KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY
COLLEGE OF ENGINEERING
DEPARTMENT OF MATERIALS ENGINEERING
BSC. METALLURGICAL ENGINEERING

COMPUTERIZATION OF CHARGE CALCULATION FOR FERROUS METALS

A PROJECT REPORT SUBMITTED TO THE MATERIAL ENGINEERING DEPARTMENT IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE BACHELOR DEGREE IN METALLURGICAL ENGINEERING

COMPILED BY:

ARTHUR KOBENA ARKO
APPOH LAWRENCE AMOAFO

SUPERVISORS:
DR. EMMANUEL KWESI ARTHUR
DR. EMMANUEL GIKUNOO
DR. GRIFFITH SELORM KLOGO

MAY, 2018
KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY
KUMASI, GHANA

COLLEGE OF ENGINEERING

DEPARTMENT OF MATERIALS ENGINEERING

BSC. METALLURGICAL ENGINEERING

COMPUTERIZATION OF CHARGE CALCULATION FOR FERROUS METALS

COMPILED BY:

APPOH LAWRENCE AMOAFIO

ARTHUR KOBENA ARKO
DECLARATION

We hereby declare that, we the student mentioned below under supervision personally undertook this project and research work. It is being submitted as a final year project in partial fulfillment of the requirement in awarding BSc Degree in Metallurgical Engineering in Kwame Nkrumah University of Science and Technology.

ARTHUR KOBENA ARKO .......................... ......................
2202414  Signature                        Date

APPOH LAWRENCE AMOAFO ......................... ......................
2202214  Signature                        Date

CERTIFIED BY

DR. EMMANUEL KWESI ARTHUR ......................... ......................
(Supervisor)  Signature                        Date

DR. EMMANUEL GIKUNOO  ......................... ......................
(Supervisor)  Signature                        Date

DR. GRIFFITH SELORM KLOGO  ......................... ......................
(Supervisor)  Signature                        Date
ACKNOWLEDGEMENT

We are most grateful to the Almighty God for His grace, strength and guidance throughout this entire project and research work. Our sincerest appreciation goes to our humble supervisor Dr. Emmanuel Kwesi Arthur for his support, suggestions and guidance which gave us great insight into this study.

Many thanks to Dr. Emmanuel Gikunoo and the entire academic and technical staff of the Material/Metallurgical Engineering Department for their support and during the course of our research.

Many thanks also goes to Mr. Solomon and his team from Tema Steel Company for accepting us which helped in completion of our research work.

Lastly we want to say a big thank you to Dr. Griffith Selorm Klogo for his passionate and willingness to assist us through our research work.
ABSTRACT

The use of a programming language in computerizing melting charge calculation has been accomplished through the development of an interface and MATLAB R2013A codes to run it. Tema Steels Company Tema, Ghana, was used as the reference steel recycling company. First of all, random sampling of scraps were obtained by hand from the four buckets to be charged into the furnace. Elemental composition analysis was done on the sampled scraps using Mass Spectrometer (V-950 spectrometer, Angstrom, USA). The total electric furnace weight was calculated to be 23.4 tons from the weight of each of the four buckets. The total weight of the electric furnace, the individual weight of the buckets and the results of the elemental analysis on the sampled scraps were needed to compute for the melting charge. The calculation was done analytically and using the MATLAB R2013A interface developed, the results of both were compared against the elemental test results from the first bath. Refinement of the bath was done as 70wt% ferrosilicon, alloy of Silicon and Manganese, and 70wt% ferrochromium were added to increase the composition of Silicon (Si), Manganese (Mn) and Chromium (Cr) respectively. The criterion for the acceptable final product (billet) according to ASTM A615/A615M, the main elemental composition should be in the range, 0.08-0.2wt%C, 0.7-1.0wt%Mn, 0.2-0.27wt%Si, 0.2-0.35wt%Cr, 0.1-0.2wt%Ni, 0.03-0.05wt%P.
Table of Contents

DECLARATION ................................................................................................................... 2

ACKNOWLEDGEMENT .................................................................................................... 3

ABSTRACT .......................................................................................................................... 4

Table of equations ............................................................................................................. 8

Table of Figures .................................................................................................................. 9

Table of Tables ................................................................................................................... 10

CHAPTER ONE .................................................................................................................. 11

1.0 INTRODUCTION ....................................................................................................... 11

1.1 BACKGROUND .......................................................................................................... 11

1.2 PROBLEM STATEMENT ........................................................................................... 12

1.3 AIM AND OBJECTIVES ............................................................................................ 12

1.4 SPECIFIC OBJECTIVES ............................................................................................ 12

1.5 JUSTIFICATION ......................................................................................................... 13

1.6 SCOPE OF WORK ...................................................................................................... 13

CHAPTER TWO ................................................................................................................ 14

2.0 LITERATURE REVIEW ............................................................................................. 14

2.1 INTRODUCTION ....................................................................................................... 14

2.2 METALS .................................................................................................................... 15

2.2.1 GENERAL PROPERTIES OF METALS ............................................................... 15

2.2.2 CATEGORIES OF METALS .................................................................................. 16

5
INTRODUCTION TO FERROUS METALS ........................................................................ 17

2.3.1 PROPERTIES OF FERROUS METALS .............................................................. 18

2.3.2 TYPES OF FERROUS METALS ..................................................................... 18

2.4 PRODUCTION OF FERROUS METALS ................................................................. 25

2.4.1 IRON ORES AND OTHER RAW MATERIALS ............................................... 25

2.4.2 IRON MAKING ............................................................................................... 26

2.4.3 STEEL MAKING ............................................................................................ 28

2.4.4 PROPERTIES OF PIG IRON ............................................................................ 31

2.5 RECYCLING OF FERROUS METALS ................................................................. 32

2.5.1 PROCESSES INVOLVED IN RECYCLING OF FERROUS METALS .......... 32

2.5.2 CHARGE CALCULATION .............................................................................. 34

2.5.3 COST OF RECYCLING ................................................................................... 35

2.6 OVERVIEW OF MATLAB R2013A SOFTWARE .............................................. 35

2.7 APPLICATIONS OF MATLAB R2013A .......................................................... 36

CHAPTER THREE ....................................................................................................... 37

3.0 METHODOLOGY .................................................................................................. 37

3.1 SAMPLING OF SCRAPS .................................................................................... 37

3.2 MELTING CHARGE EQUATIONS ....................................................................... 37

3.3 MATLAB R2013A CODES AND INTERFACE .................................................. 39

3.4 ELEMENTAL ANALYSIS ..................................................................................... 41
3.4.1 SAMPLE PREPARATION ................................................................. 41

3.4.2 TESTING OF SAMPLED SCRAPS .................................................. 42

3.5 MELTING CHARGE CALCULATION .................................................. 43

3.6 MELTING AND TRANSFORMATION OF SCRAPS ............................. 44

3.7 VALIDATIONS OF COMPOSITION USING MATLAB R2013A .......... 46

CHAPTER FOUR ................................................................................. 49

4.0 RESULTS AND DISCUSSION .......................................................... 49

4.1 SAMPLE TYPE DETERMINATION .................................................. 49

4.2 ELEMENTAL ANALYSIS ON FIRST BATH ..................................... 54

4.3 FINAL ANALYTICAL RESULTS ...................................................... 57

CHAPTER FIVE .................................................................................. 60

5.0 CONCLUSION AND RECOMMENDATION ..................................... 60

5.1 CONCLUSION ................................................................................. 60

5.2 RECOMMENDATIONS .................................................................... 61

REFERENCES .................................................................................... 62

APPENDICES ..................................................................................... 64

Appendix A ......................................................................................... 64

APPENDIX B ......................................................................................... 65

APPENDIX C ......................................................................................... 67
Table of equations

**Fe₂O₃ + CO → 2FeO + CO₂**  Equation 1 .......................................................... 26

**CO₂ + C(oke) → 2CO**  Equation 2 ................................................................. 26

**FeO + CO → Fe + CO₂**  Equation 3 ............................................................. 26

**CaCO₃ → CaO + CO₂**  Equation 4 ................................................................. 28

**3C + 2O₂ → 2CO + CO₂**  Equation 5 ............................................................ 30

**Si + O₂ → SiO₂**  Equation 6 ................................................................. 30

**2Mn + O₂ → 2MnO**  Equation 7 ................................................................. 30

**4P + 5O₂ → 2P₂O₅**  Equation 8 ................................................................. 30
Table of Figures

Figure 2.1 Cross section of iron making blast furnace showing major components
(Mikell P. Groover, 4th edition). ..............................................................27

Figure 2.2 Schematic diagram indicating details of the blast furnace operation (Mikell

Figure 2.3 Basic oxygen furnace showing BOF vessel during processing (Mikell P.
Groover, 4th edition) ........................................................................29

Figure 2.4 BOF sequence during processing cycle: (1) charging of scrap and (2) pig
iron; (3) blowing (Figure 2.0-3); (4) tapping the molten steel; and (5) pouring off the
slag. (Mikell P. Groover, 4th edition) ..................................................30

Figure 3.1: (a) magnetic separation, (b) sampling of scraps, (c) melting furnace .................38

Figure 3.2 MATLAB R2013A interface ..................................................................40

Figure 3.3 Editor Window showing MATLAB R2013A codes .................................41

Figure 3.4 Labelled sampled scraps ......................................................................42

Figure 3.5: (a) final product; billet, (b) continuous casting of metal .........................46

Figure 3.6 A graph of theoretical results and MATLAB ........................................47

Figure 3.7 Results of MATLAB computation for the first bath ...............................48

Figure 4.1 Results of MATLAB computation for the first bath ..................................56

Figure 4.2 A graph showing Theoretical, MATLAB and Experimental results ..........56

Figure 4.3 A graph showing MATLAB and Experimental results ..........................57

Figure 4.4 results of MATLAB computation of composition of final product ..........66
Table of Tables

Table 2.1 Basic data on the metallic elements: Iron ................................................................. 18
Table 2.2 types of ferrous metals, their compositions and properties ......................... 188
Table 2.3 Compositions and mechanical properties of selected cast irons .................. 199
Table 3.1 Theoretical charge calculation ................................................................................. 43
Table 3.2 Composition of element in electric furnace ......................................................... 43
Table 3.3 Elemental weight in samples .................................................................................... 44
Table 3.4 Results of melting charge calculation ................................................................. 45
Table 4.1 Elemental analysis of samples from bucket one using Mass Spectrometer .. 50
Table 4.2 Elemental analysis of samples from bucket two ............................................... 51
Table 4.3 Elemental analysis of samples from bucket three ............................................. 52
Table 4.4 Elemental analysis of samples from bucket four ............................................ 53
Table 4.5 Elemental results of the first bath sampled ..................................................... 54
Table 4.6 Results of the theoretical charge calculation .................................................... 54
Table 4.7 Elemental analysis of the final product .............................................................. 57
CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

The world as it stand is integrated with engineering structures which makes movement and living comes at ease. These structures include cars, houses, bridges, skyscrapers, processing companies and many more, and among all these, metals such as cast iron, steels, etc. are used to primarily hold these structures together.

Metals primarily contains specified chemical element that gives its properties such as strength, hardness, conductivity, resistivity etc. Ferrous metals as one of the main classes of metals has a significant use in engineering structures because of its high content in Iron, carbon and other element.

Ferrous metals are produced in two ways; either by extraction and/or recycling. The quality of production of ferrous metals for a specific application depends on known composition and amount of each element to be used. This is mostly done by a mathematical application known as charge calculation. Charge calculation is basically done to ensure that the final product contains the right amount and composition of each element used.

Failures may exist if a specified ferrous metal used for a particular structure does not contain the right amount and composition thus affecting its properties. Like the Dee Bridge, the Tay collapsed when a train passed over it, killing 75 people, the bridge failed because it was constructed from poorly made cast iron (Tay Bridge disaster, 1879). A possible flaw was detected in a large steel sheets called gusset plates which were used during the construction of the truss arch bridge in Mississippi (1-35 Mississippi Bridge, 2007).
1.2 PROBLEM STATEMENT

Most of the structural failures are associated with materials and are the consequence of human blunder, involving a lack of know-how about materials or the combination of contrary materials. Too much reliance is given on modern structural materials yet the manufacturing or production faults may exist even in dependable materials, such as standard structural steels. Recycling companies such as “Suame” lacks quality production of ferrous metals due to insufficient knowledge about the amount and composition of final product. In association, production in most ferrous metals recycling is based on time to produce hundreds of products in a day for consumers. Calculating the amount and composition of each component manually during production can be time consuming and might lead to low production income. Nevertheless ignoring this procedure may go a long way to affect certain properties leading to a shorter life span of the product.

1.3 AIM AND OBJECTIVES

The aim of this project is to computerize charge calculation for ferrous metals.

1.4 SPECIFIC OBJECTIVES

The specific objectives are:

- To sample ferrous metal scraps from different location
- To develop mathematical equation for determine specific composition
- To develop mathematical codes and interface for calculating the amount and composition of scraps
- To validate the MATLAB R2013A codes with experimental results
1.5 JUSTIFICATION

MATLAB R2013A application which is a programming language allowing creation of user interface and interfacing with other language, including C, C++, Java etc. has proven to be an easier way of solving mathematical and engineering problems. MATLAB R2013A lets you check an answer is correct, and then viable to put into practice. Ferrous metals are used to hold engineering structures in place, this gives the need to produce quality part with their standard composition. A stainless steel contains chromium (12-30%), molybdenum (0.2-1%), nickel (8-22%) and carbon (about 0.1-1%). This is to say if the composition of any of the element falls out of place it ceases to be the required product. Different types of ferrous metals contains their unique elements and their right composition, this gives them their specified application.

1.6 SCOPE OF WORK

The development of the user interface using MATLAB R2013A application is to be used for charge calculations for ferrous metals. This include a literature review on ferrous metals, charge calculations and MATLAB R2013A, the methodology in which the work will be carried out.
CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

Modern-day business organizations strive to achieve certain goals for the benefit of their owners and clients, these goals are usually expressed in terms of objectives such as: increase in turnover, cost reduction, profit maximization and improvements in services. Such objectives will need to be met within the confines of the available resources.

In order to meet these objectives, an organization should be able to:

a) Plan ahead
b) Control cost
c) Coordinate its activities

Today, large business organizations have discovered that the best means to deliver high quality service is by embracing computerization.

In this modern age, computerization has proven to be a prolific and efficient way to conduct business. Programming language such as database, C++, java and MATLAB R2013A saves the individual and/or company the time and labor force required for a particular job. Information relay, calculations, data storage with the aid of computerized programming language has made business less clumsy.
2.2 METALS

A metal is a category of materials generally characterized by properties of ductility, malleability, luster, and high electrical and thermal conductivity. Metals have properties that satisfy a wide range of design requirements and applications.

Metals have crystalline structures in the solid state, almost without exception. The unit cells of these crystal structures are almost always BCC, FCC, or HCP. The atoms of the metals are held together by metallic bonding, which means that their valence electrons can move about with relative freedom (Holleman, A.F. et al.). These structures and bonding generally make the metals strong and hard. Metals are converted into parts and products using a variety of manufacturing processes.

The starting form of metals differs, depending on the process. The major categories are (1) cast metal, in which the initial form is a casting. (2) Wrought metal, metals have been worked on or can be worked on after casting. (3) Powdered metal, metal in the form of very small powered and converted into parts using powered metallurgy technique.

2.2.1 GENERAL PROPERTIES OF METALS

Metals are usually inclined to form cations through electron loss, reacting with oxygen in air to form oxides. E.g. \(4\text{Al} + 3\text{O}_2 = 2\text{Al}_2\text{O}_3\). Most metals have higher densities than most metals most non-metals. However there are wide variations in the densities of metals. Metals in group IA and IIA are referred to as light metals because they have low density, low hardness, and low melting point (Holleman 2001). The high density of most metals is due to the tightly packed crystal lattice of the metallic structure.

The technological and commercial importance of metals results from the following general properties possessed by virtually all of the common metals:
- **High strength and stiffness**: metals can be alloyed for high rigidity, strength, and hardness.

- **Toughness**: metals have the capacity to absorb energy better than other classes of materials.

- **Ductility**: metals have the capacity for plastic deformation.

- **Good electrical and thermal conductivity**: metals are good conductors because of the metallic bonding that allows the free movement of electrons as carriers.

  (Bauccio. M. (ed.))

### 2.2.2 CATEGORIES OF METALS

The metals of engineering importance is categorized into two major groups: **ferrous** metal and **nonferrous** metals.

**Nonferrous** metals, in metallurgy include metal elements and alloys not based on Iron. The most important engineering metals in the nonferrous group are Aluminum, Copper, Magnesium, Nickel, Titanium, and Zinc, and their alloys. Nonferrous metals are used for many engineering applications irrespective of it being expensive than ferrous metals due to its desirable properties such as low weight (Aluminum), high conductivity (copper), non-magnetic and resistance to corrosion (Bauccio 1993).

Nonferrous metals are usually recycled due to their extensive usage. The secondary material in scraps are vital to the metallurgy industry as the production of new metals often needs them (Bureau of International Recycling). Some recycling facilities melts and the metal fumes are filtered and collected. Scraps from nonferrous metals are sourced from industrial scrap materials, particle emission and obsolete technology scraps (e.g. copper cables). (Environment Agency)
Ferrous metals, a group of metals including all the types of iron, steel and their alloys. Iron (Fe) is the principal element of Ferrous Materials.

In present, their role in the engineering industries can be easily described as “most dominating”. In all the jobs ranging from the manufacture of a primitive type of agricultural implements to advanced types of Air Crafts, ferrous metal and their alloys occupy a prominent position. In the automotive, building and bridge construction, railways, light and heavy machinery, shipping and transportation, and in any other field of engineering activity, it may not be possible to move ahead without metals. This is explained by a number of reasons:

1. The wide abundance of iron ore in almost all parts of the world.
2. The economical extraction iron from its ore.
3. The flexibility that can be induced in the mechanical properties of iron by combining it with other metals and/or by heat treatment and such other methods.

These facts explain the reason that for the considerable time, the annual global production of Ferrous Metals has been far in excess than the combined production of all Non-Ferrous Metals produced in all the countries of the world. (Inamullah Khan, 2017)

2.3 INTRODUCTION TO FERROUS METALS

The ferrous metals are based on Iron, one of the oldest metals known to humans. The properties and other data relating to iron are listed in Table 2.1. The ferrous metals of engineering importance are alloys of Iron and carbon. These alloys divide into two major groups: steel and cast Iron. Together, they constitute approximately 85% of the metal tonnage in the United States (Flinn, R.A. et al.)
Table 2.1 Basic data on the metallic elements: Iron.

<table>
<thead>
<tr>
<th>Symbol: Fe</th>
<th>Principal ore: Hematite (Fe₂O₃)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic number: 26</td>
<td>Alloying elements: Carbon; also</td>
</tr>
<tr>
<td>Specific gravity: 7.87</td>
<td>chromium, manganese, nickel,</td>
</tr>
<tr>
<td>Crystal structure: BCC</td>
<td>molybdenum, vanadium, and silicon</td>
</tr>
<tr>
<td>Melting temperature: 1539°C (2802°F)</td>
<td>Typical applications: Construction,</td>
</tr>
<tr>
<td>Elastic modulus: 209,000 MPa (30*10⁶ lb/in²)</td>
<td>machinery, automotive, railway tracks</td>
</tr>
<tr>
<td></td>
<td>and equipment</td>
</tr>
</tbody>
</table>

Compiled from Flinn, R.A., et al., Metal Handbook vol. 1

2.3.1 PROPERTIES OF FERROUS METALS

The main elemental component of ferrous metals are iron and carbon. Other elements added defines the type of ferrous metal and in turn its properties as shown in Table 2.2.

Table 2.2 Types of ferrous metals, their compositions and properties

<table>
<thead>
<tr>
<th>Name</th>
<th>Composition</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast iron</td>
<td>Alloy of iron and 2.5% carbon, 1-3% silicon and traces of magnesium, sulfur and phosphorus.</td>
<td>Hard skin, softer underneath but brittle</td>
</tr>
<tr>
<td>Mild steel</td>
<td>Alloy of iron and 0.15-0.3% carbon</td>
<td>Tough, ductile and malleable, good tensile strength, poor resistance to corrosion</td>
</tr>
<tr>
<td>Medium carbon steel</td>
<td>Alloy of iron and 0.35-0.7% carbon</td>
<td>Strong, hard and tough with high tensile strength</td>
</tr>
<tr>
<td>High carbon steel</td>
<td>Alloy of iron and 0.7-1.5% carbon</td>
<td>Harder than medium carbon steel and more brittle</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>Alloy of iron and carbon with 16-26% chromium, 8-22% nickel and 8% magnesium</td>
<td>Hard, tough, resist wear and corrosion</td>
</tr>
<tr>
<td>High speed steel</td>
<td>Alloy of iron and 0.35-0.7% carbon with tungsten, chromium, vanadium and sometimes cobalt</td>
<td>Very hard, high abrasion and heat resistant</td>
</tr>
</tbody>
</table>

Compiled from Pense, A. W., et al.

2.3.2 TYPES OF FERROUS METALS

Ferrous metals characterized by iron and the amount of other elements is categorized into two main groups: cast iron and steels.
Cast iron is an iron alloy containing from 2.1% to about 4% carbon and from 1% to 3% silicon. Cast irons also contain phosphorus and sulfur usually totaling less than 0.3%. Its composition makes it highly suitable as a casting metal. In fact, the tonnage of cast iron castings is several times that of all other cast metal parts combined. The overall tonnage of cast iron is second only to steel among metals (Metal handbook, Vol. 1). Gray cast iron and white cast iron makes up the two most important cast irons. Other types include ductile iron, malleable iron and various alloy cast irons. Typical chemical compositions of gray and white cast irons are shown in Table 2.3 indicating their relationship with cast steel.

**Table 2.3 Compositions and mechanical properties of selected cast irons.**

<table>
<thead>
<tr>
<th>Type</th>
<th>Typical composition n, %</th>
<th>Tensile strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fe</td>
<td>C</td>
</tr>
<tr>
<td>Gray cast iron</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM Class 20</td>
<td>93.0</td>
<td>3.5</td>
</tr>
<tr>
<td>ASTM Class 30</td>
<td>93.6</td>
<td>3.2</td>
</tr>
<tr>
<td>ASTM Class 40</td>
<td>93.8</td>
<td>3.1</td>
</tr>
<tr>
<td>ASTM Class 50</td>
<td>93.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Ductile irons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM A395</td>
<td>94.4</td>
<td>3.0</td>
</tr>
<tr>
<td>ASTM A476</td>
<td>93.8</td>
<td>3.0</td>
</tr>
<tr>
<td>White cast iron</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low-C</td>
<td>92.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Malleable irons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ferritic</td>
<td>95.3</td>
<td>2.6</td>
</tr>
<tr>
<td>Pearlitic</td>
<td>95.1</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Compiled from Metal Handbook vol. 1

Gray cast iron accounts for the largest tonnage among the cast irons. It has a composition in the range 2.5% to 4% carbon and 1% to 3% silicon. This chemistry results in the formation of graphite (carbon) flakes distributed throughout the cast product upon solidification (Mikell P. Groover, 4th edition). The structure causes the surface of the metal to have a gray color when fractured; hence the name gray cast iron. The dispersion of
graphite flakes accounts for two attractive properties: (1) good vibration damping, which is desirable in engines and other machinery; and (2) internal lubricating qualities, which makes the cast metal machinable. Ductility of gray cast iron is very low; it is a relatively brittle material. Products made from gray cast iron include automotive engine blocks and heads, motor housings, and machine tool bases. **Ductile iron** is an iron with the composition of gray iron in which the molten metal is chemically treated before pouring to cause the formation of graphite spheroids rather than flakes. This results in a stronger and more ductile iron, hence its name. Applications include machinery components requiring high strength and good wear resistance.

**White cast iron** has a composition in the range of 2% to 3% carbon and 1% to 1.8% silicon (Mikell P. Groover, 4th edition). It is formed by more rapid cooling of the molten metal after pouring, thus causing the carbon to remain chemically combined with iron in the form of cementite \((\text{Fe}_3\text{C})\), rather than precipitating out of solution in the form of flakes. When fractured, the surface has a white crystalline appearance that gives the iron its name. Owing to the cementite, white cast iron is hard and brittle, and its wear resistance is excellent giving its applications such as railway brake shoes. **Malleable iron** is produced when castings of white cast iron are heat treated to separate the carbon out of solution and form graphite aggregates, the resulting metal is called malleable iron. The new microstructure can possess substantial ductility (up to 20% elongation); a significant difference from the metal out of which it was transformed. Typical products made of malleable cast iron include pipe fittings and flanges, steering-gear housing, and railroad equipment parts.

**Alloy Cast Irons**, This group includes those types of cast iron in which one or more alloying elements have been incorporated with a view of increasing the utility of the metal. These alloy cast irons are classified as follows: (1) heat-treatable types that can be hardened
by martensite formation; (2) corrosion-resistant types, whose alloying elements include nickel and chromium; and (3) heat-resistant types containing high proportions of nickel for hot hardness and resistance to high temperature oxidation.

**Steels** are alloys of iron that contains carbon ranging by weight between 0.02% and 2.11% (most steels range between 0.05% and 1.1%C). It often includes other alloying ingredients, such as manganese, chromium, nickel, and/or molybdenum; but it is the carbon content that turns iron into steel (Mikell P. Groover, 4th edition). Hundreds of compositions of steel are available commercially. For purposes of organization here, the vast majority of commercially important steels can be grouped into the following categories: (1) plain carbon steels, (2) low alloy steels, (3) stainless steels, (4) tool steels, and (5) specialty steels.

**Plain Carbon Steels:** These steels contain carbon as the principal alloying element, with only small amounts of other elements such as Manganese, Silicon, Phosphorus and Sulphur. The plain carbon steels are typically classified into three groups according to their Carbon content:

1. **Low Carbon Steels** contain less than 0.20% C and are by far the most widely used Steels. Typical applications are automobile sheet-metal parts, plate Steel for fabrication, and railroad rails. These steels are relatively easy to form, which accounts for their popularity where high strength is not required.

2. **Medium Carbon Steels** range in carbon between 0.20% and 0.50% and are specified for applications requiring higher strength than the low-C steels. Applications include machinery components and engine parts such as crank shafts and connecting rods.
3. **High Carbon Steels** contain Carbon in amounts greater than 0.50%. They are specified for still higher strength applications and where stiffness and hardness are needed. Springs, cutting tools and blades, and wear-resistant parts are examples. Increasing Carbon content strengthens and hardens the Steel, but its ductility is reduced. Also, High Carbon Steels can be heat treated to form martensite, making the Steel very hard and strong (Mikell P. Groover, 4th edition).

**Low Alloy Steels** are Iron–Carbon alloys that contain additional alloying elements in amounts totaling less than about 5% by weight. Owing to these additions, Low Alloy Steels have mechanical properties that are superior to those of the Plain Carbon Steels for given applications. Superior properties usually mean higher strength, hardness, hot hardness, wear resistance, toughness, and more desirable combinations of these properties. Heat treatment is often required to achieve these improved properties. Common alloying elements added to Steel are Chromium, Manganese, Molybdenum, Nickel, and Vanadium, sometimes individually but usually in combinations. The effects of the principal alloying ingredients can be summarized as follows:

- **Chromium (Cr)** improves strength, hardness, wear resistance, and hot hardness. It is one of the most effective alloying ingredients for increasing hardenability. In significant proportions, Cr improves corrosion resistance.
- **Manganese (Mn)** improves the strength and hardness of steel. When the steel is heat treated, hardenability is improved with increased manganese. Because of these benefits, manganese is a widely used alloying ingredient in steel.
- **Molybdenum (Mo)** increases toughness and hot hardness. It also improves hardenability and forms carbides for wear resistance.
• **Nickel (Ni)** improves strength and toughness. It increases hardenability but not as much as some of the other alloying elements in steel. In significant amounts it improves corrosion resistance and is the other major ingredient (besides chromium) in certain types of stainless steel.

• **Vanadium (V)** inhibits grain growth during elevated temperature processing and heat treatment, which enhances strength and toughness of steel. It also forms carbides that increase wear resistance.

These elements typically form solid solutions with iron and metallic compounds with carbon (carbides), assuming sufficient carbon is present to support a reaction.

**Stainless Steels** are a group of highly alloyed steels designed to provide high corrosion resistance. The principal alloying element in stainless steel is chromium, usually above 15% (Mikell P. Groover, 4th edition). The Chromium in the alloy forms a thin, impervious oxide film in an oxidizing atmosphere, which protects the surface from corrosion. Nickel is another alloying ingredient used in certain Stainless Steels to increase corrosion protection. Carbon is used to strengthen and harden the metal; however, increasing the Carbon content has the effect of reducing corrosion protection because Chromium carbide forms to reduce the amount of free Cr available in the alloy. In addition to corrosion resistance, Stainless Steels are noted for their combination of strength and ductility. Stainless Steels are traditionally divided into three groups:

1. **Austenitic Stainless** have a typical composition of around 18% Cr and 8% Ni and are the most corrosion resistant of the three groups. They are nonmagnetic and very ductile; but they show significant work hardening. Austenitic Stainless Steels are
used to fabricate chemical and food processing equipment, as well as machinery parts requiring high corrosion resistance.

2. **Ferritic Stainless** have around 15% to 20% Chromium, low carbon, and no nickel. This provides a ferrite phase at room temperature. Ferritic stainless steels are magnetic and are less ductile and corrosion resistant than the austenitic. Parts made of ferritic stainless range from kitchen utensils to jet engine components.

3. **Martensitic stainless** have a higher Carbon content than ferritic stainless, thus permitting them to be strengthened by heat treatment. They have as much as 18% Cr but no Ni. They are strong, hard, and fatigue resistant, but not generally as corrosion resistant as the other two groups. Typical products include cutlery and surgical instruments.

**Tool Steels** are a class of highly alloyed Steels designed for use as industrial cutting tools, dies, and molds. To perform in these applications, they must possess high strength, hardness, hot hardness, wear resistance, and toughness under impact. To obtain these properties, Tool Steels are heat treated. Principal reasons for the high levels of alloying elements are (1) improved hardenability, (2) reduced distortion during heat treatment, (3) hot hardness, (4) formation of hard metallic carbides for abrasion resistance, and (5) enhanced toughness. The Tool Steels divide into major types, according to application and composition:

- **High-speed Tool Steels** are used as cutting tools in machining processes. They are formulated for high wear resistance and hot hardness. The two principal alloying elements are tungsten and molybdenum.

- **Hot-working Tool Steels** are intended for hot-working dies in forging, extrusion, and die-casting.
- **Cold-work Tool Steels** are die steels used for cold working operations such as sheet metal press working, cold extrusion, and certain forging operations. They provide good wear resistance and low distortion.

- **Water-hardening Tool Steels** have high carbon with little or no other alloying elements. They can only be hardened by fast quenching in water. They are widely used because of low cost, but they are limited to low temperature applications.

- **Shock-resistant Tool Steels** are intended for use in applications where high toughness is required, as in many sheet metal shearing, punching, and bending operations.

- **Mold Steels** are used to make molds for molding plastics and rubber.

### 2.4 PRODUCTION OF FERROUS METALS

#### 2.4.1 IRON ORES AND OTHER RAW MATERIALS

The principal ore used in the production of Iron and Steel is Hematite (Fe₂O₃). Other Iron ores include Magnetite (Fe₃O₄), Siderite (FeCO₃), and Limonite (Fe₂O₃-xH₂O), in which x is typically around 1.5). Iron ores contain from 50% to around 70% iron, depending on grade (hematite is almost 70% iron), (Mikell P. Groover, 4th edition). In addition, scrap Iron and Steel are widely used today as raw materials in Iron and Steelmaking. Other raw materials needed to reduce iron from the ores are coke and limestone. **Coke** is a high carbon fuel produced by heating bituminous coal in a limited oxygen atmosphere for several hours, followed by water spraying in special quenching towers. Coke serves two functions in the reduction process: (1) it is a fuel that supplies heat for the chemical reactions; and (2) it produces Carbon monoxide (CO) to reduce the iron ore. **Limestone** is a
rock containing high proportions of Calcium carbonate (CaCO₃). The limestone is used in the process as a flux to react with and remove impurities in the molten iron as slag.

### 2.4.2 IRON MAKING

To produce Iron, a charge of ore, coke, and limestone are dropped into the top of a blast furnace. A blast furnace is a refractory-lined chamber with a diameter of about 9 to 11m (30–35ft) at its widest and a height of 40m (125ft), in which hot gases are forced into the lower part of the chamber at high rates to accomplish combustion and reduction of the iron. A typical blast furnace and some of its technical details are illustrated in Figures 2.1 and 2.2. The charge slowly descends from the top of the furnace toward the base and is heated to temperatures around 1650°C (3000°F). Burning of the coke is accomplished by the hot gases (CO, H₂, CO₂, H₂O, N₂, O₂, and fuels) as they pass upward through the layers of charge material (Mikell P. Groover, 4th edition). The carbon monoxide is supplied as hot gas, and it is also formed from combustion of coke. The CO gas has a reducing effect on the Iron ore; the reaction can be written as follows (using hematite as the starting ore)

\[
\text{Fe}_2\text{O}_3 + \text{CO} \rightarrow 2\text{FeO} + \text{CO}_2 \quad \text{Equation 1}
\]

Carbon dioxide reacts with coke to form more carbon monoxide

\[
\text{CO}_2 + C(\text{coke}) \rightarrow 2\text{CO} \quad \text{Equation 2}
\]

Which then accomplishes the final reduction of FeO to iron

\[
\text{FeO} + \text{CO} \rightarrow \text{Fe} + \text{CO}_2 \quad \text{Equation 3}
\]
The molten iron drips downward, collecting at the base of the blast furnace. This is periodically tapped into hot iron ladle cars for transfer to subsequent steelmaking operations.

The role played by limestone can be summarized as follows. First the limestone is reduced to lime (CaO) by heating, as follows
The lime combines with impurities such as silica (SiO₂), sulfur (S), and alumina (Al₂O₃) in reactions that produce a molten slag that floats on top of the iron.

2.4.3 STEEL MAKING

Since the mid-1800s, a number of processes have been developed for refining pig iron into steel. Today, the two most important processes are the basic oxygen furnace (BOF) and the electric furnace. Both are used to produce carbon and alloy steels.
The **basic oxygen furnace** accounts for about 70% of U.S. steel production (Mikell P. Groover, 4th edition). The BOF is an adaptation of the Bessemer converter. Whereas the Bessemer process used air blown up through the molten pig iron to burn off impurities, the basic oxygen process uses pure oxygen. A diagram of the conventional BOF during the middle of a heat is illustrated in Figure 2.3. The typical BOF vessel is about 5m (16ft) inside diameter and can process 150 to 200 tons in a heat (Mikell P. Groover, 4th edition).

![Diagram of the basic oxygen furnace](image)

**Figure 2.3 Basic oxygen furnace showing BOF vessel during processing (Mikell P. Groover, 4th edition)**

The BOF steelmaking sequence is shown in Figure 2.4. Integrated steel mills transfer the molten pig iron from the blast furnace to the BOF in railway cars called hot-iron ladle cars. In modern practice, steel scrap is added to the pig iron, accounting for about 30% of a typical BOF charge.

Lime (CaO) is also added. After charging, the lance is inserted into the vessel so that its tip is about 1.5 m (5ft) above the surface of the molten iron (Mikell P. Groover, 4th edition). Pure O₂ is blown at high velocity through the lance, causing combustion and heating at the
surface of the molten pool. Carbon dissolved in the iron and other impurities such as Silicon, Manganese, and Phosphorus are oxidized. The reactions are:

\[ 3C + 2O_2 \rightarrow 2CO + CO_2 \]  \hspace{1cm} \text{Equation 5}

\[ Si + O_2 \rightarrow SiO_2 \]  \hspace{1cm} \text{Equation 6}

\[ 2Mn + O_2 \rightarrow 2MnO \]  \hspace{1cm} \text{Equation 7}

\[ 4P + 5O_2 \rightarrow 2P_2O_5 \]  \hspace{1cm} \text{Equation 8}

![Figure 2.4 BOF sequence during processing cycle: (1) charging of scrap and (2) pig iron; (3) blowing (Figure 2.3); (4) tapping the molten steel; and (5) pouring off the slag. (Mikell P. Groover, 4th edition)](image)

The CO and CO\(_2\) gases produced in the first reaction escape through the mouth of the BOF vessel and are collected by the fume hood; the products of the other three reactions are removed as slag, using the lime as a fluxing agent. The Carbon content in the iron decreases almost linearly with time during the process, thus permitting fairly predictable control over carbon levels in the steel. After refining to the desired level, the molten steel is tapped; alloying ingredients and other additives are poured into the heat; then the slag is poured. A
200-ton heat of steel can be processed in about 20 min, although the entire cycle time (tap-to-tap time) takes about 45 min.

The Electric Arc furnace accounts for about 30% of U.S. steel production (Mikell P. Groover, 4th edition). Although pig iron was originally used as the charge in this type of furnace, scrap iron and scrap steel are the primary raw materials today. Electric arc furnaces are available in several designs; the direct arc type shown in Figure 2.5 is currently the most economical type. These furnaces have removable roofs for charging from above; tapping is accomplished by tilting the entire furnace. Scrap Iron and Steel selected for their compositions, together with alloying ingredients and limestone (flux), are charged into the furnace and heated by an electric arc that flows between large electrodes and the charge metal. Complete melting requires about 2 hours; tap-to-tap time is 4 hours. Capacities of electric furnaces commonly range between 25 and 100 tons per heat. Electric Arc furnaces are noted for better-quality steel but higher cost per ton, compared with the BOF. The electric arc furnace is generally associated with production of alloy steels, tool steels, and stainless steels (Mikell P. Groover, 4th edition).

**2.4.4 PROPERTIES OF PIG IRON**

Pig iron is the first or basic form in which Iron is prepared as a metal from its ores. It is considered crude, impure and therefore needs subsequent processing to develop cast Irons and Steels. The pig iron tapped from the base of the blast furnace contains more than 4% C, plus other impurities: 0.3–1.3% Si, 0.5–2.0% Mn, 0.1–1.0% P, and 0.02–0.08% S (Metal handbook vol. 1).
2.5 RECYCLING OF FERROUS METALS

Metal recycling refers to systematically collecting various metals at the end of their useful life, and sorting them according to metal types and quality. This step is followed by processing, purifying and finally making brand new products using the recycled metals.

Metals can be recycled over and over again without altering their properties. According to American Iron and Steel Institute (AISI), steel is the most recycled material on the planet.

Scrap metal is any bit or piece of metal that no longer functions as part of a whole. It can be found almost anywhere and is actually quite valuable. Scrap metal has value, which motivates people to collect it for sale to recycling operations.

In addition to a financial incentive, there is also an environmental imperative. The recycling of metals enables us to preserve natural resources while requiring less energy to process than the manufacture of new products using virgin raw materials. Recycling emits less carbon dioxide and other harmful gasses. More importantly, it saves money and allows manufacturing businesses to reduce their production cost and also creates jobs. (Rick LeBlanc, 2016)

2.5.1 PROCESSES INVOLVED IN RECYCLING OF FERROUS METALS

Recycling of ferrous metals is most predominant in the world due the opportunity to recover large structures as well as the ease of processing. Following are the main stages involved in recycling process:

Collection: The collection process for metals differs than that for other materials because of higher scrap value. As such, it is more likely to be sold to scrap yards than sent to the landfill. The largest source of scrap ferrous metal in U.S. is from scrap vehicles. Other sources include large steel structures, railroad tracks, ships and consumer scrap.
Sorting: Sorting involves separating metals from the mixed scrap metal stream or the mixed multi-material waste stream. In automated recycling operations, magnets and sensors are used to aid in material separation. At the entrepreneurial level, scrappers may employ a magnet, as well as use material weight or color to help determine the metal type. Scrappers will improve the value of their material by segregating clean metal from the dirty material.

Processing: To allow further processing, metals are shredded. Shredding is done to promote the melting process as small shredded metals have large surface to volume ratio. Steels are converted to steel blocks. As a result, they can be melted using comparatively less energy.

Melting: Scrap metal is melted in a large furnace. Each metal is taken to a specific furnace designed to metal. A considerable amount of metals is used in this step. Based on the size of the furnace, the degree of heat of the furnace and volume of metal, melting can take from a few minutes to hours.

Purification: Purification is done to ensure the final product is of high quality and free of contaminants. One of the most common methods used for purification is Electrolysis.

Solidifying: After purification, melted metals are carried by conveyor belt to cool and solidify the metals. In this stage, scrap metals are formed into specific shapes such as bars that can be easily used for the production of various metal products.

Transportation: Once the metals are cooled and solidified, they are ready to use. They are then transported to various factories where they are used as raw material for the production of brand new products.

Recycling process cycle begins again once these products come to the end of their useful life. (Rick LeBlanc, 2016)
2.5.2 CHARGE CALCULATION

In foundry (recycling), it is important to know the final composition of the metal being obtained, so as to control it properly. The elements in the final analysis are essentially the sum total of what is combined in each of the charge ingredients, with some losses or picked up in the electric furnace. The electric furnace is 5 meter in height, about 1 meter in diameter and cylindrical in shape. The cylinder has an inner lining of Refractory Bricks which is provided with tuyers near the bottom for injecting the supply of air blast. Out of the various elements, the ones that are relevant are carbon, silicon, Manganese and Sulphur.

As the charge comes through the coke bed, some amount of carbon is picked up by the metal depending on the temperature and the time when the metal is in contact with the coke. However, it may be reasonable to assume a pickup of 0.15% carbon.

Silicon is likely to get oxidized in the electric furnace and therefore, a loss of 10% of the total silicon contained in the charge is normal. Under the worst conditions it may go as high as 30%. If the silicon content is not high, extra silicon can be added by inoculating the metal in the ladle with ferrosilicon.

Manganese is also likely to be lost in the melting process. The loss could be of the order of 15%-20%. Loss of Manganese in the final analysis, can be made up by the addition of ferromanganese.

Similar to carbon, Sulphur is also likely to be picked up from coke during melting. The picked up depends on the Sulphur content of the coke, but a reasonable could be 0.03 to 0.05%.
2.5.3 COST OF RECYCLING

Traditionally, metal recycling has been regarded as a profitable business opportunity. But throughout 2015, the prices of various scrap metals kept on falling. As a result, many scrap recyclers shut their businesses or downsized operations. Throughout 2016, though, prices started to increase and the market looked to be trending modestly upward. At an entrepreneurial level, a common entry point into the metal recycling business is through starting scrap metal collection business or scrap metal vendor. (Rick LeBlanc, 2016)

2.6 OVERVIEW OF MATLAB R2013A SOFTWARE

MATLAB R2013A (matrix laboratory) is a programming language developed by Mathworks. It started out as a matrix programming language, where linear programming was simple. MATLAB R2013A is a fourth-generation high-level programming language and interactive environment for numerical computation, visualization and programming. It allows creation of user interfaces, and interfacing with other language, including C, C++ and Java to analyze data, develop algorithms, and create models and applications.

MATLAB R2013A has evolved over a period of years with input from many users. In university environments, it is the standard instructional tool for introductory and advanced coursed on mathematics, engineering, and science. In industry, MATLAB R2013A is the tool of choice for high-productivity research, development, and analysis.

MATLAB R2013A has extensive facilities for displaying vectors and matrices as graphs, as well as annotating and printing these graphs. It includes high-level functions two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level functions that allow you to fully customize
the appearance of graphics as well as to build complete graphical user interfaces on your MATLAB R2013A applications. (The Mathworks Inc.)

2.7 APPLICATIONS OF MATLAB R2013A

MATLAB R2013A widely used as a computational tool in science and engineering encompassing the fields of physics, chemistry, math and all engineering streams. It is used in a range of applications including:

1. Signal Processing and Communications
2. Image and Video Processing
3. Control Systems
4. Test and Measurement
5. Computational Finance
6. Computational Biology
CHAPTER THREE

3.0 METHODOLOGY

3.1 SAMPLING OF SCRAPs

At the Tema Steel Company, magnetic separation was done to separate ferrous metals from non-ferrous metals, the ferrous metals was loaded into huge containers called buckets as shown in Figure 3.1a. Depending on the amount of product specifically to be produced, 3 to 5 buckets may be filled each not weighing less than 5tons. Sampling of the ferrous scraps was done from 4 buckets as shown in Figure 3.1b. The total weight of the 4 buckets was 23.4tons; the first bucket weighed 5.85tons, the second bucket weighed 6.12tons, the third bucket weighed 5.96tons and the fourth bucket weighed 5.47tons. From each bucket, 4 different ferrous metals were sampled making a total of 16 samples. Sampling was done by hand, and effectively sampled metals ranging from high carbon to low carbon, rich in chromium and manganese, and scraps from their foundry department.

3.2 MELTING CHARGE EQUATIONS

Mathematical equation for calculating the theoretical melting charge calculation are as follows

\[
\text{weight of element} = \frac{\text{wt\% of the element}}{100} \times \text{weight fraction in cupola} \quad \text{Equation 9}
\]

\[
\text{total wt\% of element} = \frac{\text{total weight of element}}{\text{cupola weight}} \times 100\% \quad \text{Equation 10}
\]
Figure 3.1: (a) magnetic separation, (b) sampling of scraps, (c) electric furnace
3.3 MATLAB R2013A CODES AND INTERFACE

A program called “guide” in MATLAB R2013A was used to create the graphic user interface (GUI) as shown as Figure 3.2. First, “guide” is typed at the command window which displays a blank GUI, which can be designed based on the user’s preference. In creating the interface, edit boxes were used as input option, static boxes were used as output display and pushbutton was used as execution of commands. After designing the interface, the interface was saved by clicking the run button, which in turn displayed an editor as shown as Figure 3.3, for the writing of the codes. By using the “get function”, string variables were converted to numbers, this allow programming the codes in a mathematical language. Percentage sign was used to comment on variables used. After the codes were developed, results to be displayed on the interface were converted from numbers to a string variable. The Run button clicked on the editor’s toolbar displayed the interface as shown as Figure 3.3.
Figure 3.2: MATLAB R2013A interface

<table>
<thead>
<tr>
<th>Element</th>
<th>Al</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Mn</th>
<th>Ni</th>
<th>P</th>
<th>N</th>
</tr>
</thead>
</table>

Calculate

Solve

Final elemental composition with tons of late additions and weight percent (wt%)

<table>
<thead>
<tr>
<th>Budget</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
</table>

Weight of constituents in cubic meters (tons) and calculate weight matrix

Composition of element in the constituents (wt%)
3.4 ELEMENTAL ANALYSIS

3.4.1 SAMPLE PREPARATION

Resources allowed the use of Mass Spectrometer (V-950 spectrometer, Angstrom, USA) to carry out the elemental analysis. According to specifications and rules governing elemental analysis using the Mass Spectrometer (V-950 spectrometer, Angstrom, USA), a small piece was cut off from large sampled ferrous scraps. Grinding of metal surfaces was done next to remove dust and smoothing the surface. Polishing is also a required step to smoothing the surface further and remove any roughness made when grinding.
3.4.2 TESTING OF SAMPLED SCRAPS

Prepared samples were grouped according to how they were sampled, that is, the four samples from the individual buckets. Labels B1, B2, B3, B4 were given to bucket 1, bucket 2, bucket 3 and bucket 4, respectively, and the individual 4 samples from each bucket were labeled with A, B, C, D (example B1 A, meaning bucket 1 sample A) shown as Figure 3.4. On each sample, two elemental tests were carried out and an average of the two was calculated to be the definite composition. This was done for all the 16 samples with a hopeful results.

Figure 3.4 Labelled sampled scraps
### 3.5 MELTING CHARGE CALCULATION

#### Table 3.1 Theoretical charge calculation

<table>
<thead>
<tr>
<th>Buckets</th>
<th>Weight of fraction, tons</th>
<th>Composition of elements, wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fe</td>
</tr>
<tr>
<td>1</td>
<td>5.85</td>
<td>94.647</td>
</tr>
<tr>
<td>2</td>
<td>6.12</td>
<td>97.477</td>
</tr>
<tr>
<td>3</td>
<td>5.96</td>
<td>97.896</td>
</tr>
<tr>
<td>4</td>
<td>5.47</td>
<td>98.053</td>
</tr>
</tbody>
</table>

\[
M_{\text{element}} = \frac{\text{wt}\%_{\text{element}}}{100} \times \text{weight of fraction in electric furnace} \quad \text{Equation 11}
\]

\[
\text{wt}\%_{\text{element in cupola}} = \frac{\text{total weight of element}}{\text{total electric furnace weight}} \times 100 \quad \text{Equation 12}
\]

#### Table 3.2 Composition of element in electric furnace

<table>
<thead>
<tr>
<th>Element</th>
<th>Wt% element in electric furnace</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>(\frac{22.702}{23.4} \times 100 = 97.01\text{wt}%_\text{Fe})</td>
</tr>
<tr>
<td>C</td>
<td>(\frac{0.0591t}{23.4t} \times 100 = 0.252\text{wt}%_\text{C})</td>
</tr>
<tr>
<td>Mn</td>
<td>(\frac{0.0465}{23.4} \times 100 = 0.199\text{wt}%_\text{Mn})</td>
</tr>
<tr>
<td>Si</td>
<td>(\frac{0.006}{23.4} \times 100 = 0.026\text{wt}%_\text{Si})</td>
</tr>
<tr>
<td>Cr</td>
<td>(\frac{0.0397}{23.4} \times 100 = 0.161\text{wt}%_\text{Cr})</td>
</tr>
<tr>
<td>Cu</td>
<td>(\frac{0.0483}{23.4} \times 100 = 0.206\text{wt}%_\text{Cu})</td>
</tr>
<tr>
<td>Ni</td>
<td>(\frac{0.022}{23.4} \times 100 = 0.094\text{wt}%_\text{Ni})</td>
</tr>
</tbody>
</table>
### Table 3.3 Elemental weight in samples

<table>
<thead>
<tr>
<th>Elements</th>
<th>Weight (tons) of element in Bucket 1</th>
<th>Weight (tons) of element in Bucket 2</th>
<th>Weight (tons) of element in Bucket 3</th>
<th>Weight (tons) of element in Bucket 4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>M&lt;sub&gt;Fe&lt;/sub&gt; = 94.647 &lt;br&gt;× 5.85t = 5.538t</td>
<td>M&lt;sub&gt;Fe&lt;/sub&gt; = 97.477 &lt;br&gt;× 6.1 = 5.966t</td>
<td>M&lt;sub&gt;Fe&lt;/sub&gt; = 98.896 &lt;br&gt;× 5.96 = 5.835t</td>
<td>M&lt;sub&gt;Fe&lt;/sub&gt; = 98.053 &lt;br&gt;× 5.47 = 5.363t</td>
<td>22.702t</td>
</tr>
<tr>
<td>C</td>
<td>M&lt;sub&gt;C&lt;/sub&gt; = 0.493 &lt;br&gt;× 6.12t = 0.0288t</td>
<td>M&lt;sub&gt;C&lt;/sub&gt; = 0.152 &lt;br&gt;× 5.96 = 0.0093t</td>
<td>M&lt;sub&gt;C&lt;/sub&gt; = 0.167 &lt;br&gt;× 5.47 = 0.01t</td>
<td>M&lt;sub&gt;C&lt;/sub&gt; = 0.197 &lt;br&gt;× 5.47 = 0.011t</td>
<td>0.0591t</td>
</tr>
<tr>
<td>Mn</td>
<td>M&lt;sub&gt;Mn&lt;/sub&gt; = 0.121 &lt;br&gt;× 6.12t = 0.007t</td>
<td>M&lt;sub&gt;Mn&lt;/sub&gt; = 0.314 &lt;br&gt;× 5.96 = 0.0192t</td>
<td>M&lt;sub&gt;Mn&lt;/sub&gt; = 0.201 &lt;br&gt;× 5.47 = 0.0083t</td>
<td>M&lt;sub&gt;Mn&lt;/sub&gt; = 0.152 &lt;br&gt;× 5.47 = 0.0083t</td>
<td>0.0465t</td>
</tr>
<tr>
<td>Si</td>
<td>M&lt;sub&gt;Si&lt;/sub&gt; = 0.024 &lt;br&gt;× 6.12t = 0.0014t</td>
<td>M&lt;sub&gt;Si&lt;/sub&gt; = 0.035 &lt;br&gt;× 5.96 = 0.0021t</td>
<td>M&lt;sub&gt;Si&lt;/sub&gt; = 0.026 &lt;br&gt;× 5.47 = 0.0011t</td>
<td>M&lt;sub&gt;Si&lt;/sub&gt; = 0.152 &lt;br&gt;× 5.47 = 0.0083t</td>
<td>0.006t</td>
</tr>
<tr>
<td>Cr</td>
<td>M&lt;sub&gt;Cr&lt;/sub&gt; = 0.322 &lt;br&gt;× 6.12t = 0.0185t</td>
<td>M&lt;sub&gt;Cr&lt;/sub&gt; = 0.128 &lt;br&gt;× 5.96 = 0.0078t</td>
<td>M&lt;sub&gt;Cr&lt;/sub&gt; = 0.145 &lt;br&gt;× 5.47 = 0.0086t</td>
<td>M&lt;sub&gt;Cr&lt;/sub&gt; = 0.049 &lt;br&gt;× 5.47 = 0.0049t</td>
<td>0.0397t</td>
</tr>
<tr>
<td>Cu</td>
<td>M&lt;sub&gt;Cu&lt;/sub&gt; = 0.202 &lt;br&gt;× 6.12t = 0.0118t</td>
<td>M&lt;sub&gt;Cu&lt;/sub&gt; = 0.237 &lt;br&gt;× 5.96 = 0.0145t</td>
<td>M&lt;sub&gt;Cu&lt;/sub&gt; = 0.196 &lt;br&gt;× 5.47 = 0.0117t</td>
<td>M&lt;sub&gt;Cu&lt;/sub&gt; = 0.189 &lt;br&gt;× 5.47 = 0.0103t</td>
<td>0.0483t</td>
</tr>
<tr>
<td>Ni</td>
<td>M&lt;sub&gt;Ni&lt;/sub&gt; = 0.170 &lt;br&gt;× 6.12t = 0.01t</td>
<td>M&lt;sub&gt;Ni&lt;/sub&gt; = 0.089 &lt;br&gt;× 5.96 = 0.0054t</td>
<td>M&lt;sub&gt;Ni&lt;/sub&gt; = 0.067 &lt;br&gt;× 5.47 = 0.004t</td>
<td>M&lt;sub&gt;Ni&lt;/sub&gt; = 0.047 &lt;br&gt;× 5.47 = 0.0026t</td>
<td>0.022t</td>
</tr>
</tbody>
</table>

### 3.6 MELTING AND TRANSFORMATION OF SCRAPS

The furnace was first preheated to a temperature of about 1000°C with the help of coke bricks, and maintained for a while. The first bucket out of the four buckets was charged into
the furnace, it was allowed to melt but not completely before the second bucket is introduced. The same procedure was repeated until all four buckets were charged into the electric furnace. The electric furnace has a total tonnage of 25tons. After complete melting (called the bath), a part of the molten metal was sampled and quenched to solidify. The solidified sample was prepared and a compositional test using Mass Spectrometer (V-950 spectrometer, Angstrom, USA) was done to compare against set standards. The test sample was observed to have lower concentrations in Manganese (0.199wt%Mn), Silicon (0.026wt%Si) and Chromium (0.161wt%Cr).

Table 3.4 Results of melting charge calculation

<table>
<thead>
<tr>
<th>Buckets</th>
<th>Weight, tons</th>
<th>Composition of elements, wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fe</td>
</tr>
<tr>
<td>1</td>
<td>5.85</td>
<td>94.647</td>
</tr>
<tr>
<td>2</td>
<td>6.12</td>
<td>97.477</td>
</tr>
<tr>
<td>3</td>
<td>5.96</td>
<td>97.896</td>
</tr>
<tr>
<td>4</td>
<td>5.47</td>
<td>98.053</td>
</tr>
<tr>
<td>Total weight of element in electric furnace, tons</td>
<td>22.702</td>
<td>0.0591</td>
</tr>
<tr>
<td>Element in electric furnace, wt%</td>
<td>97.01</td>
<td>0.251</td>
</tr>
</tbody>
</table>

Based on this analysis, an alloy of Silicon and Manganese (kg), and 75wt%ferrochromium (kg) was added to the bath to refine the bath. Another sample was taken out the bath, cooled, prepared and test to compare against set standards. The elemental composition of the test sample proved Manganese was in range, (0.721wt%Mn) with the exception of Silicon (0.097wt%Si) and Chromium (0.190wt%Cr) when compared to set standards. Based on this analysis, 70wt%ferrosilicon (kg) and 75wt%ferrochromium (kg) was added to the bath to increase the Silicon and Chromium content. The bath was then transported.
using an overhead crane to the casting area where it is poured into the casting machine. Continuous casting is employed at this section (Figure 3.5b). The cast metal was cut into its various length and quenched in water, this is the final product called the billet (Figure 3.5a). After the cast metal had cooled off, a piece of it was cut off to be tested using the Mass Spectrometer (V-950 spectrometer, Angstrom, USA). The test results was as expected as the elements fell within range of the set standards. The products (Billet) is ready to be transported, or for further transformation.

(a) [Image](#) (b) [Image](#)

Figure 3.5 (a) final product; billet, (b) continuous casting of metal

### 3.7 VALIDATIONS OF COMPOSITION USING MATLAB R2013A

Information such as the weight of the individual buckets and the elemental compositions of the various sampled scraps was fed into the interface created by MATLAB R2013A. By
comparison, the display of the calculated results by MATLAB R2013A tallied exactly with the melting charge calculations computed in Table 3.4.

**Figure 3.6 A graph of theoretical results and MATLAB**
Figure 3.7 Results of MATLAB computation for the first bath

Composition of element in the constituents (wt%)

<table>
<thead>
<tr>
<th>Element</th>
<th>Cu</th>
<th>Fe</th>
<th>Ni</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of constituents</td>
<td>23.4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ingredients:
- Cu: 0.0096
- Fe: 0.026
- Ni: 0.008
- C: 0.003

Weight of ingredients (tons):
- Cu: 4.96
- Fe: 6.72
- Ni: 5.85
- C: 3.4
CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 SAMPLE TYPE DETERMINATION

Results acquired from the Mass Spectrometer (V-950 spectrometer, Angstrom, USA) shows that, most sampled scraps contained low carbon (0.08-0.2wt%C) which was mostly desired for production. Other sampled scraps were medium in carbon, high in carbon, high in manganese and chromium. The samples acquired proved to be the required raw material needed to produce their required final product. Table 4.1 to Table 4.4 below show the results of elemental analysis of the four samples from each of the four bucket using Mass Spectrometer (V-950 spectrometer, Angstrom, USA).
Table 4.1 Elemental analysis of samples from bucket one using Mass Spectrometer

<table>
<thead>
<tr>
<th>Elements</th>
<th>BUCKET 1 Test Samples</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>Avg</td>
<td>1</td>
<td>2</td>
<td>Avg</td>
<td>1</td>
<td>2</td>
<td>Avg</td>
</tr>
<tr>
<td>Fe</td>
<td>98.571</td>
<td>98.548</td>
<td>98.559</td>
<td>99.134</td>
<td>99.138</td>
<td>99.136</td>
<td>86.432</td>
<td>86.487</td>
<td>86.459</td>
</tr>
<tr>
<td>C</td>
<td>0.097</td>
<td>0.099</td>
<td>0.098</td>
<td>0.195</td>
<td>0.199</td>
<td>0.197</td>
<td>1.372</td>
<td>1.385</td>
<td>1.379</td>
</tr>
<tr>
<td>Mn</td>
<td>0.146</td>
<td>0.060</td>
<td>0.103</td>
<td>0.041</td>
<td>0.042</td>
<td>0.041</td>
<td>0.133</td>
<td>0.129</td>
<td>0.131</td>
</tr>
<tr>
<td>P</td>
<td>0.036</td>
<td>0.039</td>
<td>0.037</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.056</td>
<td>0.056</td>
<td>0.056</td>
</tr>
<tr>
<td>Si</td>
<td>0.012</td>
<td>0.012</td>
<td>0.012</td>
<td>0.007</td>
<td>0.007</td>
<td>0.007</td>
<td>0.052</td>
<td>0.053</td>
<td>0.052</td>
</tr>
<tr>
<td>Cu</td>
<td>0.172</td>
<td>0.174</td>
<td>0.173</td>
<td>0.092</td>
<td>0.092</td>
<td>0.092</td>
<td>0.298</td>
<td>0.294</td>
<td>0.296</td>
</tr>
<tr>
<td>Ni</td>
<td>0.023</td>
<td>0.024</td>
<td>0.023</td>
<td>0.113</td>
<td>0.113</td>
<td>0.113</td>
<td>0.455</td>
<td>0.456</td>
<td>0.456</td>
</tr>
<tr>
<td>Cr</td>
<td>0.023</td>
<td>0.023</td>
<td>0.023</td>
<td>0.011</td>
<td>0.013</td>
<td>0.012</td>
<td>1.229</td>
<td>1.233</td>
<td>1.231</td>
</tr>
<tr>
<td>Mo</td>
<td>0.063</td>
<td>0.066</td>
<td>0.065</td>
<td>0.064</td>
<td>0.063</td>
<td>0.063</td>
<td>0.293</td>
<td>0.296</td>
<td>0.295</td>
</tr>
<tr>
<td>Al</td>
<td>0.014</td>
<td>0.013</td>
<td>0.014</td>
<td>0.014</td>
<td>0.014</td>
<td>0.014</td>
<td>0.007</td>
<td>0.007</td>
<td>0.007</td>
</tr>
<tr>
<td>Co</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.033</td>
<td>0.034</td>
<td>0.033</td>
<td>0.039</td>
<td>0.040</td>
<td>0.040</td>
</tr>
<tr>
<td>Sn</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
<td>0.141</td>
<td>0.143</td>
<td>0.142</td>
</tr>
<tr>
<td>Pb</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>
### Table 4.2 Elemental analysis of samples from bucket two

<table>
<thead>
<tr>
<th>Elements</th>
<th>BUCKET 2 Test Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Fe</td>
<td>97.145</td>
</tr>
<tr>
<td>C</td>
<td>0.138</td>
</tr>
<tr>
<td>Mn</td>
<td>0.108</td>
</tr>
<tr>
<td>P</td>
<td>0.014</td>
</tr>
<tr>
<td>S</td>
<td>0.003</td>
</tr>
<tr>
<td>Si</td>
<td>0.013</td>
</tr>
<tr>
<td>Cu</td>
<td>0.155</td>
</tr>
<tr>
<td>Ni</td>
<td>0.082</td>
</tr>
<tr>
<td>Cr</td>
<td>0.083</td>
</tr>
<tr>
<td>V</td>
<td>0.014</td>
</tr>
<tr>
<td>Mo</td>
<td>0.093</td>
</tr>
<tr>
<td>Ti</td>
<td>0.007</td>
</tr>
<tr>
<td>Al</td>
<td>0.065</td>
</tr>
<tr>
<td>Nb</td>
<td>0.011</td>
</tr>
<tr>
<td>Co</td>
<td>0.018</td>
</tr>
<tr>
<td>Sn</td>
<td>0.005</td>
</tr>
<tr>
<td>B</td>
<td>0.002</td>
</tr>
<tr>
<td>Pb</td>
<td>0.006</td>
</tr>
</tbody>
</table>
Table 4.3 Elemental analysis of samples from bucket three

<table>
<thead>
<tr>
<th>Elements</th>
<th>BUCKET 3</th>
<th>Test Samples</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td></td>
<td>B</td>
<td></td>
<td>C</td>
<td></td>
<td>D</td>
<td></td>
<td>Avg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td></td>
<td>98.793</td>
<td>98.765</td>
<td>98.779</td>
<td>97.464</td>
<td>97.565</td>
<td>97.515</td>
<td>98.564</td>
<td>98.489</td>
<td>98.526</td>
<td>96.742</td>
</tr>
<tr>
<td>C</td>
<td>0.086</td>
<td>0.088</td>
<td>0.087</td>
<td>0.279</td>
<td>0.285</td>
<td>0.282</td>
<td>0.075</td>
<td>0.074</td>
<td>0.074</td>
<td>0.265</td>
<td>0.267</td>
</tr>
<tr>
<td>Mn</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
<td>0.110</td>
<td>0.116</td>
<td>0.113</td>
<td>0.045</td>
<td>0.044</td>
<td>0.045</td>
<td>0.568</td>
<td>0.574</td>
</tr>
<tr>
<td>P</td>
<td>0.038</td>
<td>0.037</td>
<td>0.037</td>
<td>0.045</td>
<td>0.046</td>
<td>0.046</td>
<td>0.060</td>
<td>0.061</td>
<td>0.061</td>
<td>0.014</td>
<td>0.014</td>
</tr>
<tr>
<td>S</td>
<td>0.038</td>
<td>0.039</td>
<td>0.038</td>
<td>0.044</td>
<td>0.042</td>
<td>0.043</td>
<td>0.037</td>
<td>0.038</td>
<td>0.037</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td>Si</td>
<td>0.012</td>
<td>0.012</td>
<td>0.012</td>
<td>0.030</td>
<td>0.032</td>
<td>0.031</td>
<td>0.037</td>
<td>0.036</td>
<td>0.037</td>
<td>0.024</td>
<td>0.024</td>
</tr>
<tr>
<td>Cu</td>
<td>0.055</td>
<td>0.061</td>
<td>0.058</td>
<td>0.243</td>
<td>0.247</td>
<td>0.245</td>
<td>0.186</td>
<td>0.188</td>
<td>0.187</td>
<td>0.294</td>
<td>0.297</td>
</tr>
<tr>
<td>Ni</td>
<td>0.023</td>
<td>0.026</td>
<td>0.024</td>
<td>0.081</td>
<td>0.084</td>
<td>0.083</td>
<td>0.064</td>
<td>0.063</td>
<td>0.063</td>
<td>0.097</td>
<td>0.097</td>
</tr>
<tr>
<td>Cr</td>
<td>0.034</td>
<td>0.035</td>
<td>0.035</td>
<td>0.439</td>
<td>0.415</td>
<td>0.412</td>
<td>0.015</td>
<td>0.015</td>
<td>0.015</td>
<td>0.118</td>
<td>0.119</td>
</tr>
<tr>
<td>V</td>
<td>0.000</td>
<td>0.003</td>
<td>0.001</td>
<td>0.005</td>
<td>0.006</td>
<td>0.006</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.012</td>
<td>0.011</td>
</tr>
<tr>
<td>Mo</td>
<td>0.063</td>
<td>0.072</td>
<td>0.068</td>
<td>0.063</td>
<td>0.075</td>
<td>0.069</td>
<td>0.072</td>
<td>0.073</td>
<td>0.072</td>
<td>0.083</td>
<td>0.081</td>
</tr>
<tr>
<td>Ti</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.008</td>
<td>0.005</td>
<td>0.007</td>
<td>0.003</td>
<td>0.005</td>
<td>0.004</td>
<td>0.022</td>
<td>0.023</td>
</tr>
<tr>
<td>Al</td>
<td>0.015</td>
<td>0.014</td>
<td>0.015</td>
<td>0.033</td>
<td>0.019</td>
<td>0.026</td>
<td>0.014</td>
<td>0.024</td>
<td>0.019</td>
<td>0.018</td>
<td>0.017</td>
</tr>
<tr>
<td>Nb</td>
<td>0.000</td>
<td>0.001</td>
<td>0.001</td>
<td>0.003</td>
<td>0.004</td>
<td>0.003</td>
<td>0.002</td>
<td>0.001</td>
<td>0.002</td>
<td>0.010</td>
<td>0.011</td>
</tr>
<tr>
<td>Co</td>
<td>0.007</td>
<td>0.007</td>
<td>0.007</td>
<td>0.012</td>
<td>0.012</td>
<td>0.012</td>
<td>0.007</td>
<td>0.006</td>
<td>0.007</td>
<td>0.014</td>
<td>0.013</td>
</tr>
<tr>
<td>Sn</td>
<td>0.003</td>
<td>0.004</td>
<td>0.003</td>
<td>0.029</td>
<td>0.030</td>
<td>0.030</td>
<td>0.009</td>
<td>0.009</td>
<td>0.009</td>
<td>0.011</td>
<td>0.011</td>
</tr>
<tr>
<td>B</td>
<td>0.002</td>
<td>0.003</td>
<td>0.002</td>
<td>0.008</td>
<td>0.004</td>
<td>0.006</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.002</td>
<td>0.022</td>
</tr>
<tr>
<td>Pb</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.011</td>
<td>0.013</td>
<td>0.012</td>
<td>0.001</td>
<td>0.000</td>
<td>0.001</td>
<td>0.011</td>
<td>0.009</td>
</tr>
</tbody>
</table>
Table 4.4 Elemental analysis of samples from bucket four

<table>
<thead>
<tr>
<th>Elements</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>Avg</td>
<td>1</td>
<td>2</td>
<td>Avg</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Fe</td>
<td>98.114</td>
<td>98.120</td>
<td>98.117</td>
<td>96.994</td>
<td>97.021</td>
<td>97.007</td>
<td>97.810</td>
<td>97.816</td>
</tr>
<tr>
<td>C</td>
<td>0.184</td>
<td>0.186</td>
<td>0.185</td>
<td>0.351</td>
<td>0.350</td>
<td>0.351</td>
<td>0.164</td>
<td>0.176</td>
</tr>
<tr>
<td>Mn</td>
<td>0.058</td>
<td>0.059</td>
<td>0.059</td>
<td>0.10</td>
<td>0.104</td>
<td>0.102</td>
<td>0.123</td>
<td>0.124</td>
</tr>
<tr>
<td>P</td>
<td>0.056</td>
<td>0.057</td>
<td>0.057</td>
<td>0.059</td>
<td>0.058</td>
<td>0.058</td>
<td>0.025</td>
<td>0.021</td>
</tr>
<tr>
<td>S</td>
<td>0.050</td>
<td>0.050</td>
<td>0.050</td>
<td>0.042</td>
<td>0.041</td>
<td>0.041</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>Si</td>
<td>0.027</td>
<td>0.028</td>
<td>0.027</td>
<td>0.013</td>
<td>0.013</td>
<td>0.013</td>
<td>0.021</td>
<td>0.020</td>
</tr>
<tr>
<td>Cu</td>
<td>0.108</td>
<td>0.110</td>
<td>0.109</td>
<td>0.364</td>
<td>0.340</td>
<td>0.367</td>
<td>0.189</td>
<td>0.188</td>
</tr>
<tr>
<td>Ni</td>
<td>0.034</td>
<td>0.033</td>
<td>0.033</td>
<td>0.082</td>
<td>0.083</td>
<td>0.083</td>
<td>0.036</td>
<td>0.035</td>
</tr>
<tr>
<td>Cr</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.127</td>
<td>0.123</td>
<td>0.125</td>
<td>0.032</td>
<td>0.032</td>
</tr>
<tr>
<td>V</td>
<td>0.027</td>
<td>0.025</td>
<td>0.026</td>
<td>0.004</td>
<td>0.005</td>
<td>0.005</td>
<td>0.006</td>
<td>0.006</td>
</tr>
<tr>
<td>Mo</td>
<td>0.067</td>
<td>0.068</td>
<td>0.068</td>
<td>0.084</td>
<td>0.082</td>
<td>0.083</td>
<td>0.077</td>
<td>0.073</td>
</tr>
<tr>
<td>Ti</td>
<td>0.003</td>
<td>0.002</td>
<td>0.003</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.085</td>
<td>0.083</td>
</tr>
<tr>
<td>Al</td>
<td>0.015</td>
<td>0.015</td>
<td>0.015</td>
<td>0.019</td>
<td>0.016</td>
<td>0.017</td>
<td>0.034</td>
<td>0.034</td>
</tr>
<tr>
<td>Nb</td>
<td>0.004</td>
<td>0.002</td>
<td>0.003</td>
<td>0.003</td>
<td>0.004</td>
<td>0.003</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>Co</td>
<td>0.012</td>
<td>0.009</td>
<td>0.011</td>
<td>0.010</td>
<td>0.009</td>
<td>0.009</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>Sn</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.019</td>
<td>0.020</td>
<td>0.019</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>B</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td>Pb</td>
<td>0.007</td>
<td>0.003</td>
<td>0.005</td>
<td>0.006</td>
<td>0.007</td>
<td>0.006</td>
<td>0.012</td>
<td>0.013</td>
</tr>
</tbody>
</table>
4.2 ELEMENTAL ANALYSIS ON FIRST BATH

From a total electric furnace weight of 23.4tons of melted scraps, Table 4.5 and Table 4.6 shows the elemental analysis done on the sample from the first bath and the results of the theoretical melting charge calculations respectively.

Table 4.5 Elemental results of the first bath sampled

<table>
<thead>
<tr>
<th>Elements</th>
<th>Fe</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt%</td>
<td>97.658</td>
<td>0.216</td>
<td>0.255</td>
<td>0.046</td>
<td>0.040</td>
<td>0.012</td>
<td>0.217</td>
<td>0.092</td>
<td>0.122</td>
</tr>
</tbody>
</table>

Table 4.6 Results of the melting charge calculation

<table>
<thead>
<tr>
<th>Total electric furnace weight = 23.4tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buckets</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>Total weight of element in electric furnace, tons</td>
</tr>
<tr>
<td>Element in electric furnace, wt%</td>
</tr>
</tbody>
</table>
In comparing the results of Table 4.5 and Table 4.6, it was realized that the values obtained from the theoretical charge calculation was close to the result of the tested sample. This can be based on the sampling, as a few scraps were taken out of the many. Using the MATLAB R2013A software, the acquired values were inputted into the corresponding cells to deliver
the results from the procedure. The calculated value tallied exactly with the results from the melting charge calculation as shown as Figure 4.1.

Figure 4.1 Results of MATLAB computation for the first bath
Results from Table 4.6 above showed that the composition of Manganese (Mn), Silicon (Si) and Chromium (Cr) according to ASTM A615/A615M were not in range to produce the required product. This may be due losses by the formation of oxides since melting was exposed to the atmosphere. Table 4.7 shows the compositions of the final product after ferrosilicon, ferromanganese and ferrochromium was added to the bath to increase the compositions of Manganese (Mn), Silicon (Si) and Chromium (Cr) to the desired composition. Figure 4.4 shows the computation of the final elemental results to be expected.
for the final product. The MATLAB R2013A was also used to calculate for the amount of needed additions with known compositions of the raw material to be added.

**Table 4.7 Elemental analysis of the final product**

<table>
<thead>
<tr>
<th>Elements</th>
<th>Fe</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt%</td>
<td>98.021</td>
<td>0.288</td>
<td>0.767</td>
<td>0.046</td>
<td>0.040</td>
<td>0.231</td>
<td>0.217</td>
<td>0.092</td>
<td>0.244</td>
</tr>
</tbody>
</table>

![A graph of wt% composition against elements](image)

**Figure 4.3 A graph showing MATLAB and Experimental results**
Results from the MATLAB R2013A computation showed hopeful feedback as it was in range with the elemental test results of the final product.

**Figure 4.4 results of MATLAB computation of composition of final product**
CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The feedback from the comparison of the various results to the results of the MATLAB R2013A proves that the interface created was functional. If the display of results from MATLAB R2013A computation of the first bath does not meet the required product specifications, additions come into consideration to compensate for the specified elements of lower concentrations. With the case of higher concentrations of the required composition, a process called lancing (a process of introducing Oxygen through lancing pipes to react with the element to form oxides, which in turn evaporates from the furnace) is employed. The dynamic of ferrous scraps are vast and complex, therefore scraps of similar characteristics in composition should be used for production. From this study, it was realized the main compositions of focus were Iron (Fe), Carbon (C), Manganese (Mn), Silicon (Si), Copper (Cu), Nickel (Ni) and Chromium (Cr). But the software developed is purposed to be used by a wide range of recycling companies. In conclusion to this study, from the results obtained, the aim to computerize charge calculation for ferrous metals was accomplished as well as the objectives to sample ferrous metal scraps from different location, to develop mathematical equation for determine specific composition, to develop mathematical codes and interface for calculating the amount and composition of scraps and to validate the MATLAB R2013A codes with experimental results was successfully achieved.
5.2 RECOMMENDATIONS

Although the use of the MATLAB R2013A software showed close results when compared to the tested results with the few sampled scraps, it is recommended that a wide range of scraps be sampled and tested to achieve a more accurate result. Based on current knowledge of ferrous alloys a wide range of element was used but it is recommended that the software be updated day in and day out as new ferrous alloys of different element may be discovered. The development of the interface using MATLAB R2013A software was limited to the use on recycling of ferrous metals but based on the software’s complexity an interface can be developed to incorporate recycling of non-ferrous metals. This can be done in the future by Material or Metallurgical Engineering final year students.
REFERENCES


11. An Introduction to Metal Recycling


APPENDICES

Appendix A

Table 3.0.1 results of melting charge calculation

<table>
<thead>
<tr>
<th>Buckets</th>
<th>Weight, tons</th>
<th>Composition of elements, wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fe</td>
<td>C</td>
</tr>
<tr>
<td>1</td>
<td>5.85</td>
<td>94.647</td>
</tr>
<tr>
<td>2</td>
<td>6.12</td>
<td>97.477</td>
</tr>
<tr>
<td>3</td>
<td>5.96</td>
<td>97.896</td>
</tr>
<tr>
<td>4</td>
<td>5.47</td>
<td>98.053</td>
</tr>
<tr>
<td></td>
<td>Total weight of element in electric furnace, tons</td>
<td>22.702</td>
</tr>
<tr>
<td></td>
<td>Element in electric furnace, wt%</td>
<td>97.01</td>
</tr>
</tbody>
</table>

Table 4.0.2 Elemental results of the first bath sampled

<table>
<thead>
<tr>
<th>Elements</th>
<th>Fe</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt%</td>
<td>97.658</td>
<td>0.216</td>
<td>0.255</td>
<td>0.046</td>
<td>0.040</td>
<td>0.012</td>
<td>0.217</td>
<td>0.092</td>
<td>0.122</td>
</tr>
</tbody>
</table>

Table 4.0.3 Elemental analysis of the final product

<table>
<thead>
<tr>
<th>Elements</th>
<th>Fe</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt%</td>
<td>98.021</td>
<td>0.288</td>
<td>0.767</td>
<td>0.046</td>
<td>0.040</td>
<td>0.231</td>
<td>0.217</td>
<td>0.092</td>
<td>0.244</td>
</tr>
</tbody>
</table>
Table 4.0.4 Results of MATLAB computation for the first bath

<table>
<thead>
<tr>
<th>Composition of Elements (wt%)</th>
<th>Late additions</th>
<th>Total</th>
<th>Late additions</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>99.69</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
</tr>
<tr>
<td>C</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Si</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>P</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Al</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Mn</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Cr</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Ni</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Cu</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Co</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Wt%</td>
<td>99.00</td>
<td>1.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Note: The table shows the composition of elements in the first bath, with the late additions and total weight of components in parentheses.
### Table 4.0.5: Results of MATLAB Computation of Composition of Final Product

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>0.0123</td>
</tr>
<tr>
<td>Fe</td>
<td>0.0132</td>
</tr>
<tr>
<td>Ni</td>
<td>0.0145</td>
</tr>
<tr>
<td>Ti</td>
<td>0.0156</td>
</tr>
<tr>
<td>Ni</td>
<td>0.0167</td>
</tr>
<tr>
<td>Fe</td>
<td>0.0178</td>
</tr>
<tr>
<td>Cu</td>
<td>0.0189</td>
</tr>
<tr>
<td>Fe</td>
<td>0.0200</td>
</tr>
<tr>
<td>Cr</td>
<td>0.0211</td>
</tr>
<tr>
<td>Fe</td>
<td>0.0222</td>
</tr>
<tr>
<td>Cu</td>
<td>0.0233</td>
</tr>
</tbody>
</table>

**Note:** The above table represents the composition of the final product, calculated using MATLAB. The values are given in weight percentages (wt%).
% --- Executes on button press in pushbutton1.
function pushbutton1_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
A = str2num(get(handles.A,'string')); % A is the total electric furnace weight
W = str2num(get(handles.W,'string')); % W is the weight of bucket 1
X = str2num(get(handles.X,'string')); % X is the weight of bucket 2
Y = str2num(get(handles.Y,'string')); % Y is the weight of bucket 3
Z = str2num(get(handles.Z,'string')); % Z is the weight of bucket 4
Fe_w = str2num(get(handles.Fe_w,'string')); % Fe_w represent iron composition in bucket 1
Fe_x = str2num(get(handles.Fe_x,'string')); % Fe_x represent iron composition in bucket 2
Fe_y = str2num(get(handles.Fe_y,'string')); % Fe_y represent iron composition in bucket 3
Fe_z = str2num(get(handles.Fe_z,'string')); % Fe_z represent iron composition in bucket 4
C_w = str2num(get(handles.C_w,'string')); % C_w represent carbon composition in bucket 1
C_x = str2num(get(handles.C_x,'string')); % C_x represent carbon composition in bucket 2
C_y = str2num(get(handles.C_y,'string')); % C_y represent carbon composition in bucket 3
C_z = str2num(get(handles.C_z,'string')); % C_z represent carbon composition in bucket 4
Mn_w = str2num(get(handles.Mn_w,'string')); % Mn_w represent manganese composition in bucket 1
Mn_x = str2num(get(handles.Mn_x,'string')); % Mn_x represent manganese composition in bucket 2
Mn_y = str2num(get(handles.Mn_y,'string')); % Mn_y represent manganese composition in bucket 3
Mn_z = str2num(get(handles.Mn_z,'string')); % Mn_z represent manganese composition in bucket 4
P_w = str2num(get(handles.P_w,'string')); % P_w represent phosphorus composition in bucket 1
P_x = str2num(get(handles.P_x,'string')); % P_x represent phosphorus composition in bucket 2
P_y = str2num(get(handles.P_y,'string')); % P_y represent phosphorus composition in bucket 3
P_z = str2num(get(handles.P_z,'string')); % P_z represent phosphorus composition in bucket 4
Si_w = str2num(get(handles.Si_w,'string')); % Si_w represent silicon composition in bucket 1
Si_x = str2num(get(handles.Si_x,'string')); % Si_x represent silicon composition in bucket 2
Si_y = str2num(get(handles.Si_y,'string')); % Si_y represent silicon composition in bucket 3
Si_z = str2num(get(handles.Si_z,'string')); % Si_z represent silicon composition in bucket 4
Cu_w = str2num(get(handles.Cu_w,'string')); % Cu_w represent copper composition in bucket 1
Cu_x = str2num(get(handles.Cu_x,'string')); % Cu_x represent copper composition in bucket 2
Cu_y = str2num(get(handles.Cu_y,'string')); % Cu_y represent copper composition in bucket 3

composition in bucket 3
Cu_z = str2num(get(handles.Cu_z,'string')); % P_z represent copper
composition in bucket 4
Ni_w = str2num(get(handles.Ni_w,'string')); % Ni_w represent nickel
composition in bucket 1
Ni_x = str2num(get(handles.Ni_x,'string')); % Ni_x represent nickel
composition in bucket 2
Ni_y = str2num(get(handles.Ni_y,'string')); % Ni_y represent nickel
composition in bucket 3
Ni_z = str2num(get(handles.Ni_z,'string')); % Ni_z represent nickel
composition in bucket 4
Cr_w = str2num(get(handles.Cr_w,'string')); % Cr_w represent chromium
composition in bucket 1
Cr_x = str2num(get(handles.Cr_x,'string')); % Cr_x represent chromium
composition in bucket 2
Cr_y = str2num(get(handles.Cr_y,'string')); % Cr_y represent chromium
composition in bucket 3
Cr_z = str2num(get(handles.Cr_z,'string')); % Cr_z represent chromium
composition in bucket 4
Ti_w = str2num(get(handles.Ti_w,'string')); % Ti_w represent titanium
composition in bucket 1
Ti_x = str2num(get(handles.Ti_x,'string')); % Ti_x represent titanium
composition in bucket 2
Ti_y = str2num(get(handles.Ti_y,'string')); % Ti_y represent titanium
composition in bucket 3
Ti_z = str2num(get(handles.Ti_z,'string')); % Ti_z represent titanium
composition in bucket 4
Al_w = str2num(get(handles.Al_w,'string')); % Ti_w represent aluminium
composition in bucket 1
Al_x = str2num(get(handles.Al_x,'string')); % Ti_x represent aluminium
composition in bucket 2
Al_y = str2num(get(handles.Al_y,'string')); % Ti_y represent aluminium
composition in bucket 3
Al_z = str2num(get(handles.Al_z,'string')); % Ti_z represent aluminium
composition in bucket 4
a_w = (Fe_w/100)*W;
a_x = (Fe_x/100)*X;
a_y = (Fe_y/100)*Y;
a_z = (Fe_z/100)*Z;
b_w = (C_w/100)*W;
b_x = (C_x/100)*X;
b_y = (C_y/100)*Y;
b_z = (C_z/100)*Z;
d_w = (Mn_w/100)*W;
d_x = (Mn_x/100)*X;
d_y = (Mn_y/100)*Y;
d_z = (Mn_z/100)*Z;
e_w = (P_w/100)*W;
e_x = (P_x/100)*X;
e_y = (P_y/100)*Y;
e_z = (P_z/100)*Z;
f_w = (Si_w/100)*W;
f_x = (Si_x/100)*X;
f_y = (Si_y/100)*Y;
f_z = (Si_z/100)*Z;
g_w = (Cu_w/100)*W;
g_x = (Cu_x/100)*X;
g_y = (Cu_y/100)*Y;
g_z = (Cu_z/100)*Z;
h_w = (Ni_w/100)*W;
h_x = (Ni_x/100)*X;
h_y = (Ni_y/100)*Y;
h_z = (Ni_z/100)*Z;
i_w = (Cr_w/100)*W;
i_x = (Cr_x/100)*X;
i_y = (Cr_y/100)*Y;
i_z = (Cr_z/100)*Z;
j_w = (Ti_w/100)*W;
j_x = (Ti_x/100)*X;
j_y = (Ti_y/100)*Y;
j_z = (Ti_z/100)*Z;
k_w = (Al_w/100)*W;
k_x = (Al_x/100)*X;
k_y = (Al_y/100)*Y;
k_z = (Al_z/100)*Z;

l = a_w+a_x+a_y+a_z; % l is the total amount of iron
m = b_w+b_x+b_y+b_z; % m is the total amount of carbon
n = d_w+d_x+d_y+d_z; % n is the total amount of Manganese
o = e_w+e_x+e_y+e_z; % o is the total amount of phosphorus
q = f_w+f_x+f_y+f_z; % q is the total amount of Silicon
r = g_w+g_x+g_y+g_z; % r is the total amount of copper
s = h_w+h_x+h_y+h_z; % s is the total amount of nickel
t = i_w+i_x+i_y+i_z; % t is the total amount of chromium
u = j_w+j_x+j_y+j_z; % u is the total amount of titanium
v = k_w+k_x+k_y+k_z; % v is the total amount of aluminum
aa = (l/A)*100; % aa is the final composition of iron
bb = (m/A)*100; % bb is the final composition of carbon
cc = (n/A)*100; % cc is the final composition of Manganese
dd = (o/A)*100; % dd is the final composition of phosphorus
eee = (q/A)*100; % eee is the final composition of silicon
ff = (r/A)*100; % ff is the final composition of copper
gg = (s/A)*100; % gg is the final composition of nickel
hh = (t/A)*100; % hh is the final composition of chromium
ii = (u/A)*100; % ii is the final composition of titanium
jj = (v/A)*100; % jj is the final composition of Aluminum

a_a = num2str(aa);
b_b = num2str(bb);
c_c = num2str(cc);
d_d = num2str(dd);
e_e = num2str(ee);
f_f = num2str(ff);
g_g = num2str(gg);
h_h = num2str(hh);
i_i = num2str(ii);
j_j = num2str(jj);
set(handles.Compo1,'string',a_a);
set(handles.Compo2,'string',b_b);
set(handles.Compo3,'string',c_c);
set(handles.Compo4,'string',d_d);
set(handles.Compo5,'string',e_e);
set(handles.Compo6,'string',f_f);
set(handles.Compo7,'string',g_g);
set(handles.Compo8,'string',h_h);
set(handles.Compo9,'string',i_i);
set(handles.Compo10,'string',j_j)