly of Iron, with carbon content ranging from 0.05% to 2.1% by weight, depending on grade (Steel Wikipedia). Carbon is the most cost effective alloying mineral for iron. However, alloying elements such as manganese, chromium, vanadium, tungsten and many others are either found or included. Alloys with higher carbon content are known as cast iron because of their lower melting point and castability. Steel is also distinguished from wrought iron as the latter can contain smaller amount of carbon in the form of slag inclusions. Two distinguishing factors of steel are increased rust resistance and better weldability.

Reinforcing steel possesses many properties. However, the ones whose specifications were given by codes such as BS, ASTMs, Euro codes and many others are the tensile properties, bend test and chemical composition.

2.2 REQUIREMENTS FOR REINFORCING STEEL

The UK Certification Authority for Reinforcing Steels (UK CARES Part 1) has prescribed that a satisfactory reinforcing steel must be able to:-

Be bent into shape with precision to fit complicated structures.

Possess a minimum strength to discharge its load bearing function.

Possess ductility to satisfy formability requirements to be bent into the designed shape and also sufficient ductility to provide progressive failure under certain conditions.

Possess good weldability in part, for site fabrications and in part to minimize damage.

For many structures of particular design, possess good fatigue properties.

Possess good bond properties.

The authority (UK CARES Part 1) went further to highlight some conflicts that often arise such as between strength and ductility or between strength and weldability which must be sorted through metallurgical controls during manufacturing processes. .

2.3 TENSILE TESTS

In the research conducted on "Verification of Properties of Concrete Reinforcement Bars": Nigeria as a case Study: - Arum, C.(2008) considered ribbed local and foreign bars of nominal diameters 10,12,16,20 and 25 mm from recognised and non recognised ISO origins for his investigations. He chose Lagos, Ibadan, Akure and Ife 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 recognisable origin have satisfied both local and ISO requirements for strength and ductility. But, those from non

recognisable origin failed to satisfy the same requirements for high tensile bars, but satisfied the local specifications for mild steel bars.

The related study conducted by Charles K.K and Mark A. (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 were investigated as these products are 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. Charles K.K and Mark A. (2002) concluded that the bars were characterised by inconsistencies in characteristic strength and ductility. The experiment did not include any bend test for comparison sake with the elongation values.

2.4 BEND TESTS

ASTM A370 -87b "Mechanical Testing of Steel Products" PP. 714 states- Bend test is one of the methods for evaluating ductility, but it cannot be considered as a quantitative means of predicting service performance in bending operations. The severity of the bend test is primarily a function of the angle of bend and inside diameter to which the specimen is bent and of the cross section of the specimen.

According to the European Standard Pr EN 10080:2005 (E) the bend test if required, shall be performed in accordance with the EN ISO 15630 with a minimum angle of bend 180^o. After testing,

the products shall show neither signs of rupture nor cracks visible to the person of normal or corrected vision.

Bend test has not been recommended by any known code as a means of evaluation of ductility. Thus, elongation tests must also be conducted.

2.5 CHEMICAL COMPOSITION

The chemical composition of Steel may vary with the source of the constituent raw materials and the production processes. According to BS4449 (1997), Carbon, Manganese, Chromium, Molybdenum, Vanadium, Nickel and Copper apart from being strength determinants, they are important coefficient of weldability parameters whose percentage composition limits as provided must not be exceeded. The code also provided for the percentage composition of many other elements that are commonly found to constitute reinforcing steel. In the steel production processes, some elements such as Nitrogen and sulphur are commonly found and their presence must be controlled during production due to their adverse effects on strength and deformation characteristics of the reinforcing steel.

In addition to these essential elements, numerous others such as Aluminium, Bromine, Tungsten, Iridium, Zirconium and many others can also be traced during analyses either as impurities, fillers or deliberately added to achieve a specific objective.

Various codes have made different prescriptions on the percentage composition of reinforcing bars.

BS4449(1997) has prescribed the following:

TABLE 2.1 CHEMICAL COMPOSITION OF STEEL GRADES: CAST ANALYSIS.

S/No.	Element	Steel Grade 250% (maximum)	Steel Grade 460% (maximum)
01	Carbon	0.25	0.25
02	Sulphur	0.060	0.050
03	Phosphorus	0.060	0.050
04	Nitrogen	0.012	0.012

Source: BS4449 - 1997

NOTE:

1. The maximum value for Nitrogen does not apply if the composition shows a minimum Aluminum content of 0.020% or if sufficient other Nitrogen binding elements are present.

2. Nitrogen content is not normally given on a release certificate.

The European Standard Pr EN 10080:2005 (E) clause 7.1.2 to 7.1.3 states that the maximum values for the following elements shall be:-

TABLE 2.2 MAXIMUM VALUES FOR SOME ELEMENTS (EUROPEAN STANDARD)

	Carbon(Max)	Sulphur (Max)	Phosphorus(Max)	Nitrogen(Max)	Copper(Max)	Ceq (Max)
Cast Analysis	0.22	0.050	0.050	0.012	0.80	0.50
Product Analysis	0.24	0.055	0.055	0.014	0.85	0.52

Source:Pr EN 10080:2005 (E) clause 7.1.2 to 7.1.3

The code further stated that it is permitted to exceed the maximum values for carbon by 0.033% by mass, provided that the carbon equivalent value is decreased by 0.02% by mass. Similarly, higher Nitrogen contents are permissible if sufficient quantities of its binding elements are present. ASTM – A38/A38M (25th Edition of 1988, pp.105) has also provided the following:

TABLE 2.3 CHEMICAL COMPOSITION OF STEEL GRADES:

Element (Maximum Percentage)	Bar Size (up to 20mm)	Bar Size (20mm – 40 mm)
Carbon	0.26	0.27
Manganese	Nil	0.60 – 0.90
Phosphorus	0.04	0.04
Sulfur	0.05	0.05
Silicon	Nil	Nil
Copper (min) for copper steel	0.20	0.20

Source: ASTM – A38/A38M (25th Edition of 1988, pp.105)

Manganese content of (0.85 to 1.35)% and Silicon content of (0.15 – 0.40) % is not applicable to bars, but for required shapes over 634 Kg/m .

According to STO ASChM 7-93 (Steel Grade Standard with application to concrete reinforcement) as certified by the Russia Scientific & Research Institute of Steel, the chemical composition of steel has been prescribed table 2.4 below:

TABLE 2.4 CHEMICAL COMPOSITION LIMITS FOR REINFORCING STEEL BASED ON RUSSIAN STANDARDS:

	C	Si	Mn	P	S	Cr	Ni	Cu	N
MINIMUM	0.18	-	0.08	-	-	-	-	-	-
MAXIMUM	0.22	0.15	1.00	0.040	0.050	0.30	0.30	0.30	0.012

Source: Russian Scientific & Research Institute of Steel.

The Chinese standard GB/T 17107 gave their specifications which recognised the presence of Molybdenum and Vanadium with no imposed limit unlike the BS and the Russian standards in table 2.5 below:

TABLE 2.5 CHEMICAL COMPOSITION LIMITS FOR REINFORCING STEEL BASED ON CHINESE STANDARDS:

Chinese Symbol	ISO	C	Si	Mn	Cr	Ni	Mo	V	S	P	Cu
Q235	Fe360-A	0.14~0.22	<0.30	0.30~0.65	<0.30	<0.30	-	-	< 0.05	< 0.045	<0.30
15	Fe360-A	0.12~0.19	0.17~0.37	0.35~0.65	<0.25	<0.25	-	-	< 0.035	< 0.035	<0.25
20	–	0.17~0.24	0.17~0.37	0.35~0.65	< 0.25	< 0.25	-	-	< 0.035	< 0.035	< 0.25
25	–	0.22~0.30	0.17~0.37	0.50~0.80	< 0.25	< 0.25	-	-	< 0.035	< 0.035	< 0.25
30	C25E4	0.27~0.35	0.17~0.37	0.50~0.80	< 0.25	< 0.25	-	-	< 0.035	< 0.035	< 0.25
35	C30E4	0.32~0.40	0.17~0.37	0.50~0.80	< 0.25	< 0.25	-	-	< 0.035	< 0.035	< 0.25
40	C35E4	0.37~0.45	0.17~0.37	0.50~0.80	< 0.25	< 0.25	-	-	< 0.035	< 0.035	< 0.25
45	C40E4	0.42~0.50	0.17~0.37	0.50~0.80	< 0.25	< 0.25	-	-	< 0.035	< 0.035	< 0.25
50	C45E4	0.47~0.55	0.17~0.37	0.50~0.80	< 0.25	< 0.25	-	-	< 0.035	< 0.035	< 0.25
55	C50E4	0.52~0.60	0.17~0.37	0.50~0.80	< 0.25	< 0.25	-	-	< 0.035	< 0.035	< 0.25

Source: Chinese Standard GB/T 17107-1997

Sharp (1966) in his studies of the properties of steel concluded that "by nature of the raw materials and method of manufacture, all steel products contain varying amounts of alloying minerals such as sulphur, manganese, phosphorus and traces of other elements, if other elements are added to the steel, such as chromium, cobalt, or nickel, the steel becomes an alloy steel". Steels are described as mild, medium- or high-carbon steels depending on the percentage of carbon they contain, although this is never greater than about 1.5%. Kareem, B. (2009), in his related studies,

corroborated the earlier statement by confirming that the classification of steel into various grades is done based on the percentage composition of carbon which usually ranges from 0.05% to 0.15 %.

The percentages of carbon and other elements such as Manganese, Molybdenum, Vanadium, Silicon, Chromium, Nitrogen and Sulphur in steel have a direct effect on its strength and deformation characteristics - John (1993), Amstead (1987), Colin (1987), and Kareem, B. (2002). This implies that the chemical composition of steel is a determinant of its classification, strength and deformation characteristics such as yield and tensile strengths, elongation and bendability which are important to engineers in the design of safe, functional and economical structure.

They further asserted that steel grades with a high level of dissolved gases, particularly oxygen and nitrogen, if not controlled by addition of small elements with a particular affinity for them to float out in the liquid steel at high temperature, can behave in a brittle manner. Manganese, chromium, molybdenum, nickel and copper also affect the strength to a lesser extent than carbon, although their sole effect is on the microstructure of the steel Charles, K.K and Mark, A. (2002) also stated that varying the amount of alloying elements and the form of their presence in the steel (solute elements, precipitated phase) controls properties such as the hardiness, ductility, and tensile strength of the resulting steel. Steel with increased carbon content can be made harder and stronger than iron, but such steel is also less ductile than iron.

Kareem, B. (2009) referred to previous literatures by Skinner and Rogers (1979), Walker, R.D. (1986) and Gilchrist, J.D (1989) relating to the oxidation of carbon in steel and its relationship with harness as highlighted by John, V.B.(1983), Amstead, B.H. (1987) and Colin, R. (1987). They investigated the tensile and chemical composition of some selected locally produced reinforcement bars and compared the results with global standards. It was concluded that the physical properties of the selected bars are in good agreement with what is obtainable in both local and international

standards except in the case of the chemical analysis results where it was discovered that the percentage carbon content in steel is relatively low as compared to similar local product.

The definitions made in the Wikipedia (2010) & studies conducted by John, V.B. (1983), Amstead, B.H (1987), Colin, R.(1987), Kareem, B. (2002), MIT (1999) and Carbon steel (Carbon steel structure & composite journal-2008) revealed the relevance of the following elements as constituents of reinforcing steel.

Aluminium is added as a deoxidizer and also helps form a more fine-grained crystalline micro structure and is usually used in combination with silicon to form a semi or fully killed steel. Source: MIT (1999).

Calcium is added for sulphide-inclusion and shape control which increases formability. Source: **Carbon Steel (2008).**

Carbon: Carbon is the most common and important alloying element in steel that acts as a hardening agent, prevents dislocations in the iron atom crystal lattice from sliding past one another and can exist either dissolved in the iron or in a combined form, such as iron carbide. On the other hand, increased amounts of carbon reduce weldability. Increased amounts of carbon increase hardness and tensile strength as well as response to heat treatment (hardenability), with a corresponding decrease in ductility. According to Ashby, M.F. (1992), Carbon is the most common alloying material for iron, but various other alloying minerals are used which include manganese, chromium, vanadium and tungsten.

Chromium: Chromium is a powerful alloying element in steel. It is added for two principal reasons: first, it greatly increases the hardenability of steel; second, it markedly improves the corrosion resistance of iron and steel in oxidizing types of media. Its presence in some steels could

cause excessive hardness and cracking in and adjacent to the weld. Stainless steels contain chromium in amounts exceeding 12%. Source: Carbon Steel (2008).

Copper is added in the reinforcement steel to increase its strength and corrosion resistance. Source: Carbon Steel (2008).

Manganese: Manganese to a great extent controls machinability. Steels usually contain at least 0.3% manganese, which acts in a three-fold manner: it assists in deoxidation of the steel, prevents the formation of iron sulfide inclusions, and promotes greater strength by increasing the hardenability of the steel. BS 4449 has specified that amounts up to 2 % are commonly found in carbon steels. Manganese (up to 2%) and small quantities of Nitrogen, Chromium, Molybdenum, Titanium, Calcium and Niobium are also added for strengthening purposes. Source: Carbon Steel (2008).

Molybdenum: This element is a strong carbide former and is usually present in alloy steels in amounts less than 1.0%. It is added to increase hardenability and strength at high temperature. Source: Carbon Steel (2008). Typical amounts are 0.08 to 0.25 percent. Source: MIT (1999).

Nickel: Nickel is added to steels to increase its strength, corrosion resistance and hardenability. It performs well in this function because it often improves the toughness and ductility of the steel, even with the increased strength and hardness. Nickel is frequently used to improve steel toughness at low temperatures. Source: Carbon Steel (2008).

Niobium (Columbium): According to Carbon Steel (2008), the element behaves like vanadium and is generally considered to increase the hardenability of steel. However, due to its strong affinity for carbon, it can combine with carbon in the steel to result in an overall decrease in hardenability.

According to MIT (1999), Columbium is a strength enhancement element. Its effects are similar to those of manganese and vanadium and also has some corrosion resistance influence.

Nitrogen: Apart from being added for strengthening purposes it is related to bendability. Source: Carbon Steel (2008).

Phosphorus: Phosphorus is also considered to be an undesirable impurity in steels. It is normally found in amounts up to 0.04% in most carbon steels. Its presence must be controlled because excessive levels lead to brittle fracture and cracking problems in welded joints. For modern steel-making practice, phosphorus is preferably maintained at less than 0.005%. In hardened steels, it tends to cause brittleness. In low-alloy, high-strength steels, phosphorus can be added in amounts up to 0.10% to improve both strength and corrosion resistance, although it is not generally added for this reason in carbon steels. Source: Carbon Steel (2008).

Rare Earth Elements are added for sulphide-inclusion and shape control which increases formability. Source: Carbon Steel (2008).

Silicon: Is added in the reinforcement steel to increase its strength and corrosion resistance.Usually, only small amounts (0.2%, for example) are present in rolled steel when silicon is used as a deoxidizer. However, in steel castings, 0.35–1.0% is common. Silicon dissolves in iron and tends to strengthen it. Weld metal usually contains approximately 0.5% silicon as a deoxidizer. Some filler metals can contain up to 1.0% to provide enhanced cleaning and deoxidation for welding on contaminated surfaces. When these filler metals are used for welding of clean surfaces, the resulting weld metal strength will be markedly increased. The resulting decrease in ductility could present cracking problems in some situations. Source: Carbon Steel (2008). Along with Aluminium, Silicon is one of the deoxidizers in structural steel and appears in amounts less than 4%. Source: MIT (1999).

Sulphur: This is an undesirable impurity in steel rather than an alloying element. Special effort is made to eliminate or minimize sulfur during steelmaking. In amounts exceeding 0.05%, it tends to cause brittleness and reduce weldability. Additions of sulfur in amounts from 0.1% to 0.3% will tend to improve the machinability of steel but impair weldability. These types of steel can be referred to as free machining. Silicon, Sulphur is associated with impurities whose presence must be controlled. Excessive levels of sulphur, which is a non-metallic impurities lead to brittle fracture and cracking problems in welded joints. For modern steel-making practice, its content is preferably maintained at less than 0.005%. Source: Carbon Steel (2008).

Vanadium: The addition of vanadium will result in an increase in the hardenability of steel. It is very effective in this role, so it is generally added in minute amounts. In amounts greater than 0.05%, there can be a tendency for the steel to become embrittled during thermal stress relief treatments.Vanadium is mainly used to give added strength after hot rolling (0.05% to 0.1% Vanadium addition increases yield strength by 100N/mm^2) - John (1993), Amstead (1987), Colin (1987) and Kareem (2002).

Zirconium is added for sulphide-inclusion and shape control which increases formability. Source: Carbon Steel (2008).

2.6 CARBON EQUIVALENT VALUE:

The chemical composition of reinforcing steel bars constitute a strong determining factor of their weldability which basically refers to the property of a steel bar to form a strong welded connection and is governed by the carbon equivalent value of the steel. BS4449(1997) gives a maximum value of 0.51 for high tensile steel. Carbon equivalent value is usually a function of the percentages composition of C, Mn, Ni, Cu, Mo, V, and Cr.

BS4449(1997) - Item 8 has specified that bars of the same grade shall have a carbon equivalent value, based on cast analysis not exceeding the maximum values in table 2. The code also confirmed the relationship Ceq = C + Mn/6 + (Cr +Mo + V)/5 + (Ni + Cu)/15 as used by Sanmbo, B., David, E., Adeosun, S. and Olatunde, S. et al and also provided in table 3 the composition limits for the major steel chemical constituents.

TABLE 2.6 MAXIMUM CARBON EQUIVALENT VALUES BASED ON BS 4449 (1997)

Steel Grade (N/mm2)	Maximum Carbon Equivalent
250	0.42
460	0.51s

On Carbon Equivalent value used in the determination of coefficient of weldability, BS4449(1997) has prescribed Ceq = C + Mn/6 + (Cr +Mo + V)/5 + (Ni + Cu)/15 for steel bars. ASTM A 307 and BS4449(1997) have both provided same equation for Ceq in respect of reinforcing bars. In a sharp contrast, the ASTM A307has provided the following relationship for the carbon equivalent value as Ceq = C+ Mn/6 + Cu/40 + Ni/20 + Cr/10 – Mo/50 – V/10 for bolts &nuts. This implies Ceq formula as a function of carbon content and six other elements may change with the nature of the steel sample.

An analysis undertaken by Sanmbo, B., David, E., Adeosun, S. and Olatunde, S. (2009) revealed that the problem of low strength characteristics prevalent in hot rolled steel bars entails two factors, namely: metallurgical and process dysfunction .They further enumerated Impact strength, modulus of elasticity, percentage elongation, ultimate tensile and yield strengths as the most important mechanical characteristics of steel. Increase in any of them will increase the durability of the machine or structure in which it is used. They were also able to examine the effect of production technology and carbon contentment on the Properties. Sanmbo, B., David, E., Adeosun, S. and Olatunde, S. (2009) went further to confirm the existence of a direct correlation between microstructures of the steel and its mechanical properties. Thus, the former must be improved for better steel Properties. Further analyses of mild steel bars produced in Nigeria as compared with international standards impacted negatively on the local industry.

Investigations of metallurgical factors including chemical composition, rolling back internal soundness , level of dissolved gasses, inclusions, sulphur, phosphorus, and rolling back dysfunction factors. The later refers to soaking temperature, strain, strain rate and static and dynamic crystallization during rolling and cooling.

In conclusion, they evaluated the strain hardening factors interms of carbon, copper and the Carbon Equivalent Values (Ceq) from through relationship: –

$Ceq = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15$and made inferences on the limits $Ceq \leq 0.51$ and $Ceq > o.51$ as already provided by the BS & ASTM to assess the products and discovered the Properties of steel to depend on its charge characteristics which included levels of deoxidation, inclusions, slag composition and cleanliness with a strong emphasis on the control of sulphur and phosphorus as the two deleterious elements that must be controlled.

2.7 BS4449(1997) CODE PROVISIONS

2.7.1 REINFORCEMENT SIZES

BS4449(1997) has specified that nominal sizes of bars in grades 250 and 460 shall be from 6mm to 50 mm as follows:

Table 2.7: Recommended Bar Sizes for Grades 250 and 460 Steel

Grade	Nominal Size
250	8, 10, 12, 16
460	8, 10, 12, 16, 20, 25, 32, 40
Note 1	If a bar smaller than 8mm is required, the recommended size is 6mm.
Note 2	If a bar larger than 40mm is required, the recommended size is 50mm

Source: BS4449(1997)

2.7.2 CROSS SECTIONAL AREAS, MASSES AND PERCENTAGE TOLERANCES

According to clause 5 of BS4449(1997), the cross sectional area and mass of bars shall be calculated on the basis that steel has a mass of 0.00785Kg per Square Millimetre per Meter run and shall be accordingly tabulated based on table 2 of the code. The mass of the individual bars shall be given the same table and shall be subject to tolerances of +/_9, +/_6.5, and +/_ 4.5 % for diameter of bars in Millimetre 6, 8 and 10, and 12 respectively. The code went further to specify the cross sectional area to be calculated using A= M/0.00785 L , where M is the mass of the reinforcement sample in kilograms and L is the length in Millimetre and must not be less than 500 mm. Sanmbo, B., David, E., Adeosun, S. and Olatunde, S. (2009) revealed that the problem of low strength characteristics prevalent in hot rolled steel bars entails two factors, namely metallurgical and process dysfunction. Sanmbo, B., David, E., Adeosun, S. and Olatunde, S. (2009) further enumerated Impact strength, modulus of elasticity, percentage elongation, ultimate tensile and yield strengths as the most important mechanical characteristics of steel. Increase in any of them will increase the durability of the machine or structure in which it is used and were also able to examine

the effect of production technology and carbon content on the properties Sanmbo, B., David, E., Adeosun, S. and Olatunde, S. (2009).

The research also confirmed the existence of a direct correlation between microstructures of the steel and its mechanical properties even as they stated that the former must be improved for better steel properties. Further analyses of mild steel bars produced in Nigeria as compared with international standards impacted negatively on the local industry. Investigations of metallurgical factors including chemical composition, rolling back internal soundness, level of dissolved gasses, inclusions, sulphur, phosphorus, and rolling back dysfunction factors. The later refers to soaking temperature, strain, strain rate and static and dynamic crystallization during rolling and cooling. Sanmbo, B., David, E., Adeosun, S. and Olatunde, S. (2009)

In conclusion, Sanmbo, B., David, E., Adeosun, S. and Olatunde, S. (2009) evaluated the strain hardening factors of carbon and copper just as they confirmed the Ceq value as: $Ceq = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15$. Further, they made inferences on the limits of Carbon Equivalent Value ($Ceq \leq 0.51$). They used $Ceq > 0.51$ to assess the products and discovered the Properties of steel to depend on its charge characteristics which included levels of deoxidation, inclusions, slag composition and cleanliness with a strong emphasis on the control of sulphur and phosphorus as the two deleterious elements that must be controlled.

The percentages of carbon and other elements such as Manganese, Molybdenum, Vanadium, Silicon, Chromium, Nitrogen and Sulphur in steel have a direct effect on its strength and deformation characteristics John (1993), Amstead (1987), Colin (1987) and Kareem (2002). This implies that the chemical composition of steel is a determinant of its classification, strength and deformation characteristics such as yield and tensile strengths, elongation and bendability which are important to engineers in the design of safe, functional and economical structure.

They [John (1993), Amstead (1987), Colin (1987) and Kareem (2002)] further asserted that steel grades with a high level of dissolved gases, particularly oxygen and nitrogen, if not controlled by addition of small elements with a particular affinity for them to float out in the liquid steel at high temperature, can behave in a brittle manner. Manganese, chromium, molybdenum, nickel and copper also affect the strength to a lesser extent than carbon, although their sole effect is on the microstructure of the steel Owens and Knowles (1992) cited in Charles, K.K. and Mark, A. (2002). Varying the amount of alloying elements and the form of their presence in the steel (solute elements, precipitated phase) controls properties such as the hardiness, ductility, and tensile strength of the resulting steel. Steel with increased carbon content can be made harder and stronger than iron, but such steel is also less ductile than iron.

The code also confirmed the relationship Ceq = C + Mn/6 + (Cr +Mo + V)/5 + (Ni + Cu)/15 as used by Sanmbo, B., David, E., Adeosun, S. and Olatunde, S. (2009) and also provided the composition limits for the major steel chemical constituents as shown in table 2.1.

2.8 DEFINITION OF TERMS

In the course of undertaking the experiments, analyses of results and the review of related studies, the following terms have occurred at various times and are accordingly defined as follows:

Actinides: These are elements with properties similar to the lanthanides, but they are radioactive in nature. This implies they have no stable naturally occurring isotope or are entirely artificial. Source: Periodic Table of Elements - A. Holderness & J. Lambert (1987).

Alkaline Earth Metals: These are metallic elements found in the 2^{nd} group of the periodic table. They all have an oxidation number +2, thus making them very reactive and for this reason, they are not found naturally in a free state. Source: Periodic Table of Elements – A. Holderness & J. Lambert (1987).

Basic Metals: This refers to metals that oxidize or corrode relatively easily and reacts variably with diluted Hydrochloric Acid to form hydrogen. However, Copper is considered as a basic metal because as it oxidizes relatively easily, it does not react with Hydrochloric Acid. Alkali/ Basic metal are generally less dense than other metals. Source: Periodic Table of Elements – A. Holderness & J. Lambert (1987).

Characteristic strength: According to BS4449: 1997 – PP.2, is the value of the yield strength having a prescribed probability of not being attained in a hypothetical unlimited test series. The characteristic value is the lower limit of the one sided statistical tolerance interval at which there is a 90 % probability (i.e.; 1 – alpha = 0.90) that 95% (P=0.95) of the values are at or above this lower limit.

Cold worked deformed bar: A bar that has been worked to conform with the property requirement of the British standard and that conforms to either geometrical or performance test classification in clause 9 - BS 4449 (1997).

Ductility: The ductility of a material is a measure of the extent to which a material will deform before fracture. The amount of ductility is an important factor when considering forming operations such as rolling and extrusion. It also provides an indication of how visible overload damage to a component might become before the component fractures. Ductility is also used a quality control measure to assess the level of impurities and proper processing of a material.

Hot rolled deformed bar: A bar that has been shaped during hot rolling to conform with either the geometrical or performance test classification in clause 9 - BS4449(1997).

Lanthanides: This is a group of inner Transition Metals of the periodic table of chemistry and is generally classified as rare earth metals. Source: Periodic Table of Elements – A. Holderness & J. Lambert (1987).

Metals: These are lustrous, malleable and ductile solids at room temperature (except mercury). They are characterized by their high melting points and densities, large atomic radius, low ionization energy and low electronegativity due to the fact that their electrons can be easily removed. An important feature of metals is their ability to be deformed without breaking. Because the valence electrons can move freely, metals are good thermal and electrical conductors.

Mill: A mill consists of a series of stands, each of which consists of two cylindrical rolls, into which grooves are cut to accommodate the material being rolled. The sizes of the grooves are progressively reduced through the mill, so that the cross-sectional area of the product is continuously reduced as it is rolled.

Per Capita Steel Consumption [PCSC]: As defined by Daniel (2005), is an expression of a country's total quantity of steel consumed over the total population in Kilogrammes.

Phase: In the physical science, a phase is a region of space (a thermodynamic system), throughout which all physical properties of a material are essentially uniform. Example of physical properties includes density, index of refraction, and chemical composition.

Radio-Active Elements: These are elements with unstable nucleus that emit alpha, beta or gamma radiation (particles) and then get converted to a stable element. By emission of particles the unstable nucleus gets converted into a more stable nucleus and this is called radioactive decay. This decay may occur in as alpha, beta, or gamma. Source: Periodic Table of Elements – A. Holderness & J. Lambert (1987).

Radio Active Isotopes: When two nuclei have the same atomic number, but different atomic weight or mass numbers, they are said to be isotopes. Isotopes have the same chemical properties but different physical properties. Example Carbon has two isotopes, ${}_6C^{14}$ and ${}_6C^{12}$, both have the same atomic number, but different number of neutrons. The former being with 2 extra neutrons is

radioactive and undergoes radioactive decay. Source: Periodic Table of Elements – Chemistry Text by Holderness & Lambert.

Transition Elements: These possess properties of metals. Their presence in Iron is generally to give protective surface by coating it to prevent corrosion. Apart form being very hard, they also have the following characteristics:- positive oxidation states, high melting/ boiling points, high electrical conductivity, malleable and their 5d orbital become more filled from left to right on the periodic table. Transition metals are good electrical conductors and very malleable. Source: Periodic Table of Elements - A. Holderness & J. Lambert (1987).

Malleability: This is the ability of a metal to be hammered into shapes.

2.9 BOND CLASSIFICATION

Bond refers to composite characteristics of reinforcing steel in a particular concrete. Reinforcing steel standards specify bond performance by either measurement of rib geometry or by standardized bond tests or, in the case of BS 449, both (CARES Part 3, 1999). BS 4449: 1997 approach defines bond primarily in terms of the projected rib area. This is a measure of the rib area in a unit length perpendicular to the axis of the bar.

2.10 ROUTINE INSPECTION AND TESTING

BS4449(1997) clause 14 states that where the mechanical properties of a material are in dispute, they shall be verified by selecting and testing of three specimens from different bars in the batch. If any of the specimens fail to conform to sub clause 11.1 or 11.3, then sub clause 14.2 shall apply. However, if all the three specimens pass the tests, the batch shall be deemed to comply with the British Standard. If one or more specimens fail the tests as above, then ten more specimens shall be selected from different bars in the batch for testing.

If for characteristic strength tests, any one test result from the ten specimens is less than 95% of the value specified in table 2.10 below or if any one of the ten specimens fails the test for the other properties, then both the test specimen and the test method shall be carefully examined. If there is local fault in the specimen, or if there is any reason to believe that an error has occurred in the test, then the bar from which the test specimen was taken shall be disregarded and the test result shall be ignored. If the failures described above occur, and no local faults are found in the test specimens and no errors found in the tests, then the batch shall be deemed not to conform to this British Standard.

Table 2.8 TENSILE PROPERTIES

Grade	Yield Strength N/mm2	Tensile/ Yield Ratio	Elongation at Fracture %	Total Elong at Max Force %
250	250	1.15	22	-
460A	460	1.05	12	2.5
460B	460	1.08	14	5

Source: BS4449(1997)

2.11 MECHANICAL PROPERTIES OF REINFORCING BARS

According to the BS4449(1997), the main mechanical properties of reinforcing steel are: Tensile properties (yield stress, tensile strength and elongation), Bend, Fatigue and Bond.

Tensile properties indicate how reinforcing steel bar will react when subjected to tensile forces. A tensile test is a fundamental mechanical test where a carefully prepared specimen is loaded in a very controlled manner while measuring the applied load and the elongation of the specimen over some distance. Tensile tests results are used to deduce the modulus of elasticity, elastic limit, elongation, proportional limit, reduction in area, tensile strength, yield point, yield strength amongst various others. The tensile properties of reinforcing steel bar is related to the ultimate tensile strength (UTS), often shortened to tensile strength (TS) or ultimate strength of reinforcing steel bar

which is the maximum stress that a material (reinforcing steel bar) can withstand while being stretched or pulled before necking.

Tensile strength refers to the amount of tensile (stretching) stress a material can withstand before breaking or failing. The ultimate tensile strength of a material is calculated by dividing the area of the material tested (the cross section) by the stress placed on the material, generally expressed in Newtons per square Millimetre. Generally, elements as shown by the periodic table are classified into metals, non- metals halogens and noble gases. The metals comprise alkali metals, alkaline earth metals, transition metals and the Inner transitions which are the lanthanides and actinides. Source: Periodic Table of Elements – A. Holderness & J. Lambert (1987).

2.12 REVIEW OF SOME RELATED WORKS.

In the research conducted on "Verification of properties of Concrete Reinforcement Bars": Nigeria as a case study: Arum, C. (2008) considered ribbed local and foreign bars of nominal diameters 10,12,16,20 and 25 mm from recognised and non recognised ISO origins for his investigations. He choose Lagos, Ibadan, Akure and Ife to represent the general market situation in the country, with 15 specimens each from the 12mm and 16mm representing Lagos, while the 10, 20, and 25mm representing the remaining. The investigation showed that steel from recognisable origin satisfied both local and ISO requirements for strength and ductility. But, those from non recognisable origin failed to satisfy the same requirement for high tensile but satisfied local specifications for mild steel bars.

The related study conducted by Charles, K.K. and Mark, A. (2002) on strength and Ductility Characteristic 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 were investigated as these products are already in use in structural works. The samples

steel bars were obtained from three local manufacturing companies and their yeild strength values were 190,230 & 550 N/mm^2 for ultimate tensile strength correspondingly with corresponding elongations values of 9.6, 11.8 & 10.6 mm respectively. 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. Charles concluded that the bars were characterised by inconsistencies in characteristic strength and ductility.

2.13 STEEL MAKING PROCESS

In the UK, and in many other parts of the world, reinforcing steels are specified to British Standards. BS4449(1997) contains no specific requirements for manufacturing processes, although they can have a significant effect on the properties of reinforcing steels. Therefore within a British Standard grade designation, different process routes can produce different mechanical characteristics.

Generally, there are three stages in producing final steel products when utilizing iron ore no matter which production method is employed. These are iron making, steel making and rolling.

The most widely used processes used for the manufacture of steel are:

The Blast Furnace (BFM);

The Direct Reduction Method (DRM);

The Mini Mill: and

The COREX.

The Blast Furnace is a conventional method of production involves heavy construction works at site and usually takes a relatively lengthy construction period. The Direct Reduction method comprises a package of prefabricated components which are normally brought from the workshop and assembled at site, within a relatively shorter time frame. While the Mini Mills only

an assembly of smaller processing units designed to specifically produce smaller quantities of steel products, while the Mini Mills is only applicable for mills designed with smaller outputs, the COREX is a rare advance in technology that is not very common. Shumacher, K and Sathaye , J. (1998).

As stated in various codes, the percentages by weight of elemental composition of reinforcement steel constituents varies with the production process, the UK CARES has given a typical example of the results obtained from the chemical composition of reinforcement bars of same raw materials using the Blast Furnace and Direct Reduction Methods respectively as per the UK CARES (1999) "Guide to Reinforcing Steels"– Manufacturing Process Routes for reinforcing steels (Part 2) given in table 2.9 below:

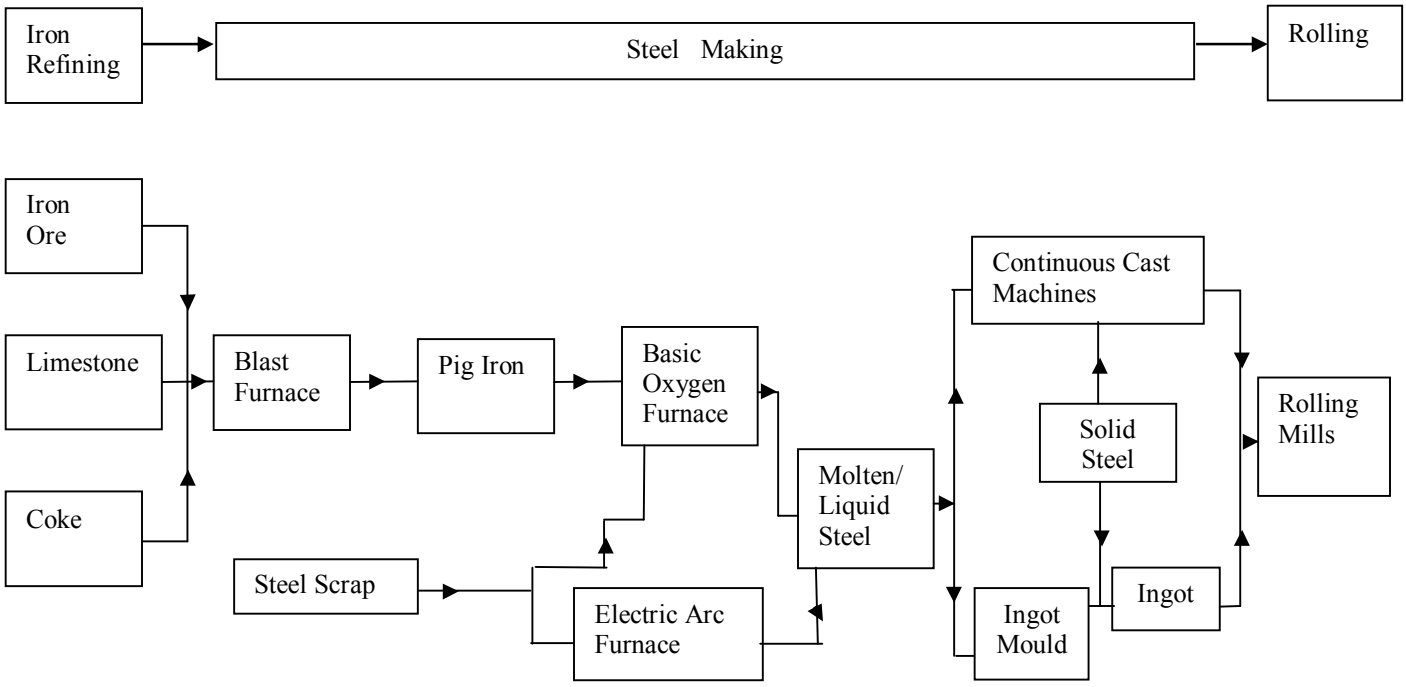
TABLE 2.9: COMPARATIVE ANALYSIS (WT %) OF BLAST FURNACE METHOD AND DIRECT REDUCTION METHOD PRODUCTION PROCESSES FOR REINFORCING BARS.

Methods	C	Mn	Si	S	P	Cu	Ni	Cr	Mo	Sn	N
BFM	0.20	0.80	0.15	0.01	0.005	0.03	0.02	0.02	0.01	0.010	0.006
DRM	0.20	0.80	0.15	0.03	0.02	0.03	0.15	0.15	0.05	0.025	0.010

Source: UK CARES (1999) "Guide to Reinforcing Steels"– Manufacturing Process Routes for reinforcing steels "Part 2.

2.13.1 THE BLAST FURNACE METHOD

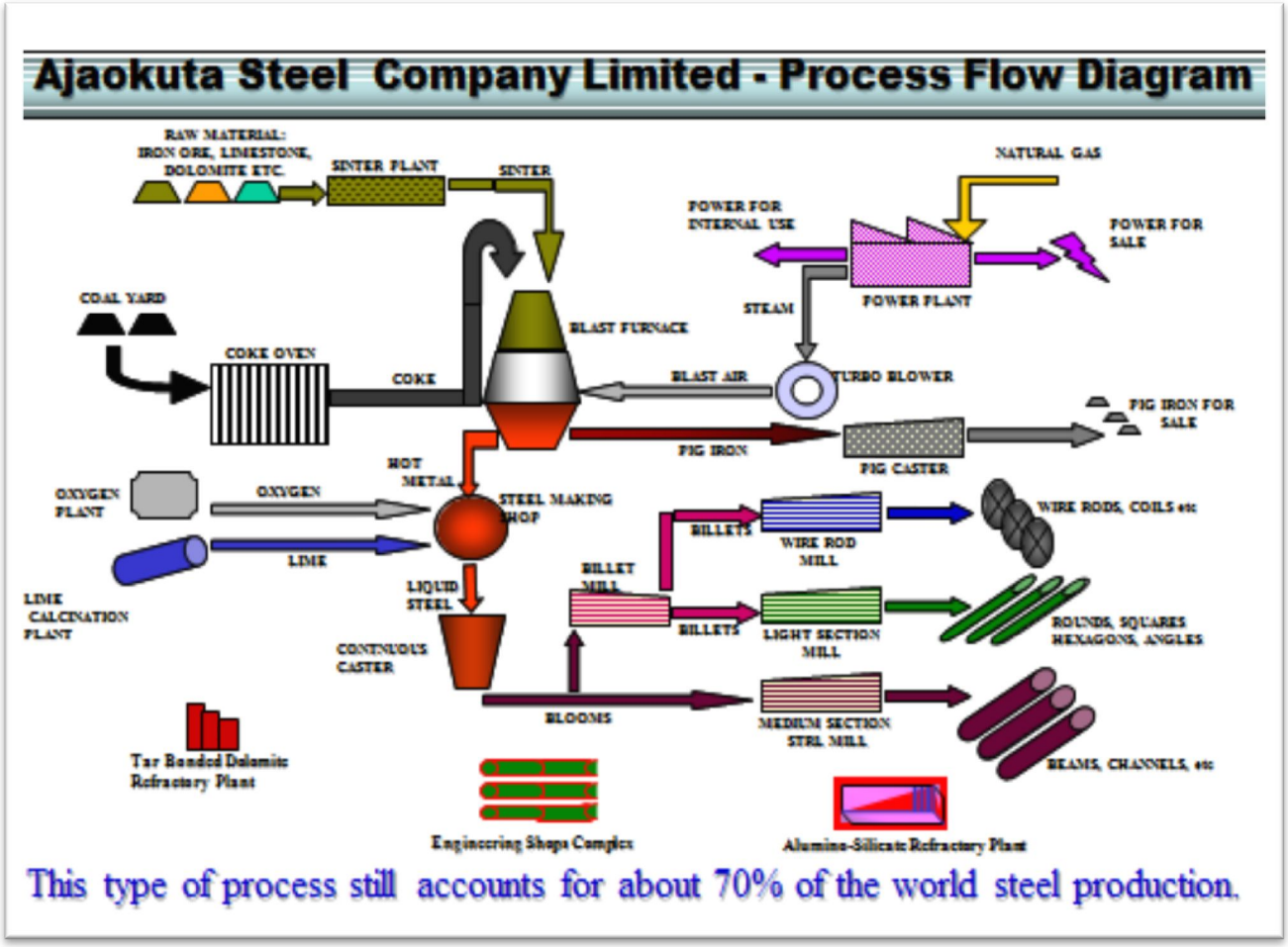
In this process, molten iron is first produced by smelting iron ore in a blast furnace along with lime stone and coke. This pig iron is then transferred to a steel making vessel called a converter or basic oxygen furnace. Some clean and carefully sorted steel scrap (up to 30%) may also be added. High velocity oxygen is then blasted into the molten iron, generating heat due to a process of oxidation. Impurity elements are removed, and the iron is refined into steel. This method / process requires a high level of capital investment, and is therefore only used by large steel producing works, typically with an output of several million tonnes of steel per annum. An example of this technology is the Ajaokuta Steel Rolling Company. Figure 2.1 gives the illustration of the production process in the blast furnace line as given by Omoweh (2005).



Source: Omoweh, D.(2005)

Figure 2.1: Flow Chart of Iron and Steel Making Blast Furnace

The flow chart below shows a detailed process of production stages in Ajaokuta Steel Company which is based on Blast Furnace Method. The top right corner of the chart indicates a natural gas (Blast Furnace Gas + Carbon Monoxide) to jump start the process.



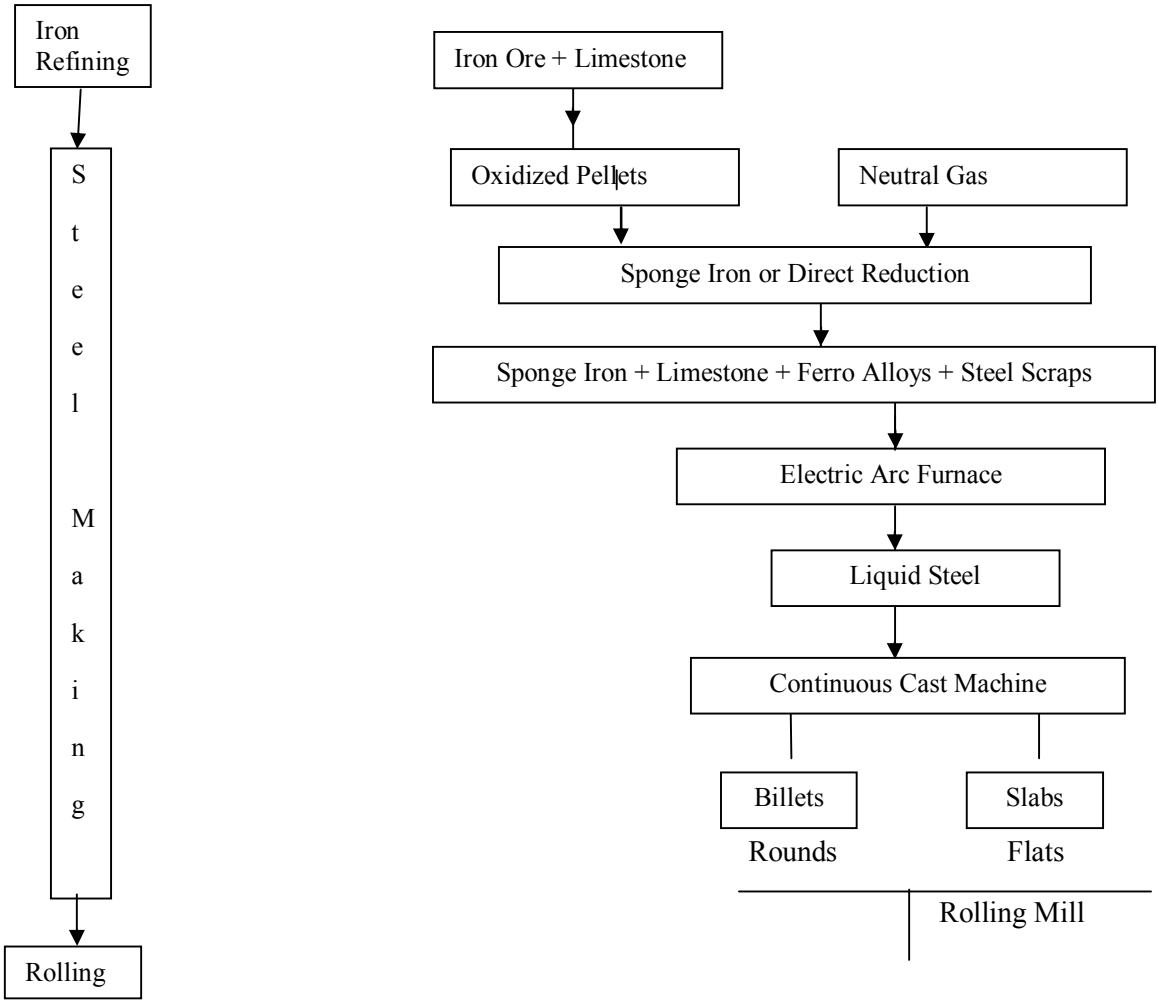
Source: Inuwa, I.K.(2011)

Figure 2.2: Flow Chart of Iron and Steel Making Blast Furnace in the Ajaokuta Steel Company.

2.13.2 THE DIRECT REDUCTION METHOD

The Direct Reduction involves the combination of the Iron Ore with Limestone to form the Oxygen pellets which mixes with the natural gas which acts as a reducing agent to form the sponge iron otherwise called direct reduced iron. At this stage, steel scraps are added to the sponge iron along with all alloying minerals and calcium carbonate. These are passed through the Electric arc furnace which produces the liquid steel. At this stage, the liquid steel passes through a continuous cast

machine to form the billets (Rounds) and slabs (flats) Scrap metal is charged into the furnace which are finally rolled. An example of this technology is The Delta Steel Company. Figure 2.3 gives the illustration of the production process in the direct reduction method line as given by Omoweh (2005).

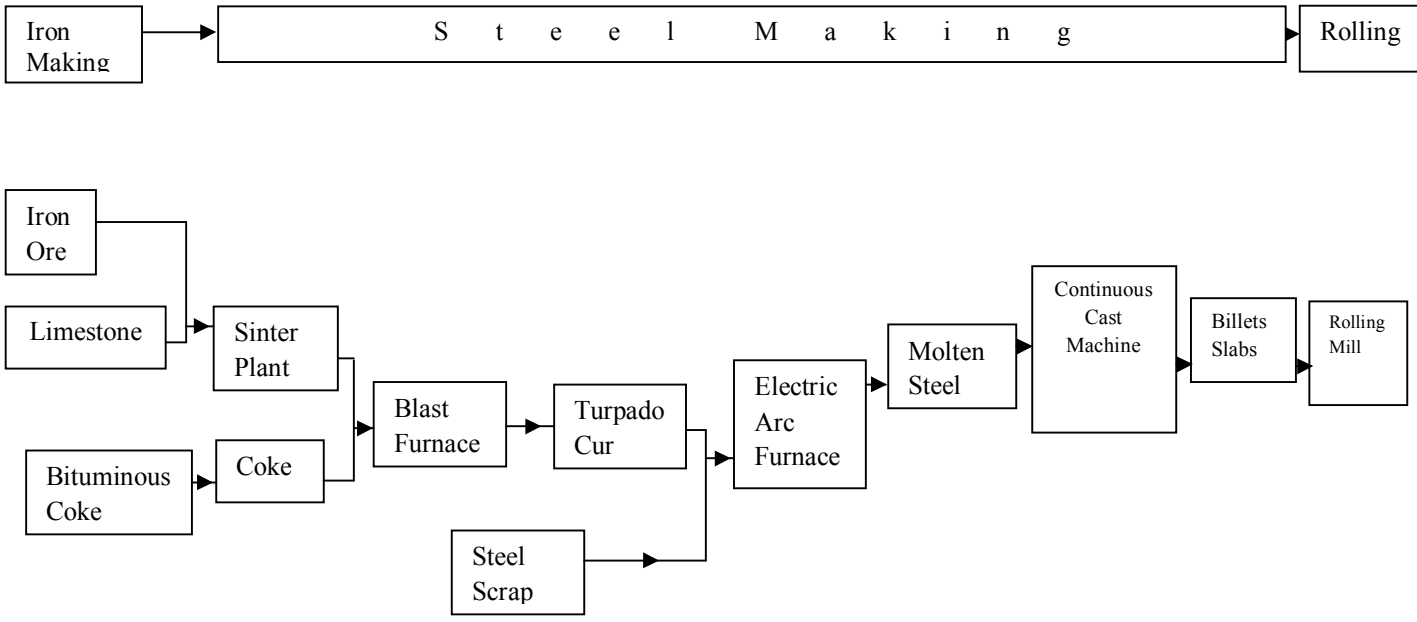


Source: Omoweh (2005).

Figure 2.3: Production Chart of Iron and Steel Making – Direct Reduction Process

2.13.3 THE MINI MILL

In the mini mill, the coke plant feed the sinister plant with bituminous coke. In parallel, limestone and iron ore are fed simultaneously. The trio then moves to the blast furnace and at this stage clean and carefully sorted scrap metals are added. These are passed to the electric arc furnace and it is at this stage, the molten steel is produce rolled as bars. The high temperature liquid passes through the continuous cast machines and are converted to billets which are finally rolled as bars. These technologies can be found at Sunflag and Sankyo both in Lagos. It can also be seen in the Nigerian-Spanish company in Kano. Figure 2.4 gives the illustration of the production process in the Mini Mill production method line as given by Omoweh (2005).



Source: Omoweh, D. (2005).

Figure 2.4: Production Chart of Iron and Steel Making based on TheMini Mill Process

2.13.4 THE COREX

COREX is not an abbreviation as it is the popular name adopted in India. The process uses smelt reduction and present one of the most advanced iron making technologies available in the world. The process combines coal gasification with reduction of iron oxides to produce pig iron and reusable gas as by product. Under this process, the use of coking coal is unnecessary –Schumacher, K and Sathaye, J. (1998).

COREX process may be beneficial in saving energy and investment costs, while reducing environmental pollution. As at today, world wide, only one operating COREX plant exists. Schumacher, K and Sathaye, J. (1998).

Figure 2.5 gives the illustration of the production process in the COREX method as given by Omoweh, D. (2005).

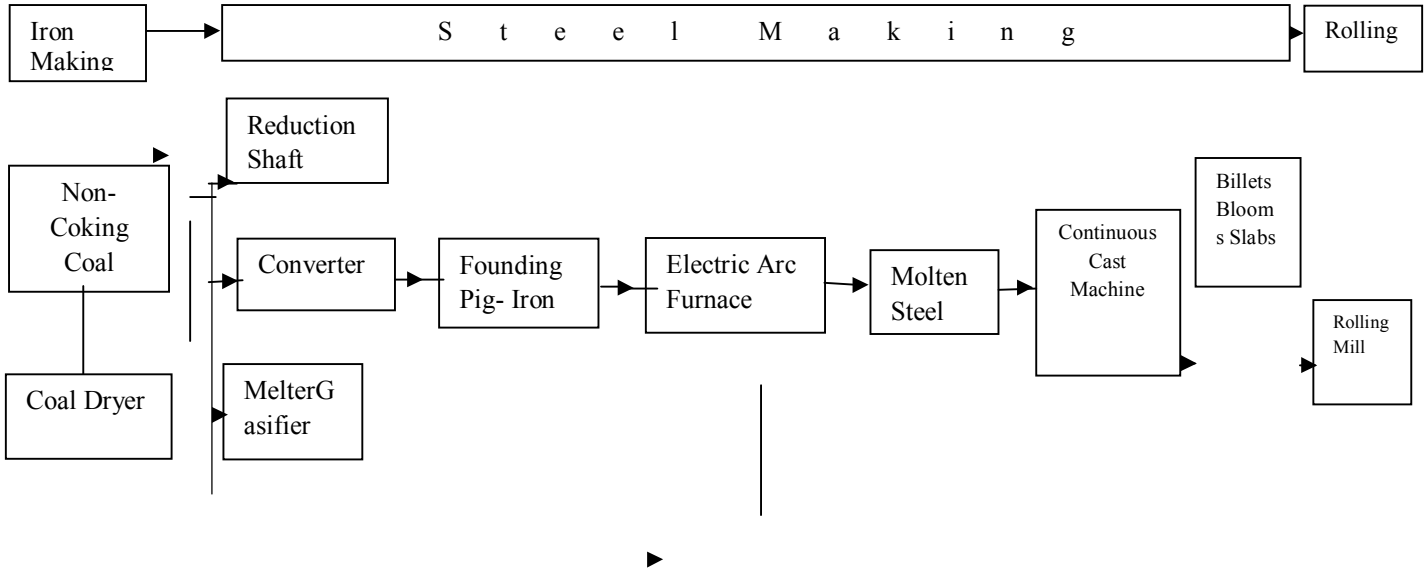


Figure 2.5: Flow Chart of Iron and Steel Making: COREX

2.14 WORLD STEEL PRODUCTION

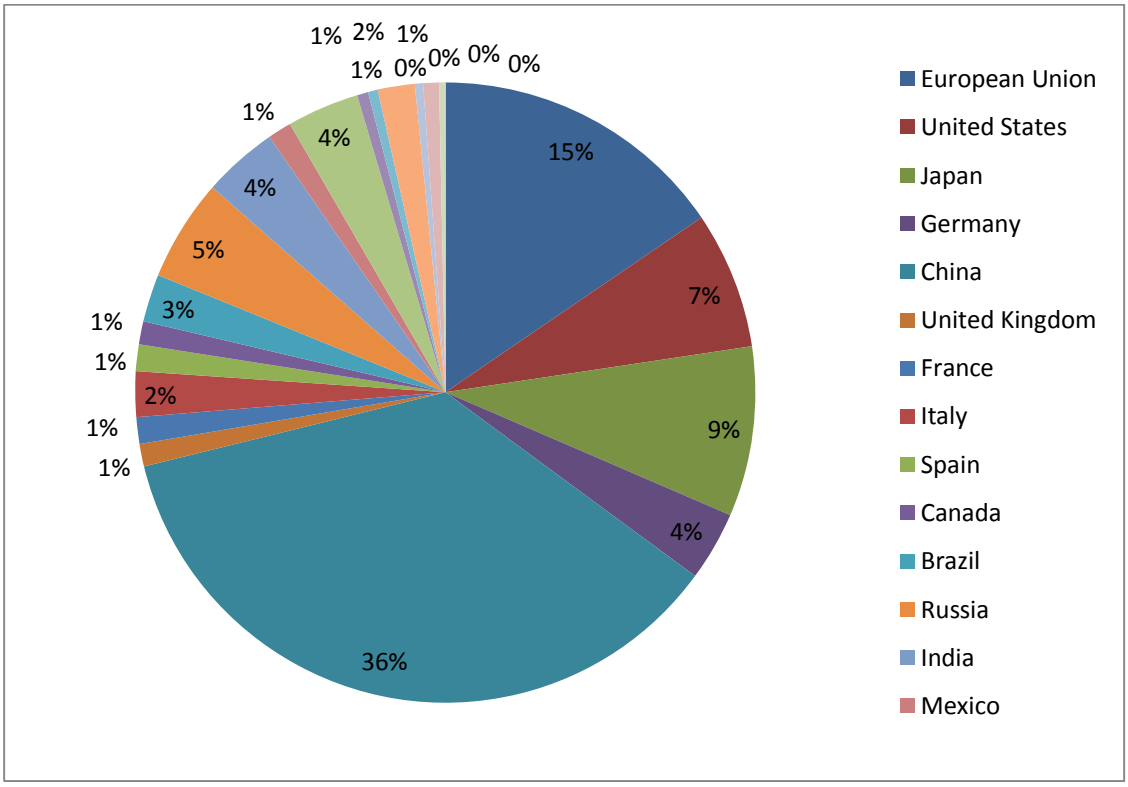
The World steel production in terms of the Gross Domestic Product in Million US Dollars and the Steel Production in Million Tonnes per year for the first twenty countries in the world are presented below, with Nigeria conspicuously ranking as number 41 as given by Inuwa (2011) in table 2.11 below:.

TABLE 2.10 WORLD STEEL PRODUCING COUNTRIES.

RANK	COUNTRY	GDP (USD X 10^6)	STEEL PRODUCTION(TONNES / YEAR X 10^6)
-	**WORLD TOTAL**	**54,584,918**	**1,343**
-	**European Union**	**16,905,620**	**210**
1	United States	13,807,550	97
2	Japan	4,381,576	120
3	Germany	3,320,913	49
4	China	3,280,224	489
5	United Kingdom	2,804,437	16
6	France	2,593,779	19
7	Italy	2,104,666	32
8	Spain	1,439,983	19
9	Canada	1,436,086	16
10	Brazil	1,313,590	34
11	Russia	1,289,535	72
12	India	1,100,695	53
13	Mexico	1,022,816	17
14	South Korea	969,871	51
15	Australia	908,990	8
16	Netherlands	777,241	7
17	Turkey	659,276	26
18	Sweden	454,839	6
19	Belgium	453,283	11
20	Indonesia	432,944	4
41	**Nigeria**	**166,985**	**0.30**

SOURCE: Inuwa (2011)

The world steel production based on countries has accordingly been presented as a percentage of total in the pie chart below:



Derived from the data obtained from INUWA (2011)

Figure 2.6: Pie Chart for World Steel Production:

2.14.1 TOP STEEL PRODUCING COMPANIES IN THE WORLD (2005)

The top thirty steel producing companies in the world are also presented in table 2.12 below. It may be noted that out of these companies whose names and countries of origin have been stated, no African based company has been stated. By implication, Nigeria is not considered as a world steel player. Source: Metal Bulletin and Nippon Steel Corporation, Basic Facts About Nippon Steel, (2005).

TABLE 2.11 WORLD STEEL PRODUCING COMPANIES

Ranking	Company	Country	Year 2004 (Million Tonnes)
1	Arcelon (Luxembourg)	Luxembourg	46.90
2	LNM Holdings (Netherlands)	Netherlands	42.84
3	Nippon Steel (Japan)	Japan	31.41
4	JFE Steel (Japan)	Japan	31.13
5	Posco (South Korea)	South Korea	31.05
6	ShanhaiBoosteel (China)	China	21.41
7	US Steel (USA)	USA	20.83
8	Corus Group (UK)	UK	19.94
9	Nucor (USA)	USA	17.91
10	Thyssen Krupp (Germany)	Germany	17.58
11	Riva Group (Italy)	Italy	16.70
12	International Steel Group (USA)	USA	16.11
13	Gerdav Group (Brazil)	Brazil	13.4
14	Severstal (Russia)	Russia	12.80
15	China Steel (Taiwan)	Taiwan	12.53
16	Sumitomo Metal Industry (Japan)	Japan	12.33
17	Evraz Holding (Russia)	Russia	12.33
`18	SailSail (India)	India	12.14
19	Anshan (China)	China	11.93
20	Magnitogorsk (Russia)	Russia	11.28
21	Wuhan (China)	China	9.31
22	Novolipetsk (Russia)	Russia	9.10
23	Usimas Group (Brazil)	Brazil	8.95
24	Imidro (Iran)	Iran	8.70
25	Salzgitter (Germany)	Germany	8.69
26	Shougang (China)	China	8.48
27	Maanshan (China)	China	8.03
28	INI Steel (South Korea)	South Korea	7.92
29	Kobe Steel (Japan)	Japan	7.67
30	Tangshan (China)	China	7.66

Source: Metal Bulletin and Nippon Steel Corporation, Basic Facts About Nippon Steel, 2005

The world steel production for the 20 top most companies in Million Tonnes for the year 2004 has also been accordingly been presented as a percentage of total in the pie chart below:

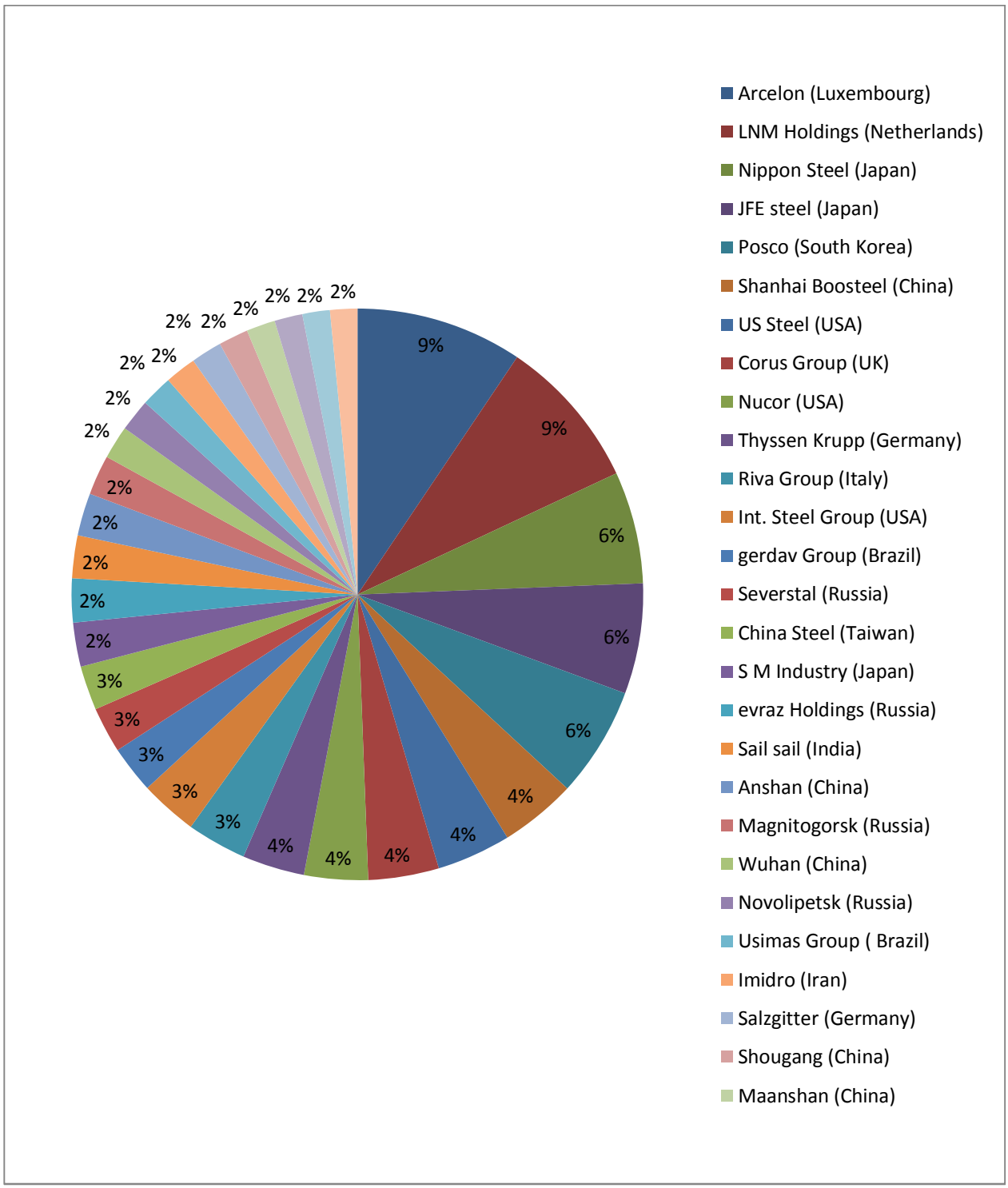


Figure 2.9: Pie Chart for World Steel Production:

2.15 STEEL PRODUCTION IN AFRICA

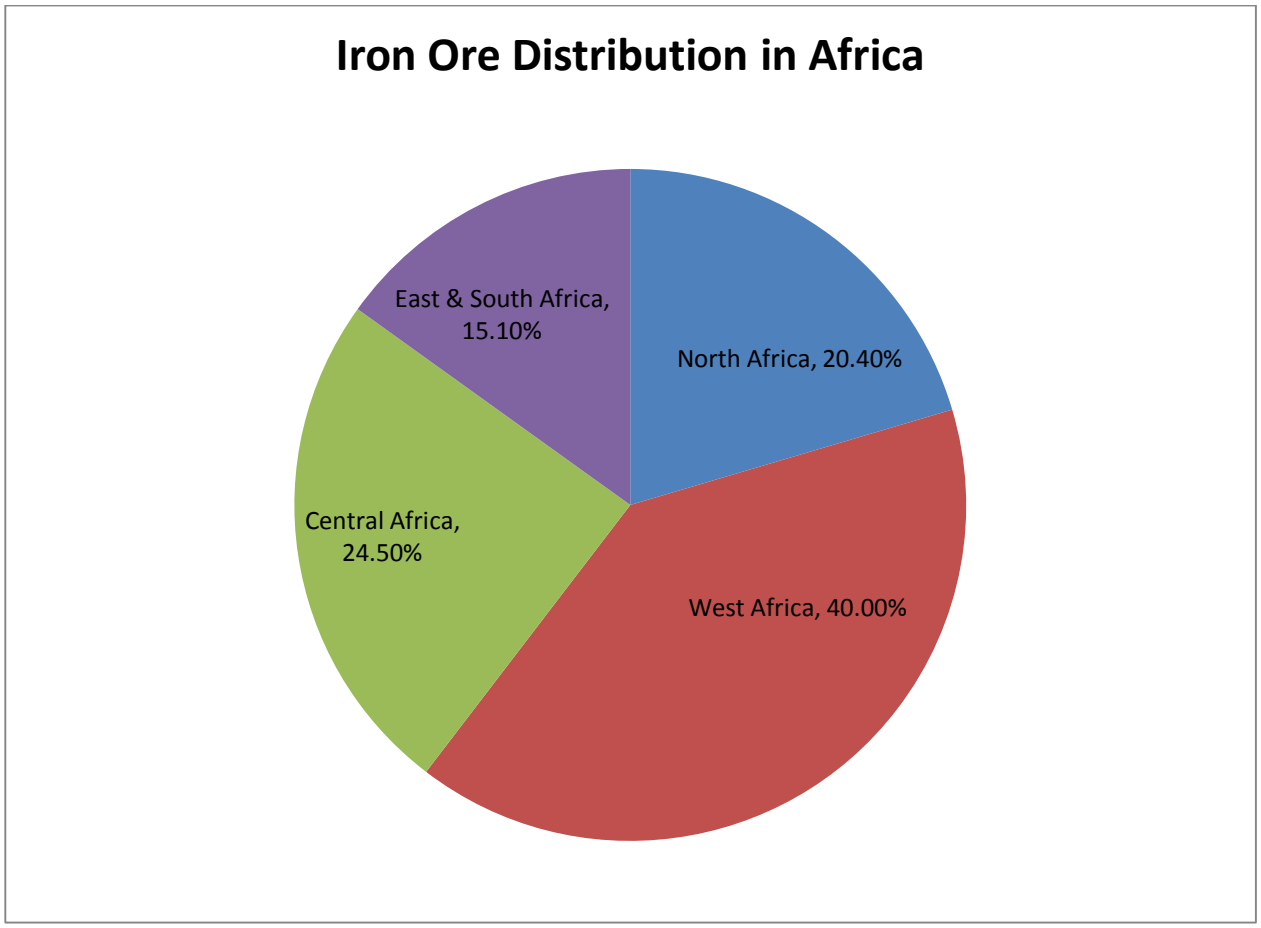
Africa with the exception of South Africa has iron ore reserve estimated at over 34 billion tons representing about 15 percent of the world's total reserve with 11 countries having reserve greater than one billion tons. The distribution of the ore is uneven as North Africa has 20.4%, West Africa has 40%, Central Africa has 24.5% and East and South Africa has 15.1% of the total. The largest reserve occurs in areas such as Democratic Republic of Congo, Zimbabwe and Algeria with Kilomoto hematite deposit of 5 billion tons, Manesi deposit of 3.3 billion tons and Gora Djebilet deposit of 3.025 billion tons respectively. Other large deposits of iron ore occur in Liberia, Mauritania, Angola, Cote d'Ivoire, Libya, Sierra Leone and Nigeria. Source: World Steel Association Report (2010).

Africa has not made extensive use of its vast iron ore deposit as only a few deposits are being commercially exploited. As a result, only Algeria, Egypt, Liberia, Mauritania, Morocco, Nigeria, Tunisia and Zimbabwe rank among the world's iron ore producers just as Liberia, Mauritania and Algeria are the only African exporters of iron ore. Egypt, Morocco, Nigeria, Tunisia and Zimbabwe produce for their domestic steel plants only. World Steel Association Report (2010),

The current annual combined installed capacity of existing integrated plants in Africa has been estimated at about 16.0 million tonnes and that for semi-integrated mini-plants at 1.7 million tonnes of steel. The total annual combined capacity of existing African production units (8 integrated 29 mini-plants and 45 rolling mills) in metric tonnes is Iron - 8.50 ; Steel - 10.40; Long rolled product - 8.00; Flats- 3.30 and Pipes - 0.25 Source: Steel and Trade in Sub-Saharan Africa, (2002).

In terms of semi-integrated mini-plants, 15 countries have 29 mini-plants comprising units ranging in size from 10,000/year in Mauritania and Ethiopia to over 200,000/year in Nigeria and Egypt. The average capacity utilization is about 25%. Most of Africa's iron ore resources remain largely undeveloped owing to such constraints as non-availability of the necessary investment

resources from both domestic and international sources, the general sluggishness of the world iron ore market, the relative inaccessibility of many reserves (necessitating large investment in transportation and other infrastructures), and civil and political strife that hamper development.



Derived from World Steel Association Report (2010)

Figure 2.10: Iron Ore Distribution in Africa

2.16 CRUDE STEEL OUTPUT (PER ANNUM) OF SOME AFRICAN COUNTRIES THAT STARTED AT THE SAME TIME AS NIGERIA.

From table 2.12 below, it can be seen that South Africa based on 2006 estimate, is the leading nation in terms of steel output in Africa and ranks 20th in the world. The country is followed by Egypt, Algeria and Libya as distant 2nd, 3rd and 4th in Africa as they rank 27th, 48th and 49th respectively in the world.

Nigeria's estimated output from the table indicates it is not a major steel producer even in Africa.

Table 2.12: CRUDE STEEL OUTPUT (PER ANNUM) OF SOME AFRICAN COUNTRIES THAT STARTED AT THE SAME TIME AS NIGERIA.

COUNTRY	PRODUCTION (TONS/ANNUM X10^6)	POSITION IN THE WORLD OF STEEL
South Africa	9.7	20th
Egypt	6.0	27th
Algeria	1.2	48th
Libya	1.2	49th
Nigeria	0.3(Estimate)	?

SOURCE: Inuwa (2011)

CHAPTER THREE

MATERIALS AND METHOD

3.1 PREAMBLE

Steel mills in the country can be generally classified into three as follows:

Ajaokuta Steel Company.

Delta Steel Company with the Inland rolling mills at Katsina, Jos and Osogbo.

Mini Mills groups together.

While Ajaokuta is yet to be completed, Delta's concept is to process and pass billets as raw materials for Katsina, Jos and Oshogbo rolling mills. The mini mills which are mainly foreign dominated are privately owned. Many of them have been in operation even before the establishment of the ones stated above.

As mentioned earlier, Ajaokuta is yet to be completed. Jos and Oshogbo have been sold out while Katsina seems to be importing billets for its milling operations.

3.2 STEEL PRODUCTION IN NIGERIA

The idea that led to the development of Iron and steel industry in Nigeria was born in 1958 by the Federal Government. To a very large extent the different establishments that make up the steel industry in Nigeria are interdependent to the level that under performance of one adversely affects the other. A proper understanding of this interrelationship and interdependence will not only direct policy construct but will go a long way to stabilize and advance the steel sub-sector in the country. The readiness on the part of the government to revamp the steel sector and achieve the goal of industrialization for the country has led to the establishment of the various bodies and industry with the dissolution of the National Steel Development Agency in (1979).

Government's effort to industrialize the nation through development of steel practically began in 1958 with the invitation of steel consultancy firms by the Federal Ministry of Industries to

undertake a feasibility of setting up steel plants in the country. The first steel plant in Nigeria (a Mini Plant) was established at Emene, near Enugu, in 1962 by the Eastern Nigerian Government. Two similar plants were established in Lagos in 1968 and 1970 respectively, through private initiative.

The dissolution of the National Steel Development Authority ultimately led to the establishment of the following:

Delta Steel Company, Aladja, Delta State.

Jos Steel Rolling, Jos, Plateau State.

Katsina Steel Rolling Company, Katsina State.

Osogbo Steel Rolling Company, Osun State.

Ajaokuta Steel Company, Kogi State.

Others are:

National Iron Ore Mining Company, Itakpe, Kogi State.

National Steel Raw Materials Exploration Agency, Kaduna State.

National Metallurgical Development Centre, Jos, Plateau State and

Metallurgical Training Institute, Onitsha, Anambra State

3.3 THE AJAOKUTA STEEL PROJECT

The Ajaokuta Steel Plant construction commenced around 1980 as an integrated steel plant, which is based on the Blast Furnace/Basic Oxygen Furnace route of steel production. The plant was designed to produce 1.3 million tonnes of cast blooms per annum in the first phase, with inbuilt facility to expand to 2.6 million tonnes and 5.2 million tonnes in the second and third phases respectively. All the steel produced in the first phase (1.3 million tonnes) was to be processed into long products, while the additional production from the second and third phases were to be dedicated for flat steel production and capacity enhancement respectively.

The Rolling Mills comprise a billet mill, which produces billets for the Medium Section and Structural Mill, the Light Section Mill and the Wire Rod Mill. Commercial activities have only taken place in the light section mill, the wire rod mill, the power plant, the engineering workshop complex and the Manufacturing and erection base. Consequently due to prolonged delay in the completion of the Ajaokuta Steel Plant, the Federal Government commissioned Messrs. Tyajpromexport (TPE) to carry out a technical evaluation of the plant to assess the requirements for the rehabilitation, completion and commissioning of the plant.

However, it must be emphasized that the problem of providing raw materials inthe required quantities, qualities and at the right time must be faced squarely. In some cases there is still need to even locate economic deposits of suitable raw materials locally (e.g. Coking coal). Where such deposits have been located (limestone, clay, and dolomite) there are the requirements of opening mines with adequate equipment and infrastructure and providing logistics for timely delivery of raw materials from mine to site. The plant is yet to be commissioned.

3.4 THE DELTA STEEL COMPANY

The Delta Steel Plant, a midrex Direct Reduction integrated steel plant, was built as a turnkey project and commissioned in 1982 to produce 1 million metric tonnes of liquid steel per annum. The plant however, only attained a maximum production capacity of 25% in 1985. Production declined progressively thereafter until 1996 when the plant was finally shut down due to none availability of funds. The company was in 2005 privatized to Global Infrastructure Nigeria Limited.

3.5 THE INLAND STEEL ROLLING COMPANIES:

The three Inland Steel Rolling Companies located at Katsina, Oshogbo and Jos were commissioned between1982 and 1983 with installed capacity of 210,000 tonnes of assorted rolled products each. The Rolling Mills have had their share of low capacity utilization as a result of inconsistent Government policies, inability of Delta Steel Company to supply them billet, dumping and market saturation amongst others. The companies were in December 2004 privatized and the new owners of the companies have since taken over the operation.

3.6 ASSOCIATED AGENCIES

In order to address the raw materials and training needs of low to middle level manpower of the Steel/Aluminum and related sectors of the economy, the Federal Government set up the National Steel Raw Materials Exploration Agency (NSRMEA), National Metallurgical Development Centre (NMDC) and Metallurgical Training Institute (MTI). These Agencies are still being funded by Government in view of their crucial importance to the metal Industry.

3.7 THE NATIONAL IRON ORE MINING COMPANY, ITAKPE.

The National Iron Ore Mining Company, Itakpe, Kogi State was established in 1979 and is charged with the responsibility of mining and processing iron ore concentrate and super concentrate for Ajaokuta and Delta Steel respectively.

3.8 THE NATIONAL METALLURGICAL DEVELOPMENT CENTRE, JOS.

This is the laboratory unit of the steel sector in Nigeria. The laboratory has the capacity to undertake the analysis of most steel related materials. Established in 1992, the Centre is also mandated to concentrate on the development of metallurgical processes that will harness the abundant local raw materials in the country for use in the metallurgical industry there by bringing about the much needed input substitution and to play a decisive role in adapting metallurgical processes for economic production of steel and other engineering alloys including the upgrading the

quantities of the Nigerian ores for steel and other metallurgical production particularly through the beneficiation of local iron ore.

3.9 THE NATIONAL STEEL RAW MATERIALS EXPLORATION AGENCY, KADUNA.

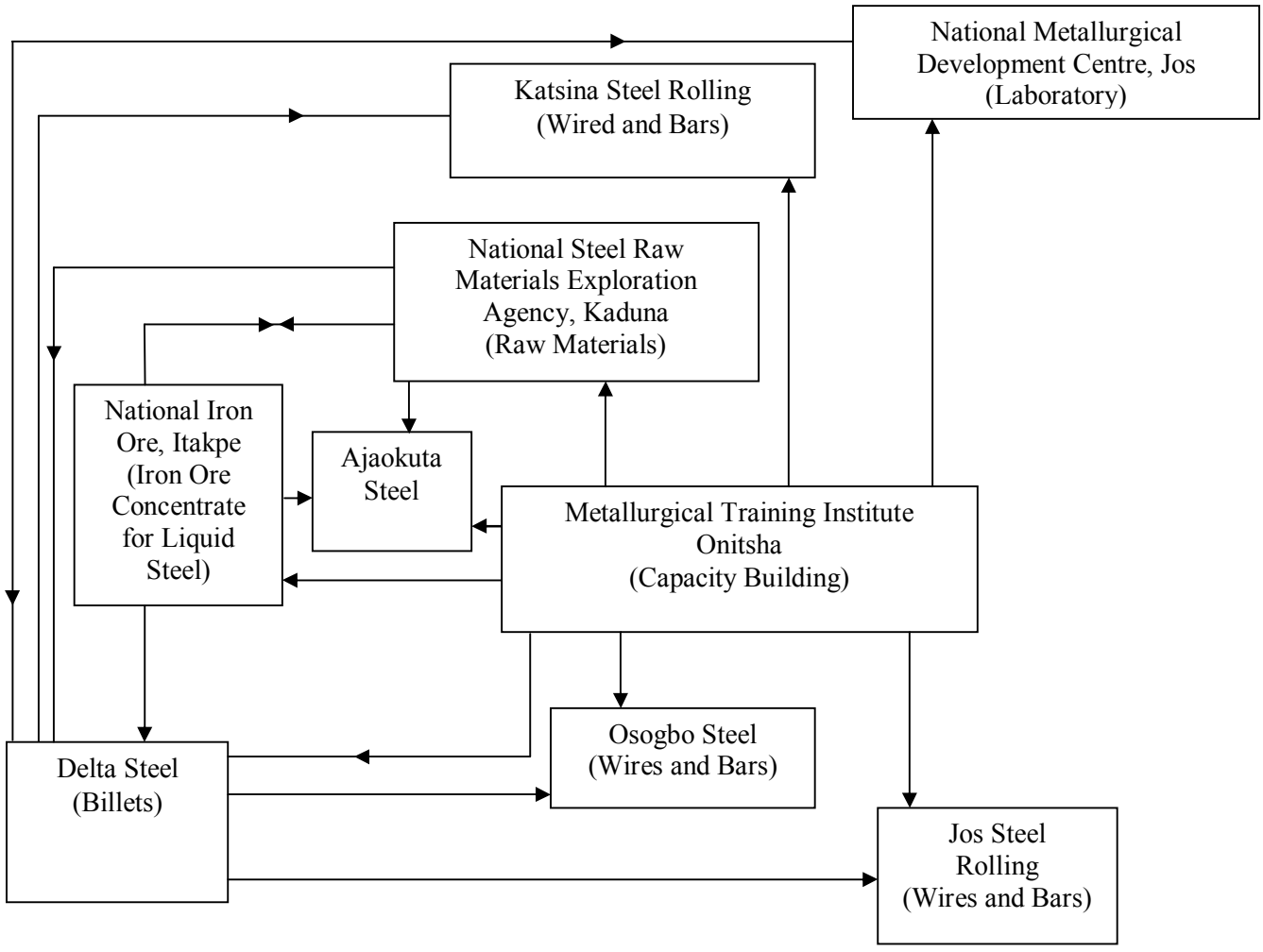
This is where the National Steel Development Authority (NSDA) started. The idea behind establishing the Agency in 1992 is to generate a reliable mineral raw materials data bank for prospective investors in the steel and industrial minerals sector of the Nigerian economy and to undertake effective and efficient exploration of materials in large quantity for the iron, steel and solid minerals based industries.

3.10 METALLURGICAL TRAINING INSTITUTE, ONITSHA.

The metallurgical Training Institute was designed for the development of a mass of highly skilled, practical and production-oriented middle-level technical manpower to efficiently and effectively maintain the steel and allied metallurgical industries in the steel sector of the economy. This will drastically cut down on Nigeria's dependence on foreign technical training thereby conserving foreign exchange.

3.11 INTERDEPENDENCE IN THE NIGERIAN STEEL SUB-SECTOR

The various steel rolling mills, laboratory, capacity building institution, raw material supplying organisations, research and documentation centres have created an inter organisational synergy required for the development of the Nigeria's steel sector as represented in figure 3.1 below.



Source: Drawn from survey of steel establishments in Nigeria.

Figure 3.1: Interdependence in the Nigerian Steel Sub-Sector

3.12.0 PRIVATE STEEL COMPANIES IN NIGERIA

The major private steel companies operating in Nigeria are Continental Iron and Steel Company, Mayor Engineering Company, Nigerian–Spanish Company, Universal Steel Company, Federated Steel Company, KEW Metal Industry and Kwara Continental Metal and Chemical Company. Others are Allied Steel Company Limited, Mandarin Industry, Niger Steel Company, Qua Steel Products Company, Sankyo and Sunflag.

3.12.1 CONTINENTAL IRON AND STEEL COMPANY

One of the prominent private steel Companies operating in Nigeria is Continental Iron and Steel Company located at Ikeja, Lagos. The company is jointly owned by British/ Hong Kong in partnership with Nigerians. The plant which operates using Electric Arc Furnace has an installed capacity of 90,000 metric tonnes of crude steel, uses local metal scraps and billets and also imports additional billets. It finally rolls out 8mm, 10mm & 12mm diameter reinforcement bars and coils as its end products.

3.12.2 MAYOR ENGINEERING COMPANY

Mayor Engineering Company is located at Ikorodu, Lagos, The Company is jointly owned by British/ Hong Kong in partnership with Nigerians. The plant has an installed capacity of 100,000 metric tonnes of crude steel, uses purely imported billets. It does only rolling of reinforcement bars and coils as end products. Available bars in the market are 6mm, 10mm and 16 mm diameter high tensile steel. Source:

3.12.3 NIGERIAN–SPANISH COMPANY

Nigerian-Spanish Limited is located at Sharada, Kano. The company is jointly owned by the Spanish in partnership with Nigerians. The plant which operates using Electric Arc Furnace has an

installed capacity of 100,000 metric tonnes of crude steel, uses local metal scraps and imported billets. It finally rolls out reinforcement bars and tractor implements as its end products. Available bar in the market is 12 mm high tensile steel.

3.12.4 UNIVERSAL STEEL COMPANY

Universal Steel Company is located at Ikeja, Lagos. The Company is jointly owned by British/ Hong Kong in partnership with Nigerians. The Electric Arc Furnace plant has an installed capacity of 90,000 metric tonnes of crude steel, uses local metal scraps and also imports billets. It finally rolls out reinforcement bars, enamel wire and cans as its end products. Available bars in the market are (8mm, 10mm and 12mm diameter high tensile steel.

3.12.5 FEDERATED STEEL COMPANY

Federated Steel Company located at Otta, Ogun State is jointly owned by British/Hong Kong in partnership with Nigerians. The plant which operates using Electric Arc Furnace has an installed capacity of 25,000 metric tonnes of crude steel, uses local metal scraps and also imports billets. It finally rolls out 8mm, 10mm & 12mm diameter reinforcement bars, as its end products.

3.12.6 KEW METAL INDUSTRY

KEW Metal Industry is domiciled at Ikeja, Lagos: The Company is jointly owned by British/ Hong Kong in partnership with Nigerians. The plant which operates using Electric Arc Furnace has an installed capacity of 20,000 metric tonnes of crude steel, uses local metal scraps and also imports billets. It finally rolls out 8mm, 10mm &12mm diameter reinforcement bars, enamel wire, bolts and nuts as its end products.

3.12.7 KWARA CONTINENTAL METAL AND CHEMICAL COMPANY

Kwara Continental Metal and Chemical Company is located at Ilorin, Kwara. The Company is owned by Nigerians. The plant which operates using Electric Arc Furnace has an installed capacity of 25,000 metric tonnes of crude steel, imports billets. It finally rolls out 8mm, 10mm & 12mm diameter reinforcement bars, enamel wire and cans as its end products which are now not available in the market.

3.12.8 ALLIED STEEL COMPANY LIMITED

The Company is owned by Nigerians. The plant which operates rolls our only bars has an installed capacity of 25,000 metric tonnes of crude steel ,uses imports billets as raw materials to roll 8mm, 10mm & 12mm diameter reinforcing bars.

3.12.9 MANDARIN INDUSTRY

The mini mill is jointly owned by Indians in partnership with Nigerians. The plant which operates does only rolling has an installed capacity of 15,000 metric tonnes of crude steel, uses imported billets. It finally rolls out reinforcement bars. Source: Omoweh, D. (2005).

3.12.10 NIGER STEEL COMPANY

The Company is jointly owned by the defunct Anambra State Government in partnership with Germans. The plant which operates using Electric Arc Furnace has an installed capacity of 50,000 metric tonnes of crude steel, uses local metal scraps and also imports billets as raw materials. It finally rolls out 8mm, 10mm &12mm reinforcement bars and coils as end products.

3.12.11 QUA STEEL PRODUCTS COMPANY

Qua Steel Products Company is located in Eket, Cross Rivers State. The Company is jointly owned by Cross Rivers State in partnership with Nigerians. The plant which operates using Electric Arc Furnace has an installed capacity of 100,000 metric tonnes of crude steel and uses imported billets as raw materials. It finally rolls out reinforcement bars as its end products. Source: Omoweh, D. (2005).

3.12.12 SANKYO

Sankyo is a product of some Nigerians partnership. Though, the installed capacity of the plant is not known, the company uses imported billets as raw materials. It finally rolls out reinforcement bars as its end products. Available products in the market are20mm and 25mm high tensile bars.

3.12.13 SUNFLAG

Sunflag is located in Lagos. The Company is a product of some Nigerians partnership. Though, the installed capacity of the plant is not known, the company uses imported billets as raw materials. It finally rolls out reinforcement bars as its end products. Available products in the market are 10mm and 12mm high tensile bars.

The summary of the firms, location and installed capacities are as shown in table 3.2 below:

TABLE 3.1 LOCATION AND INSTALLED CAPACITY OF PRIVATELY OWNED MILLS IN NIGERIA.

S/N	FIRM	LOCATION	CAPACITY 10,000T/YR
1	Qua Steel	Eket	10
2	Universal steel	Ikeja	8
3	Continental Iron and Steel	Ikeja	15
4	Sels Metal	Ikeja	10
5	Federated Mills	Offa	14
6	Allied Steel	Onitsha	10
7	Generated Steel Mill	Asaba	5
8	Nigerian Spanish Engineering	Kano	19
9	Mayor engineering	Ikorodu	29
10	Oro Steel	Ilorin	n.a
11	Kwara Commercial Metal and Chemical Industry	Ilorin	4
12	Union Steel	Ilorin	n.a
13	Asiatic Manjarin	Ikorodu	6
14	Niger Steel	Enugu	3
15	Metcom Nigeria Limited	Owerri	3
16	Others (Estimated)		2

3.13 SAMPLES COLLECTION

The samples were collected from 14 different companies. Six of the companies are foreign and their actual names are not known but only the countries of origin are specified. Thus, there are nineteen samples from fourteen different companies including the foreign ones that were considered for the test.

The samples collected from the following companies/countries are as shown in table 3.2 below.

TABLE 3.2 STEEL REINFORCING BAR SAMPLES COLLECTION

S/No	Company/Country	Diameter Collected (mm)
01	Sunflag Steel Company, Lagos, Nigeria.	10 , 12
02	Universal Steel Company, Lagos, Nigeria.	8 , 10
03	Mayor Steel Company, Lagos, Nigeria.	8 , 10 , 16
04	Sankyo, Lagos, Nigeria.	20 , 25
05	Nigerian – Spanish, Kano.	12
06	Katsina Steel Rolling Mill, Katsina, Nigeria.	12
07	Delta Steel Company Ltd, Warri, Nigeria.	16
08	Oshogbo Steel Rolling Company Ltd, Oshogbo, Nigeria.	12
09	Ukraine, Asia.	8
10	Cote D'ivoire , West Africa.	8
11	Russia, Asia.	12
12	Brazil, South America.	10
13	Holland, Europe.	16
14	Unknown – Foreign Source.	10

The Samples diameters collected from the local sources depended on the available sizes within the company. For samples from foreign sources, only diameters available in the Nigerian Construction Industry were collected. There are other indigenous rolling mills as mentioned in the survey that are supposed to produce steel reinforcing bars for use but are not into production. Thus, samples were not available for collection from these sources and the companies were accordingly not represented. Most of the mini mills working in Nigeria have foreign dominant partners with little or no Nigerian presence occupying key positions and many of them are importing their raw materials. This is very unfair to Nigerians and there seemed to be nobody to check them.

3.14 SAMPLES LABELING

All the fourteen companies from where the samples were collected have been labeled in an alphabetical order as A, B, C, D,……N. The order of identification does not mean A is better than B, as the designations are only for identification purposes.

For example: $A_{12}T_1$ and $A_{10}T_2$ imply company A twelve MILLIMETRE diameter sample one for tension test and company A ten MILLIMETRE diameter sample two for tension test respectively. Similarly $A_{12}B_1$ and $A_{10}B_2$ imply company A twelve MILLIMETRE diameter sample 1 for bend test and company A ten MILLIMETRE diameter sample 2 for bend test respectively.

$A_{12}C_1$ and $A_{10}C_2$ imply company A twelve MILLIMETRE diameter samples 1 for chemical concentration and company A ten MILLIMETRE diameter for sample 2 chemical concentration respectively. While $A_{12}P_1$ and $A_{10}P_2$ refer to company A diameter twelve millimetres diameter sample 1 for percentage composition and company A diameter ten millimetres sample 2 for percentage composition respectively.

$B_{12}T_1$ and $B_{10}T_2$ imply company B twelve millimetre diameter sample one for tension test and company B ten MILLIMETRE diameter sample 2 for tension test respectively, and so on.

3.15 SAMPLES PREPARATION

For the tension test, ten samples were tested for each diameter. Each sample consists of a length of 500Millimetres. Each sample diameter is measured in three places and the average is obtained as the diameter. The results are as shown in table 3.3 below. The tests are in accordance to BS4449 (1997) clause 1.9 and BS4449: 1969 clause 15 respectively.

The determination of the effective cross sectional areas was done based on the relationship

A^{eff} = M/ 0.0785L as provided by BS4449 (1997); where A^{eff} = Effective Cross Sectional Area ; M = Mass in Kilogrammes and L= Length of Sample.

TABLE 3.3: MEASURED DIAMETERS AND CROSS SECTIONAL AREAS FROM ALL SAMPLES.

S/No	Mark	Market Assumed Diameter (mm)	Measured Average Diameter (mm)	Average Mass (Kg)	Average Effective Cross- Sectional Area (mm^2)
01	$A_{12}T$	12.00	11.88	0.338	86.14
02	$A_{10}T_0$	10.00	9.65	0.282	71.96
03	$B_{10}T$	10.00	9.56	0.279	70.98
04	B_8T	8.00	7.44	0.189	48.37
05	$C_{16}T$	16.00	15.82	0.629	160.14
06	$C_{10}T$	10.00	9.55	0.284	72.42
07	C_8T	8.00	7.46	0.196	49.85
08	D_8T	8.00	7.23	0.143	36.27
09	$E_{25}T$	25.00	24.56	1.244	316.93
10	$E_{20}T$	20.00	19.57	1.103	281.13
11	$F_{12}T$	12.00	11.4	0.349	88.84
12	$G_{12}T$	12.00	11.48	0.334	85.17
13	$H_{16}T$	16.00	15.52	0.376	95.77
14	$I_{12}T$	12.00	11.40	0.343	87.47
15	J_8T	8.00	6.50	0.136	34.74
16	$K_{10}T$	10.00	9.36	0.275	70.12
17	$L_{12}T$	12.00	11.82	0.430	110.30
18	$M_{10}T$	10.00	9.23	0.282	71.77
19	$N_{16}T$	16.00	15.60	0.829	211.28

3.16 TENSILE TESTS

The tensile test results are as shown in tables 3.4 to 3.22 below. Recall$A_{12}T_1$ and$A_{10}T_2$ imply company A twelve MILLIMETRE diameter sample one for tension test and company A ten MILLIMETRE diameter sample two for tension test respectively and so on..

Company A, Samples 1-10 in Tension

TABLE 3.4: TWELVE MILLIMETRE DIAMETER BARS.

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	$A_{12}T_1$	11.88	110.79	361.04	541.57	16.0
02	$A_{12}T_2$	11.88	110.79	352.02	523.51	15.0
03	$A_{12}T_3$	11.88	110.79	352.02	523.51	18.3
04	$A_{12}T_4$	11.88	110.79	361.04	532.54	16.7
05	$A_{12}T_5$	11.88	110.79	352.02	523.51	16.0
06	$A_{12}T_6$	11.88	110.79	361.04	523.51	15.7
07	$A_{12}T_7$	11.88	110.79	361.04	532.54	16.7
08	$A_{12}T_8$	11.88	110.79	361.04	532.54	17.3
09	$A_{12}T_9$	11.88	110.79	361.04	532.54	16.7
10	$A_{12}T_{10}$	11.88	110.79	352.02	532.54	16.7
Average Ultimate Strength = 529.83N/mm^2 ; Average Elongation = 16.50						
Characteristic Strength = 350.0N/mm^2 ; Standard Deviation = 4.65						

TABLE 3.5: TEN MILLIMETRE DIAMETER BARS.

Company A, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	$A_{10}T_1$	9.65	73.10	410.4	656.6	15.0
02	$A_{10}T_2$	9.65	73.10	410.4	643.0	12.3
03	$A_{10}T_3$	9.65	73.10	410.4	656.6	15.0
04	$A_{10}T_4$	9.65	73.10	410.4	656.6	15.0
05	$A_{10}T_5$	9.65	73.10	410.4	656.6	13.3
06	$A_{10}T_6$	9.65	73.10	410.4	656.6	15.0
07	$A_{10}T_7$	9.65	73.10	410.4	656.6	13.3
08	$A_{10}T_8$	9.65	73.10	410.4	670.3	13.3
09	$A_{10}T_9$	9.65	73.10	410.4	656.6	13.3
10	$A_{10}T_{10}$	9.65	73.10	410.4	656.6	13.3
Average Ultimate Strength = 656.60N/mm^2 ; Average Elongation = 13.90						
Characteristic Strength = 410.0N/mm^2 ; Standard Deviation = **0**.00						

TABLE 3.6: TEN MILLIMETRE DIAMETER BARS.

Company B, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	$B_{10}T_1$	9.56	71.74	390.3	529.7	18.3
02	$B_{10}T_2$	9.56	71.74	390.3	543.6	20.0
03	$B_{10}T_3$	9.56	71.74	390.3	529.7	17.3
04	$B_{10}T_4$	9.56	71.74	390.3	543.6	20.0
05	$B_{10}T_5$	9.56	71.74	390.3	529.7	20.3
06	$B_{10}T_6$	9.56	71.74	390.3	529.7	20.0
07	$B_{10}T_7$	9.56	71.74	390.3	543.6	20.0
08	$B_{10}T_8$	9.56	71.74	390.3	543.6	21.7
09	$B_{10}T_9$	9.56	71.74	390.3	543.6	18.3
10	$B_{10}T_{10}$	9.56	71.74	390.3	529.7	20.0
Average Ultimate Strength = 536.70N/mm^2 ; Average Elongation = 19.60						
Characteristic Strength = 390.0N/mm^2 ; Standard Deviation = **0**.00						

TABLE 3.7: EIGHT MILLIMETRE DIAMETER BARS.

Company B, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	B_8T_1	7.44	43.45	368.2	483.3	23.3
02	B_8T_2	7.44	43.45	368.2	483.3	23.3
03	B_8T_3	7.44	43.45	368.2	483.3	25.0
04	B_8T_4	7.44	43.45	368.2	483.3	23.3
05	B_8T_5	7.44	43.45	368.2	483.3	21.7
06	B_8T_6	7.44	43.45	368.2	483.3	23.3
07	B_8T_7	7.44	43.45	368.2	483.3	23.3
08	B_8T_8	7.44	43.45	368.2	483.3	25.0
09	B_8T_9	7.44	43.45	368.2	483.3	25.0
10	B_8T_{10}	7.44	43.45	368.2	483.3	25.0

Average Ultimate Strength = 483.30N/mm^2 ; Average Elongation = 23.82

Characteristic Strength = 368.0N/mm^2 ; Standard Deviation = **0**.00

TABLE 3.8: SIXTEEN MILLIMETRE DIAMETER BARS.

Company C, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	$C_{16}T_1$	15.82	196.46	493.7	911.1	8.3
02	$C_{16}T_2$	15.82	196.46	493.7	916.2	8.3
03	$C_{16}T_3$	15.82	196.46	493.7	911.1	8.3
04	$C_{16}T_4$	15.82	196.46	493.7	911.1	8.3
05	$C_{16}T_5$	15.82	196.46	493.7	916.2	8.3
06	$C_{16}T_6$	15.82	196.46	509.0	916.2	8.3
07	$C_{16}T_7$	15.82	196.46	493.7	911.1	8.3
08	$C_{16}T_8$	15.82	196.46	519.2	931.5	8.3
09	$C_{16}T_9$	15.82	196.46	524.3	931.5	8.3
10	$C_{16}T_{10}$	15.82	196.46	519.2	931.5	8.3
Average Ultimate Strength = 918.80N/mm^2 ; Average Elongation = 8.33						
Characteristic Strength = 482.0N/mm^2 ; Standard Deviation = 13.02						

TABLE 3.9: TEN MILLIMETRE DIAMETER BARS.

Company C, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	$C_{10}T_1$	9.55	71.59	377.15	530.8	19.3
02	$C_{10}T_2$	9.55	71.59	363.18	519.8	20.0
03	$C_{10}T_3$	9.55	71.59	363.18	530.8	20.0
04	$C_{10}T_4$	9.55	71.59	363.18	530.8	20.0
05	$C_{10}T_5$	9.55	71.59	363.18	530.8	20.0
06	$C_{10}T_6$	9.55	71.59	363.18	530.8	21.7
07	$C_{10}T_7$	9.55	71.59	363.18	530.8	20.0
08	$C_{10}T_8$	9.55	71.59	363.18	530.8	20.0
09	$C_{10}T_9$	9.55	71.59	363.18	544.8	21.7
10	$C_{10}T_{10}$	9.55	71.59	363.18	530.8	16.7
Average Ultimate Strength = 531.10N/mm^2 ; Average Elongation = 19.93						
Characteristic Strength = 357.0N/mm^2 ; Standard Deviation = 4.42						

TABLE 3.10: EIGHT MILLIMETRE DIAMETER BARS.

Company C, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	C_8T_1	7.46	43.69	412.0	549.32	23.3
02	C_8T_2	7.46	43.69	412.0	549.32	20.0
03	C_8T_3	7.46	43.69	412.0	549.32	21.7
04	C_8T_4	7.46	43.69	412.0	549.32	21.7
05	C_8T_5	7.46	43.69	389.1	549.32	21.7
06	C_8T_6	7.46	43.69	412.0	549.32	20.0
07	C_8T_7	7.46	43.69	389.1	549.32	20.0
08	C_8T_8	7.46	43.69	389.1	549.32	21.7
09	C_8T_9	7.46	43.69	412.0	549.32	21.7
10	C_8T_{10}	7.46	43.69	412.0	549.32	20.0
Average Ultimate Strength = 549.30N/mm^2 ; Average Elongation = 21.70						
Characteristic Strength = 387.0N/mm^2 ; Standard Deviation = 11.05						

TABLE 3.11: EIGHT MILLIMETRE DIAMETER BARS

Company D, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	D_8T_1	7.23	41.03	463.1	609.3	1.7
02	D_8T_2	7.23	41.03	463.1	633.7	1.7
03	D_8T_3	7.23	41.03	463.1	609.3	1.7
04	D_8T_4	7.23	41.03	463.1	609.3	1.7
05	D_8T_5	7.23	41.03	463.1	633.7	1.7
06	D_8T_6	7.23	41.03	463.1	633.7	1.7
07	D_8T_7	7.23	41.03	463.1	633.7	1.7
08	D_8T_8	7.23	41.03	463.1	609.3	1.7
09	D_8T_9	7.23	41.03	463.1	609.3	3.3
10	D_8T_{10}	7.23	41.03	463.1	633.7	1.7
Average Ultimate Strength = 621.50N/mm^2 ; Average Elongation = 1.70						
Characteristic Strength = 463.0N/mm^2 ; Standard Deviation = 0.05						

TABLE 3.12: TWENTY FIVE MILLIMETRE DIAMETER BARS.

Company E, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	$E_{25}T_1$	24.56	473.51	371.7	570.2	18.3
02	$E_{25}T_2$	24.56	473.51	371.7	574.4	20.0
03	$E_{25}T_3$	24.56	473.51	367.5	574.4	20.0
04	$E_{25}T_4$	24.56	473.51	367.5	574.4	20.0
05	$E_{25}T_5$	24.56	473.51	367.5	578.7	20.0
06	$E_{25}T_6$	24.56	473.51	367.5	574.4	20.0
07	$E_{25}T_7$	24.56	473.51	363.2	574.4	20.0
08	$E_{25}T_8$	24.56	473.51	363.2	578.7	20.0
09	$E_{25}T_9$	24.56	473.51	367.5	578.7	20.0
10	$E_{25}T_{10}$	24.56	473.51	367.5	578.7	20.0

Average Ultimate Strength = 576.10N/mm^2 ; Average Elongation = 19.80

Characteristic Strength = 363.0N/mm^2 ; Standard Deviation = 2.4

TABLE 3.13: TWENTY MILLIMETRE DIAMETER BARS.

Company E, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	$E_{20}T_1$	19.57	300.64	319.3	452.4	25.0
02	$E_{20}T_2$	19.57	300.64	319.3	452.4	23.3
03	$E_{20}T_3$	19.57	300.64	319.3	452.4	25.0
04	$E_{20}T_4$	19.57	300.64	319.3	452.4	25.0
05	$E_{20}T_5$	19.57	300.64	319.3	445.7	23.3
06	$E_{20}T_6$	19.57	300.64	319.3	445.7	25.0
07	$E_{20}T_7$	19.57	300.64	319.3	445.7	23.3
08	$E_{20}T_8$	19.57	300.64	319.3	445.7	22.7
09	$E_{20}T_9$	19.57	300.64	319.3	445.7	25.0
10	$E_{20}T_{10}$	19.57	300.64	319.0	445.7	25.0
Average Ultimate Strength = 449.40N/mm^2 ; Average Elongation = 24.30						
Characteristic Strength = 317.0N/mm^2 ; Standard Deviation = 1.04						

TABLE 3.14: TWELVE MILLIMETRE DIAMETER BARS.

Company F, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	$F_{12}T_1$	11.40	102.02	392.1	607.7	18.3
02	$F_{12}T_2$	11.40	102.02	392.1	607.7	20.0
03	$F_{12}T_3$	11.40	102.02	392.1	607.7	17.3
04	$F_{12}T_4$	11.40	102.02	392.1	607.7	20.0
05	$F_{12}T_5$	11.40	102.02	392.1	588.1	20.3
06	$F_{12}T_6$	11.40	102.02	509.7	774.4	20.0
07	$F_{12}T_7$	11.40	102.02	392.1	588.1	20.0
08	$F_{12}T_8$	11.40	102.02	392.1	588.1	21.7
09	$F_{12}T_9$	11.40	102.02	392.1	588.1	18.3
10	$F_{12}T_{10}$	11.40	102.02	509.7	774.4	20.0
Average Ultimate strength = 633.20N/mm^2 ; Average Elongation = 19.10						
Characteristics Strength= 334.0N/mm^2 ; Standard Deviation = 49.60						

TABLE 3.15: EIGHT MILLIMETRE DIAMETER BARS.

Company G, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	G_8T_1	6.50	33.17	572.8	693.4	3.3
02	G_8T_2	6.50	33.17	572.8	693.4	3.3
03	G_8T_3	6.50	33.17	572.8	693.4	3.3
04	G_8T_4	6.50	33.17	572.8	693.4	3.3
05	G_8T_5	6.50	33.17	572.8	693.4	1.7
06	G_8T_6	6.50	33.17	572.8	693.4	3.3
07	G_8T_7	6.50	33.17	572.8	693.4	1.7
08	G_8T_8	6.50	33.17	572.8	693.4	1.7
09	G_8T_9	6.50	33.17	572.8	693.4	1.7
10	G_8T_{10}	6.50	33.17	572.8	693.4	3.3
Average Ultimate strength = 693.40 N/mm^2 ; Average Elongation =2.7						
Characteristics Strength=573.0 N/mm^2 ; Standard Deviation = 0.0N/mm^2						

TABLE 3.16: TWELVE MILLIMETRE DIAMETER BARS.

Company H, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	$H_{12}T_1$	11.48	103.46	425.29	705.59	15.0
02	$H_{12}T_2$	11.48	103.46	415.62	705.59	15.0
03	$H_{12}T_3$	11.48	103.46	415.62	715.25	13.3
04	$H_{12}T_4$	11.48	103.46	405.95	715.25	15.0
05	$H_{12}T_5$	11.48	103.46	425.29	724.92	15.0
06	$H_{12}T_6$	11.48	103.46	415.62	715.25	13.3
07	$H_{12}T_7$	11.48	103.46	425.29	715.25	15.0
08	$H_{12}T_8$	11.48	103.46	425.29	724.92	16.7
09	$H_{12}T_9$	11.48	103.46	425.29	715.25	16.7
10	$H_{12}T_{10}$	11.48	103.46	415.62	715.25	13.3
Mean yield strength = 715.30N/mm^2 ; Average Elongation = 14.83						
Characteristics Strength= 408.0N/mm^2 ; Standard Deviation = 6.83						

TABLE 3.17: SIXTEEN MILLIMETRE DIAMETER BARS.

Company I, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	$I_{16}T_1$	15.52	189.08	502.43	608.21	11.7
02	$I_{16}T_2$	15.52	189.08	502.43	608.21	11.7
03	$I_{16}T_3$	15.52	189.08	497.14	597.63	15.0
04	$I_{16}T_4$	15.52	189.08	497.14	592.34	15.0
05	$I_{16}T_5$	15.52	189.08	502.43	602.92	16.0
06	$I_{16}T_6$	15.52	189.08	502.43	597.63	15.0
07	$I_{16}T_7$	15.52	189.08	491.86	602.92	13.3
08	$I_{16}T_8$	15.52	189.08	491.86	597.63	16.7
09	$I_{16}T_9$	15.52	189.08	497.14	597.63	16.0
10	$I_{16}T_{10}$	15.52	189.08	497.14	592.34	15.0

Average Ultimate Strength = 599.30N/mm^2 ; Average Elongation = 14.5 Characteristics

Strength = 493.0N/mm^2 ; Standard Deviation = 3.70

TABLE 3.18: TWELVE MILLIMETRE DIAMETER BARS.

Company J, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	$J_{12}T_1$	11.40	100.24	369.11	618.52	13.3
02	$J_{12}T_2$	11.40	100.24	369.11	618.52	13.3
03	$J_{12}T_3$	11.40	100.24	369.11	608.54	15.0
04	$J_{12}T_4$	11.40	100.24	369.11	608.54	15.0
05	$J_{12}T_5$	11.40	100.24	369.11	608.54	15.0
06	$J_{12}T_6$	11.40	100.24	369.11	608.54	13.3
07	$J_{12}T_7$	11.40	100.24	369.11	608.54	16.7
08	$J_{12}T_8$	11.40	100.24	369.11	618.52	13.3
09	$J_{12}T_9$	11.40	100.24	369.11	608.54	15.0
10	$J_{12}T_{10}$	11.40	100.24	369.11	618.52	15.0

Average Ultimate Strength = 612.50N/mm^2 ; Average Elongation = 14.50

Characteristics Strength= 369.0N/mm^2 ; Standard Deviation = 0.00

TABLE 3.19: TEN MILLIMETRE DIAMETER BARS.

Company K, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	$K_{10}T_1$	9.36	68.77	581.7	581.7	11.7
02	$K_{10}T_2$	9.36	68.77	538.0	538.0	6.7
03	$K_{10}T_3$	9.36	68.77	581.7	581.7	11.7
04	$K_{10}T_4$	9.36	68.77	581.7	581.7	10.0
05	$K_{10}T_5$	9.36	68.77	581.7	581.7	10.7
06	$K_{10}T_6$	9.36	68.77	581.7	581.7	10.0
07	$K_{10}T_7$	9.36	68.77	581.7	581.7	10.0
08	$K_{10}T_8$	9.36	68.77	581.7	581.7	10.0
09	$K_{10}T_9$	9.36	68.77	581.7	581.7	10.0
10	$K_{10}T_{10}$	9.36	68.77	552.6	552.6	10.0
Average Ultimate Strength = 660.20N/mm^2 ; Average Elongation = 10.10						
Characteristics Strength= 549.0N/mm^2 ; Standard Deviation= 15.71						

TABLE 3.20: TWELVE MILLIMETRE DIAMETER BARS

Company L, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	$L_{12}T_1$	11.82	109.07	504.3	568.4	13.3
02	$L_{12}T_2$	11.82	109.07	504.3	605.1	16.7
03	$L_{12}T_3$	11.82	109.07	504.3	605.1	16.7
04	$L_{12}T_4$	11.82	109.07	504.3	605.1	15.0
05	$L_{12}T_5$	11.82	109.07	504.3	596.0	11.7
06	$L_{12}T_6$	11.82	109.07	504.3	596.0	16.7
07	$L_{12}T_7$	11.82	109.07	504.3	605.1	15.0
08	$L_{12}T_8$	11.82	109.07	504.3	605.1	15.0
09	$L_{12}T_9$	11.82	109.07	504.3	605.1	15.0
10	$L_{12}T_{10}$	11.82	109.07	505.2	605.1	14.3
Average Ultimate Strength = 599.60N/mm^2 ; Average Elongation = **14.90**						
Characteristics Strength =500.00N/mm^2 ; Standard Deviation = 2.90						

TABLE 3.21: TEN MILLIMETRE DIAMETER BARS

Company M, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	$M_{10}T_1$	9.23	66.88	553.2	642.9	10.0
02	$M_{10}T_2$	9.23	66.88	568.2	642.9	11.7
03	$M_{10}T_3$	9.23	66.88	568.2	642.9	11.7
04	$M_{10}T_4$	9.23	66.88	553.2	642.9	11.7
05	$M_{10}T_5$	9.23	66.88	583.1	642.9	13.3
06	$M_{10}T_6$	9.23	66.88	553.2	642.9	11.7
07	$M_{10}T_7$	9.23	66.88	568.2	642.9	11.3
08	$M_{10}T_8$	9.23	66.88	568.2	642.9	11.7
09	$M_{10}T_9$	9.23	66.88	568.2	642.9	12.0
10	$M_{10}T_{10}$	9.23	66.88	553.2	642.9	12.7
Average Ultimate Strength = 643.00N/mm^2 ; Average Elongation=11.8						
Characteristics Strength=547.00N/mm^2 ; Standard Deviation = 10.09						

TABLE 3.22: SIXTEEN MILLIMETRE DIAMETER BARS.

Company N, Samples 1-10 in Tension

S/No	Identification Number	Nominal Diameter Measured (mm)	Cross Sectional Area(mm^2)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)
01	$N_{16}T_1$	15.60	191.04	549.6	649.1	15.0
02	$N_{16}T_2$	15.60	191.04	549.6	638.6	13.3
03	$N_{16}T_3$	15.60	191.04	549.6	649.1	14.0
04	$N_{16}T_4$	15.60	191.04	549.6	643.8	13.3
05	$N_{16}T_5$	15.60	191.04	549.6	643.8	13.3
06	$N_{16}T_6$	15.60	191.04	549.6	643.8	15.0
07	$N_{16}T_7$	15.60	191.04	549.6	643.8	13.3
08	$N_{16}T_8$	15.60	191.04	554.9	649.1	13.3
09	$N_{16}T_9$	15.60	191.04	560.1	649.1	13.3
10	$N_{16}T_{10}$	15.60	191.04	554.9	643.8	15.0
Average Ultimate Strength = 645.40N/mm^2 ; Average Elongation = 13.90						
Characteristics Strength= 546.00N/mm^2 ; Standard Deviation = 3.66						

The pictorial view of some broken test specimens after the tensile tests have been presented in plate one below:



Plate 1: Some broken test specimens after tensile tests.

3.17 BEND TEST

The bend test was carried out in accordance with the BS4449(1997) provisions, in the heavy concrete laboratory of the civil engineering department of A.B.U. Zaria. Plate two below shows the tested samples and the results are presented in tables 3.23 to 3.41 below:



Plate 2: Some specimens after the bend tests.

TABLE 3.23: TWELVE MILLIMETRE DIAMETER BARS FROM COMPANY A. (SAMPLES 1-10)

S/No.	IDENTIFICATION NO.	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	$A_{12}B_1$	12.0	39.0	No Cracks	Ok
02	$A_{12}B_2$	12.0	39.0	No Cracks	Ok
03	$A_{12}B_3$	12.0	39.0	No Cracks	Ok
04	$A_{12}B_4$	12.0	39.0	No Cracks	Ok
05	$A_{12}B_5$	12.0	39.0	No Cracks	Ok
06	$A_{12}B_6$	12.0	39.0	No Cracks	Ok
07	$A_{12}B_7$	12.0	39.0	No Cracks	Ok
08	$A_{12}B_8$	12.0	39.0	No Cracks	Ok
09	$A_{12}B_9$	12.0	39.0	No Cracks	Ok
10	$A_{12}B_{10}$	12.0	39.0	No Cracks	Ok

TABLE 3.24: TEN MILLIMETRE DIAMETER BARS FROM COMPANY A (SAMPLES 1-10)

S/No.	IDENTIFICATION NUMBER	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	$A_{10}B_1$	10.0	33.0	No Cracks	Ok
02	$A_{10}B_2$	10.0	33.0	No Cracks	Ok
03	$A_{10}B_3$	10.0	33.0	No Cracks	Ok
04	$A_{10}B_4$	10.0	33.0	No Cracks	Ok
05	$A_{10}B_5$	10.0	33.0	No Cracks	Ok
06	$A_{10}B_6$	10.0	33.0	No Cracks	Ok
07	$A_{10}B_7$	10.0	33.0	No Cracks	Ok
08	$A_{10}B_8$	10.0	33.0	No Cracks	Ok
09	$A_{10}B_9$	10.0	33.0	No Cracks	Ok
10	$A_{10}B_{10}$	10.0	33.0	No Cracks	Ok

TABLE 3.25: TEN MILLIMETRE DIAMETER BARS FROM COMPANY B (SAMPLES 1-10)

S/No.	IDENTIFICATION NUMBER	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	$B_{10}B_1$	10.0	33.0	No Cracks	Ok
02	$B_{10}B_2$	10.0	33.0	No Cracks	Ok
03	$B_{10}B_3$	10.0	33.0	No Cracks	Ok
04	$B_{10}B_4$	10.0	33.0	No Cracks	Ok
05	$B_{10}B_5$	10.0	33.0	No Cracks	Ok
06	$B_{10}B_6$	10.0	33.0	No Cracks	Ok
07	$B_{10}B_7$	10.0	33.0	No Cracks	Ok
08	$B_{10}B_8$	10.0	33.0	No Cracks	Ok
09	$B_{10}B_9$	10.0	33.0	No Cracks	Ok
10	$B_{10}B_{10}$	10.0	33.0	No Cracks	Ok

TABLE 3.26: EIGHT MILLIMETRE DIAMETER BARS FROM COMPANY B (SAMPLES 1-10)

S/No.	IDENTIFICATION NUMBER	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	B_8B_1	8.0	27.0	No Cracks	Ok
02	B_8B_2	8.0	27.0	No Cracks	Ok
03	B_8B_3	8.0	27.0	No Cracks	Ok
04	B_8B_4	8.0	27.0	No Cracks	Ok
05	B_8B_5	8.0	27.0	No Cracks	Ok
06	B_8B_6	8.0	27.0	No Cracks	Ok
07	B_8B_7	8.0	27.0	No Cracks	Ok
08	B_8B_8	8.0	27.0	No Cracks	Ok
09	B_8B_9	8.0	27.0	No Cracks	Ok
10	B_8B_{10}	8.0	27.0	No Cracks	Ok

TABLE 3.27: SIXTEEN MILLIMETRE DIAMETER BARS FROM COMPANY C (SAMPLES 1-10)

S/No.	IDENTIFICATION NUMBER	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	$C_{16}B_1$	16.0	51.0	Total Breakage	Not Ok
02	$C_{16}B_2$	16.0	51.0	Total Breakage	Not Ok
03	$C_{16}B_3$	16.0	51.0	Total Breakage	Not Ok
04	$C_{16}B_4$	16.0	51.0	Total Breakage	Not Ok
05	$C_{16}B_5$	16.0	51.0	Total Breakage	Not Ok
06	$C_{16}B_6$	16.0	51.0	Total Breakage	Not Ok
07	$C_{16}B_7$	16.0	51.0	Total Breakage	Not Ok
08	$C_{16}B_8$	16.0	51.0	Total Breakage	Not Ok
09	$C_{16}B_9$	16.0	51.0	Total Breakage	Not Ok
10	$C_{16}B_{10}$	16.0	51.0	Total Breakage	Not Ok

TABLE 3.28: TEN MILLIMETRE DIAMETER BARS FROM COMPANY C (SAMPLES 1-10)

S/No.	IDENTIFICATION NUMBER	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	$C_{10}B_1$	10.0	33.0	No Cracks	Ok
02	$C_{10}B_2$	10.0	33.0	No Cracks	Ok
03	$C_{10}B_3$	10.0	33.0	No Cracks	Ok
04	$C_{10}B_4$	10.0	33.0	No Cracks	Ok
05	$C_{10}B_5$	10.0	33.0	No Cracks	Ok
06	$C_{10}B_6$	10.0	33.0	No Cracks	Ok
07	$C_{10}B_7$	10.0	33.0	No Cracks	Ok
08	$C_{10}B_8$	10.0	33.0	No Cracks	Ok
09	$C_{10}B_9$	10.0	33.0	No Cracks	Ok
10	$C_{10}B_{10}$	10.0	33.0	No Cracks	Ok

TABLE 3.29: EIGHT MILLIMETRE DIAMETER BARS FROM COMPANY C (SAMPLES 1-10)

S/No.	IDENTIFICATION NUMBER	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	C_8B_1	8.0	27.0	No Cracks	Ok
02	C_8B_2	8.0	27.0	No Cracks	Ok
03	C_8B_3	8.0	27.0	No Cracks	Ok
04	C_8B_4	8.0	27.0	No Cracks	Ok
05	C_8B_5	8.0	27.0	No Cracks	Ok
06	C_8B_6	8.0	27.0	No Cracks	Ok
07	C_8B_7	8.0	27.0	No Cracks	Ok
08	C_8B_8	8.0	27.0	No Cracks	Ok
09	C_8B_9	8.0	27.0	No Cracks	Ok
10	C_8B_{10}	8.0	27.0	No Cracks	Ok

TABLE 3.30: EIGHT MILLIMETRE DIAMETER BARS FROM COMPANY D (SAMPLES 1-10)

S/No.	IDENTIFICATION NUMBER	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	D_8B_1	8.0	27.0	No Cracks	Ok
02	D_8B_2	8.0	27.0	No Cracks	Ok
03	D_8B_3	8.0	27.0	No Cracks	Ok
04	D_8B_4	8.0	27.0	No Cracks	Ok
05	D_8B_5	8.0	27.0	No Cracks	Ok
06	D_8B_6	8.0	27.0	No Cracks	Ok
07	D_8B_7	8.0	27.0	No Cracks	Ok
08	D_8B_8	8.0	27.0	No Cracks	Ok
09	D_8B_9	8.0	27.0	No Cracks	Ok
10	D_8B_{10}	8.0	27.0	No Crack	Ok

TABLE 3.31 : TWENTY FIVE MILLIMETRE DIAMETER BARS FROM COMPANY E (SAMPLES1-10)

S/No.	IDENTIFICATION NUMBER	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	$E_{25}B_1$	25.0	78.0	No Cracks	Ok
02	$E_{25}B_2$	25.0	78.0	No Cracks	Ok
03	$E_{25}B_3$	25.0	78.0	No Cracks	Ok
04	$E_{25}B_4$	25.0	78.0	No Cracks	Ok
05	$E_{25}B_5$	25.0	78.0	No Cracks	Ok
06	$E_{25}B_6$	25.0	78.0	No Cracks	Ok
07	$E_{25}B_7$	25.0	78.0	No Cracks	Ok
08	$E_{25}B_8$	25.0	78.0	No Cracks	Ok
09	$E_{25}B_9$	25.0	78.0	No Cracks	Ok
10	$E_{25}B_{10}$	25.0	78.0	No Cracks	Ok

TABLE 3.32: TWENTY MILLIMETRE DIAMETER BARS FROM COMPANY E (SAMPLES 1-10)

S/No.	IDENTIFICATION NUMBER	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	$E_{20}B_1$	20.0	63.0	No Cracks	Ok
02	$E_{20}B_2$	20.0	63.0	No Cracks	Ok
03	$E_{20}B_3$	20.0	63.0	No Cracks	Ok
04	$E_{20}B_4$	20.0	63.0	No Cracks	Ok
05	$E_{20}B_5$	20.0	63.0	No Cracks	Ok
06	$E_{20}B_6$	20.0	63.0	No Cracks	Ok
07	$E_{20}B_7$	20.0	63.0	No Cracks	Ok
08	$E_{20}B_8$	20.0	63.0	No Cracks	Ok
09	$E_{20}B_9$	20.0	63.0	No Cracks	Ok
10	$E_{20}B_{10}$	20.0	63.0	No Cracks	Ok

TABLE 3.33: TWELVE MILLIMETRE DIAMETER BARS FROM COMPANY F (SAMPLES 1-10)

S/No.	IDENTIFICATION NUMBER	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	$F_{12}B_1$	12.0	39.0	No Cracks	Ok
02	$F_{12}B_2$	12.0	39.0	No Cracks	Ok
03	$F_{12}B_3$	12.0	39.0	No Cracks	Ok
04	$F_{12}B_4$	12.0	39.0	No Cracks	Ok
05	$F_{12}B_5$	12.0	39.0	No Cracks	Ok
06	$F_{12}B_6$	12.0	39.0	No Cracks	Ok
07	$F_{12}B_7$	12.0	39.0	No Cracks	Ok
08	$F_{12}B_8$	12.0	39.0	No Cracks	Ok
09	$F_{12}B_9$	12.0	39.0	No Cracks	Ok
10	$F_{12}B_{10}$	12.0	39.0	No Cracks	Ok

TABLE 3.34: SEVEN MILLIMETRE DIAMETER BARS FROM COMPANY G (SAMPLES 1-10)

S/No.	IDENTIFICATION NUMBER	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	G_8B_1	7.0	24.0	No Cracks	Ok
02	G_8B_2	7.0	24.0	No Cracks	Ok
03	G_8B_3	7.0	24.0	No Cracks	Ok
04	G_8B_4	7.0	24.0	No Cracks	Ok
05	G_8B_5	7.0	24.0	No Cracks	Ok
06	G_8B_6	7.0	24.0	No Cracks	Ok
07	G_8B_7	7.0	24.0	No Cracks	Ok
08	G_8B_8	7.0	24.0	No Cracks	Ok
09	G_8B_9	7.0	24.0	No Cracks	Ok
10	G_8B_{10}	12.0	39.0	No Cracks	Ok

TABLE 3.35: TWELVE MILLIMETRE DIAMETER BARS FROM COMPANY H (SAMPLES 1-10)

S/No.	IDENTIFICATION NO.	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	$H_{12}B_1$	12.0	39.0	No Cracks	Ok
02	$H_{12}B_1$	12.0	39.0	No Cracks	Ok
03	$H_{12}B_1$	12.0	39.0	No Cracks	Ok
04	$H_{12}B_1$	12.0	39.0	No Cracks	Ok
05	$H_{12}B_1$	12.0	39.0	No Cracks	Ok
06	$H_{12}B_1$	12.0	39.0	No Cracks	Ok
07	$H_{12}B_1$	12.0	39.0	No Cracks	Ok
08	$H_{12}B_1$	12.0	39.0	No Cracks	Ok
09	$H_{12}B_1$	12.0	39.0	No Cracks	Ok
10	$H_{12}B_1$	12.0	39.0	No Cracks	Ok

TABLE 3.36: SIXTEEN MILLIMETRE DIAMETER BARS FROM COMPANY I (SAMPLES 1-10)

S/No.	IDENTIFICATION NO.	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	$I_{16}B_1$	16.0	51.0	No Cracks	Ok
02	$I_{16}B_2$	16.0	51.0	No Cracks	Ok
03	$I_{16}B_3$	16.0	51.0	No Cracks	Ok
04	$I_{16}B_4$	16.0	51.0	No Cracks	Ok
05	$I_{16}B_5$	16.0	51.0	No Cracks	Ok
06	$I_{16}B_6$	16.0	51.0	No Cracks	Ok
07	$I_{16}B_7$	16.0	51.0	No Cracks	Ok
08	$I_{16}B_8$	16.0	51.0	No Cracks	Ok
09	$I_{16}B_9$	16.0	51.0	No Cracks	Ok
10	$I_{16}B_{10}$	16.0	51.0	No Cracks	Ok

TABLE 3.37: DIAMETER TWELVE MILLIMETRE BARS FROM COMPANY J (SAMPLES 1-10)

S/No.	IDENTIFICATION NO.	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	$J_{12}B_1$	12.0	39.0	No Cracks	Ok
02	$J_{12}B_2$	12.0	39.0	No Cracks	Ok
03	$J_{12}B_3$	12.0	39.0	No Cracks	Ok
04	$J_{12}B_4$	12.0	39.0	No Cracks	Ok
05	$J_{12}B_5$	12.0	39.0	No Cracks	Ok
06	$J_{12}B_6$	12.0	39.0	No Cracks	Ok
07	$J_{12}B_7$	12.0	39.0	No Cracks	Ok
08	$J_{12}B_8$	12.0	39.0	No Cracks	Ok
09	$J_{12}B_9$	12.0	39.0	No Cracks	Ok
10	$J_{12}B_{10}$	12.0	39.0	No Cracks	Ok

TABLE 3.38: DIAMETER TEN MILLIMETRE BARS FORM COMPANY K (SAMPLES 1-10)

S/No.	IDENTIFICATION NO.	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TESTS	REMARKS
01	$K_{10}B_1$	10.0	33.0	No Cracks	Ok
02	$K_{10}B_2$	10.0	33.0	No Cracks	Ok
03	$K_{10}B_3$	10.0	33.0	No Cracks	Ok
04	$K_{10}B_4$	10.0	33.0	No Cracks	Ok
05	$K_{10}B_5$	10.0	33.0	No Cracks	Ok
06	$K_{10}B_6$	10.0	33.0	No Cracks	Ok
07	$K_{10}B_7$	10.0	33.0	No Cracks	Ok
08	$K_{10}B_8$	10.0	33.0	No Cracks	Ok
09	$K_{10}B_9$	10.0	33.0	No Cracks	Ok
10	$K_{10}B_{10}$	10.0	33.0	No Cracks	Ok

TABLE 3.39: TWELVE MILLIMETRE DIAMETER BARS FROM COMPANY L (SAMPLES 1-10)

S/No.	IDENTIFICATION NO.	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	$L_{12}B_1$	12.0	39.0	No Cracks	Ok
02	$L_{12}B_2$	12.0	39.0	No Cracks	Ok
03	$L_{12}B_3$	12.0	39.0	No Cracks	Ok
04	$L_{12}B_4$	12.0	39.0	No Cracks	Ok
05	$L_{12}B_5$	12.0	39.0	No Cracks	Ok
06	$L_{12}B_6$	12.0	39.0	No Cracks	Ok
07	$L_{12}B_7$	12.0	39.0	No Cracks	Ok
08	$L_{12}B_8$	12.0	39.0	No Cracks	Ok
09	$L_{12}B_9$	12.0	39.0	No Cracks	Ok
10	$L_{12}B_{10}$	12.0	39.0	No Cracks	Ok

TABLE 3.40: TEN MILLIMETRE DIAMETER BARS FROM COMPANY M (SAMPLES 1-10)

S/No.	IDENTIFICATION NO.	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	$M_{10}B_1$	10.0	33.0	No Cracks	Ok
02	$M_{10}B_2$	10.0	33.0	No Cracks	Ok
03	$M_{10}B_3$	10.0	33.0	No Cracks	Ok
04	$M_{10}B_4$	10.0	33.0	No Cracks	Ok
05	$M_{10}B_5$	10.0	33.0	No Cracks	Ok
06	$M_{10}B_6$	10.0	33.0	No Cracks	Ok
07	$M_{10}B_7$	10.0	33.0	No Cracks	Ok
08	$M_{10}B_8$	10.0	33.0	No Cracks	Ok
09	$M_{10}B_9$	10.0	33.0	No Cracks	Ok
10	$M_{10}B_{10}$	10.0	33.0	No Cracks	Ok

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TABLE 3.41: SIXTEEN MILLIMETRE DIAMETER BARS FROM COMPANY N (SAMPLES 1-10)

S/No.	IDENTIFICATION NUMBER	BAR SIZE (mm)	FORMER DIAMETER	OBSERVATIONS AFTER TEST	REMARKS
01	$N_{16}B_1$	16.0	51.0	No Cracks	Ok
02	$N_{16}B_2$	16.0	51.0	No Cracks	Ok
03	$N_{16}B_3$	16.0	51.0	No Cracks	Ok
04	$N_{16}B_4$	16.0	51.0	No Cracks	Ok
05	$N_{16}B_5$	16.0	51.0	No Cracks	Ok
06	$N_{16}B_6$	16.0	51.0	No Cracks	Ok
07	$N_{16}B_7$	16.0	51.0	No Cracks	Ok
08	$N_{16}B_8$	16.0	51.0	No Cracks	Ok
09	$N_{16}B_9$	16.0	51.0	No Cracks	Ok
10	$N_{16}B_{10}$	16.0	51.0	No Cracks	Ok

3.18 CHEMICAL TESTS

Under the Chemical tests, two types of experiments were performed (a) Chemical concentration and (b) percentage composition. The actual difference is that the former is the concentration with respect to milligrammes of the element per litre and the latter refers to the percentage composition of the reinforcement by weight.

3.18.1 DETERMINATION OF CHEMICAL CONCENTRATION IN MILLIGRAMS PER LITRE

This was conducted at National Research Institute for Chemical Technology in Zaria. A total of twelve (12) elements were identified.. The tables 3.42 and 3.43 below show the data obtained in respect of this test.

In the determination of the elemental concentrations in milligrams per litre of the samples, stock solutions were prepared by the National Research Institute for Chemical Technology (NARICT) personnel using analar. An analar is a compound that matches with the element to be identified and capable of digesting same to form a stock solution.

For example, to identify Calcium, Calcium Chloride ($CaCl_2$) or Calcium Carbonate ($CaCO_3$) used serial dilutions were made from the prepared stock solution within the range 1ppm, 2ppm, 3ppm, 4ppm and 5ppm. Each of the Samples was subjected to Atomic Spectrometer – Shimadzu model fuelled by acetylene/ air whose output comes as a calibration curve relating the absorbance of the element and concentration. The concentrations in mg/litre are read directly from the digitized system. The concentrations of twelve (12) constituent elements and compounds comprising Al, C, Co, Cr, Fe, Mn, N, Ni, Pb, S, Zn and PO_3 were obtained and shown in table 3.42and 3.43 below. Recall $A_{12}C$ implies Sample from company A under chemical concentration and so on.

TABLE 3.42: CHEMICAL CONCENTRATION OF SAMPLE BARS IN MILLIGRAMS/ LITRE FOR COMPANIES A TO F.

Elements	$A_{12}C$	$A_{10}C$	$B_{10}C$	B_8C	$C_{16}C$	$C_{10}C$	C_8C	D_8C	$E_{25}C$	$E_{20}C$	$F_{12}C$
Aluminium (Al)	3.9	2.16	3.06	1.45	1.51	3	1.35	1.77	11.1	7.87	7.1
Cobalt (Co)	1.55	2.23	2.03	0.7	1.99	0.32	0.48	1.88	2.44	2.27	0.9
Copper (Cu)	7.1	7.26	8.74	2.74	7.89	1.38	1.54	9.59	8.85	8.98	2.09
Chromium (Cr)	3	3.05	4.26	0.88	2.39	0.84	0.71	1.36	2.82	2.98	1.23
Manganese (Mn)	6.05	5.9	5.96	6.09	6.03	6.08	6	6	5.91	6.07	5.85
Iron (Fe)	40.7	32.4	22	33.3	20.7	23.3	25	19	23.5	31.9	31.8
Lead (Pb)	0.98	0.46	0.27	0.18	0.64	0.95	0.3	0.49	0.24	0.33	0.22
Nickel (Ni)	2.36	2.45	2.83	0.97	2.55	0.5	0.61	2.95	2.57	2.88	1.09
Nitrogen(N)	0.14	0.7	0.4	0.1	2.8	4.2	4	0.31	0.08	0.7	0.8
Zinc (Zn)	1.05	0.66	0.13	0.06	1.05	0.1	0.09	0.26	0.52	0.77	0.37
Phosphate (Po3)	5.3	13.6	3	3	7.3	1.6	13	3.5	8	0.6	11.8
Sulphide (S)	0.24	2.34	2.5	0.5	0.02	0.1	0.45	1.5	2.01	0.02	0.2

TABLE 3.43: CHEMICAL CONCENTRATION OF SAMPLE BARS IN MILLIGRAMS/ LITRE FOR COMPANIES G TO N.

Elements	$G_{12}C$	$H_{16}C$	$I_{12}C$	J_8C	$K_{10}C$	$L_{12}C$	$M_{10}C$	$N_{16}C$
Aluminium (Al)	1.19	3.55	2.42	1.1	3.68	4.77	2.23	5.26
Cobalt (Co)	1.94	2.25	3.32	2.11	1.49	2.24	1.57	2.38
Copper (Cu)	6.64	9.14	9.59	10.9	9.32	9.98	9.07	
Chromium (Cr)	1.96	2.98	4.65	2.24	2.66	1.55	2.07	3.21
Manganese (Mn)	6	6.08	6.01	6.04	6.06	5.94	5.88	6.01
Iron (Fe)	26.9	29.9	20.7	15.8	34.1	26.3	31.3	32
Lead (Pb)	0.92	0.22	0.64	0.42	0.49	0.67	0.48	0.55
Nickel (Ni)	2.3	3.83	3.82	2.8	3.26	3.05	3.83	
Nitrogen(N)	2.4	3.1	0.05	0.95	0.02	0.3	0.01	2.05
Zinc (Zn)	0.7	0.37	1	0.52	0.51	0.4	0.31	0.34
Phosphate (Po3)	0.4	39	0.3	3.4	47.7	4.8	20.3	2.1
Sulphide (S)	0.21	0.06	0.15	0.04	3.2	0.03	0.05	0.01

TABLE 3.43.1 STANDARD VALUES FOR CHEMICAL CONCENTRATION – COMPANY A - N

Elements	Standard Value (mg/l)	Reference Code
Aluminium (Al)	< 0.2	BS4449(1997)
Cobalt (Co)	None	-
Copper (Cu)	3.0	Max. Asch M (Russia)
Chromium (Cr)	None	-
Manganese(Mn)	6.0 – 9.0	BS4449
Iron (Fe)	None	-
Lead (Pb)	None	-
Nickel (Ni)	< 0.3	Max. Asch M (Russia)
Nitrogen (N_2)	< 0.12	BS4449(1997)
Zinc (Zn)	None	-
Phosphate (PO_3)	None	-
Sulphur (S)	< 0.5	BS4449(1997)
Percentage Total		

3.18.2 DETERMINATION OF ELEMENTAL PERCENTAGE COMPOSITION BY WEIGHT

In the determination of the elemental composition of the samples, the XRF spectrometer was used. The system is capable of performing both quantitative and qualitative elemental analyses of pastes and powdered industrial minerals using the accepted and respected techniques of X- ray fluorescence and bench top Nuclear Magnetic Resonance (NMR). The major advantage of this method is that the test can be conducted within a short period of time. Other advantages are that the method analyses minute particles in various layers just as it requires minimal or no sample preparation. Further, it is non destructive and the system is automated with high accuracy. In addition, the test harbours no hazardous chemicals

It is observed that in this elemental percentage composition by weight, twenty eight (28) elements were discovered as compared to twelve (12) elements in chemical concentrations. The elements discovered include Aluminium (Al) , Barium (Ba) , Bromine (Br) , Cadmium (Cd), Calcium (Ca) , Carbon (C), Chlorine (Cl) , Chromium (Cr,) Copper (Cu) , Gallium (Ga), Iron (Fe) , Irridium (Ir) ,Manganese (Mn) , Molybdenum (Mo), Nickel (Ni) ,Nitrogen (N) , Osmium (Os) , Phosphorus (P) , Platinium (Pt), Radium (Ra), Rhodium (Rh), Sulphur (S), Silicon (Si), Tellurium (Te), Titanium (Ti), Vanadium (V), Zinc (Zn) and Zirconium (Zr) . These are shown in

tables 3.44 and 3.45 below. Recall $A_{12}P$ implies Sample from company A under percentage composition and so on.

TABLE3.44 PERCENTAGE CHEMICAL COMPOSITION OF SAMPLE STEEL BARS FOR COMPANIES A TO F.

Elements	**$A_{12}P$**	**$A_{10}P$**	**$B_{10}P$**	**B_8P**	**$C_{16}P$**	**$C_{20}P$**	**C_8P**	**D_8P**	**$E_{25}P$**	**$E_{20}P$**	**$F_{12}P$**
Aluminium (Al)	0	2	3	0	0	0	0	3	1.6	3.1	3
Barium (Ba)	0.14	0	0	0	0	0.13	0	0.24	0	0	0
Bromine (Br)	2.2	2.6	2.4	0	0	0	0	2.3	0	2.2	2.4
Cadmium (Cd)	4	3	4.9	3.9	2	3.1	2.5	5.8	4.3	3	3.5
Calcium (Ca)	0.06	0.02	0.09	0.66	0.28	0	0.01	0.48	0.11	0.13	0.07
Carbon (C)	0.05	0.13	0.04	0.07	0.06	0.07	0.09	0.08	0.07	0.04	0.07
Chlorine (Cl)	0.1	0.07	0.9	0.09	0.07	0.11	0.07	0.13	0.08	0.07	0.08
Chromium (Cr)	0.31	0.24	0.27	0.14	0.11	0.19	0.14	0.24	0.2	0.28	0.22
Copper (Cu)	0.31	0.27	0.33	0.12	0.37	0.1	0.1	0.31	0.33	0.28	0.32
Galium (Ga)	0.18	0	0.06	0.07	0	0.08	0.03	0.06	0	0.15	0.09
Iron (Fe)	89.4	89.3	86.8	93.6	94.8	92.8	94.1	84	87.8	88	87.4
Irridium (Ir)	0	0	0	0	0	0.55	0.5	0	0	0	0
Manganese(Mn)	0.75	0.9	0.84	0.71	0.65	0.74	0.83	0.84	1.01	0.91	0.76
Molybdenum (Mo)	0	0	0.04	0	0	0	0	0	0	0	0
Nickel (Ni)	0.1	0.05	0.06	0	0.07	0	0	0.07	0.06	0.09	0.06
Nitrogen (N_2)	0.014	0.007	0.04	0.01	0.28	0.42	0.40	0.31	0.008	0.007	0.08
Osmium (Os)	0.56	0.39	0.28	0.35	0.31	0.42	0.37	0.31	0.35	0.46	0.35
Phosphorus (P)	0	0	0.06	0.09	0.08	0	0.1	0.04	0	0	0
Platinium (Pt)	0.1	0	0	0	0	0	0	0.05	0	0	0
Rhenium (Re)	0.2	0.1	0.1	0	0.24	0.24	0.2	0.07	0.2	0.1	0.1
Rhodium (Rh)	0.68	0.42	0.25	0.34	0.28	0.57	0.48	0.24	0.35	0.62	0.42
Silicon (Si)	0.7	0.7	0.9	0.6	0.7	0.59	0.41	1.7	3.53	0.72	1
Sulphur (S)	0	0	0.03	0	0	0	0	0	0	0.14	0
Tellurium (Te)	0	0	0	0	0	0.05	0.14	0	0	0	0
Titanium (Ti)	0.16	0	0	0	0	0.15	0	0.13	0	0	0
Vanadium (V)	0	0	0.03	0	0	0	0	0	0	0	0
Zinc (Zn)	0.17	0.04	0.07	0	0.01	0.02	0.02	0.13	0.08	0.15	0.04
Zirconium (Zr)	0	0	0	0	0	0	0	0	0	0	0
Total (%)	100	100	101	101	100	99.9	100	100	100	100	99.9

TABLE 3.45: PERCENTAGE CHEMICAL COMPOSITION OF SAMPLE STEEL BARS FOR COMPANIES G TO N.

Elements	**$G_{12}P$**	**$H_{16}P$**	**IP_{12}**	**J_8P**	**$K_{10}P$**	**$L_{12}P$**	**$M_{10}P$**	**$N_{16}P$**
Aluminium (Al)	3	2	2	1	2	2	3	0.5
Barium (Ba)	0	0	0	0	0	0	0.15	0
Bromine (Br)	1.9	1.8	1.8	2.7	2.5	2.6	1.9	0
Cadmium (Cd)	1.2	1.7	1.8	3.4	3.8	3.8	2.2	3
Calcium (Ca)	0	0	0	0.11	0.06	0.09	0.88	0.06
Carbon (C)	0.03	0.15	0.09	0.02	0.08	0.14	0.13	0.18
Chlorine (Cl)	0.15	0.16	0.13	0.05	0.09	0.07	0.66	0.08
Chromium (Cr)	0.22	0.28	0.31	0.14	0.21	0.16	0.24	0.26
Copper (Cu)	0.07	0.18	0.15	0.41	0.32	0.34	0.36	0.44
Gallium (Ga)	0	0	0	0.05	0.07	0	0	0
Iron (Fe)	80.1	77	74.5	89.7	87.9	87.6	86.7	92
Irridium (Ir)	0	0	0	0	0	0	0	0
Manganese(Mn)	0.9	0.87	0.94	0.56	0.89	0.88	0.91	0.71
Molybdenum (Mo)	0	0	0	0	0	0	0.3	0
Nickel (Ni)	0.06	0.09	0.07	0.05	0.07	0.06	0.11	0.18
Nitrogen (N_2)	0.24	0.31	0.005	0.095	0.002	0.03	0.001	0.21
Osmium (Os)	0.42	0.37	0.34	0.25	0.27	0.32	0.62	0.61
Phosphorus (P)	0	0	0	0.06	0.08	0	0	0
Platinium (Pt)	0	0	0	0.04	0	0	0	0
Rhenium (Re)	0.1	0	0	0.1	0.1	0.1	0.2	0.3
Rhodium (Rh)	0.32	0	0	0.2	0.39	0.32	0.63	0.6
Silicon (Si)	0.5	0.25	0.27	0.91	0.84	1.1	1	1.1
Sulphur (S)	0	0	0	0	0	0	0.31	0
Tellurium (Te)	0	0	0	0	0	0	0	0
Titanium (Ti)	0	0	0	0	0	0	0.18	0
Vanadium (V)	0	0.05	0	0	0	0.02	0	0
Zinc (Zn)	0.06	0.05	0.06	0.04	0.06	0.61	0.15	0.14
Zirconium (Zr)	0	0	1.1	0	0	0	0	0
Percentage Total	99.8	100	99.7	99.8	99.7	100	101	100

TABLE 3.45.1 STANDARDS FOR CHEMICAL PERCENTAGE COMPOSITION COMPANY A- N

Elements	Standard Value (%)	Reference Code
Aluminium (Al)	< 0.02	BS4449(1997)
Barium (Ba)	None	-
Bromine (Br)	None	-
Cadmium (Cd)	None	-
Calcium (Ca)	None	-
Carbon (C)	< 0.25	BS4449(1997)
Chlorine (Cl)	None	-
Chromium (Cr)	0.30	Max. Asch M (Russia)
Copper (Cu)	0.30	Max. Asch M (Russia)
Gallium (Ga)	None	-
Iron (Fe)	None	-
Irridium (Ir)	None	-
Manganese(Mn)	0.60 - 0.90	BS4449
Molybdenum (Mo)	None	-
Nickel (Ni)	< 0.30	Max. Asch M (Russia)
Nitrogen (N_2)	< 0.012	BS4449(1997)
Osmium (Os)	None	-
Phosphorus (P)	0.05	BS4449(1997)
Platinium (Pt)	None	-
Rhenium (Re)	None	-
Rhodium (Rh)	None	-
Silicon (Si)	< 0.15	BS4449(1997)
Sulphur (S)	< 0.05	BS4449(1997)
Tellurium (Te)	None	-
Titanium (Ti)	None	-
Vanadium (V)	0.02 - 0.15	MIS(1998)
Zinc (Zn)	None	-
Zirconium (Zr)	None	-
Percentage Total		

TABLE 3.46: SAMPLE TOTAL ELEMENTS, FREQUENCY AND DIFFERENCES (COMPANIES A TO F).

Elements	$A_{12}P$	$A_{10}P$	$B_{10}P$	B_8P	$C_{16}P$	$C_{20}P$	C_8P	D_8P	$E_{25}P$	$E_{20}P$	$F_{12}P$
Total Elements	28	28	28	28	28	28	28	28	28	28	28
Frequency	19	16	21	13	15	17	17	21	15	18	17
Differences	8	11	6	14	12	10	10	6	12	9	10

TABLE3.47: SAMPLE TOTAL ELEMENTS, FREQUENCY AND DIFFERENCES (COMPANIES G TO N).

Elements	$G_{12}P$	$H_{16}P$	IP_{12}	J_8P	$K_{10}P$	$L_{12}P$	$M_{10}P$	$N_{16}P$
Total Elements	28	28	28	28	28	28	28	28
Frequency	15	14	14	19	18	17	20	15
Differences	12	13	13	8	9	10	7	12

CHAPTER FOUR

ANALYSES OF RESULTS

4.1 GENERAL INTRODUCTION:

The analysis of the results obtained from the experiment in chapter three is hereby presented in chapter four for analyses and discussions.

4.2 CROSS SECTIONAL AREA

From table 3.3, one can clearly observe that the assumed market diameters for all the reinforcing steel bars are greater than the measured diameters for all the bars considered. Avery large discrepancy was also observed on sample J_8T which is designated and sold in the market as 8 mm bar against its measured diameter of 6.5mm.

TABLE 4.1: MEASURED AND MARKET DIAMETER DIFFERENCES FOR FOURTEEN COMPANIES

S/No	Mark	Market Assumed Diameter (mm)	Measured Diameter (mm)	Percentage Difference
01	$A_{12}T$	12.00	11.88	1.00
02	$A_{10}T$	10.00	9.65	3.50
03	$B_{10}T$	10.00	9.56	4.40
04	B_8T	8.00	7.44	7.00
05	$C_{16}T$	16.00	15.82	1.13
06	$C_{10}T$	10.00	9.55	4.50
07	C_8T	8.00	7.46	6.75
08	D_8T	8.00	7.23	9.63
09	$E_{25}T$	25.00	24.56	1.76
10	$E_{20}T$	20.00	19.57	2.15
11	$F_{12}T$	12.00	11.40	5.00
12	$G_{12}T$	12.00	11.48	4.33
13	$H_{16}T$	16.00	15.52	3.00
14	$I_{12}T$	12.00	11.40	5.00
15	J_8T	8.00	6.50	18.75
16	$K_{10}T$	10.00	9.36	6.40
17	$L_{12}T$	12.00	11.82	1.50
18	$M_{10}T$	10.00	9.23	7.70
19	$N_{16}T$	16.00	15.60	2.25

4.3 EFFECTIVE CROSS SECTIONAL AREAS AND TOLERANCES

In line with BS4449(1997) requirements which specify ± 6.0 % for 8mm and 10 mm bars and ± 4.5% for 12mm bars and above, it can be seen from table 4.2 below that the tolerances for most of the reinforcement bars irrespective of origin fall out of range. Thirteen bars are out of range, while only six fall within the acceptable range.

TABLE 4.2: DIFFERENCE IN MEASURED AND EFFECTIVE CROSS SECTIONAL AREAS OF BARS.

S/No	Mark	Source	Measured Cross-Sectional Area (mm2)	Effective Cross- Sectional Area (mm2)	Tolerance (%)	BS4449/1997 Tolerance (%)	Remarks
1	$A_{12}T$	Local	110.79	86.14	+22.25	± 4.5	Out of Range
2	$A_{10}T$	Local	73.10	71.96	+1.56	± 6.5	Within Range
3	$B_{10}T$	Local	71.74	70.98	+1.06	± 6.5	Within Range
4	$B_{8}T$	Local	43.45	48.37	-11.32	± 6.5	Out of Range
5	$C_{16}T$	Local	196.46	160.14	+18.49	± 4.5	Out of Range
6	$C_{10}T$	Local	71.59	72.42	-1.16	± 6.5	Within Range
7	$C_{8}T$	Local	43.69	49.85	-14.10	± 6.5	Out of Range
8	$D_{8}T$	Foreign	41.03	36.27	+11.60	± 6.5	Out of Range
9	$E_{25}T$	Local	473.51	316.93	+33.07	± 4.5	Out of Range
10	$E_{20}T$	Local	300.64	281.13	+6.49	± 4.5	Out of Range
11	$F_{12}T$	Local	102.02	88.84	+12.92	± 4.5	Out of Range
12	$G_{8}T$	Local	103.46	85.17	+17.68	± 6.5	Out of Range
13	$H_{12}T$	Local	189.08	95.77	+49.35	± 4.5	Out of Range
14	$I_{16}T$	Local	100.24	87.47	+12.74	± 4.5	Out of Range
15	$J_{12}T$	Foreign	33.17	34.74	-4.73	± 6.5	Within Range
16	$K_{10}T$	Foreign	68.77	70.12	-1.96	± 6.5	Within Range
17	$L_{12}T$	Foreign	109.07	110.30	-1.13	± 6.5	Within Range
18	$M_{10}T$	Foreign	66.88	71.77	-7.31	± 4.5	Out of Range
19	$N_{16}T$	Foreign	191.04	211.28	-10.60	± 6.5	Out of Range

Out of Range => Not Satisfactory and Within Range => Satisfactory

This indicates that the thirteen bars that are out of range have varying diameters along the length which is not the best for reinforcing bars. This should be carefully checked to ensure an average close diameter throughout the length.

4.4 CHARACTERISTIC STRENGTHS

The characteristic strengths computed from the yield strengths are shown in table 4.3 and are compared with the code requirements. From table 4.3 below, it is clear that only two samples ($C_{16}T$ & $H_{12}T$) out of the thirteen (13) local bars tested were able to meet the minimum code provisions. Even samples $C_{10}T$ and C_8T from the same company as $C_{16}T$ could not meet the code's minimum requirements. However, all the six foreign bar samples considered have been able to meet the minimum code provisions.

Table 4.3: CHARACTERISTIC STENGTH VALUES FOR THE NINETEEN SAMPLES

S/No	Mark	Source	Characteristic Strength(N/mm^2)	Min. Characteristic Strength based on BS4449/1997 Provisions	Remarks
1	$A_{12}T$	Local	350.00	460.00	Below Code, Unsatisfactory
2	$A_{10}T$	Local	410.00	460.00	Below Code, Unsatisfactory
3	$B_{10}T$	Local	390.00	460.00	Below Code, Unsatisfactory
4	B_8T	Local	368.00	460.00	Below Code, Unsatisfactory
5	$C_{16}T$	Local	482.00	460.00	Above Code, Satisfactory
6	$C_{10}T$	Local	357.00	460.00	Below Code, Unsatisfactory
7	C_8T	Local	387.00	460.00	Below Code, Unsatisfactory
8	D_8T	Foreign	463.00	460.00	Above Code, Satisfactory
9	$E_{25}T$	Local	363.00	460.00	Below Code, Unsatisfactory
10	$E_{20}T$	Local	317.00	460.00	Below Code, Unsatisfactory
11	$F_{12}T$	Local	334.00	460.00	Below Code, Unsatisfactory
12	$G_{12}T$	Local	408.00	460.00	Below Code, Unsatisfactory
13	$H_{16}T$	Local	493.00	460.00	Above Code, Satisfactory
14	$I_{12}T$	Local	369.00	460.00	Below Code, Unsatisfactory
15	J_8T	Foreign	573.00	460.00	Above Code, Satisfactory
16	$K_{10}T$	Foreign	549.00	460.00	Above Code, Satisfactory
17	$L_{12}T$	Foreign	500.00	460.00	Above Code, Satisfactory
18	$M_{10}T$	Foreign	547.00	460.00	Above Code, Satisfactory
19	$N_{16}T$	Foreign	545.00	460.00	Above Code, Satisfactory

Thus, all foreign bars met the code requirements for characteristic strength. Most of the local industries (12 out of 14) failed to meet the characteristic strength requirement. The table shows a mean of 431.84N/mm2 and a standard deviation of 83.07 for the nineteen samples. Both the mean and standard deviation are unsatisfactory.

4.5 ULTIMATE TO YIELD STRENGTH RATIO

Table 4.4 below shows the ratio of the ultimate to yield strength. It can be seen that the ultimate to yield strength ratio values in respect of all the nineteen samples are above the minimum code provisions. The values obtained for the fourteen local samples are relatively higher than those obtained for the foreign bar samples, which are very close to the minimum.

Table 4.4: ULTIMATE TO YIELD STRENGTH RATIO VALUES FOR THE NINETEEN SAMPLES

S/No	Mark	Source	Ultimate to Yield Ratio	Min. BS4449/ 1997 Provision	Remarks
1	$A_{12}T$	Local	1.55	>1.15	Above Code, Satisfactory
2	$A_{10}T$	Local	1.60	>1.15	Above Code, Satisfactory
3	$B_{10}T$	Local	1.46	>1.15	Above Code, Satisfactory
4	B_8T	Local	1.31	>1.15	Above Code, Satisfactory
5	$C_{16}T$	Local	1.84	>1.15	Above Code, Satisfactory
6	$C_{10}T$	Local	1.52	>1.15	Above Code, Satisfactory
7	C_8T	Local	1.35	>1.15	Above Code, Satisfactory
8	D_8T	Foreign	1.39	>1.15	Above Code, Satisfactory
9	$E_{25}T$	Local	1.64	>1.15	Above Code, Satisfactory
10	$E_{20}T$	Local	1.43	>1.15	Above Code, Satisfactory
11	$F_{12}T$	Local	1.52	>1.15	Above Code, Satisfactory
12	$G_{12}T$	Local	1.69	>1.15	Above Code, Satisfactory
13	$H_{16}T$	Local	1.22	>1.15	Above Code, Satisfactory
14	$I_{12}T$	Local	1.69	>1.15	Above Code, Satisfactory
15	J_8T	Foreign	1.21	>1.15	Above Code, Satisfactory
16	$K_{10}T$	Foreign	1.22	>1.15	Above Code, Satisfactory
17	$L_{12}T$	Foreign	1.21	>1.15	Above Code, Satisfactory
18	$M_{10}T$	Foreign	1.08	>1.15	Below Code, Unsatisfactory
19	$N_{16}T$	Foreign	1.26	>1.15	Above Code, Satisfactory

It can be observed that bars samples $M_{10}T$ which is a foreign sample is below minimum requirement. This could be as a result of cooling process which is a manufacturing fault within the line of production. However, when the ratio is high, it is not good either. It implies high carbon content which may lack ductility. The table shows a mean of 1.40 N/mm2 and a standard deviation of 0.21 for the nineteen samples. Both mean and standard deviation are satisfactory.

4.6 PERCENTAGE ELONGATION

From the table below, it can be seen that most of the local bar samples met the minimum code requirements on elongation, while most of the foreign bars did not meet the minimum codes requirements. Serial numbers 5, 8, 15, 16 and 18 failed to reach the value of 14 percent and on observing carefully sample nos. 5, 6 and 7 are of the same company, but sample no. 5 failed to satisfy the elongation requirement. Secondly, samples nos. 15 to 19 and also no. 8 are foreign companies and only the sample with serial number 17 passed.

Table 4.5: PERCENTAGE ELONGATION VALUES FOR THE NINETEEN SAMPLES

S/No	Mark	Source	Percentage Elongation	Min. BS4449/1997 Provisions	Remarks
1	$A_{12}T$	Local	16.50	14.00	Above Code, Satisfactory
2	$A_{10}T$	Local	13.90	14.00	Below Code, Unsatisfactory
3	$B_{10}T$	Local	19.60	14.00	Above Code, Satisfactory
4	B_8T	Local	23.82	14.00	Above Code, Satisfactory
5	$C_{16}T$	Local	8.33	14.00	Below Code, Unsatisfactory
6	$C_{10}T$	Local	19.93	14.00	Above Code, Satisfactory
7	C_8T	Local	21.17	14.00	Above Code, Satisfactory
8	D_8T	Foreign	1.67	14.00	Below Code, Unsatisfactory
9	$E_{25}T$	Local	19.83	14.00	Above Code, Satisfactory
10	$E_{20}T$	Local	24.27	14.00	Above Code, Satisfactory
11	$F_{12}T$	Local	19.07	14.00	Above Code, Satisfactory
12	$G_{12}T$	Local	14.83	14.00	Above Code, Satisfactory
13	$H_{16}T$	Local	14.53	14.00	Above Code, Satisfactory
14	$I_{12}T$	Local	14.50	14.00	Above Code, Satisfactory
15	J_8T	Foreign	2.67	14.00	Below Code, Unsatisfactory
16	$K_{10}T$	Foreign	10.07	14.00	Below Code, Unsatisfactory
17	$L_{12}T$	Foreign	14.93	14.00	Above Code, Satisfactory
18	$M_{10}T$	Foreign	11.77	14.00	Below Code, Unsatisfactory
19	$N_{16}T$	Foreign	13.90	14.00	Below Code, Unsatisfactory

These samples that failed in elongation should not be used in reinforcement as they will not give warning prior to failure due to low ductility. The table shows a mean of 15.02 mm and a standard deviation of 6.24 for the nineteen samples. The mean is satisfactory while the standard deviation is unsatisfactory.

4.7 SOME MEASURED PARAMETERS:

Some measured parameters during the tension test are selected and compared to design strength. The minimum design strength for reinforcement is 0.87 fy. In table 4.6 below, the characteristic strengths are compared with the design strength which is 400N/mm^2, when the minimum characteristic strength is 460N/mm^2 as specified by the code.

TABLE 4.6: COMPARISON OF CHARACTERISTIC STRENGTH WITH DESIGN STRENGTH.

S/N	Mark	Market Assumed Diameter (mm)	Measured Diameter (mm)	Cross Sectional Area (mm^2)	Tolerances	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Ultimate: Yield Ratio	Elongation (%)	Xtics Strength (N/mm^2)	Computed Design Strength (N/mm^2)	Reccomm Design Strength (N/mm^2)
01	$A_{12}T$	12.00	11.88	110.79	+22.25	357.43	529.83	1.55	16.50	350.00	400.00	304.50
02	$A_{10}T$	10.00	9.65	73.10	+1.56	410.40	656.60	1.60	13.90	410.00	400.00	356.70
03	$B_{10}T$	10.00	9.56	71.74	+1.06	390.30	536.60	1.46	19.60	390.00	400.00	339.30
04	B_8T	8.00	7.44	43.45	-11.32	368.24	483.31	1.31	23.82	368.00	400.00	320.16
05	$C_{16}T$	16.00	15.82	196.46	+18.49	503.41	918.82	1.84	8.33	482.00	400.00	419.34
06	$C_{10}T$	10.00	9.55	71.59	-1.16	364.58	531.10	1.52	19.93	357.00	400.00	310.59
07	C_8T	8.00	7.46	43.69	-14.10	405.13	549.32	1.35	21.17	387.00	400.00	336.69
08	D_8T	8.00	7.23	41.03	+11.60	463.08	621.50	1.39	1.67	463.00	400.00	402.81
09	$E_{25}T$	25.00	24.56	473.51	+33.07	367.05	576.12	1.64	19.83	363.00	400.00	315.81
10	$E_{20}T$	20.00	19.57	300.64	+6.49	318.95	449.38	1.43	24.27	317.00	400.00	275.79
11	$F_{12}T$	12.00	11.4	102.02	+12.92	415.60	633.21	1.52	19.07	334.00	400.00	290.58
12	$G_{12}T$	12.00	11.48	103.46	+17.68	419.56	715.25	1.69	14.83	408.00	400.00	354.96
13	$H_{16}T$	16.00	15.52	189.08	+49.35	499.26	599.75	1.22	14.53	493.00	400.00	428.91
14	$I_{12}T$	12.00	11.40	100.24	+12.74	369.11	612.53	1.69	14.50	369.00	400.00	321.03
15	J_8T	8.00	6.50	33.17	-4.73	572.81	693.40	1.21	2.67	573.00	400.00	498.51
16	$K_{10}T$	10.00	9.36	68.77	-1.96	574.38	660.17	1.22	10.07	549.00	400.00	477.63
17	$L_{12}T$	12.00	11.82	109.07	-1.13	505.18	599.62	1.21	14.93	500.00	400.00	435.00
18	$M_{10}T$	10.00	9.23	66.88	-7.31	563.70	642.94	1.08	11.77	547.00	400.00	475.89
19	$N_{16}T$	16.00	15.60	191.04	-10.60	551.72	645.41	1.26	13.90	545.00	400.00	474.15

The characteristric strength has been calculated using the equation: $f_c = f_m - 1.64\ ð$:

where f_c = characteristic strength, f_m = mean strength and ð = standard deviation.

From table 4.6 above, it can be observed that nine samples which are mostly local steel reinforcement out of fourteen local ones failed to meet up with the minimum design strength of 400N/mm^2. That is to say sixty five percent (65%) of the local samples failed to meet up with the minimum design strength. This is very dangerous.

Thus, the last column has featured a recommendation (Recc.) of 0.87fy for design applications. Fy in this case, is the calculated characteristic strength of the tested bars.

The summary of the various parameter values for the different diameters tested as shown in table 3.23 below is:

TABLE 4.7 PARAMETER SUMMARY FOR TENSILE TESTS (COMPANIES A TO E):

S/No.	SAMPLE PRARAMETER	$A_{12}T$	$A_{10}T$	$B_{10}T$	B_8T	$C_{16}T$	$C_{10}T$	C_8T	D_8T	$E_{25}T$	$E_{20}T$
01	Diameter(mm)	12	10	10	8	16	10	8	8	25	20
02	Characteristic Strength(N/mm^2)	350.0	410.0	390.3	368.2	482.0	357.0	387.0	463.0	363.0	317.0
03	Standard Deviation	4.65	0.0	0.0	0.0	13.0	4.4	11.1	0.0	2.4	1.0
04	Average Elongation (%)	16.5	13.9	19.6	23.8	8.3	19.9	21.2	1.7	19.8	24.3

TABLE 4.8 PARAMETER SUMMARY FOR TENSILE TESTS (COMPANIES F TO N):

S/No.	SAMPLE PRARAMETER	$F_{12}T$	G_8T	$H_{12}T$	$I_{16}T$	$J_{12}T$	$K_{10}T$	$L_{12}T$	$M_{10}T$	$N_{16}T$
01	Diameter(mm)	12	8	12	16	12	10	12	10	16
02	Characteristic Strength(N/mm^2)	334.0	573.0	408.0	493.0	369.0	549.0	500.0	547.0	546.0
03	Standard Deviation	49.6	0.0	6.8	3.7	0.0	15.71	2.9	10.1	3.7
04	Average Elongation (%)	19.1	2.7	14.8	14.5	14.5	10.1	14.9	11.8	13.9

The value of standard deviation will determine the quality of product based on the skilled personnel and equipment. The small the value indicates high skilled personnel were employed. Values below or equal to five are an indicative of highly skilled personnel and above five indicates employment of low skilled men which lead to bad products, etc. About five samples from company C, F, H, K and M have values above five. A balance must be maintained for effective administration and good output.

4.8 BEND TESTS

Eighteen out of the nineteen samples have passed the bend test as neither micro cracks were observed, nor any form of unacceptable deformation. However, all the ten specimens constituting sample $C_{16}B$ as reflected in table 4.5 below have not complied with the codes requirement. It is worthy to note that $C_{16}B$, $C_{10}B$ and C_8Bare from the same company.

TABLE 4.9: BEND TEST RESULTS FOR FOURTEEN COMPANIES

S/No.	Identification No.	Bar Size (mm)	Former Diameter	Observations	Remarks
01	$A_{12}B$	12.0	39.0	No Cracks	Satisfactory
02	$A_{10}B$	10.0	33.0	No Cracks	Satisfactory
03	$B_{10}B$	10.0	33.0	No Cracks	Satisfactory
04	B_8B	8.0	27.0	No Cracks	Satisfactory
05	$C_{16}B$	16.0	51.0	Total Breakage	Unsatisfactory
06	$C_{10}B$	10.0	33.0	No Cracks	Satisfactory
07	C_8B	8.0	27.0	No Cracks	Satisfactory
08	D_8B	8.0	27.0	No Cracks	Satisfactory
09	$E_{25}B$	25.0	78.0	No Cracks	Satisfactory
10	$E_{20}B$	20.0	63.0	No Cracks	Satisfactory
11	$F_{12}B$	12.0	39.0	No Cracks	Satisfactory
12	$G_{12}B$	12.0	39.0	No Cracks	Satisfactory
13	$H_{16}B$	16.0	51.0	No Cracks	Satisfactory
14	$I_{12}B$	12.0	39.0	No Cracks	Satisfactory
15	J_8B	8.0	27.0	No Cracks	Satisfactory
16	$K_{10}B$	10.0	33.0	No Cracks	Satisfactory
17	$L_{12}B$	12.0	39.0	No Cracks	Satisfactory
18	$M_{10}B$	10.0	33.0	No Cracks	Satisfactory
19	$N_{16}B$	16.0	51.0	No Cracks	Satisfactory

If such reinforcement like $C_{16}B$, which is company C with bar diameter 16 Millimetre are used in structural elements, the element may fail without warning. On observing the bar carefully, the ultimate to yield strength ratio is 1.84, characteristic strength is 482N/mm^2, the cross sectional area percentage tolerance is +18.49 which is out of range. The elongation is 8.3 percent which is far below the 14 percent. The company has to check the production line carefully. This situation indicates high content of carbon with no elements for ductility. There is a need to reduce high carbon content.

4.9 CHEMICAL CONCENTRATION IN (mg/l)

The facilities used could only identify the presence of twelve (12) elements which have been considered to be inadequate for any comprehensive inference. Thus, the chemical percentage composition method was also considered. The highest concentration element for all the samples is Iron, followed by manganese and copper, while the rest depend on the sample.

4.10 CHEMICAL PERCENTAGE COMPOSITION BY WEIGHT

A total of nineteen samples were considered in the determination of the percentage chemical composition. As earlier explained, the designation $A_{12}P$ implies sample A with diameter 12 Millimetre for percentage composition, $B_{10}P$ implies sample B with diameter ten Millimetre for percentage composition, and so on. A specimen was randomly selected from the ten constituting the sample for the test. The twenty seven elements discovered in this test are Aluminium (Al), Bromine (Br), Calcium (Ca), Carbon (C), Chlorine(Cl), Chromium(Cr), Cupper (Cu), Gallium (Ga),Iron(Fe),Iridium(Ir),Manganese (Mn), Molybdenum(Mo), Nickel (Ni), Nitrogen (N), Osmium(Os), Platinium(Pt), Rhenium (Re), Rhodium(Rh), Silicon (Si), Sulphur (S),Tellurium (Te), Titanium (Ti), Vanadium (V), Zinc (Zn) and Zirconium. Again the highest percentage element is Iron (Fe) which ranges from 84 percent to 94.8 percent for all samples tested. This is therefore the best way of determining the composition.

4.10.1 ALUMINIUM:

This element has been classified as a transition metal in the periodic table and is present in fourteen out of the nineteen samples. From table 4.8 below, samples $A_{12}P$ & $A_{10}P$ are from the same company..The former contains no Aluminium trace, while the later contains up to 2%. Similarly, $B_{10}P$ &$B_8P$are from the same company, but the later does not contain any Aluminium trace, while the former contains up to 3%. All the samples from company designated as C have been observed not to contain any Aluminium trace. Aluminium is one of the alloying minerals in steel. BS4449(1997) did not impose any limit on the percentage composition of this element. However, it only states that if its content is less than 0.02%, then the maximum percentage values for Nitrogen do not apply. Table 4.10.1 below shows the percentage composition of Aluminium across the nineteen samples. A mean of 1.64% and a standard deviation of 1.23 were calculated and found to have exceeded the BS4449(1997) provision.

TABLE 4.10.1: PERCENTAGE COMPOSITION BY WEIGHT FOR ALUMINIUM.

S/No	Mark	Source	Al Content (%)	BS4449/1997 Provisions	Remarks
1	$A_{12}P$	Local	0.00	< 0.02	N2 Max. Values do not apply
2	$A_{10}P$	Local	2.00	< 0.02	N2 Max. Values apply
3	$B_{10}P$	Local	3.00	< 0.02	N2 Max. Values apply
4	B_8P	Local	0.00	< 0.02	N2 Max. Values do not apply
5	$C_{16}P$	Local	0.00	< 0.02	N2 Max. Values do not apply
6	$C_{10}P$	Local	0.00	< 0.02	N2 Max. Values do not apply
7	C_8P	Local	0.00	< 0.02	N2 Max. Values do not apply
8	D_8P	Foreign	3.00	< 0.02	N2 Max. Values apply
9	$E_{25}P$	Local	1.60	< 0.02	N2 Max. Values apply
10	$E_{20}P$	Local	3.10	< 0.02	N2 Max. Values apply
11	$F_{12}P$	Local	3.00	< 0.02	N2 Max. Values apply
12	$G_{12}P$	Local	3.00	< 0.02	N2 Max. Values apply
13	$H_{16}P$	Local	2.00	< 0.02	N2 Max. Values apply
14	$I_{12}P$	Local	2.00	< 0.02	N2 Max. Values apply
15	J_8P	Foreign	1.00	< 0.02	N2 Max. Values apply
16	$K_{10}P$	Foreign	2.00	< 0.02	N2 Max. Values apply
17	$L_{12}P$	Foreign	2.00	< 0.02	N2 Max. Values apply
18	$M_{10}P$	Foreign	3.00	< 0.02	N2 Max. Values apply
19	$N_{16}P$	Foreign	0.50	< 0.02	N2 Max. Values apply

4.10.2 BARIUM:

This element has been classified as an alkali earth metal in the periodic table and it has appeared in only four out of the nineteen samples considered. Sample $A_{12}P$showedthe presence of this element while sample $A_{10}P$which is from same company did not show any trace. Similarly, out of samples $C_{16}P$, $C_{10}P$ and C_8P, only $C_{10}P$ showed the presence of this element as shown in table 4.9. Two foreign bars D_8P and $M_{10}P$ have also shown some traces. The element has not been mentioned in the BS4449(1997) and as such, it has no code provision. By disposition as a metal, it may possibly have some alloying properties. No code provision has been made on Barium.

TABLE 4.10.2: PERCENTAGE COMPOSITION BY WEIGHT FOR BARIUM.

S/No	Mark	Source	Barium Content (%)	Max. BS4449/1997 Provisions
1	$A_{12}P$	Local	0.14	N
2	$A_{10}P$	Local	0.00	O
3	$B_{10}P$	Local	0.00	
4	B_8P	Local	0.00	
5	$C_{16}P$	Local	0.00	C
6	$C_{10}P$	Local	0.13	O
7	C_8P	Local	0.00	D
8	D_8P	Foreign	0.24	E
9	$E_{25}P$	Local	0.00	
10	$E_{20}P$	Local	0.00	
11	$F_{12}P$	Local	0.00	P
12	$G_{12}P$	Local	0.00	R
13	$H_{16}P$	Local	0.00	O
14	$I_{12}P$	Local	0.00	V
15	J_8P	Foreign	0.00	I
16	$K_{10}P$	Foreign	0.00	S
17	$L_{12}P$	Foreign	0.00	I
18	$M_{10}P$	Foreign	0.15	O
19	$N_{16}P$	Foreign	0.00	N

4.10.3 BROMINE:

This element has been classified under group 7 in the periodic table popularly called halogen family. Elements in this group exist in solid, liquid and gaseous forms. It has featured in thirteen out of the nineteen samples considered for the test as shown in table 4.10.3. Samples $B_{10}P$ and B_8P are from the same company but the later has not shown any trace. Interestingly, all the three samples from company C have not shown any trace of this element. $E_{25}P$ and $E_{20}P$are from company E, but only $E_{20}P$ has shown the presence of this element. The element has not been mentioned in BS4449(1997) thus, no code provision has been made. No code provision has been made on the composition of Bromine.

TABLE 4.10.3 : PERCENTAGE COMPOSITION BY WEIGHT FOR BROMINE.

S/No	Mark	Source (L/F)	Bromine Content (%)	Max. BS4449/1997 Provisions
1	$A_{12}P$	Local	2.20	N
2	$A_{10}P$	Local	2.60	O
3	$B_{10}P$	Local	2.40	
4	B_8P	Local	0.00	
5	$C_{16}P$	Local	0.00	C
6	$C_{10}P$	Local	0.00	O
7	C_8P	Local	0.00	D
8	D_8P	Foreign	2.30	E
9	$E_{25}P$	Local	0.00	
10	$E_{20}P$	Local	2.20	
11	$F_{12}P$	Local	2.40	P
12	$G_{12}P$	Local	1.90	R
13	$H_{16}P$	Local	1.80	O
14	$I_{12}P$	Local	1.80	V
15	J_8P	Foreign	2.70	I
16	$K_{10}P$	Foreign	2.50	S
17	$L_{12}P$	Foreign	2.60	I
18	$M_{10}P$	Foreign	1.90	O
19	$N_{16}P$	Foreign	0.00	N

4.10.4 CADMIUM:

This element is a transition metal and has occurred in all the nineteen samples and is known to be an alloying mineral for steel. No provision has been made in its respect by the BS4449(1997).From table 4.10.4 below, it can be seen that the cadmium content varies even amongst the samples from companies A, B, C, and E. The highest value was obtained in company D with a value of 5.8 percent, while the least was 1.2 percent from company G. No code provision for the composition of Cadmium.

TABLE 4.10.4: PERCENTAGE COMPOSITION BY WEIGHT FOR CADMIUM.

S/No	Mark	Source (L/F)	Cadmium Content (%)	Max. BS4449/1997 Provisions
1	$A_{12}P$	Local	4.0	N
2	$A_{10}P$	Local	3.0	O
3	$B_{10}P$	Local	4.9	
4	B_8P	Local	3.9	
5	$C_{16}P$	Local	2.0	C
6	$C_{10}P$	Local	3.1	o
7	C_8P	Local	2.5	d
8	D_8P	Foreign	5.8	e
9	$E_{25}P$	Local	4.3	
10	$E_{20}P$	Local	3.0	
11	$F_{12}P$	Local	3.5	P
12	$G_{12}P$	Local	1.2	r
13	$H_{16}P$	Local	1.7	o
14	$I_{12}P$	Local	1.8	v
15	J_8P	Foreign	3.4	i
16	$K_{10}P$	Foreign	3.8	s
17	$L_{12}P$	Foreign	3.8	i
18	$M_{10}P$	Foreign	2.2	o
19	$N_{16}P$	Foreign	3.0	n

4.10.5 CALCIUM:

This is an alkali earth metal that acts as an alloying mineral that essentially adds to strength. BS4449(1997) has not imposed any limit on its percentage composition in steel. On careful observation of table 4.10.5 below, it is clear that the distribution of the element does not follow any specific order, as even samples from the same source showed difference in percentage compositions. They are mostly traces in amounts. No code provision for the composition of Calcium.

TABLE 4.10.5: PERCENTAGE COMPOSITION BY WEIGHT FOR CALCIUM.

S/No	Mark	Source (L/F)	Calcium Content (%)	Max. BS4449/1997 Provisions
1	$A_{12}P$	Local	0.06	N
2	$A_{10}P$	Local	0.02	o
3	$B_{10}P$	Local	0.09	
4	B_8P	Local	0.66	
5	$C_{16}P$	Local	0.28	C
6	$C_{10}P$	Local	0.00	o
7	C_8P	Local	0.01	d
8	D_8P	Foreign	0.48	e
9	$E_{25}P$	Local	0.11	
10	$E_{20}P$	Local	0.13	
11	$F_{12}P$	Local	0.07	P
12	$G_{12}P$	Local	0.00	r
13	$H_{16}P$	Local	0.00	o
14	$I_{12}P$	Local	0.00	v
15	J_8P	Foreign	0.11	i
16	$K_{10}P$	Foreign	0.06	s
17	$L_{12}P$	Foreign	0.09	i
18	$M_{10}P$	Foreign	0.88	o
19	$N_{16}P$	Foreign	0.06	n

4.10.6 CARBON:

Carbon is under other non metals and is the principal additive to iron that makes it to be called steel. Its content between 0.05–1.5% in reinforcing steel is required to retain its formability and weldability. It is also the principal determinant of the steel's strength and also acts as a hardening agent that prevents dislocations in the iron atom crystal lattice from sliding past one another. Table 4.10.6 below compares the carbon content of all the samples with the code provisions. A mean of 0.08% and a standard deviation of 0.04 for the nineteen samples were calculated and found to be within a satisfactory limit.

TABLE 4.10.6: PERCENTAGE COMPOSITION BY WEIGHT FOR CARBON.

S/No	Mark	Source	Carbon Content (%)	Max. BS4449/1997 Provisions	Remarks
1	$A_{12}P$	Local	0.05	0.25	Within Code Limit
2	$A_{10}P$	Local	0.13	0.25	Within Code Limit
3	$B_{10}P$	Local	0.04	0.25	Within Code Limit
4	$B_{8}P$	Local	0.07	0.25	Within Code Limit
5	$C_{16}P$	Local	0.06	0.25	Within Code Limit
6	$C_{10}P$	Local	0.07	0.25	Within Code Limit
7	$C_{8}P$	Local	0.09	0.25	Within Code Limit
8	$D_{8}P$	Foreign	0.08	0.25	Within Code Limit
9	$E_{25}P$	Local	0.07	0.25	Within Code Limit
10	$E_{20}P$	Local	0.04	0.25	Within Code Limit
11	$F_{12}P$	Local	0.07	0.25	Within Code Limit
12	$G_{12}P$	Local	0.03	0.25	Within Code Limit
13	$H_{16}P$	Local	0.15	0.25	Within Code Limit
14	$I_{12}P$	Local	0.09	0.25	Within Code Limit
15	$J_{8}P$	Foreign	0.02	0.25	Within Code Limit
16	$K_{10}P$	Foreign	0.08	0.25	Within Code Limit
17	$L_{12}P$	Foreign	0.10	0.25	Within Code Limit
18	$M_{10}P$	Foreign	0.13	0.25	Within Code Limit
19	$N_{16}P$	Foreign	0.18	0.25	Within Code Limit

Within Code Limit => Satisfactory and Outside Code Limit => Not Satisfactory

4.10.7 CHLORINE:

Chlorine is a halogen and is found in the group 7 in the periodic table. Elements in this group are known to be generally very reactive and hardly exist in a free state. From table 4.10.7 below, it can clearly be seen that the element does not show any consistent behaviour even in samples that are from the same source. They are mostly trace in amount. No code provision has been made on chlorine.

TABLE 4.10.7: PERCENTAGE COMPOSITION BY WEIGHT FOR CHLORINE.

S/No	Mark	Source (L/F)	Chlorine Content (%)	Max. BS4449/1997 Provisions
1	$A_{12}P$	Local	0.10	N
2	$A_{10}P$	Local	0.07	o
3	$B_{10}P$	Local	0.90	
4	B_8P	Local	0.09	
5	$C_{16}P$	Local	0.07	C
6	$C_{10}P$	Local	0.11	o
7	C_8P	Local	0.07	d
8	D_8P	Foreign	0.13	e
9	$E_{25}P$	Local	0.08	
10	$E_{20}P$	Local	0.07	
11	$F_{12}P$	Local	0.08	P
12	$G_{12}P$	Local	0.15	r
13	$H_{16}P$	Local	0.16	o
14	$I_{12}P$	Local	0.13	v
15	J_8P	Foreign	0.05	i
16	$K_{10}P$	Foreign	0.09	s
17	$L_{12}P$	Foreign	0.07	i
18	$M_{10}P$	Foreign	0.66	o
19	$N_{16}P$	Foreign	0.08	n

4.10.8 CHROMIUM:

The element has been classified under the transition metals in the periodic table. From table 4.10.8 below, the element's percentage composition has not been specified by the BS4449. However, despite most of the samples are within the Russian and Chinese standards, no evidence of consistence from the samples has been shown. A mean of 0.22% and a standard deviation of 0.06 for the nineteen samples were calculted and are considered to be satisfactory.

TABLE 4.10.8: PERCENTAGE COMPOSITION BY WEIGHT FOR CHROMIUM.

S/No	Mark	Source	Chromium Content (%)	Max.ASChM (Russia) 7-93 and GT/T 17107 (Chinese) Provisions	Remarks
1	$A_{12}P$	Local	0.31	0.30	Outside Code Provision
2	$A_{10}P$	Local	0.24	0.30	Within Code Provision
3	$B_{10}P$	Local	0.27	0.30	Within Code Provision
4	B_8P	Local	0.14	0.30	Within Code Provision
5	$C_{16}P$	Local	0.11	0.30	Within Code Provision
6	$C_{10}P$	Local	0.19	0.30	Within Code Provision
7	C_8P	Local	0.14	0.30	Within Code Provision
8	D_8P	Foreign	0.24	0.30	Within Code Provision
9	$E_{25}P$	Local	0.20	0.30	Within Code Provision
10	$E_{20}P$	Local	0.28	0.30	Within Code Provision
11	$F_{12}P$	Local	0.22	0.30	Within Code Provision
12	$G_{12}P$	Local	0.22	0.30	Within Code Provision
13	$H_{16}P$	Local	0.28	0.30	Within Code Provision
14	$I_{12}P$	Local	0.31	0.30	Outside Code Provision
15	J_8P	Foreign	0.14	0.30	Within Code Provision
16	$K_{10}P$	Foreign	0.21	0.30	Within Code Provision
17	$L_{12}P$	Foreign	0.16	0.30	Within Code Provision
18	$M_{10}P$	Foreign	0.24	0.30	Within Code Provision
19	$N_{16}P$	Foreign	0.26	0.30	Within Code Provision

Within Code Provision => Satisfactory and Outside Code Provision => Not Satisfactory

4.10.9 COPPER

Copper is classified under other non metals which act as an alloying mineral that adds to the strength and resistance to corrosion. From table 4.16 below, it can be seen that the element has appeared in all the nineteen samples. BS4449(1997) has not made any provision on the limit of copper. However, ASTM A36/A, 36M has provided 0.3% minimum when copper steel is specified. A mean of 0.27% and a standard deviation of 0.11 for the nineteen samples were calculated and are considered to be satisfactory based on the Russian standards.

TABLE 4.10.9: PERCENTAGE COMPOSITION BY WEIGHT FOR COPPER.

S/No	Mark	Source	Copper Content (%)	Max.ASChM (Russia) 7-93 and GT/T 17107 (Chinese) Provisions	Remarks
1	$A_{12}P$	Local	0.31	0.30	Outside Code Provision
2	$A_{10}P$	Local	0.27	0.30	Within Code Provision
3	$B_{10}P$	Local	0.33	0.30	Outside Code Provision
4	B_8P	Local	0.12	0.30	Within Code Provision
5	$C_{16}P$	Local	0.37	0.30	Outside Code Provision
6	$C_{10}P$	Local	0.10	0.30	Within Code Provision
7	C_8P	Local	0.10	0.30	Within Code Provision
8	D_8P	Foreign	0.31	0.30	Outside Code Provision
9	$E_{25}P$	Local	0.33	0.30	Outside Code Provision
10	$E_{20}P$	Local	0.28	0.30	Within Code Provision
11	$F_{12}P$	Local	0.32	0.30	Outside Code Provision
12	$G_{12}P$	Local	0.07	0.30	Within Code Provision
13	$H_{16}P$	Local	0.18	0.30	Within Code Provision
14	$I_{12}P$	Local	0.15	0.30	Within Code Provision
15	J_8P	Foreign	0.41	0.30	Outside Code Provision
16	$K_{10}P$	Foreign	0.32	0.30	Outside Code Provision
17	$L_{12}P$	Foreign	0.34	0.30	Outside Code Provision
18	$M_{10}P$	Foreign	0.36	0.30	Outside Code Provision
19	$N_{16}P$	Foreign	0.44	0.30	Outside Code Provision

Within Code Provision => Satisfactory and Outside Code Provision => Not Satisfactory

4.10.10 GALIUM:

This element falls under the category of other metals in the periodic table. From table 4.10.10 below, it can be seen that the element is generally in traces and no consistency has be seen especially when comparison is made amongst samples from the same source. No code provision has been made.

TABLE 4.10.10: PERCENTAGE COMPOSITION BY WEIGHT FOR GALIUM.

S/No	Mark	Source (L/F)	Galium Content (%)	Max. BS4449/1997 Provisions
1	$A_{12}P$	Local	0.18	N
2	$A_{10}P$	Local	0.00	o
3	$B_{10}P$	Local	0.06	
4	B_8P	Local	0.07	
5	$C_{16}P$	Local	0.00	C
6	$C_{10}P$	Local	0.08	o
7	C_8P	Local	0.03	d
8	D_8P	Foreign	0.06	e
9	$E_{25}P$	Local	0.00	
10	$E_{20}P$	Local	0.15	
11	$F_{12}P$	Local	0.09	P
12	$G_{12}P$	Local	0.00	r
13	$H_{16}P$	Local	0.00	o
14	$I_{12}P$	Local	0.00	v
15	J_8P	Foreign	0.05	i
16	$K_{10}P$	Foreign	0.07	s
17	$L_{12}P$	Foreign	0.00	i
18	$M_{10}P$	Foreign	0.00	o
19	$N_{16}P$	Foreign	0.00	n

4.10.11 IRON:

Iron is the principal constituent element in reinforcing steel bars. From table 4.10.11 below, it can be seen that sample $C_{16}P$ and $I_{16}P$ have recorded the highest and lowest values of 94.8% and74.5% respectively. Both bar samples are from two local sources. No code has specified the amount of Iron in steel. However, the inconsistencies noted as reflected in the table appear worrisome. All the bars from same company are supposed to have almost the same percentage Iron Composition. But on a closer examination, this is not the case in samples from companies A, B, C and E. A mean of 87.55% and a standard deviation of 5.49 for the nineteen samples were calculated. Though no code provision has been made on percentage composition of Iron, a standard deviation of 5.49 is not satisfactory.

TABLE 4.10.11: PERCENTAGE COMPOSITION BY WEIGHT FOR IRON.

S/No	Mark	Source (L/F)	Iron Content (%)	Max. BS4449/1997 Provisions
1	$A_{12}P$	Local	89.4	N
2	$A_{10}P$	Local	89.3	o
3	$B_{10}P$	Local	86.8	
4	B_8P	Local	93.6	
5	$C_{16}P$	Local	94.8	C
6	$C_{10}P$	Local	92.8	o
7	C_8P	Local	94.1	d
8	D_8P	Foreign	84.0	e
9	$E_{25}P$	Local	87.8	
10	$E_{20}P$	Local	88.0	
11	$F_{12}P$	Local	87.4	P
12	$G_{12}P$	Local	80.1	r
13	$H_{16}P$	Local	77.0	o
14	$I_{12}P$	Local	74.5	v
15	J_8P	Foreign	89.7	i
16	$K_{10}P$	Foreign	87.9	s
17	$L_{12}P$	Foreign	87.6	i
18	$M_{10}P$	Foreign	86.7	o
19	$N_{16}P$	Foreign	92.0	n

4.10.12 IRIDIUM:

The element has been classified under the transition metals in the periodic table. It has been observed to be present in only samples D_8P and $E_{25}P$ as seen in table 4.10.12 below illustrates the composition of Iridium across the nineteen samples. No code provision has been made on the percentage composition of Iridium.

TABLE 4.10.12: PERCENTAGE COMPOSITION BY WEIGHT FOR IRIDIUM.

S/No	Mark	Source (L/F)	Iridium Content (%)	Max. BS4449/1997 Provisions
1	$A_{12}P$	Local	0.00	N
2	$A_{10}P$	Local	0.00	o
3	$B_{10}P$	Local	0.00	
4	B_8P	Local	0.00	
5	$C_{16}P$	Local	0.00	C
6	$C_{10}P$	Local	0.00	o
7	C_8P	Local	0.00	d
8	D_8P	Foreign	0.55	e
9	$E_{25}P$	Local	0.50	
10	$E_{20}P$	Local	0.00	
11	$F_{12}P$	Local	0.00	P
12	$G_{12}P$	Local	0.00	r
13	$H_{16}P$	Local	0.00	o
14	$I_{12}P$	Local	0.00	v
15	J_8P	Foreign	0.00	i
16	$K_{10}P$	Foreign	0.00	s
17	$L_{12}P$	Foreign	0.00	i
18	$M_{10}P$	Foreign	0.00	o
19	$N_{16}P$	Foreign	0.00	n

4.10.13 MANGANESE:

Manganese is a transition metal which acts as an alloying mineral that adds to the tensile strength of steel bars and the element is also required for the control of machinability. It is also very important determinant of the steel's carbon equivalent value as reflected in the relationship specified by BS4449(1997).Table 4.10.13 below compares the percentage composition values for manganese with the code provisions. A mean of 0.82% and a standard deviation of 0.11 were calculated for the nineteen samples and are within the range of code provisions.

TABLE 4.10.13: PERCENTAGE COMPOSITION BY WEIGHT FOR MANGANESE.

S/No	Mark	Source (L/F)	Manganese Content (%)	BS4449/1997 Provisions	Remarks
1	$A_{12}P$	Local	0.75	0.60 to 0.90	Within Range
2	$A_{10}P$	Local	0.90	0.60 to 0.90	Within Range
3	$B_{10}P$	Local	0.84	0.60 to 0.90	Within Range
4	B_8P	Local	0.71	0.60 to 0.90	Within Range
5	$C_{16}P$	Local	0.65	0.60 to 0.90	Within Range
6	$C_{10}P$	Local	0.74	0.60 to 0.90	Within Range
7	C_8P	Local	0.83	0.60 to 0.90	Within Range
8	D_8P	Foreign	0.84	0.60 to 0.90	Within Range
9	$E_{25}P$	Local	1.01	0.60 to 0.90	Outside Range
10	$E_{20}P$	Local	0.91	0.60 to 0.90	Outside Range
11	$F_{12}P$	Local	0.76	0.60 to 0.90	Within Range
12	$G_{12}P$	Local	0.90	0.60 to 0.90	Within Range
13	$H_{16}P$	Local	0.87	0.60 to 0.90	Within Range
14	$I_{12}P$	Local	0.94	0.60 to 0.90	Outside Range
15	J_8P	Foreign	0.56	0.60 to 0.90	Outside Range
16	$K_{10}P$	Foreign	0.89	0.60 to 0.90	Within Range
17	$L_{12}P$	Foreign	0.88	0.60 to 0.90	Within Range
18	$M_{10}P$	Foreign	0.91	0.60 to 0.90	Outside Range
19	$N_{16}P$	Foreign	0.71	0.60 to 0.90	Within Range

Within Range => Satisfactory and Outside Range => Not Satisfactory.

4.10.14 MOLYBDENUM:

Molybdenum is a transition metal that acts as an alloying mineral that adds to the strength. It is also an important determinant of carbon equivalent value for steel as provided in the relationship Ceqv = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15 .No provision on its composition limit has been made by the code. Table 4.10.14 below illustrates the composition of Molybdenum across the nineteen samples. No code provision has been made on the percentage composition of molybdenum.

TABLE 4.10.14: PERCENTAGE COMPOSITION BY WEIGHT FOR MOLYBDENUM.

S/No	Mark	Source (L/F)	Molybdenum Content (%)	Max. BS4449/1997 Provisions
1	$A_{12}P$	Local	0.00	N
2	$A_{10}P$	Local	0.00	o
3	$B_{10}P$	Local	0.04	
4	B_8P	Local	0.00	
5	$C_{16}P$	Local	0.00	C
6	$C_{10}P$	Local	0.00	o
7	C_8P	Local	0.00	d
8	D_8P	Foreign	0.00	e
9	$E_{25}P$	Local	0.00	
10	$E_{20}P$	Local	0.00	
11	$F_{12}P$	Local	0.00	P
12	$G_{12}P$	Local	0.00	r
13	$H_{16}P$	Local	0.00	o
14	$I_{12}P$	Local	0.00	v
15	J_8P	Foreign	0.00	i
16	$K_{10}P$	Foreign	0.00	s
17	$L_{12}P$	Foreign	0.00	i
18	$M_{10}P$	Foreign	0.30	o
19	$N_{16}P$	Foreign	0.00	n

4.10.15 NICKEL:

Nickel is a transition metal in the periodic table. No provision has been made by the British Standard. The Russian and Chinese standards were considered and all samples have complied. However, the behaviour of the composition across the nineteen samples has not been unique in any way. Table 4.10.15 below illustrates the composition of Nickel across the samples.

A mean of 0.07% and a standard deviation of 0.04 were calculated for the nineteen samples which are considered to be satisfactory based on Russian standards as BS4449(1997) has not made any provision of the percentage composition of Nickel.

TABLE 4.10.15: PERCENTAGE COMPOSITION BY WEIGHT FOR NICKEL.

S/No	Mark	Source (L/F)	Nickel Content (%)	Max. Russia & Chinese Provisions	Remarks
1	$A_{12}P$	Local	0.10	<0.30%	Satisfactory
2	$A_{10}P$	Local	0.05	<0.30%	Satisfactory
3	$B_{10}P$	Local	0.06	<0.30%	Satisfactory
4	B_8P	Local	0.00	<0.30%	Satisfactory
5	$C_{16}P$	Local	0.07	<0.30%	Satisfactory
6	$C_{10}P$	Local	0.00	<0.30%	Satisfactory
7	C_8P	Local	0.00	<0.30%	Satisfactory
8	D_8P	Foreign	0.07	<0.30%	Satisfactory
9	$E_{25}P$	Local	0.06	<0.30%	Satisfactory
10	$E_{20}P$	Local	0.09	<0.30%	Satisfactory
11	$F_{12}P$	Local	0.06	<0.30%	Satisfactory
12	$G_{12}P$	Local	0.06	<0.30%	Satisfactory
13	$H_{16}P$	Local	0.09	<0.30%	Satisfactory
14	$I_{12}P$	Local	0.07	<0.30%	Satisfactory
15	J_8P	Foreign	0.05	<0.30%	Satisfactory
16	$K_{10}P$	Foreign	0.07	<0.30%	Satisfactory
17	$L_{12}P$	Foreign	0.06	<0.30%	Satisfactory
18	$M_{10}P$	Foreign	0.11	<0.30%	Satisfactory

19	$N_{16}P$	Foreign	0.18	<0.30%	Satisfactory

4.10.16 NITROGEN:

This element has appeared in the entire nineteen samples. BS4449 has clearly stated its presence as an impurity if it exceeds the prescribed limit and the need for control. The code states that if Aluminium content is less than 0.02%, then the maximum percentage values for Nitrogen do not apply. From the table, it can clearly be seen that the percentage by weight of Nitrogen in most of the samples has exceeded the code provisions. Table 4.10.16 below illustrates the composition of Nitrogen across the nineteen samples. A mean of 0. 50% and a standard deviation of 1.58 for the nineteen samples were calculated and found to be satisfactorily within the code provisions.

TABLE 4.10.16: PERCENTAGE COMPOSITION BY WEIGHT FOR NITROGEN.

S/No	Mark	Source (L/F)	Nitrogen Content (%)	Max. BS4449/1997 Provisions	Remarks
1	$A_{12}P$	Local	0.04	0.012	Above
2	$A_{10}P$	Local	0.07	0.012	Above
3	$B_{10}P$	Local	0.04	0.012	Above
4	B_8P	Local	0.01	0.012	Below
5	$C_{16}P$	Local	0.28	0.012	Above
6	$C_{10}P$	Local	0.42	0.012	Above
7	C_8P	Local	0.40	0.012	Above
8	D_8P	Foreign	0.31	0.012	Above
9	$E_{25}P$	Local	0.008	0.012	Below
10	$E_{20}P$	Local	0.07	0.012	Above
11	$F_{12}P$	Local	0.08	0.012	Above
12	$G_{12}P$	Local	0.24	0.012	Above
13	$H_{16}P$	Local	0.31	0.012	Above
14	$I_{12}P$	Local	0.005	0.012	Below
15	J_8P	Foreign	0.095	0.012	Above
16	$K_{10}P$	Foreign	0.002	0.012	Above
17	$L_{12}P$	Foreign	0.03	0.012	Above
18	$M_{10}P$	Foreign	0.001	0.012	Below
19	$N_{16}P$	Foreign	0.21	0.012	Above

Above =>Not Satisfactory and Below => Satisfactory

4.10.17 OSMIUM:

This has also been classified as a transition metal in the periodic table. No provision has been made by any code. However, the behaviour of the composition across the nineteen samples has not been unique in any way looks like a trace of it in amount. Table 4.10.17 below illustrates the composition of Osmium across the nineteen samples. No code provision has been made in respect of percentage composition of Osmium.

TABLE 4.10.17: PERCENTAGE COMPOSITION BY WEIGHT FOR OSMIUM.

S/No	Mark	Source (L/F)	Osmium Content (%)	Max. BS4449/1997 Provisions
1	$A_{12}P$	Local	0.56	N
2	$A_{10}P$	Local	0.39	o
3	$B_{10}P$	Local	0.28	
4	B_8P	Local	0.35	
5	$C_{16}P$	Local	0.31	C
6	$C_{10}P$	Local	0.42	o
7	C_8P	Local	0.37	d
8	D_8P	Foreign	0.31	e
9	$E_{25}P$	Local	0.35	
10	$E_{20}P$	Local	0.46	
11	$F_{12}P$	Local	0.35	P
12	$G_{12}P$	Local	0.42	r
13	$H_{16}P$	Local	0.37	o
14	$I_{12}P$	Local	0.34	v
15	J_8P	Foreign	0.25	i
16	$K_{10}P$	Foreign	0.27	s
17	$L_{12}P$	Foreign	0.32	i
18	$M_{10}P$	Foreign	0.62	o
19	$N_{16}P$	Foreign	0.61	n

4.10.18 PHOSPHORUS

This is a non metal. Excessive levels of phosphorus and sulphur, which are non-metallic impurities lead to brittle fracture and cracking problems in welded joints. For modern steel-making practice, sulphur and phosphorus are preferably maintained at less than 0.01%.

However, the presence of Silicon and Phosphorus must be controlled as they are associated with impurities. Table 4.10.18 below illustrates the composition of Phosphorus across the nineteen samples. The table also illustrates mixed output with almost a half of the results each indicating unsatisfactory and no trace of the element.

TABLE 4.10.18: PERCENTAGE COMPOSITION BY WEIGHT FOR PHOSPHORUS.

S/No	Mark	Source	Phosphorus Content (%)	Max. BS4449/1997 Provisions	Remarks
1	$A_{12}P$	Local	0.00	0.05	No trace
2	$A_{10}P$	Local	0.00	0.05	No trace
3	$B_{10}P$	Local	0.06	0.05	Above, Unsatisfactory
4	B_8P	Local	0.09	0.05	Above, Unsatisfactory
5	$C_{16}P$	Local	0.08	0.05	Above, Unsatisfactory
6	$C_{10}P$	Local	0.00	0.05	No Trace
7	C_8P	Local	0.10	0.05	Above, Unsatisfactory
8	D_8P	Foreign	0.04	0.05	Below, Satisfactory
9	$E_{25}P$	Local	0.00	0.05	No Trace
10	$E_{20}P$	Local	0.00	0.05	No Trace
11	$F_{12}P$	Local	0.00	0.05	No Trace
12	$G_{12}P$	Local	0.00	0.05	No Trace
13	$H_{16}P$	Local	0.00	0.05	No Trace
14	$I_{12}P$	Local	0.00	0.05	No Trace
15	J_8P	Foreign	0.06	0.05	Above, Unsatisfactory
16	$K_{10}P$	Foreign	0.08	0.05	Above, Unsatisfactory
17	$L_{12}P$	Foreign	0.00	0.05	No Trace
18	$M_{10}P$	Foreign	0.00	0.05	No Trace
19	$N_{16}P$	Foreign	0.00	0.05	No Trace

Outside Code =>Not Satisfactory, Within Code => Satisfactory and No Trace => Satisfactory

4.10.19 PLATINIUM:

This has also been classified as a transition metal in the periodic table. No provision has been made by any code. However, the behaviour of the composition across the nineteen samples has not been unique in any way. Table 4.10.19 below illustrates the composition of Platinium across the nineteen samples. It is traces only in two out of nineteen samples.

TABLE 4.10.19: PERCENTAGE COMPOSITION BY WEIGHT FOR PLATINIUM.

S/No	Mark	Source (L/F)	Indium Content (%)	Max. BS4449/1997 Provisions
1	$A_{12}P$	Local	0.10	N
2	$A_{10}P$	Local	0.00	o
3	$B_{10}P$	Local	0.00	
4	B_8P	Local	0.00	
5	$C_{16}P$	Local	0.00	C
6	$C_{10}P$	Local	0.00	o
7	C_8P	Local	0.00	d
8	D_8P	Foreign	0.05	e
9	$E_{25}P$	Local	0.00	
10	$E_{20}P$	Local	0.00	
11	$F_{12}P$	Local	0.00	P
12	$G_{12}P$	Local	0.00	r
13	$H_{16}P$	Local	0.00	o
14	$I_{12}P$	Local	0.00	v
15	J_8P	Foreign	0.04	i
16	$K_{10}P$	Foreign	0.00	s
17	$L_{12}P$	Foreign	0.00	i
18	$M_{10}P$	Foreign	0.00	o
19	$N_{16}P$	Foreign	0.00	n

No previous studies on Platinium percentage composition were sighted.

4.10.20 RHENIUM:

This has also been classified as a transition metal in the periodic table. No provision has been made by any code. However, the behaviour of the composition across the nineteen samples has not shown unique feature. Table 4.10.20 below illustrates the composition of Rhenium across the nineteen samples.

Table 4.10.20: PERCENTAGE COMPOSITION FOR RHENIUM.

S/No	Mark	Source (L/F)	Rhenium Content (%)	Max. BS4449/1997 Provisions
1	$A_{12}P$	Local	0.20	N
2	$A_{10}P$	Local	0.10	o
3	$B_{10}P$	Local	0.10	
4	B_8P	Local	0.00	
5	$C_{16}P$	Local	0.24	C
6	$C_{10}P$	Local	0.24	o
7	C_8P	Local	0.20	d
8	D_8P	Foreign	0.07	e
9	$E_{25}P$	Local	0.20	
10	$E_{20}P$	Local	0.10	
11	$F_{12}P$	Local	0.10	P
12	$G_{12}P$	Local	0.10	r
13	$H_{16}P$	Local	0.00	o
14	$I_{12}P$	Local	0.00	v
15	J_8P	Foreign	0.10	i
16	$K_{10}P$	Foreign	0.10	s
17	$L_{12}P$	Foreign	0.10	i
18	$M_{10}P$	Foreign	0.20	o
19	$N_{16}P$	Foreign	0.30	n

No previous studies on Rhenium percentage composition were sighted.

4.10.21 RHODIUM:

This has also been classified as a transition metal in the periodic table. No provision has been made by any code. However, the behaviour of the composition across the nineteen samples has shown it to be in traces .Table 4.10.21 below illustrates the composition of Rhodium across the nineteen samples.

TABLE 4.10. 21: PERCENTAGE COMPOSITION FOR RHODIUM.

S/No	Mark	Source (L/F)	Rhodium Content (%)	Max. BS4449/1997 Provisions
1	$A_{12}P$	Local	0.68	N
2	$A_{10}P$	Local	0.42	o
3	$B_{10}P$	Local	0.25	
4	B_8P	Local	0.34	
5	$C_{16}P$	Local	0.28	C
6	$C_{10}P$	Local	0.57	o
7	C_8P	Local	0.48	d
8	D_8P	Foreign	0.24	e
9	$E_{25}P$	Local	0.35	
10	$E_{20}P$	Local	0.62	
11	$F_{12}P$	Local	0.42	P
12	$G_{12}P$	Local	0.32	r
13	$H_{16}P$	Local	0.00	o
14	$I_{12}P$	Local	0.00	v
15	J_8P	Foreign	0.20	i
16	$K_{10}P$	Foreign	0.39	s
17	$L_{12}P$	Foreign	0.32	i
18	$M_{10}P$	Foreign	0.63	o
19	$N_{16}P$	Foreign	0.60	n

4.10.22 SILICON

Other alloying elements include silicon, which is a non metal that is added to increase corrosion resistance. However, its presence must be controlled as it is associated with impurities. Table 4.10.22 below illustrates the composition of Silicon across the nineteen samples. A mean of 0.92% and a standard deviation of 0.72 were calculated for the nineteen samples which are considered to be unsatisfactory.

TABLE 4.10.22: PERCENTAGE COMPOSITION FOR SILICON.

S/No	Mark	Source	Silicon Content (%)	Max. BS4449/1997 & Chinese Provisions	Remarks
1	$A_{12}P$	Local	0.70	<0.15%	Above, Unsatisfactory
2	$A_{10}P$	Local	0.70	<0.15%	Above, Unsatisfactory
3	$B_{10}P$	Local	0.90	<0.15%	Above, Unsatisfactory
4	B_8P	Local	0.60	<0.15%	Above, Unsatisfactory
5	$C_{16}P$	Local	0.70	<0.15%	Above, Unsatisfactory
6	$C_{10}P$	Local	0.59	<0.15%	Above, Unsatisfactory
7	C_8P	Local	0.41	<0.15%	Above, Unsatisfactory
8	D_8P	Foreign	1.70	<0.15%	Above, Unsatisfactory
9	$E_{25}P$	Local	3.53	<0.15%	Above, Unsatisfactory
10	$E_{20}P$	Local	0.72	<0.15%	Above, Unsatisfactory
11	$F_{12}P$	Local	1.00	<0.15%	Above, Unsatisfactory
12	$G_{12}P$	Local	0.50	<0.15%	Above, Unsatisfactory
13	$H_{16}P$	Local	0.25	<0.15%	Above, Unsatisfactory
14	$I_{12}P$	Local	0.27	<0.15%	Above, Unsatisfactory
15	J_8P	Foreign	0.91	<0.15%	Above, Unsatisfactory
16	$K_{10}P$	Foreign	0.84	<0.15%	Above, Unsatisfactory
17	$L_{12}P$	Foreign	1.10	<0.15%	Above, Unsatisfactory
18	$M_{10}P$	Foreign	1.00	<0.15%	Above, Unsatisfactory
19	$N_{16}P$	Foreign	1.10	<0.15%	Above, Unsatisfactory

Above => Unsatisfactory

4.10.23 SULPHUR

Excessive levels of phosphorus and sulphur, which are non-metallic impurities lead to brittle fracture and cracking problems in welded joints. For modern steel-making practice, sulphur and phosphorus are preferably maintained at less than 0.01%. However, the presence of Silicon and Phosphorus must be controlled as they are associated with impurities. Table 4.10.23 below illustrates the composition of Sulphur across the nineteen samples.

TABLE 4.10.23: PERCENTAGE COMPOSITION FOR SULPHUR.

S/No	Mark	Source	Sulphur Content (%)	Max. BS4449/1997 Provisions	Remarks
1	$A_{12}P$	Local	0.00	0.05	No Trace
2	$A_{10}P$	Local	0.00	0.05	No Trace
3	$B_{10}P$	Local	0.03	0.05	Below
4	B_8P	Local	0.00	0.05	No Trace
5	$C_{16}P$	Local	0.00	0.05	No Trace
6	$C_{10}P$	Local	0.00	0.05	No Trace
7	C_8P	Local	0.00	0.05	No Trace
8	D_8P	Foreign	0.00	0.05	No Trace
9	$E_{25}P$	Local	0.00	0.05	No Trace
10	$E_{20}P$	Local	0.14	0.05	Above
11	$F_{12}P$	Local	0.00	0.05	No Trace
12	$G_{12}P$	Local	0.00	0.05	No Trace
13	$H_{16}P$	Local	0.00	0.05	No Trace
14	$I_{12}P$	Local	0.00	0.05	No Trace
15	J_8P	Foreign	0.00	0.05	No Trace
16	$K_{10}P$	Foreign	0.00	0.05	No Trace
17	$L_{12}P$	Foreign	0.00	0.05	No Trace
18	$M_{10}P$	Foreign	0.31	0.05	Above
19	$N_{16}P$	Foreign	0.00	0.05	No Trace

Above => Not Satisfactory, Below and No Trace => Satisfactory

4.10.24 TELLURIUM:

This has been classified as a non metal in the periodic table. No provision has been made by any code. However, the behaviour of the composition across the nineteen samples has shown the presence only in traces. Table 4.10.24 below illustrates the composition of Tellurium across the nineteen samples.

TABLE 4.10.24: PERCENTAGE COMPOSITION FOR TELLURIUM.

S/No	Mark	Source (L/F)	Tellurium Content (%)	Max. BS4449/1997 Provisions
1	$A_{12}P$	Local	0.00	N
2	$A_{10}P$	Local	0.00	o
3	$B_{10}P$	Local	0.00	
4	B_8P	Local	0.00	
5	$C_{16}P$	Local	0.00	C
6	$C_{10}P$	Local	0.05	o
7	C_8P	Local	0.14	d
8	D_8P	Foreign	0.00	e
9	$E_{25}P$	Local	0.00	
10	$E_{20}P$	Local	0.00	
11	$F_{12}P$	Local	0.00	P
12	$G_{12}P$	Local	0.00	r
13	$H_{16}P$	Local	0.00	o
14	$I_{12}P$	Local	0.00	v
15	J_8P	Foreign	0.00	i
16	$K_{10}P$	Foreign	0.00	s
17	$L_{12}P$	Foreign	0.00	i
18	$M_{10}P$	Foreign	0.00	o
19	$N_{16}P$	Foreign	0.00	n

4.10.25 TITANIUM:

This has also been classified as under other metals in the periodic table. No provision has been made by any code. However, the behaviour of the composition across the nineteen samples has not been unique in any way. Table 4.10.25 below illustrates the composition of Titanium across the nineteen samples. Also looks like a trace element within reinforcing steel.

TABLE 4.10.25: PERCENTAGE COMPOSITION FOR TITANIUM.

S/No	Mark	Source (L/F)	Titanium Content (%)	Max. BS4449/1997 Provisions
1	$A_{12}P$	Local	0.16	N
2	$A_{10}P$	Local	0.00	o
3	$B_{10}P$	Local	0.00	
4	B_8P	Local	0.00	
5	$C_{16}P$	Local	0.00	C
6	$C_{10}P$	Local	0.15	o
7	C_8P	Local	0.00	d
8	D_8P	Foreign	0.13	e
9	$E_{25}P$	Local	0.00	
10	$E_{20}P$	Local	0.00	
11	$F_{12}P$	Local	0.00	P
12	$G_{12}P$	Local	0.00	r
13	$H_{16}P$	Local	0.00	o
14	$I_{12}P$	Local	0.00	v
15	J_8P	Foreign	0.00	i
16	$K_{10}P$	Foreign	0.00	s
17	$L_{12}P$	Foreign	0.00	i
18	$M_{10}P$	Foreign	0.18	o
19	$N_{16}P$	Foreign	0.00	n

4.10.26 VANADIUM

Vanadium is mainly used to give added strength after hot rolling. According to John (1993), Amsted (1987), and Kareem (2002), (0.05% to 0.1%) Vanadium addition increases the yield strength of a reinforcing bars by 100N/mm^2. From table 4.10.26 below, it can clearly be seen that this important element can only be traced in samples $B_{10}P$, $H_{16}P$ and $L_{12}P$ .In the case of $B_{10}P$, the presence of this element may only be explained by quality control problems or variation in raw material's source as sample B_8P which is from same company does not contain it. However, all the three samples have traces not exceeding 5%.

TABLE 4.10.26: PERCENTAGE COMPOSITION FOR VANADIUM.

S/No	Mark	Source (L/F)	Vanadium Content (%)	MIS (1998)	Remarks
1	$A_{12}P$	Local	0.00	0.02 – 0.15	No Trace
2	$A_{10}P$	Local	0.00	0.02 – 0.15	No Trace
3	$B_{10}P$	Local	0.03	0.02 – 0.15	Within Provision
4	B_8P	Local	0.00	0.02 – 0.15	No Trace
5	$C_{16}P$	Local	0.00	0.02 – 0.15	No Trace
6	$C_{10}P$	Local	0.00	0.02 – 0.15	No Trace
7	C_8P	Local	0.00	0.02 – 0.15	No Trace
8	D_8P	Foreign	0.00	0.02 – 0.15	No Trace
9	$E_{25}P$	Local	0.00	0.02 – 0.15	No Trace
10	$E_{20}P$	Local	0.00	0.02 – 0.15	No Trace
11	$F_{12}P$	Local	0.00	0.02 – 0.15	No Trace
12	$G_{12}P$	Local	0.00	0.02 – 0.15	No Trace
13	$H_{16}P$	Local	0.05	0.02 – 0.15	Within Provision
14	$I_{12}P$	Local	0.00	0.02 – 0.15	No Trace
15	J_8P	Foreign	0.00	0.02 – 0.15	No Trace
16	$K_{10}P$	Foreign	0.00	0.02 – 0.15	No Trace
17	$L_{12}P$	Foreign	0.02	0.02 – 0.15	Within Provision
18	$M_{10}P$	Foreign	0.00	0.02 – 0.15	No Trace
19	$N_{16}P$	Foreign	0.00	0.02 – 0.15	No Trace

Within Provision => Satisfactory and No Trace => Not Satisfactory.

4.10.27 ZINC:

This has also been classified as a transition metal in the periodic table. All the values recorded have satisfied the code provision. However, the behaviour of the composition across the nineteen samples are shown. Table 4.10.26 below illustrates the composition of Zinc across the nineteen samples.

TABLE 4.10.26: PERCENTAGE COMPOSITION FOR ZINC.

S/No	Mark	Source (L/F)	Zinc Content (%)	Max. BS4449/1997 Provisions
1	$A_{12}P$	Local	0.17	N
2	$A_{10}P$	Local	0.04	o
3	$B_{10}P$	Local	0.07	
4	B_8P	Local	0.00	
5	$C_{16}P$	Local	0.01	C
6	$C_{10}P$	Local	0.02	o
7	C_8P	Local	0.02	d
8	D_8P	Foreign	0.13	e
9	$E_{25}P$	Local	0.08	
10	$E_{20}P$	Local	0.15	
11	$F_{12}P$	Local	0.04	P
12	$G_{12}P$	Local	0.06	r
13	$H_{16}P$	Local	0.05	o
14	$I_{12}P$	Local	0.06	v
15	J_8P	Foreign	0.04	i
16	$K_{10}P$	Foreign	0.06	s
17	$L_{12}P$	Foreign	0.61	i
18	$M_{10}P$	Foreign	0.15	o
19	$N_{16}P$	Foreign	0.14	n

4.10.28 ZIRCONIUM:

The element belongs to the transition metal group and is known from previous studies to add to the strength, sulphide – inclusion and shape control which also increases formability of the steel. It is present in the sample designated as I_{16}Ponly. No code provision has been made on its limit. Table 4.10.28 below illustrates the composition of Zirconium across the nineteen samples.

TABLE 4.10.28: PERCENTAGE COMPOSITION FOR ZIRCONIUM.

S/No	Mark	Source (L/F)	Zirconium Content (%)	Max. BS4449/1997 Provisions
1	A_{12}P	Local	0.00	N
2	A_{10}P	Local	0.00	o
3	B_{10}P	Local	0.00	
4	B_8P	Local	0.00	
5	C_{16}P	Local	0.00	C
6	C_{10}P	Local	0.00	o
7	C_8P	Local	0.00	d
8	D_8P	Foreign	0.00	e
9	E_{25}P	Local	0.00	
10	E_{20}P	Local	0.00	
11	F_{12}P	Local	0.00	P
12	G_{12}P	Local	0.00	r
13	H_{16}P	Local	0.00	o
14	I_{12}P	Local	1.10	v
15	J_8P	Foreign	0.00	i
16	K_{10}P	Foreign	0.00	s
17	L_{12}P	Foreign	0.00	i
18	M_{10}P	Foreign	0.00	o
19	N_{16}P	Foreign	0.00	n

4.11 DETERMINATION OF CARBON EQUIVALENT VALUE

The weldability of the reinforcing steel bars can be understood from the table as relevant code and standards BS 4449 (1997) stipulates a maximum value of 0.51 for high tensile steel given that Carbon equivalent value is usually a function of the percentages composition of C, Mn, Ni, Cu, Mo, V, and Cr. The weldability statistics of the tested steel bars are hereby presented in table 4.11 below. BS4449 (Table4) Table 2.6 of this research prescribes a maximum value of 0.51 for high tensile steel bars. Thus, data obtained was used to compute the carbon equivalent value using the formula: Ceqv = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15 as provided by the code and confirmed by many scholars. A mean of 0.29% and a standard deviation of 0.06 was calculated for the nineteen samples which are considered to be satisfactory.

TABLE 4.11 CARBON EQUIVALENT VALUE (WELDABILITY COEFFICIENT) OF STEEL BARS

S/No	Mark	Source	Calculated Carbon Equivalent Value (Ceq.)	Remarks as per BS4449(1997) Code
1	$A_{12}P$	Local	0.26	Code compliant
2	$A_{10}P$	Local	0.35	Code compliant
3	$B_{10}P$	Local	0.27	Code compliant
4	$B_{8}P$	Local	0.23	Code compliant
5	$C_{16}P$	Local	0.22	Code compliant
6	$C_{10}P$	Local	0.24	Code compliant
7	$C_{8}P$	Local	0.26	Code compliant
8	$D_{8}P$	Foreign	0.29	Code compliant
9	$E_{25}P$	Local	0.31	Code compliant
10	$E_{20}P$	Local	0.27	Code compliant
11	$F_{12}P$	Local	0.26	Code compliant
12	$G_{12}P$	Local	0.24	Code compliant
13	$H_{16}P$	Local	0.38	Code compliant
14	$I_{12}P$	Local	0.32	Code compliant
15	$J_{8}P$	Foreign	0.17	Code compliant
16	$K_{10}P$	Foreign	0.29	Code compliant
17	$L_{12}P$	Foreign	0.34	Code compliant
18	$M_{10}P$	Foreign	0.42	Code compliant
19	$N_{16}P$	Foreign	0.39	Code compliant

Code compliant => Satisfactory

4.12 CROSS - CHECKING SAMPLES WITH PARAMETERS TESTED

From the table 4.12 below, five tested parameters are cross checked with each diameter samples and see if each parameter sample passed all the parameters. Such parameters are Tolerance on cross – sectional area, Characteristics Strength, Ultimate to Yield strength ratio, Elongation, and Bend test. The remark column indicates how each diameter sample performed. The keys are given at the end of the table. The table for percentage chemical compositions are given in tables 4.13 and 4.14 that followed.

TABLE 4.12: TESTING OF SOME SELECTED TENSILE AND BEND TEST PARAMETERS.

S/No	Mark	Source	Percentage Tolerances on Areas & Masses	Characteristic Strength (N/mm^2)	Ultimate to Yield Str. Ratio	Percentage Elongation (%)	Bend Test	Remarks
1	$A_{12}T$	Local	×	×	√	√	√	Not Satisfactory
2	$A_{10}T$	Local	√	×	√	×	√	Not Satisfactory
3	$B_{10}T$	Local	√	×	√	√	√	Not Satisfactory
4	B_8T	Local	×	×	√	√	√	Not Satisfactory
5	$C_{16}T$	Local	×	√	√	×	×	Not Satisfactory
6	$C_{10}T$	Local	√	×	√	√	√	Not Satisfactory
7	C_8T	Local	×	×	√	√	√	Not Satisfactory
8	D_8T	Foreign	×	√	√	×	√	Not Satisfactory
9	$E_{25}T$	Local	×	×	√	√	√	Not Satisfactory
10	$E_{20}T$	Local	×	×	√	√	√	Not Satisfactory
11	$F_{12}T$	Local	×	×	√	√	√	Not Satisfactory
12	$G_{12}T$	Local	×	×	√	√	√	Not Satisfactory
13	$H_{16}T$	Local	×	√	√	√	√	Not Satisfactory
14	$I_{12}T$	Local	×	×	√	√	√	Not Satisfactory
15	J_8T	Foreign	√	√	×	√	√	Not Satisfactory
16	$K_{10}T$	Foreign	√	√	√	×	√	Not Satisfactory
17	$L_{12}T$	Foreign	√	√	√	√	√	Satisfactory
18	$M_{10}T$	Foreign	×	√	×	√	√	Not Satisfactory
19	$N_{16}T$	Foreign	×	√	√	×	√	Not Satisfactory

Legend :√=> Within Code Provision; X=> Outside Code Provision; - => No Trace of the Element

TABLE 4.13: TESTING OF PERCENTAGE CHEMICAL COMPOSITION PARAMETERS COMPANIES (A - F)WHOSE SPECIFICATIONS WERE GIVEN BY THE CODE.

S/No	Element	$A_{12}P$	$A_{10}P$	$B_{10}P$	B_8P	$C_{16}P$	$C_{10}P$	C_8P	D_8P	$E_{25}P$	$E_{20}P$	$F_{12}P$
1	Al	━	X	X	━	━	━	━	x	x	x	–
2	C	√	√	√	√	√	√	√	√	√	√	√
3	Cr	x	√	√	√	√	√	√	√	√	√	√
4	Cu	x	√	X	√	x	√	√	x	x	√	x
5	Mn	√	√	√	√	√	√	√	√	x	x	√
6	Ni	√	√	√	√	√	√	√	√	√	√	√
7	N_2	x	x	X	√	X	X	x	x	√	x	X
8	P	–	–	×	×	×	–	×	×	–	–	–
9	Si	x	x	X	x	X	x	x	x	x	x	X
10	**S**	━	━	×	×	×	–	×	×	━	━	━

Legend :√=> Within Code Provision; - X=> Outside Code Provision ; - => No Trace of Element

TABLE 4.14: TESTING OF PERCENTAGE CHEMICAL COMPOSITION PARAMETERS

COMPANIES (G - N)WHOSE SPECIFICATIONS WERE GIVEN BY THE CODE.

S/No	Element	$G_{12}P$	$HA_{16}P$	$I_{12}P$	J_8P	$KA_{10}P$	$L_{12}P$	$M_{10}P$	$N_{16}P$
1	Al	–	–	–	–	–	–	–	–
2	C	√	√	√	√	√	√	√	√
3	Cr	√	√	√	X	√	√	√	√
4	Cu	√	√	√	X	x	X	x	X
5	Mn	√	√	x	√	√	√	x	√
6	Ni	√	√	√	√	√	√	√	√
7	N_2	x	X	√	X	√	X	√	X
8	P	–	–	–	×	×	–	–	–
9	Si	x	X	x	x	x	X	x	x
10	**S**	━	━	━	×	×	━	━	━

Legend :√=> Within Code Provision; X=> Outside Code Provision ; - => No Trace of the Element

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Based on the results of the tests conducted, the following conclusions were made.

1. Most of the bars could not comply with the rolling deviations over and under nominal mass as provided by BS4449:1969, 1995 and 1997 respectively.
2. The characteristic strength values for 92% of the locally produced bar samples are low compared to the BS4449:1969, 1995& 1997 standards for high tensile steel which is 460N/mm^2 minimum value.
3. The characteristic strength values in respect of the local bars suggest similarities with that of mild steel as determined by the tensile test and chemical composition results. This implies the products are actually mild steel rolled and openly sold as high tensile steel after rethreading.
4. 95 % of the reinforcement bar samples complied with the minimum ultimate to yield strength ratio as specified by BS 4449: 1969 and 1997 code provisions.
5. The percentage elongation values for 92 % of the locally produced bar samples are within acceptable code limits.
6. The percentage elongation values for 67 % of the foreign bar samples are below the minimum standard provisions.
7. 95% of all the samples tested have passed the bend test. However, one sample out of the three samples from company C, i.e. (C_{16} B) failed the bend test.
8. The chemical concentration test results showed 12 elemental constituents only, while the percentage composition showed 27 elements.

9. BS4449(1997) gave specifications in respect of only 10 of the elements. However, Russian standards and ASTM were used to make other inferences.
10. All the bar samples tested could not fully comply with the chemical percentage composition requirements as prescribed by the codes.
11. Some of the elements showed presence only in traces and this may be due to their unavailability in the locations where the steel raw materials were obtained.
12. There is a strong indication of the presence of impurities as evidenced by the percentage compositions of silicon, phosphorus, sulphur or their combination in most of the samples tested.
13. Elements that add to strength and carbon equivalent value like Molybdenum, Vanadium, Nickel, Copper, etc. were conspicously not present in all the samples.
14. Iron being the principal component of reinforcement steel varies from 74.5% to 98.4% in the samples.
15. All the samples tested complied with BS4449(1997) value on carbon equivalent values.

5.2 RECOMMENDATIONS

On the basis of the findings of this study, the following recommendations are hereby made.

1. There is a need to develop a local standard which will give clear guidelines based on characteristics strength, bend tests, elongation and percentage elemental compositions as determined in the laboratory for applications in structural design.
2. There should be technical information on all steel reinforcement sold in the open markets so as to guide the designers on their strength and deformation characteristics.

3. Regulatory authorities such as the Standards Organisation of Nigeria, Council for the Regulation of Engineering in Nigeria and tertiary institutions should strengthen their collaborations on ensuring quality standards through materials testing.
4. Steel rolling mills in the country should be compelled to carry along or make their quality testing facilities available to regulatory and other quality enforcement agencies for periodic inspection and compliance.
5. All imported reinforcing steel must be checked for quality compliance prior to accepting such consignment into the country and such must be accompanied with an accredited certification.

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APPENDIX A

RAW DATA FROM TENSILE TESTS

TABLE A-01 : TENSILE TESTS RESULTS FOR SAMPLE $A_{12}T$

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	40	60	348	8.22	11.88	1	300	500	12.0
2	39	58	345	8.02	11.88	1	300	500	12.0
3	39	58	355	8.30	11.88	1	300	500	12.0
4	40	59	350	8.11	11.88	1	300	500	12.0
5	39	58	348	8.04	11.88	1	300	500	12.0
6	40	58	347	8.19	11.88	1	300	500	12.0
7	40	59	350	7.72	11.88	1	300	500	12.0
8	40	59	352	8.70	11.88	1	300	500	12.0
9	40	59	350	8.11	11.88	1	300	500	12.0
10	39	59	350	8.70	11.88	1	300	500	12.0

TABLE A-02: TENSILE TESTS RESULTS FOR SAMPLE $A_{10}T$

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	30	48	345	7.69	9.65	2	300	500	10.0
2	30	47	337	7.88	9.65	2	300	500	10.0
3	30	48	345	7.89	9.65	2	300	500	10.0
4	30	48	345	7.29	9.65	2	300	500	10.0
5	30	48	340	7.50	9.65	2	300	500	10.0
6	30	48	345	7.19	9.65	2	300	500	10.0
7	30	48	340	7.29	9.65	2	300	500	10.0
8	30	49	340	7.52	9.65	2	300	500	10.0
9	30	48	340	8.01	9.65	2	300	500	10.0
10	30	48	340	7.29	9.65	2	300	500	10.0

TABLE A-03: TENSILE TESTS RESULTS FOR SAMPLE $B_{10}T$

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	30	38	355	7.12	9.56	3	300	500	10.0
2	30	39	360	6.27	9.56	3	300	500	10.0
3	30	38	352	6.66	9.56	3	300	500	10.0
4	30	39	360	6.47	9.56	3	300	500	10.0
5	30	38	360	6.48	9.56	3	300	500	10.0
6	30	38	360	6.21	9.56	3	300	500	10.0
7	30	39	360	5.77	9.56	3	300	500	10.0
8	30	39	365	6.07	9.56	3	300	500	10.0
9	30	39	355	6.81	9.56	3	300	500	10.0
10	30	38	360	6.72	9.56	3	300	500	10.0

TABLE A-04: TENSILE TESTS RESULTS FOR SAMPLE B_8T

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	16	21	370	3.95	7.44	4	300	500	8.0
2	16	21	370	4.22	7.44	4	300	500	8.0
3	16	21	375	4.32	7.44	4	300	500	8.0
4	16	21	370	4.28	7.44	4	300	500	8.0
5	16	21	365	4.47	7.44	4	300	500	8.0
6	16	21	370	4.15	7.44	4	300	500	8.0
7	16	21	370	4.27	7.44	4	300	500	8.0
8	16	21	375	4.31	7.44	4	300	500	8.0
9	16	21	375	4.11	7.44	4	300	500	8.0
10	16	21	375	4.37	7.44	4	300	500	8.0

TABLE A-05: TENSILE TESTS RESULTS FOR SAMPLE $C_{16}T$

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	97	179	325	14.12	15.82	5	300	500	16.0
2	97	180	325	14.68	15.82	5	300	500	16.0
3	97	179	325	14.61	15.82	5	300	500	16.0
4	97	179	325	14.44	15.82	5	300	500	16.0
5	97	180	325	14.04	15.82	5	300	500	16.0
6	100	180	320	14.98	15.82	5	300	500	16.0
7	97	179	325	14.84	15.82	5	300	500	16.0
8	102	183	325	14.03	15.82	5	300	500	16.0
9	103	183	325	14.25	15.82	5	300	500	16.0
10	102	183	325	14.88	15.82	5	300	500	16.0

TABLE A-06: TENSILE TESTS RESULTS FOR SAMPLE $C_{10}T$

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	18	24	370	6.55	9.55	6	300	500	10.0
2	18	24	360	6.57	9.55	6	300	500	10.0
3	18	24	365	6.45	9.55	6	300	500	10.0
4	18	24	365	6.47	9.55	6	300	500	10.0
5	17	24	365	6.67	9.55	6	300	500	10.0
6	18	24	360	6.57	9.55	6	300	500	10.0
7	17	24	360	6.54	9.55	6	300	500	10.0
8	17	24	365	6.66	9.55	6	300	500	10.0
9	18	24	365	6.62	9.55	6	300	500	10.0
10	18	24	360	6.56	9.55	6	300	500	10.0

TABLE A-07: TENSILE TESTS RESULTS FOR SAMPLE C_8T

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	18	24	370	4.90	7.46	7	300	500	8.0
2	18	24	360	4.67	7.46	7	300	500	8.0
3	18	24	365	5.40	7.46	7	300	500	8.0
4	18	24	365	4.99	7.46	7	300	500	8.0
5	17	24	365	4.98	7.46	7	300	500	8.0
6	18	24	360	4.99	7.46	7	300	500	8.0
7	17	24	360	4.59	7.46	7	300	500	8.0
8	17	24	365	4.52	7.46	7	300	500	8.0
9	18	24	365	5.01	7.46	7	300	500	8.0
10	18	24	360	5.10	7.46	7	300	500	8.0

TABLE A-08: TENSILE TESTS RESULTS FOR SAMPLE D_8T

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	19	25	305	5.61	7.23	8	300	500	8.0
2	19	26	305	5.27	7.23	8	300	500	8.0
3	19	25	305	5.77	7.23	8	300	500	8.0
4	19	25	305	5.49	7.23	8	300	500	8.0
5	19	26	305	5.68	7.23	8	300	500	8.0
6	19	26	305	5.58	7.23	8	300	500	8.0
7	19	26	310	6.08	7.23	8	300	500	8.0
8	19	25	305	6.19	7.23	8	300	500	8.0
9	19	25	310	5.47	7.23	8	300	500	8.0
10	19	26	305	5.28	7.23	8	300	500	8.0

TABLE A-09: TENSILE TESTS RESULTS FOR SAMPLE $E_{25}T$

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	176	270	360	18.77	24.56	9	300	500	25.0
2	176	272	360	18.67	24.56	9	300	500	25.0
3	174	272	360	18.79	24.56	9	300	500	25.0
4	174	272	360	18.33	24.56	9	300	500	25.0
5	174	274	360	18.46	24.56	9	300	500	25.0
6	174	272	360	18.57	24.56	9	300	500	25.0
7	172	272	360	18.49	24.56	9	300	500	25.0
8	172	274	360	18.88	24.56	9	300	500	25.0
9	174	274	360	18.78	24.56	9	300	500	25.0
10	174	274	360	18.49	24.56	9	300	500	25.0

TABLE A-10: TENSILE TESTS RESULTS FOR SAMPLE $E_{20}T$

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	96	136	375	12.59	19.57	10	300	500	20.0
2	96	136	375	12.69	19.57	10	300	500	20.0
3	96	136	370	12.48	19.57	10	300	500	20.0
4	96	136	375	12.68	19.57	10	300	500	20.0
5	96	134	370	11.52	19.57	10	300	500	20.0
6	96	134	368	11.11	19.57	10	300	500	20.0
7	96	135	375	11.63	19.57	10	300	500	20.0
8	96	135	375	12.44	19.57	10	300	500	20.0
9	96	135	370	12.43	19.57	10	300	500	20.0
10	96	134	370	12.77	19.57	10	300	500	20.0

TABLE A-11: TENSILE TESTS RESULTS FOR SAMPLE $F_{12}T$

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	40	62	360	7.79	11.40	11	300	500	12.0
2	40	62	362	8.45	11.40	11	300	500	12.0
3	40	62	360	8.20	11.40	11	300	500	12.0
4	40	62	360	8.67	11.40	11	300	500	12.0
5	40	60	360	8.21	11.40	11	300	500	12.0
6	40	79	345	9.12	11.40	11	300	500	12.0
7	40	60	345	7.93	11.40	11	300	500	12.0
8	40	60	360	8.10	11.40	11	300	500	12.0
9	40	60	360	8.22	11.40	11	300	500	12.0
10	79	79	350	9.24	11.40	11	300	500	12.0

TABLE A-12: TENSILE TESTS RESULTS FOR SAMPLE $G_{12}T$

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	44	73	345	8.81	11.48	12	300	500	12.0
2	43	73	345	8.51	11.48	12	300	500	12.0
3	43	74	340	8.29	11.48	12	300	500	12.0
4	42	74	345	8.66	11.48	12	300	500	12.0
5	44	75	345	8.28	11.48	12	300	500	12.0
6	43	74	340	8.94	11.48	12	300	500	12.0
7	44	74	345	8.17	11.48	12	300	500	12.0
8	44	75	350	8.69	11.48	12	300	500	12.0
9	44	74	350	8.86	11.48	12	300	500	12.0
10	43	74	340	8.56	11.48	12	300	500	12.0

TABLE A-13: TENSILE TESTS RESULTS FOR SAMPLE $H_{16}T$

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	95	115	335	12.10	15.52	13	300	500	16.0
2	95	115	335	12.12	15.52	13	300	500	16.0
3	94	113	345	12.32	15.52	13	300	500	16.0
4	94	112	345	11.82	15.52	13	300	500	16.0
5	95	114	350	11.71	15.52	13	300	500	16.0
6	95	113	345	12.24	15.52	13	300	500	16.0
7	95	114	340	11.42	15.52	13	300	500	16.0
8	93	113	350	11.18	15.52	13	300	500	16.0
9	94	113	348	11.18	15.52	13	300	500	16.0
10	94	112	345	10.77	15.52	13	300	500	16.0

TABLE A-14: TENSILE TESTS RESULTS FOR SAMPLE $I_{12}T$

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	37	62	340	7.91	11.30	14	300	500	12.0
2	37	62	340	7.68	11.30	14	300	500	12.0
3	37	61	345	8.16	11.30	14	300	500	12.0
4	37	61	345	8.15	11.30	14	300	500	12.0
5	37	61	345	8.70	11.30	14	300	500	12.0
6	37	61	340	8.02	11.30	14	300	500	12.0
7	37	61	350	7.88	11.30	14	300	500	12.0
8	37	62	340	7.88	11.30	14	300	500	12.0
9	37	61	345	8.18	11.30	14	300	500	12.0
10	37	62	345	7.36	11.30	14	300	500	12.0

TABLE A-15: TENSILE TESTS RESULTS FOR SAMPLE J_8T

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	19	23	310	4.70	6.50	15	300	500	7.0
2	19	23	310	5.50	6.50	15	300	500	7.0
3	19	23	310	5.31	6.50	15	300	500	7.0
4	19	23	310	4.56	6.50	15	300	500	7.0
5	19	23	305	4.96	6.50	15	300	500	7.0
6	19	23	310	5.28	6.50	15	300	500	7.0
7	19	23	305	4.88	6.50	15	300	500	7.0
8	19	23	305	5.17	6.50	15	300	500	7.0
9	19	23	305	5.67	6.50	15	300	500	7.0
10	19	23	310	4.46	6.50	15	300	500	7.0

TABLE A-16: TENSILE TESTS RESULTS FOR SAMPLE $K_{10}T$

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	40	46	335	7.76	9.36	16	300	500	10.0
2	37	42	320	6.25	9.36	16	300	500	10.0
3	40	46	335	6.99	9.36	16	300	500	10.0
4	40	47	330	6.84	9.36	16	300	500	10.0
5	40	46	335	6.76	9.36	16	300	500	10.0
6	40	46	332	6.92	9.36	16	300	500	10.0
7	40	46	330	6.92	9.36	16	300	500	10.0
8	40	46	330	6.46	9.36	16	300	500	10.0
9	40	46	330	6.56	9.36	16	300	500	10.0
10	38	44	330	6.39	9.36	16	300	500	10.0

TABLE A-17: TENSILE TESTS RESULTS FOR SAMPLE $L_{12}T$

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	40	62	340	9.88	11.82	17	300	500	12.0
2	37	66	350	7.56	11.82	17	300	500	12.0
3	40	66	350	9.85	11.82	17	300	500	12.0
4	40	66	345	7.59	11.82	17	300	500	12.0
5	40	65	335	9.52	11.82	17	300	500	12.0
6	40	65	350	7.62	11.82	17	300	500	12.0
7	40	66	345	8.51	11.82	17	300	500	12.0
8	40	66	345	7.37	11.82	17	300	500	12.0
9	40	66	343	7.70	11.82	17	300	500	12.0
10	38	66	347	8.52	11.82	17	300	500	12.0

TABLE A-18: TENSILE TESTS RESULTS FOR SAMPLE $M_{10}T$

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	40	62	330	7.20	9.23	18	300	500	10.0
2	37	66	335	6.70	9.23	18	300	500	10.0
3	40	66	335	6.78	9.23	18	300	500	10.0
4	40	66	335	7.18	9.23	18	300	500	10.0
5	40	65	330	6.88	9.23	18	300	500	10.0
6	40	65	335	7.22	9.23	18	300	500	10.0
7	40	66	334	7.32	9.23	18	300	500	10.0
8	40	66	335	6.98	9.23	18	300	500	10.0
9	40	66	336	6.88	9.23	18	300	500	10.0
10	38	66	338	7.12	9.23	18	300	500	10.0

TABLE A-19: TENSILE TESTS RESULTS FOR SAMPLE $N_{16}T$

S/No.	Yield Load (kn)	Ultimate Load (kn)	Increase in Length (mm)	Decrease in Diameter (mm)	Measured Diameter (mm)	Sample No.	Gauge Length (mm)	Actual Length (mm)	Size (mm)
1	105	124	345	11.49	15.60	19	300	500	16.0
2	105	122	340	11.15	15.60	19	300	500	16.0
3	105	124	342	11.57	15.60	19	300	500	16.0
4	105	123	340	11.36	15.60	19	300	500	16.0
5	105	123	340	11.15	15.60	19	300	500	16.0
6	105	123	345	10.99	15.60	19	300	500	16.0
7	105	123	340	10.98	15.60	19	300	500	16.0
8	106	124	340	11.66	15.60	19	300	500	16.0
9	107	124	340	11.72	15.60	19	300	500	16.0
10	106	123	345	12.36	15.60	19	300	500	16.0

APPENDIX B

RAW DATA FROM BEND TESTS

TABLE B-01: BEND TEST RESULTS FOR SAMPLE $A_{12}B$

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	A_{12} B_1	12	39	1	No Cracks Observed
2	$A_{12}B_2$	12	39	2	No Cracks Observed
3	$A_{12}B_3$	12	39	3	No Cracks Observed
4	$A_{12}B_4$	12	39	4	No Cracks Observed
5	$A_{12}B_5$	12	39	5	No Cracks Observed
6	$A_{12}B_6$	12	39	6	No Cracks Observed
7	$A_{12}B_7$	12	39	7	No Cracks Observed
8	$A_{12}B_8$	12	39	8	No Cracks Observed
9	$A_{12}B_9$	12	39	9	No Cracks Observed
10	$A_{12}B_{10}$	12	39	10	No Cracks Observed

TABLE B-02 :BEND TEST RESULTS FOR SAMPLE $A_{10}B$

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	$A_{10}B_1$	10	39	1	No Cracks Observed
2	$A_{10}B_2$	10	39	2	No Cracks Observed
3	$A_{10}B_3$	10	39	3	No Cracks Observed
4	$A_{10}B_4$	10	39	4	No Cracks Observed
5	$A_{10}B_5$	10	39	5	No Cracks Observed
6	$A_{10}B_6$	10	39	6	No Cracks Observed
7	$A_{10}B_7$	10	39	7	No Cracks Observed
8	$A_{10}B_8$	10	39	8	No Cracks Observed
9	$A_{10}B_9$	10	39	9	No Cracks Observed
10	$A_{10}B_{10}$	10	39	10	No Cracks Observed

TABLE B-03 :BEND TEST RESULTS FOR SAMPLE $B_{10}B$

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	$B_{10}B_1$	10	39	1	No Cracks Observed
2	$B_{10}B_2$	10	39	2	No Cracks Observed
3	$B_{10}B_3$	10	39	3	No Cracks Observed
4	$B_{10}B_4$	10	39	4	No Cracks Observed
5	$B_{10}B_5$	10	39	5	No Cracks Observed
6	$B_{10}B_6$	10	39	6	No Cracks Observed
7	$B_{10}B_7$	10	39	7	No Cracks Observed
8	$B_{10}B_8$	10	39	8	No Cracks Observed
9	$B_{10}B_9$	10	39	9	No Cracks Observed
10	$B_{10}B_{10}$	10	39	10	No Cracks Observed

TABLE B-04 :BEND TEST RESULTS FOR SAMPLE $B_{10}B$

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	B_8B_1	8	27	1	No Cracks Observed
2	B_8B_2	8	27	2	No Cracks Observed
3	B_8B_3	8	27	3	No Cracks Observed
4	B_8B_4	8	27	4	No Cracks Observed
5	B_8B_5	8	27	5	No Cracks Observed
6	B_8B_6	8	27	6	No Cracks Observed
7	B_8B_7	8	27	7	No Cracks Observed
8	B_8B_8	8	27	8	No Cracks Observed
9	B_8B_9	8	27	9	No Cracks Observed
10	B_8B_{10}	8	27	10	No Cracks Observed

TABLE B-05: BEND TEST RESULTS FOR SAMPLE $C_{16}B$

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	$C_{16}B_1$	16	51	1	Total Breakage
2	$C_{16}B_2$	16	51	2	Total Breakage
3	$C_{16}B_3$	16	51	3	Total Breakage
4	$C_{16}B_4$	16	51	4	Total Breakage
5	$C_{16}B_5$	16	51	5	Total Breakage
6	$C_{16}B_6$	16	51	6	Total Breakage
7	$C_{16}B_7$	16	51	7	Total Breakage
8	$C_{16}B_8$	16	51	8	Total Breakage
9	$C_{16}B_9$	16	51	9	Total Breakage
10	$C_{16}B_{10}$	16	51	10	Total Breakage

TABLE B-06 :BEND TEST RESULTS FOR SAMPLE $C_{10}B$

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	$C_{10}B_1$	10	39	1	No Cracks Observed
2	$C_{10}B_2$	10	39	2	No Cracks Observed
3	$C_{10}B_3$	10	39	3	No Cracks Observed
4	$C_{10}B_4$	10	39	4	No Cracks Observed
5	$C_{10}B_5$	10	39	5	No Cracks Observed
6	$C_{10}B_6$	10	39	6	No Cracks Observed
7	$C_{10}B_7$	10	39	7	No Cracks Observed
8	$C_{10}B_8$	10	39	8	No Cracks Observed
9	$C_{10}B_9$	10	39	9	No Cracks Observed
10	$C_{10}B_{10}$	10	39	10	No Cracks Observed

TABLE B-07: BEND TEST RESULTS FOR SAMPLE C_8B

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	C_8B_1	8	27	1	No Cracks Observed
2	C_8B_2	8	27	2	No Cracks Observed
3	C_8B_3	8	27	3	No Cracks Observed
4	C_8B_4	8	27	4	No Cracks Observed
5	C_8B_5	8	27	5	No Cracks Observed
6	C_8B_6	8	27	6	No Cracks Observed
7	C_8B_7	8	27	7	No Cracks Observed
8	C_8B_8	8	27	8	No Cracks Observed
9	C_8B_9	8	27	9	No Cracks Observed
10	C_8B_{10}	8	27	10	No Cracks Observed

TABLE B-08: BEND TEST RESULTS FOR SAMPLE D_8B

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	D_8B_1	8	27	1	No Cracks Observed
2	D_8B_2	8	27	2	No Cracks Observed
3	D_8B_3	8	27	3	No Cracks Observed
4	D_8B_4	8	27	4	No Cracks Observed
5	D_8B_5	8	27	5	No Cracks Observed
6	D_8B_6	8	27	6	No Cracks Observed
7	D_8B_7	8	27	7	No Cracks Observed
8	D_8B_8	8	27	8	No Cracks Observed
9	D_8B_9	8	27	9	No Cracks Observed
10	D_8B_{10}	8	27	10	No Cracks Observed

TABLE B-09: BEND TEST RESULTS FOR SAMPLE $E_{25}B$

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	$E_{25}B_1$	25	78	1	No Cracks Observed
2	$E_{25}B_2$	25	78	2	No Cracks Observed
3	$E_{25}B_3$	25	78	3	No Cracks Observed
4	$E_{25}B_4$	25	78	4	No Cracks Observed
5	$E_{25}B_5$	25	78	5	No Cracks Observed
6	$E_{25}B_6$	25	78	6	No Cracks Observed
7	$E_{25}B_7$	25	78	7	No Cracks Observed
8	$E_{25}B_8$	25	78	8	No Cracks Observed
9	$E_{25}B_9$	25	78	9	No Cracks Observed
10	$E_{25}B_{10}$	25	78	10	No Cracks Observed

TABLE B-10: BEND TEST RESULTS FOR SAMPLE $E_{20}B$

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	$E_{20}B_1$	20	63	1	No Cracks Observed
2	$E_{20}B_2$	20	63	2	No Cracks Observed
3	$E_{20}B_3$	20	63	3	No Cracks Observed
4	$E_{20}B_4$	20	63	4	No Cracks Observed
5	$E_{20}B_5$	20	63	5	No Cracks Observed
6	$E_{20}B_6$	20	63	6	No Cracks Observed
7	$E_{20}B_7$	20	63	7	No Cracks Observed
8	$E_{20}B_8$	20	63	8	No Cracks Observed
9	$E_{20}B_9$	20	63	9	No Cracks Observed
10	$E_{20}B_{10}$	20	63	10	No Cracks Observed

TABLE B-11: BEND TEST RESULTS FOR SAMPLE $F_{12}B$

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	$F_{12}B_1$	12	39	1	No Cracks Observed
2	$F_{12}B_2$	12	39	2	No Cracks Observed
3	$F_{12}B_3$	12	39	3	No Cracks Observed
4	$F_{12}B_4$	12	39	4	No Cracks Observed
5	$F_{12}B_5$	12	39	5	No Cracks Observed
6	$F_{12}B_6$	12	39	6	No Cracks Observed
7	$F_{12}B_7$	12	39	7	No Cracks Observed
8	$F_{12}B_8$	12	39	8	No Cracks Observed
9	$F_{12}B_9$	12	39	9	No Cracks Observed
10	$F_{12}B_{10}$	12	39	10	No Cracks Observed

TABLE B-12: BEND TEST RESULTS FOR SAMPLE $G_{12}B$

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	$G_{12}B_1$	8	27	1	No Cracks Observed
2	$G_{12}B_2$	8	27	2	No Cracks Observed
3	$G_{12}B_3$	8	27	3	No Cracks Observed
4	$G_{12}B_4$	8	27	4	No Cracks Observed
5	$G_{12}B_5$	8	27	5	No Cracks Observed
6	$G_{12}B_6$	8	27	6	No Cracks Observed
7	$G_{12}B_7$	8	27	7	No Cracks Observed
8	$G_{12}B_8$	8	27	8	No Cracks Observed
9	$G_{12}B_9$	8	27	9	No Cracks Observed
10	$G_{12}B_{10}$	8	27	10	No Cracks Observed

TABLE B-13: BEND TEST RESULTS FOR SAMPLE $H_{16}B$

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	$H_{16}B_1$	16	51	1	No Cracks Observed
2	$H_{16}B_1$	16	51	2	No Cracks Observed
3	$H_{16}B_1$	16	51	3	No Cracks Observed
4	$H_{16}B_1$	16	51	4	No Cracks Observed
5	$H_{16}B_1$	16	51	5	No Cracks Observed
6	$H_{16}B_1$	16	51	6	No Cracks Observed
7	$H_{16}B_1$	16	51	7	No Cracks Observed
8	$H_{16}B_1$	16	51	8	No Cracks Observed
9	$H_{16}B_1$	16	51	9	No Cracks Observed
10	$H_{16}B_1$	16	51	10	No Cracks Observed

TABLE B-14: BEND TEST RESULTS FOR SAMPLE $I_{12}B$

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	$I_{12}B_1$	12	39	1	Total Breakage
2	$I_{12}B_2$	12	39	2	Total Breakage
3	$I_{12}B_3$	12	39	3	Total Breakage
4	$I_{12}B_4$	12	39	4	Total Breakage
5	$I_{12}B_5$	12	39	5	Total Breakage
6	$I_{12}B_6$	12	39	6	Total Breakage
7	$I_{12}B_7$	12	39	7	Total Breakage
8	$I_{12}B_8$	12	39	8	Total Breakage
9	$I_{12}B_9$	12	39	9	Total Breakage
10	$I_{12}B_{10}$	12	39	10	Total Breakage

TABLE B-15: BEND TEST RESULTS FOR SAMPLE J_8B

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	J_8B_1	8	27	1	No Cracks Observed
2	J_8B_2	8	27	2	No Cracks Observed
3	J_8B_3	8	27	3	No Cracks Observed
4	J_8B_4	8	27	4	No Cracks Observed
5	J_8B_5	8	27	5	No Cracks Observed
6	J_8B_6	8	27	6	No Cracks Observed
7	J_8B_7	8	27	7	No Cracks Observed
8	J_2B_8	8	27	8	No Cracks Observed
9	J_8B_9	8	27	9	No Cracks Observed
10	J_8B_{10}	8	27	10	No Cracks Observed

TABLE B-15: BEND TEST RESULTS FOR SAMPLE $K_{10}B$

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	$K_{10}B_1$	10	39	1	No Cracks Observed
2	$K_{10}B_2$	10	39	2	No Cracks Observed
3	$K_{10}B_3$	10	39	3	No Cracks Observed
4	$K_{10}B_4$	10	39	4	No Cracks Observed
5	$K_{10}B_5$	10	39	5	No Cracks Observed
6	$K_{10}B_6$	10	39	6	No Cracks Observed
7	$K_{10}B_7$	10	39	7	No Cracks Observed
8	$K_{10}B_8$	10	39	8	No Cracks Observed
9	$K_{10}B_9$	10	39	9	No Cracks Observed
10	$K_{10}B_{10}$	10	39	10	No Cracks Observed

TABLE B-16: BEND TEST RESULTS FOR SAMPLE $L_{12}B$

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	$L_{12}B_1$	12	39	1	No Cracks Observed
2	$L_{12}B_2$	12	39	2	No Cracks Observed
3	$L_{12}B_3$	12	39	3	No Cracks Observed
4	$L_{12}B_4$	12	39	4	No Cracks Observed
5	$L_{12}B_5$	12	39	5	No Cracks Observed
6	$L_{12}B_6$	12	39	6	No Cracks Observed
7	$L_{12}B_7$	12	39	7	No Cracks Observed
8	$L_{12}B_8$	12	39	8	No Cracks Observed
9	$L_{12}B_9$	12	39	9	No Cracks Observed
10	$L_{12}B_{10}$	12	39	10	No Cracks Observed

TABLE B-17: BEND TEST RESULTS FOR SAMPLE $M_{10}B$

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	$M_{10}B_1$	10	39	1	No Cracks Observed
2	$M_{10}B_2$	10	39	2	No Cracks Observed
3	$M_{10}B_3$	10	39	3	No Cracks Observed
4	$M_{10}B_4$	10	39	4	No Cracks Observed
5	$M_{10}B_5$	10	39	5	No Cracks Observed
6	$M_{10}B_6$	10	39	6	No Cracks Observed
7	$M_{10}B_7$	10	39	7	No Cracks Observed
8	$M_{10}B_8$	10	39	8	No Cracks Observed
9	$M_{10}B_9$	10	39	9	No Cracks Observed
10	$M_{10}B_{10}$	10	39	10	No Cracks Observed

TABLE B-17: BEND TEST RESULTS FOR SAMPLE $N_{16}B$

S/No.	Identification No.	Diameter of Bar (mm)	Diameter of Former(mm)	Sample No.	Observations After Bending
1	$N_{16}B_1$	16	51	1	Total Breakage
2	$N_{16}B_2$	16	51	2	Total Breakage
3	$N_{16}B_3$	16	51	3	Total Breakage
4	$N_{16}B_4$	16	51	4	Total Breakage
5	$N_{16}B_5$	16	51	5	Total Breakage
6	$N_{16}B_6$	16	51	6	Total Breakage
7	$N_{16}B_7$	16	51	7	Total Breakage
8	$N_{16}B_8$	16	51	8	Total Breakage
9	$N_{16}B_9$	16	51	9	Total Breakage
10	$N_{16}B_{10}$	16	51	10	Total Breakage

APPENDIX “C”

RAW DATA FROM CHEMICAL TESTS

TABLE C-01: CHEMICAL CONCENTRATION FOR FOR SAMPLE ($A_{12}C$)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	3.9	1.55	7.1	3.0	6.05	40.7

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.98	2.36	0.14	1.05	5.3	0.24

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-02: CHEMICAL CONCENTRATION FOR FOR SAMPLE ($A_{10}C$)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	2.26	2.23	7.26	3.05	5.9	32.4

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.46	2.45	0.7	0.66	13.6	2.34

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-03: CHEMICAL CONCENTRATION FOR FOR SAMPLE ($B_{10}C$)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	3.06	2.03	2.74	4.26	5.96	22.0

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.27	2.83	0.4	0.13	3.0	2.5

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-04: CHEMICAL CONCENTRATION FOR FOR SAMPLE (B_8C)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	1.45	0.7	2.74	0.88	6.09	33.3

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.18	0.97	0.1	0.06	3.0	0.5

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-05: CHEMICAL CONCENTRATION FOR FOR SAMPLE ($C_{16}C$)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	1.51	1.99	7.89	2.39	6.03	20.7

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.64	2.55	2.8	1.05	7.3	0.02

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-06: CHEMICAL CONCENTRATION FOR FOR SAMPLE ($C_{10}C$)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	3.0	0.32	1.38	0.84	6.08	23.3

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.95	0.5	4.2	0.1	1.6	0.1

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-07: CHEMICAL CONCENTRATION FOR FOR SAMPLE (C_8C)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	1.35	0.48	1.54	0.71	6.0	25.0

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.3	0.61	4.0	0.09	13.0	0.45

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-08: CHEMICAL CONCENTRATION FOR FOR SAMPLE (D_8C)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	1.77	1.88	9.19	1.36	6.0	19.0

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.49	2.95	0.31	0.26	3.5	1.5

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-09: CHEMICAL CONCENTRATION FOR FOR SAMPLE ($E_{25}C$)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	11.1	2.44	8.85	2.82	5.91	23.5

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.24	2.57	0.08	0.52	8.0	2.01

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-10: CHEMICAL CONCENTRATION FOR FOR SAMPLE ($E_{20}C$)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	7.87	2.27	8.98	2.98	6.07	31.9

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.33	2.88	0.7	0.77	0.6	0.02

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-11: CHEMICAL CONCENTRATION FOR FOR SAMPLE ($F_{12}C$)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	7.1	0.9	2.09	1.23	5.85	31.8

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.22	0.09	0.8	0.37	11.8	0.2

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-12: CHEMICAL CONCENTRATION FOR FOR SAMPLE ($G_{12}C$)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	1.19	1.94	6.64	1.96	6.0	26.9

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.92	2.3	2.4	0.7	0.4	0.21

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-13: CHEMICAL CONCENTRATION FOR FOR SAMPLE ($H_{16}C$)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	3.55	2.25	9.14	2.98	6.08	29.9

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.22	3.83	3.1	0.37	39.0	0.06

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-14: CHEMICAL CONCENTRATION FOR FOR SAMPLE ($I_{12}C$)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	12.42	3.32	9.59	4.65	6.01	20.7

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.64	3.82	0.05	1.0	0.3	0.15

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-15: CHEMICAL CONCENTRATION FOR FOR SAMPLE (J_8C)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	1.1	2.11	10.9	2.24	6.04	15.8

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.42	2.8	0.95	0.52	3.4	0.04

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-16: CHEMICAL CONCENTRATION FOR FOR SAMPLE ($K_{10}C$)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	3.68	1.49	9.32	2.66	6.06	34.1

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.49	3.26	0.02	0.51	47.7	3.2

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-17: CHEMICAL CONCENTRATION FOR FOR SAMPLE ($L_{12}C$)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	4.77	2.24	9.98	1.55	5.94	26.3

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.67	3.05	0.3	0.4	4.8	0.03

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-18: CHEMICAL CONCENTRATION FOR FOR SAMPLE ($M_{10}C$)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	2.23	1.57	9.07	2.07	5.88	31.3

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.48	3.83	0.01	0.31	20.3	0.05

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-19: CHEMICAL CONCENTRATION FOR FOR SAMPLE ($N_{16}C$)

ELEMENT	Al Aluminum	Co Cobalt	Cu Copper	Cr Chromium	Mn Manganese	Fe Iron
CONC. (mg/l)	5.26	2.38		3.21	6.01	32.0

ELEMENT	Pb Lead	Ni Nickel	N_2 Nitrogen	Zn Zinc	PO_3 Phosphate	S Sulphides
CONC. (mg/l)	0.55		2.05	0.34	2.1	0.01

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-20: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE ($A_{12}P$)

ELEMENT	Si Silicon	Cl Chlorine	Ca Calcium	Ti Titanium	Cr Chromium	Mn Manganese	Fe Iron	Ni Nickel	Cu Copper
CONC. (%)	0.69	0.10	0.059	0.16	0.306	0.753	89.38	0.097	0.31

ELEMENT	Zn Zinc	Ga Gallium	Br Bromine	Rh Rhodium	Cd Cadmium	Ba Barium	Re Rhenium	Os Osmium	Pt Platinum
CONC. (%)	0.17	0.18	2.2	0.68	4.0	0.14	0.2	0.56	0.1

TOTAL NUMBER OF ELEMENTS PRESENT = 18

TABLE C-21: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE ($A_{10}P$)

ELEMENT	Al Aluminum	Si Silicon	Cl Chlorine	Ca Calcium	Cr Chromium	Mn Manganese	Fe Iron	Ni Nickel
CONC. (%)	2	0.72	0.068	0.02	0.243	0.896	89.26	0.048

ELEMENT	Cu Copper	Zn Zinc	Br Bromine	Rh Rhodium	Cd Cadmium	Te Tellurium	Re Rhenium	Os Osmium
CONC. (%)	0.27	0.04	2.6	0.42	3.0	0.12	0.1	0.39

TOTAL NUMBER OF ELEMENTS PRESENT = 16

TABLE C-22: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE ($B_{10}P$)

ELEMENT	Al Aluminum	Si Silicon	P Phosphorous	S Sulphur	Cl Chlorine	Ca Calcium	V Vanadium	Cr Chromium	Mn Manganese	Fe Iron
CONC. (%)	3	0.78	0.06	0.03	0.09	0.086	0.032	0.273	0.804	86.76

ELEMENT	Ni Nickel	Cu Copper	Zn Zinc	Ga Gallium	Br Bromine	Mo Molybdenum	Rh Rhodium	Cd Cadmium	Re Rhenium	Os Osmium
CONC. (%)	0.055	0.33	0.065	0.060	2.4	0.04	0.25	4.9	0.1	0.28

TOTAL NUMBER OF ELEMENTS PRESENT = 20

TABLE C-23: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE (B_8P)

ELEMENT	Si Silicon	P Phosphorous	Cl Chlorine	Ca Calcium	Cr Chromium	Mn Manganese
CONC. (%)	0.57	0.09	0.092	0.066	0.14	0.712

ELEMENT	Fe Iron	Cu Copper	Ga Gallium	Rh Rhodium	Cd Cadmium	Os Osmium
CONC. (%)	93.56	0.12	0.072	0.34	3.9	0.35

TOTAL NUMBER OF ELEMENTS PRESENT = 12

TABLE C-24: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE ($C_{16}P$)

ELEMENT	Si Silicon	P Phosphorous	Cl Chlorine	Ca Calcium	Cr Chromium	Mn Manganese	Fe Iron
CONC. (%)	0.70	0.08	0.067	0.28	0.11	0.651	94.79

ELEMENT	Ni Nickel	Cu Copper	Zn Zinc	Rh Rhodium	Cd Cadmium	Re Rhenium	Os Osmium
CONC. (%)	0.068	0.37	0.008	0.28	2.0	0.24	0.31

TOTAL NUMBER OF ELEMENTS PRESENT = 14

TABLE C-25: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE ($C_{20}P$)

ELEMENT	Si Silicon	Cl Chlorine	Ti Titanium	Cr Chromium	Mn Manganese	Fe Iron	Cu Copper	Zn Zinc
CONC. (%)	0.59	0.11	0.15	0.19	0.739	92.84	0.10	0.02

ELEMENT	Ga Gallium	Rh Rhodium	Cd Cadmium	Te Tellurium	Ba Barium	Re Rhenium	Os Osmium	Ir Iridium
CONC. (%)	0.081	0.57	3.1	0.05	0.13	0.3	0.42	0.55

TOTAL NUMBER OF ELEMENTS PRESENT = 16

TABLE C-26: CHEMICAL PERCENTAGE COMPOSITION FOR AMPLE (C_8P)

ELEMENT	Si Silicon	P Phosphorous	Cl Chlorine	Ca Calcium	Cr Chromium	Mn Manganese	Fe Iron	Cu Copper
CONC. (%)	0.41	0.10	0.073	0.01	0.14	0.832	94.11	0.10

ELEMENT	Zn Zinc	Ga Gallium	Rh Rhodium	Cd Cadmium	Te Tellurium	Re Rhenium	Os Osmium	Ir Iridium
CONC. (%)	0.02	0.03	0.48	2.5	0.14	0.2	0.37	0.47

TOTAL NUMBER OF ELEMENTS PRESENT = 16

TABLE C-27: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE (D_8P)

ELEMENT	Al Aluminum	Si Silicon	P Phosphorus	Cl Chlorine	Ca Calcium	Ti Titanium	Cr Chromium
CONC. (%)	3	1.7	0.04	0.13	0.481	0.13	0.237

ELEMENT	Mn Manganese	Fe Iron	Ni Nickel	Cu Copper	Zn Zinc	Ga Gallium	Br Bromine
CONC. (%)	0.841	84.04	0.068	0.31	0.13	0.060	2.3

ELEMENT	Zr Zirconium	Rh Rhodium	Cd Cadmium	Ba Barium	Re Rhenium	Os Osmium	Pt Platinum
CONC. (%)	0	0.24	5.8	0.24	0.07	0.31	0.05

TOTAL NUMBER OF ELEMENTS PRESENT = 21

TABLE C-28: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE ($E_{25}P$)

ELEMENT	Al Aluminum	Si Silicon	Cl Chlorine	Ca Calcium	Cr Chromium	Mn Manganese	Fe Iron
CONC. (%)	1.6	3.53	0.075	0.11	0.204	1.01	87.81

ELEMENT	Ni Nickel	Cu Copper	Zn Zinc	Rh Rhodium	Cd Cadmium	Re Rhenium	Os Osmium
CONC. (%)	0.063	0.33	0.083	0.35	4.3	0.2	0.35

TOTAL NUMBER OF PRESENT = 14

TABLE C-29: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE ($E_{20}P$)

ELEMENT	Al Aluminum	Si Silicon	S Sulphur	Cl Chlorine	Ca Calcium	Cr Chromium	Mn Manganese	Fe Iron
CONC. (%)	3	0.72	0.14	0.067	0.13	0.283	0.913	88.02

ELEMENT	Ni Nickel	Cu Copper	Zn Zinc	Ga Gallium	Br Bromine	Rh Rhodium	Cd Cadmium	Re Rhenium	Os Osmium
CONC. (%)	0.091	0.28	0.15	0.15	2.2	0.62	3.0	0.1	0.46

TOTAL NUMBER OF ELEMENTS PRESENT = 17

TABLE C-30: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE ($F_{12}P$)

ELEMENT	Al Aluminum	Si Silicon	Cl Chlorine	Ca Calcium	Cr Chromium	Mn Manganese	Fe Iron	Ni Nickel
CONC. (%)	3	1.0	0.076	0.074	0.215	0.763	87.43	0.060

ELEMENT	Cu Copper	Zn Zinc	Ga Gallium	Br Bromine	Rh Rhodium	Cd Cadmium	Re Rhenium	Os Osmium
CONC. (%)	0.32	0.04	0.091	2.4	0.42	3.5	0.1	0.35

TOTAL NUMBER OF ELEMENTS PRESENT = 16

TABLE C-31: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE ($G_{12}P$)

ELEMENT	Al Aluminum	Si Silicon	Cl Chlorine	Cr Chromium	Mn Manganese	Fe Iron	Ni Nickel
CONC. (%)	3	0.50	0.15	0.221	0.895	80.08	0.062

ELEMENT	Cu Copper	Zn Zinc	Br Bromine	Rh Rhodium	Cd Cadmium	Re Rhenium	Os Osmium
CONC. (%)	0.068	0.06	1.9	0.32	11.8	0.1	0.42

TOTAL NUMBER OF ELEMENTS PRESENT = 14

TABLE C-32: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE ($H_{12}P$)

ELEMENT	Al Aluminum	Si Silicon	Cl Chlorine	V Vanadium	Cr Chromium	Mn Manganese	Fe Iron
CONC. (%)	2	0.25	0.16	0.045	0.277	0.871	76.97

ELEMENT	Ni Nickel	Cu Copper	Zn Zinc	Br Bromine	Cd Cadmium	Os Osmium
CONC. (%)	0.091	0.18	0.054	1.8	17.4	0.37

TOTAL NUMBER OF ELEMENTS PRESENT = 13

TABLE C-33: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE ($I_{12}P$)

ELEMENT	Al Aluminum	Si Silicon	Cl Chlorine	Cr Chromium	Mn Manganese	Fe Iron	Ni Nickel
CONC. (%)	2	0.27	0.13	0.308	0.938	74.48	0.067

ELEMENT	Cu Copper	Zn Zinc	Br Bromine	Cd Cadmium	Os Osmium	Pb Lead
CONC. (%)	0.15	0.062	1.8	18.2	0.34	1.1

TOTAL NUMBER OF ELEMENTS PRESENT = 13

TABLE C-34: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE (J_8P)

ELEMENT	Al Aluminum	Si Silicon	P Phosphorous	Cl Chlorine	Ca Calcium	Cr Chromium	Mn Manganese	Fe Iron	Ni Nickel
CONC. (%)	1	0.91	0.06	0.05	0.11	0.14	0.561	89.66	0.050

ELEMENT	Cu Copper	Zn Zinc	Ga Gallium	Br Bromine	Zr Zirconium	Rh Rhodium	Cd Cadmium	Re Rhenium	Os Osmium	Pt Platinum
CONC. (%)	0.41	0.04	0.048	2.7	0.2	0.20	3.4	0.1	0.25	0.04

TOTAL NUMBER OF ELEMENTS PRESENT = 19

TABLE C-35: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE ($K_{10}P$)

ELEMENT	Al Aluminum	Si Silicon	P Phosphorous	Cl Chlorine	Ca Calcium	Cr Chromium	Mn Manganese	Fe Iron	Ni Nickel
CONC. (%)	2	0.84	0.08	0.093	0.063	0.213	0.887	87.91	0.071

ELEMENT	Cu Copper	Zn Zinc	Ga Gallium	Br Bromine	Zr Zirconium	Rh Rhodium	Cd Cadmium	Re Rhenium	Os Osmium
CONC. (%)	0.32	0.060	0.065	2.5	0	0.39	3.8	0.1	0.27

TOTAL NUMBER OF ELEMENTS PRESENT = 18

TABLE C-36: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE ($L_{12}P$)

ELEMENT	Al Aluminum	Si Silicon	Cl Chlorine	Ca Calcium	V Vanadium	Cr Chromium	Mn Manganese	Fe Iron
CONC. (%)	2	1.1	0.069	0.088	0.022	0.16	0.883	87.59

ELEMENT	Ni Nickel	Cu Copper	Zn Zinc	Br Bromine	Rh Rhodium	Cd Cadmium	Re Rhenium	Os Osmium
CONC. (%)	0.056	0.34	0.061	2.6	0.32	3.8	0.1	0.32

TOTAL NUMBER OF ELEMENTS PRESENT = 16

TABLE C-37: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE ($M_{10}P$)

ELEMENT	Al Aluminum	Si Silicon	S Sulphur	Cl Chlorine	Ca Calcium	Ti Titanium	Cr Chromium	Mn Manganese	Fe Iron
CONC. (%)	3	1.0	0.31	0.066	0.880	0.18	0.237	0.907	86.72

ELEMENT	Ni Nickel	Cu Copper	Zn Zinc	Br Bromine	Mo Molybdenum	Rh Rhodium	Cd Cadmium	Ba Barium	Re Rhenium	Os Osmium
CONC. (%)	0.11	0.36	0.15	1.9	0.3	0.63	2.2	0.15	0.2	0.62

TOTAL NUMBER OF ELEMENTS PRESENT = 19

TABLE C-37: CHEMICAL PERCENTAGE COMPOSITION FOR SAMPLE ($N_{16}P$)

ELEMENT	Al Aluminum	Si Silicon	Cl Chlorine	Ca Calcium	Cr Chromium	Mn Manganese	Fe Iron
CONC. (%)	0.5	1.1	0.077	0.058	0.261	0.713	92.02

ELEMENT	Ni Nickel	Cu Copper	Zn Zinc	Rh Rhodium	Cd Cadmium	Re Rhenium	Os Osmium
CONC. (%)	0.18	0.44	0.14	0.60	3.0	0.3	0.61

TOTAL NUMBER OF ELEMENTS PRESENT = 14