PRODUCTION AND WELD JOINT PERFORMANCE EVALUATION OF ARC WELDING ELECTRODES FROM DANA ROLLING MILL SCALES

BY

OLAWALE ADEREMI OWOLABI

DEPARTMENT OF MECHANICAL ENGINEERING,

AHMADU BELLO UNIVERSITY, ZARIA

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BY

Olawale Aderemi OWOLABI, B.Tech. (LAUTECH) 2010
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AUGUST, 2014

DECLARATION

I declare that the work in this thesis entitled "PRODUCTION AND WELD JOINT PERFORMANCE EVALUATION OF ARC WELDING ELECTRODES FROM DANA ROLLING MILL SCALES" was carried out by me in the Department of Mechanical Engineering under the supervision of Prof.C.O Folayan and Dr. M. Dauda. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree in this university or any other Institution.

OWOLABI, Olawale Aderemi _____ _____

Signature Date

CERTIFICATION

This thesis entitled "PRODUCTION AND WELD JOINT PERFORMANCE EVALUATION OF ARC WELDING ELECTRODES FROM DANA ROLLING MILL SCALES" by Olawale Aderemi OWOLABI, meets the regulations governing the award of Master of Science (M.Sc) degree in Mechanical Engineering of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

Prof.C.O Folayan Chairman, Supervisory Committee	Signature	Date
Dr. M. Dauda Member, Supervisory Committee	Signature	Date
Dr. M. Dauda Head of Department	Signature	Date
Prof. A.A. Joshua Dean, School of Postgraduate Studies	Signature	Date

DEDICATION

To our mothers, they are the cradle of the world.

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ABSTRACT

This study explored the possibility of producing Iron Oxide based arc welding electrodes using mill scales from Dana rolling mill. The performance of the weld joints using the produced electrodes and a foreign electrode was also examined. It is estimated that 4000-5000 tons of mill scales are produced annually without any immediate industrial application. The mill scales were collected prepared and analyzed using the Oxford 800 X Supreme XRF machine. The report of the analysis shows the presence of predominantly Iron Oxide, which is an important constituent in electrode coating. The flux compositions were generated using the Hadamard multivariate chemical model. Using this model, twelve different flux compositions emerged within given ranges of the constituent flux elements. Four of the flux compositions were used to produce electrodes using sodium silicate as binder. The electrodes were produced manually by means of a wooden mould. The produced electrodes (E6020, E6027, E6024 and E6030) and a foreign electrode were used to carry out weld on some prepared samples. The welded joints were tested for tensile, hardness, and impact tests. The results of the tests conducted on all the welded joints using the produced electrodes and the foreign electrode shows that all the produced electrodes with the exception of electrode type E6030 compete well with the foreign electrode (Oerlikon). Electrode type E6020 gave the highest tensile and hardness test results of 453N/mm^2 and 457.1N respectively. The maximum impact energy was found to be 94.9 joules on the sample welded with the electrode type E6030. The micrographs of the weld joint using electrode type E6027 revealed a coarse pearlite (black matrix) and an elongated ferrite (white matrix). To this end, this study established the need to maximize the use of mill scales (an industrial waste) for the production of arc welding electrodes and by so doing conversion of waste to worth would have been achieved.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Overview of Welding

Welding is a production or a fabrication process of joining two or more materials together, usually metals or thermoplastics to achieve coalescence. Welding is performed by the application of heat and pressure to melt the work piece together often with the addition of filler material to form a pool of molten material which form the welded joint after solidification (www.metal_processing/welding.cfm). Many welding processes are accomplished by heat alone, with no pressure applied; others by a combination of heat and pressure; and still others by pressure alone, with no external heat applied.

Welding processes are used to produce joints with properties similar to those of materials being joined, these materials are called parent materials.Welding process usually involves raising the materials at the joint to elevated temperature (Ibhadode, 2001). There are three main components to create a weld and these components are:

1 A heat source: A heat source is an important component in the creation of weld, a heat source include an electric arc, a flame, pressure or friction. However, the most common heat source is the electric arc.

2 Shielding: Shielding is the use of gas or another substance to protect the weld from atmospheric contamination of the molten weld.

3 Filler material: They are used in joining two pieces of materials together, usually metals.

Welding is extensively used in fabrication and has found application as an alternative method for casting or forging and as a replacement for bolted and riveted joints. It is also used as a repair medium, for example to reunite metals at a crack, to build up a small part that has

broken off, such as gear tooth or to repair a worn surface such as a bearing surface(Khurmi and Gupta, 2005).

The objective of welding is to join pieces of metals together by means of suitable heatsource(Lancaster, 1993).Advantages of welding as a joining process include high joint efficiency, simple set up, flexibility and low fabrication cost (Armentani *et al.,* 2007).

Today, many process of welding have been developed and probably there is no industry which is not using welding process in the fabrication of its product in one form or other, hence welding process can be broadly classified, as fusion welding and solid phase welding.

1.1.1 Types of welding

Fusion welding**:** This type of welding operation involves joining two pieces of metals together by the application of heat. The two materials or parts to be joined are placed together and heated, often with the addition of filler metal, until they melt and solidify on cooling. Types of fusion welding include electric arc welding, electrical resistance welding, gas welding etc.

Solid phase welding: This type of welding operation is achieved by bringing the clean faces of the materials to be joined into intimate contact to produce a metallic bond. Solid phase welding can be performed with or without the application of heat. However pressure application is important so as to induce plastic flow (Jain, 2008). Heat or temperature distribution that occurs during welding greatly affects the microstructure of the weld, and hence the weld properties (Kou, 2003). At the end of a welding operation, the complete weld metal and metal pieces having been joined should now to all intents, be one piece of metal (Somksy, 1986).

After welding, a number of distinct regions are identified in the weld area, the weld itself is called the fusion zone, and it is a portion where the filler metal was laid during the welding process. The property of the fusion zone is dependent on the filler metal used and its

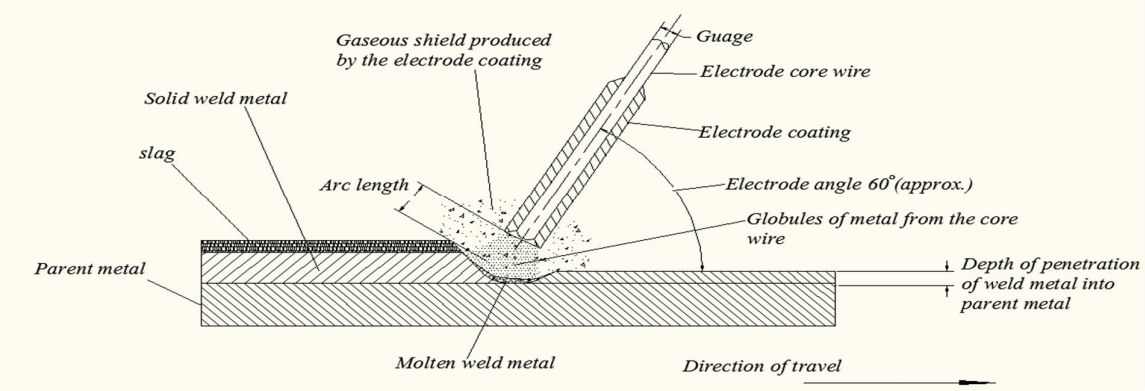
compatibility with the base materials, the fusion zone is surrounded by the heat affected zone. The heat affected zone is the area that had its microstructure and properties altered as a result of heat during welding. The fusion zone and the heat affected zone microstructure properties depend on the base materials behavior when subjected to heat(Cary and Helzer, 2005). The properties and microstructure of heat affected zone depends on the rate of heat input and cooling and also the temperature at which the zone is raised during welding (Kalpakjian and Schmid, 2006).

Arc welding is one of the several fusion processes of joining metals. By the application of intense heat, metal at the joint between two parts are melted and caused to intermix directly or, more commonly with an intermediate molten filler metal, which when solidify a metallurgical bond results which is called weldment. In arc welding, the intense heat needed to melt the metal is produced by an electric arc, and the electric arc is formed between the work pieces to be welded and an electrode that is manually or mechanically moved along the joint (Hwaiyu, 2004). An electric arc is obtained when an electric current flows between two electrodes separated by a short distance, in electric arc welding, one electrode is the welding rod and the other is the work piece being welded (Ibhadode, 2001).

1.1.2 Types of arc welding

- Shielded metal arc welding: Shielded metal arc welding is one of the oldest arc welding processes. It is also the simplest and perhaps the most versatile arc welding process used for welding ferrous based metals, because of its flexibility, simplicity and accessibility to difficult locations (Ibhadode, 2001). Shielded metal arc welding process was invented in 1907 and is still being widely used today (Kay et al., 2010). It is a manual arc welding process using coated electrodes. Since the electrodes melt and join the work piece, shielded arc welding is classed under consumable arc welding method. The coating on the electrode burns along with the core wire and produces a dense smoke which covers or shield the weld pool and thus

prevent oxidation and absorption of nitrogen by the metal, and this type welding process is used for steel fabrication. Fig 1.1 shows a shielded metal arc welding process with a consumable electrode that melts and produce gaseous shield which prevent oxidation of the molten weld metal.



Fig;1.1: Shielded metal arc welding (Source; Parking and Flood, 1974).

- Submerged arc welding: This is an automatic process developed primarily for the production of high quality butt welds in thicker steel plates. Submerged arc welding is different from other arc welding processes in a way that a blanket of fusible, granular material (flux) which consists of lime, silica, manganese oxide, calcium fluoride and other compounds is used for shielding the arc and the molten metal. The process provides very high deposition rate and a deep penetration and it is used for welding pressure vessels and high pressure pipes.
- Gas tungsten arc welding: Inert gases are used to keep contaminants away from contacting the metal. Gas tungsten arc welding is faster, produces cleaner welds and can weld metals considered to be difficult or impossible to weld, it uses a non-consumable electrode and is used for welding stainless and light gauge materials. The equipment needed for gas tungsten arc welding are welding torch, welding power source and a source of inert gas.
- Gas metal arc welding: This welding operation is performed using direct current reverse polarity as it gives both good cleaning action and fast filler metal deposition rate. Gas

metal arc welding electrode uses a consumable electrode which is fed through the electrode holder in to the arc and at the same speed the electrode is melted and deposited in the weld.

- Plasma arc welding: Plasma is defined as a gas heated to at least practically ionized condition, enabling it to conduct an electric current. Plasma arc refers to a constricted electric arc which is achieved by passing through the water cooled orifice. Plasma arc is made to pass through a small hole in a nozzle which surrounds a non-consumable electrode. This type of welding process has a small heat affected zone and has high welding speed. It is used for welding stainless steel, nickel alloys, refractory and metals in aerospace.
- Electron beam welding: In this process the metal to be joined are brought rather close together and a concentrated stream of high energy electron emitted from a high voltage (150kv) electrode gun is directed on to the surface of the work piece, causing fusion to take place. This welding process is usually performed in the vacuum and thus no flux is required, as there is no air present to contaminate the weld metal. Electron beam welding find application in aerospace and automotive industries.

1.1.3 Development of welding

Welding as we know it today was not invented until the late 19^{th} century. The earliest form of welding was the forge welding. Forge welding was used by blacksmiths to join metals by heating and pounding until bonding occurred. During the late 1800s gas welding, arc welding with carbon and resistance welding were developed. The advances in welding continued with the invention of metal electrodes which provided a more stable arc in the year 1900s.

World War1 brought a tremendous demand for a reliable and also an inexpensive joining method throughout the United States. Many companies sprang up in America and Europe to manufacture welding machines to meet the requirement, its first important use was in making repairs for many equipment being chiefly as a repair and maintenance tool, arc

welding has gradually expanded until it now constitutes an important method of fabrication in practically every industry that uses metal. Immediately after the war the America welding society was established to promote welding and other type of allied processes. During the 1900s automatic welding was introduced and various types of welding electrodes were developed. Between the year 1920 and 1960, there had been a huge breakthrough in welding with the development of several welding techniques, such as shielded manual arc welding, stud welding, gas tungsten arc welding, electro slag welding, plasma arc welding etc. Most recent was the development of friction stir welding, electron beam welding, laser beam welding and electromagnetic pulse welding (Cary, 1998).

Welding has found application in the fabrication of different components, such as pressure vessels, boilers, storage tanks, turbines etc. Today, welding is used in ship building, construction of bridges, and joining automobile parts.

1.2 Statement of Problem

Examination of mill scales from Dana steel rolling mill in Nigeria, using the Oxford 800 X supreme X-ray florescence machine shows the presence of predominantly Iron Oxide (Fe_2O_3) which constitute more than eighty percent of the total constituent elements of mill scales and which is one of the most important constituents of covering on mild steel arc welding electrodes, serving primarily as slag formers. It is estimated that 4000-5000 tons of mill scales are produced annually with no immediate industrial application (Folayan *et al*., 1992). Hence mill scales are relatively available and cheap compared to other type of slag formers like titanium oxide ($Ti0_2$). As a result of the utilization of these waste (mill scales) there will be actually little cost attached to the main raw material for the production of the electrodes, hence the unit cost of the electrodes to be produced will be affordable. Moreover the diffusible hydrogen content of weld created by rutile electrodes and most especially the cellulosic (foreign) type of electrode is always high, hence the danger of hydrogen

embrittlement of base metal is imminent and there is great possibility of inducing hydrogen cracking in the weld, as the presence of hydrogen in the weld can lead to the creation of hydrogen porosity, which reduces its ductility, strength, and fatigue resistance. Hydrogen can diffuse out of the iron lattice when in solid state resulting in lowering of the mechanical properties of the weld and increasing the tendency to cracking. Therefore use of mill scales as main constituent in the production of Iron oxide based arc welding electrodes prevents the presence of hydrogen build up and its negative consequences. Plate I shows the picture of the Oxford 800 X Supreme XRF machine used for the elemental analysis of mill scales.



Plate I: Oxford 800 X supreme XRF machine (Chemistry department ABU, Zaria).

1.3 Present Research

The importation of electrodes has over the years undermined our efforts in the search for local materials for the production of arc welding electrodes, perhaps due to the belief that the materials for the production of arc welding electrodes locally are not available in Nigeria. Therefore, this research has been conducted to investigate the feasibility of the production of arc welding electrodes using mill scales from Dana rolling mill, and to evaluate the performance of welded joint using the produced electrodes and a foreign electrode. The mill scales was collected and analyzed to determine the percentage composition of Iron oxide present in it. The produced electrodes using mill scales and other materials were used to make

welds on different samples of mild steel and the mechanical properties such as tensile strength, hardness, impact and the metallographic examination of these weldments using the produced electrodes were obtained and compared with welded joints using the foreign electrode.

1.4 Aim and Objectives

This research work is aimed at utilizing mill scales from Dana steel rolling mill for the production of arc welding electrodes and to evaluate and compare the performance of welded joints using the produced electrodes and a foreign electrode.

The specific objectives are:

1. To obtain mill scales from Dana steel rolling mill, prepare and analyze the mill scales, to determine the constituent elements.
2. To formulate a new flux composition for the electrodes to be produced
3. To produce various types of Iron oxide electrodes such as E6020, E6027, E6024, and E6030 by varying the composition of the constituent elements.
4. To determine the welded joints performance of the electrodes produced and compare them with the foreign electrodes obtained in the market.
5. To carry out the microstructural analysis of the weldments.

1.5 Justification

In Nigeria, about nine-eight percent of manufacturers in the welding electrode industry have wound up, due to high production cost. The remaining two percent that manage to remain operational sell their coated electrodes at exorbitant prices(Achebo and Dagwa, 2009).Consequently there is need for importation of electrodes in to the country to augment for the shortage in the production of electrodes, as a result of this, a large chunk of our foreign exchange is being used in the importation of arc welding electrodes and as such, production of arc welding electrodes locally using mill scales will not only help us in conserving our foreign exchange, but also help us in developing the technology especially as the availability of the

locally produced electrodes has been on the decline in recent years, and in particular the low hydrogen electrode to be produced will be cheaper when compared to the ones obtained in the market.

1.6 Research Scope

This research work shall focus on the production of arc welding electrodes using mill scales as slag formers. The research will also ensure that the produced electrode are used to weld some specimen and the mechanical properties of the welds from the produced electrode will be compare with that of existing electrodes in the market.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Electrode Overview

Electrode is a specially prepared rod or wire that not only conducts electric current and sustain the arc, but also melts and supply the filler metal to the joint; as in the case of a consumable electrode (Hwaiyu, 2004). In arc welding, an electrode is used to conduct current through a work piece to fuse two pieces of materials together. Depending upon the process, an electrode is either consumable as in the case of shielded metal arc welding or non-consumable such as gas tungsten welding (Lincoln Electric, 2006).

Electrode is a metal in rod or wire form with baked minerals around it, which can also be referred to as filler wire used in electric arc welding to maintain the arc and at the same time supply molten metal. Electrode used in arc welding is basically made of steel core wire, and the covering(coating). Electrode can be bare, fluxed and can be heavy coated. Bare electrodes have limited applications as during welding operations, they are exposed to oxygen or nitrogen of the surrounding air which form non-metallic constituents and they are trapped in the rapidly solidifying weld metal, thereby decreasing the strength, and ductility of the weld metal. When bare electrodes are used, the weld appearance is poor, and there is difficulty of maintaining a stable arc. Bare electrodes are generally used for welding wrought iron. Improved weld may be obtained by applying light coating of flux on the rod using a dusting or washing process. The flux coatingon an electrode assists both in eliminating undesirable oxides and preventing their formation. The heavy coated electrodes are by far the most important and the most widely used (Jain, 2008).

Arc welding electrodes are identified using the American welding society numbering system. The E stands for electrode, next is a four digit number, the first two number of the

four digits indicates the maximum tensile strength in thousands of pounds per square inch (psi) of the weld that the rod will produce, the third digits indicates the position in which the electrode can be used, and the last two digits together indicates the type of coatings on the electrode and the welding current the electrode can be used with. The positions in which electrodes can be used are: 1- Flat, vertical and horizontal position, 2-Horizontal and flat, while 3-Flat position. The types of coatings are: Iron oxide coating, cellulosic coating, and rutile coating.

Fluxes are chemical compound which are composed of different minerals such as oxides, carbonates and fluorides used to prevent oxidation or the formation of oxides and other unwanted chemical reactions. Fluxes help to make welding easier and ensure making of a good and sound weld (Davies, 1972). Fluxes and their slags provide a blanket to protect the weld metal from the action of extraneous gases, flux can also perform cleaning, alloying actions and also produces shielding gas that prevents molten weld metal from oxidation (Jackson, 1973). Fluxes protect, prevents atmospheric oxidation and clean up welded joint chemically and reduces impurities in the metal joining processes (Parma, 2005).

The type of flux coating depends on the weld metal composition. Electrode coating facilitate striking the arc and also provide a stable arc. Coating on an electrode also provide gaseous shield, and prevents the oxidation of molten weld metal, a good flux covered electrode will produce a weld that has an excellent physical and chemical properties.

Commercially electrodes are available in 1.5-9.5mm diameter and 35-45mm in length, the diameter of an electrode is selected depending mainly on the thickness of the material to be joined, and the welding current. Diameter of an electrode controls penetration, the thicker the material to be welded the higher the current needed and the larger the electrode needed (Jain, 2011). The size of an electrode called the gauge is the diameter of the core wire and

does not include the flux coatings. Electrodes are available in the following different type of gauges, 16G, 14G, 12G, 10G, 8G, 6G and 4G, the smallest number refers to the largest diameter.

2.2 Types of Arc Welding Electrodes

There are two main types of arc welding electrodes. These are consumable electrodes(used in shielded manual metal arc welding) and non-consumable electrodes (used in plasma arc welding and tungsten inert gas welding).

2.2.1 Consumable electrodes

These types of electrodes slowly burns away with usage and are replaced when they become too short (50mm) for further use.

2.2.2 Non consumable electrodes

These types of electrodes do not burn away with usage, hence they last longer and can be used with a wider variety of metals, especially thicker metals. Non consumable electrodes are used with inert gas for shielding the arc.

2.3 Classification of Electrode Coatings

The principal difference between various types of electrodes is in their coatings and by varying the coatings it is possible to greatly alter the operating characteristics of electrodes (Davies, 1994). Electrode coating is composed of a mixture of various organic and inorganic materials, these materials are termed components and these components can be sub divided as follows (Jain, 2008).

2.3.1 Gas forming component

The gas forming components are organic materials, such as cellulose, starch and wood pulp. They form gas layer, thus isolating the weld zone from ambient air. Organic materials are present in much larger quantities in electrodes baked at low temperature.

2.3.2 Slag forming component

These are mineral silicates, these components constitute a slag, which by covering the molten metal prevent it from the surrounding atmosphere and also ensure gradual cooling of molten metal.

2.3.3 Reducing component

These are components that reduce the oxides that are likely to be formed during welding.

2.3.4 Stabilizing component

These also form slag. In the presence of arc, the component ionizes the zone between the electrode and the part to be welded, thus ensuring a stable burning arc.

2.3.5 Binding component

These components serves for binding other components, which make it possible to obtain a solid coating which adheres to the metal core, examples of these components are sodium silicates and potassium silicates (Jain, 2008).

2.4 Types of Electrode Coatings

There are four main types of electrode coating onwhich all mild steel and low alloy steel are based.

2.4.1 Gas shielded (cellulosic) electrode coating

These coatings contains over 30 percent organic materials mostly cellulose. In the arc, the coating decompose to give a large volume of shielding gas, such as hydrogen, carbon monoxide and carbon dioxide, These gasses shield the weld and also provide good weld metal properties.

2.4.2 Rutile electrode coating

The coating contains 50 percent titanium oxide (TiO_2) as minerals, this compound gives good arc stability and low operating voltage, so that it can be readily used with alternating current.

2.4.3 Iron oxide electrode coating

This coating is based on iron oxide, manganese oxide and associated silicates. Depending on other constituents of the coating, the high oxygen content can lead to a low carbon weld deposit of low strength or a well oxidized deposit with good strength and ductility. Because of its low operating voltage, the electrode is suitable for use with DC or AC. The electrode produce low spatter, high deposition rate and a good weld penetration.

2.4.4 Basic electrode coating

These electrodes are made up of calcium carbonates, fluorite, clay, asbestos and other minerals. They are also known as low hydrogen electrode, speed of deposition and weld penetration are high (Radhakrishnan, 2005).

2.5 Review of Related Researches

Ugoamadi(2010) worked on the production of manual metal arc welding electrodes using local raw materials. In the research, several flux samples of local raw materials were collected, their chemical compositions were determined and the results utilized in producing manual arc welding electrodes. The electrodes produced were used to carry out welds on mild steel

section. The basic characteristics test criteria for determining the performance of any electrodes were carried out, the sample of the weld metal were analyzed to determine the homogeneity of the chemical composition as a result of the flux coating, welded rod, and the base plate materials.It was observed that manganese based flux covered electrode (a local electrode) with tensile strength of 585.8N/mm^2 was able to compete effectively with titanium oxide based electrode(foreign electrode) with tensile strength of 606.7N/mm^2. The compositions of the flux coated electrode are complex and a wide variety of coatings were used to cater for different types of welding application. However, in all cases, the coating on an electrode is formulated to satisfy three main objectives: to form fusible slag, to stabilize the arc, and to produce an inert gas shielding during welding operation. The research was concluded by highlighting the need to maximize the use of local raw materials aimed at reducing the cost of importation of electrodes and thereby help in conserving the scarce foreign exchange. The research also affirmed that titanium oxide based electrode are able to yield the best performance in terms of yield strength and visual appearance because these foreign electrodes are produced with more ideal chemical composition, they also have the best ability to expel atmospheric oxygen from getting in contact with the weld bead, also the chances of slag inclusion, and porosity is very low in foreign electrodes.

Nwigbo*et al.,* (2012) formulated an arc welding flux with potassium enriched sodium silicate binder. In the research a new flux for metal arc welding was developed. The basic component falls under the category of rutile electrode. These include,titanium(iv)oxide, iron powder, cellulose, sodium silicate binder and other additives. One of the major components was technically and economically substituted. The more popular but expensive potassium silicate was replaced by the more readily available sodium silicate. For the newly chosenbinder to perform effectively well, it was enriched with potassium carbonate (potash). The flux formulation was not based on the old method of trial and error, but some mathematical

models, especially experimental design approach method was applied.Four major components, titanium oxide. Iron powder, cellulose, and sodium silicate binder enriched with potash were considered as the major contributing elements. The electrode produced from the formulated flux was used by some professional welders and their comment on the quality of the electrode was quite impressive. Test on the sample of the weldment showed that it can withstand a tensile strength up to 430N/mm^2. The Brinells hardness test value gave a maximum of 608N/mm^2. Also the nick break test revealed a good penetration, no slag inclusion; the monograph presented an acceptable grain structure. The research was concluded as follows:

1. The inclusion of potash in the formulation of welding flux provedun-harmful.

2. The sodium silicate binder gained some properties, as it compared favorably with the potassium silicate binder.

3. The micro properties of the metal upon which the sample was tested, did not show any unusual behavior.

4. The chemical analysis of the weld prepared by the use of use of the flux was another gain as the poisonous gas was not introduced in to the system.

Folayan *et al.,* (1992) worked on the production of E6020 arc welding electrodes. In the research it was made known that Iron oxide is an important constituent of the following types of arc welding electrodes: E6020, E6027, E7014, E7018, E7024, and E7028. Other elements required include cellulose, calcium carbonate, fluorspar, dolomite, titanium oxide, potassium titanate, feldspar, clay, silica, manganese oxide, ferrosilicon, ferromanganese, sodium silicate and potassium silicate. These constituents were mixed in various proportions by weight depending on the type of electrode to be produced .Iron oxide, sodium silicate, potassium silicate, ferromanganese, silica, cellulose, and clay which were mixed by weight 45, 15, 5, 20, 5, 5, 5 respectively were used to produce E6020 arc welding electrode by coating the mixture

on a core mild steel wire of diameter 3mm and having it in an oven at a controlled temperature of 150$^{oC.}$ In the research, typical functions of constituent elements of electrode covering include, alloying, binder, fluxing agent, arc stabilizer, deoxidizer, slag former and shielding gas.

The produced E6020 type arc welding electrodes were used to produce different types of joints such as plain butt, lap joint, single vee, and double vee welded joints using standard mild steel of specimen thickness 6mm. The welded mild steel specimens were then tested on Denison testing machine to obtain the strength and efficiency of the weld for the different joints. Table 2.1 presents the results obtained by testing the E6020 electrode produced.

Table 2.1: E6020 electrodes test results.

Type of Joint	Input Voltage (Volts)	Current Setting (Amps)	Welding Time(sec)		Yield PointN/mm^2		Efficiency of Weld (%)	
			Commercial	Produced	Commercial	Produced	Commercial	Produced
Lap	80	97	80	75	316.7	330	92.3	96
Butt	80	97	80	85	326.7	326.7	95.2	95.2
Single Vee	80	97	85	90	266.7	323.3	77.7	94
Double Vee	80	97	90	75	330	323.3	96	94
Plain					342.3			

Efficiency of a weld is the ratio of strength of the joint to the strength of an un-welded metal (Folayan *et al.,* 1992)

That is $\eta_w = \frac{\sigma_w}{\sigma_s}$ ..... (1)

Where η_w= weld efficiency

σ_w = strength of weld joint

σ_s = strength of an un-welded material.

Sample calculation:

For the lap joint using the produced electrode,

$$\eta_w = \frac{330}{343.2} \times \frac{100}{1} = 96\%$$

The research was concluded as follows:

1. Test results obtained by using the produced electrodes shows that the yield points for all the joints with the exception of single vee joint, compared very well with those obtained from commercial electrodes of the same gauge, and similarly with the exception of single vee joints the efficiencies of the weld of the produced electrodes were higher or equal to those obtained with commercially bought electrodes of the same gauge.
2. The welding time while welding with the produced electrodes at the same input voltage and current setting compared very well and in some cases it was even shorter than when commercially bought electrodes were used.

Achebo (2009) researched into development of composition of aluminum welding fluxes using statistical method. The research describes the process of developing a model that relates the shear stresses in a gas welded aluminum alloy weldment with the corresponding flux constituent elements that make up the composition. This model considering initial composition ranges, from where 13 flux compositions were formulated and their shear stress determined and transformed in to a model. This model was used to develop 3 new flux compositions within the stipulated range. However the weldment made form 13 flux composition were subjected to evaluation by some professional welders whose judgment about the quality of the weldment were evaluated by using the rank correlation coefficient method.

Gaal (2012) worked on nickel base shielded metal arc electrodes with varying core wire composition in which a coating formulation was developed .The research examined two common types of nickel base shielded metal arc welding electrodes, ENiCrMo-4 and ENiMo-10. Both were manufactured with a baseline coating which did not contain any alloying elements. Then using the same heat of core wire and flux formulation, the electrodes were then used in welding using a specially designed mechanized shielded metal arc welding machine. The mechanized shielded metal arc welding machine repeated each weld bead as closely as possible in order to minimize any variation in arc length, which may interfere with the evaluation of the results. The effects of the various coatings were evaluated to prove the additions effectiveness. The tests used in this research work are the cast pin tear test, SS DTA measurements, and tensile testing. The effects of each coating addition on all of the alloying element's recovery rates were compared to find that addition's overall impact on the weld deposit. The solidification range was measured using the single sensor DTA to evaluate the effects of the altered weld metal composition on the solidification range. This was then compared to the solidification range predicted by modeling software. The crack susceptibility of the altered weld metal was also evaluated using the cast pin tear test. This research further demonstrates the first step in creating a logical, methodical process for the determination of the amount of the addition of the alloying elements to the weld deposit through the flux coating. Alloying through the flux allow the manufacturer to compensate for core wires of varying chemical composition. The research also outlined tests which are necessary to verify that the alloying additions did not compromise the integrity of the welding electrode. Therefore for the manufacturers of shielded metal arc welding electrodes to stay competitive, they must be able to have flexibility in the performance of their products as well as flexibility in the manufacturing process. Nickel base welding consumables often require specialized chemical compositions which are more stringent than the requirements for the base material

on which they are welded. To complicate this problem further, the core wire chemistry often has a target which is a different chemical composition and different manufacturers may not have the same target composition. To compensate for these variances, alloying elements are often added through the flux coating to adjust the weld deposit composition.

Achebo and Ibhadode (2008) developed a new flux for aluminum gas welding, a new flux on Nacl-$Cacl_2$-Caf_2-$Na_3Alf_6$was developed for the gas welding of aluminum and its alloys. The flux was generated by the application of the Hadamard multivariate chemical composition model. The model uses a 8x8 matrix and a full factorial analysis to generate several compositions within given ranges of the constituent flux elements. Mechanical and field tests were carried out weldments made with the flux. The tensile strength, Izod impact strength and hardness of the all weld metals were 310Mpa, 5.35J and 100BHN. The weld deposition efficiency was 90.3 percent. The new flux and two popular commercial fluxes were given to five expert aluminum welders to use for three months, and were requested to rate the performances. The results showed that there was an agreement between the responses of the welders that the new flux performed better than the commercial versions available in Nigeria.

Achebo and Ibhadode (2009) worked on the development of several welding flux composition and came up with an optimum composition using the bending test technique. The technological performance of the optimum flux composition with respect to the bend test was 230kN/m^2. Preliminary weld tests showed that the flux performed well.

Adeyeye and Oyawale (2008) the traditional welding flux development has been by cost, material, time and labour intensive experiments. The expensive trial and error experimentation is needed because it is often difficult to know a priori how the flux ingredients interact to determine the operational characteristics of the flux and the final performance of the welded structure. The limitation of the traditional approach includes: (1)

long lead time (2) expensive experiments in terms of materials and energy consumption and labour requirements (3) the flux developed cannot be guaranteed to be optimal and (4) inability to identify and quantify direct and interaction effects of flux ingredients. These constraints are due to the paucity of statistical modeling tools in welding flux technology. Since prediction models are derived from designed experiments, flux researchers need other methods by which flux experiment may be designed. This paper discusses a statistical modeling tool known as mixture experiment which has the potential to revolutionizewelding flux development technology. Mixture design is discussed a lot but not fully developed. The procedure of mixture experiment, analytical model forms and the sequence of model fitting are discussed. Areas of welding flux research where the various mixture designs may be useful were suggested.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

This chapter outlines the various materials and equipment used for this research work as well as the production process adopted.

3.2 Materials

- Mill scales
- Sodium silicate
- Calcium carbonate
- Manganese dioxide
- Silica
- Calcium fluoride
- Feldspar
- Mild steel wire
- Wooden mould.

Mill scales: The mill scales used for this research was obtained from Dana steel rolling mill. Mill scales are available in abundance as an industrial waste in Dana steel rolling mill. The mill scales was prepared and analyzed using the modern Oxford 800 X Supreme XRF machine to determine the percentage by weight of all the elements that constitute the mill scales. Primary function is to act as the slag former and also stabilizes the arc.

Sodium silicate: Sodium silicate acts as the binder that is, it binds the flux materials together and also to the core wire. Binders are needed to hold the materials together, so that the flux

won't flake off the core wire. A measured quantity of sodium silicate (water glass) on a weighing balance (Plate II).



Plate; II:Sodium silicate on the weighing balance (Mechanical Engineering Department)

Calcium carbonate: It ensures sufficient shielding of the slag and also forms shielding or protective gas around the electrode end, arc and the weld pool. Calcium carbonate also ensures that the arc is stable.

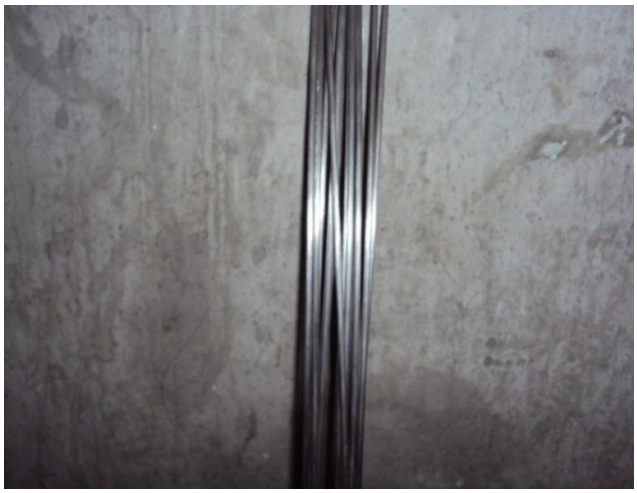
Manganese dioxide: One of the most important factors in weld quality is the removal of oxides from the surface of the metal to be welded, and unless the oxides are removed, fusion may be difficult. Manganese dioxide being an efficient deoxidizer was added to prevent the formation of harmful oxides and to improve arc stability.

Silica: Fresh water sand was collected from the river, the sand was dried and pulverized. Silica was added to improve the weld appearance and slag detachability, it also aids the current capacity of the electrode.

Calcium fluoride: Calcium fluoride acts as surfactants, decreasing the surface tension between the flux and the metal and between the flux and the oxides. Calcium fluoride also reduces the amount of diffusible hydrogen in the weld.

Feldspar: Feldspar is an anhydrous silicate of aluminum associated with potash or calcium, the potash feldspar was used. It act as slag producing substance and also gives strength to the coating.

Mild steel wire: This is also known as the core wire, which was obtained from Dana steel rolling mill, in Katsina state. It is on it that the baked chemical coating was applied. Plate III shows the mild steel core wire used for the production of electrodes.



Plate; III: Mild steel core wire

Wooden mould:The mould used for the production of electrodes was made in civil engineering department, Ahmadu Bello University, Zaria. Plate IV shows each halves of the mould used while plate V shows the complete mould. It should be noted that the interests to use these materials is as a result of their availability in our environment and their cost.



Plate; IV: Split mould halves



Plate; V: Wooden mould

3.3 Equipment

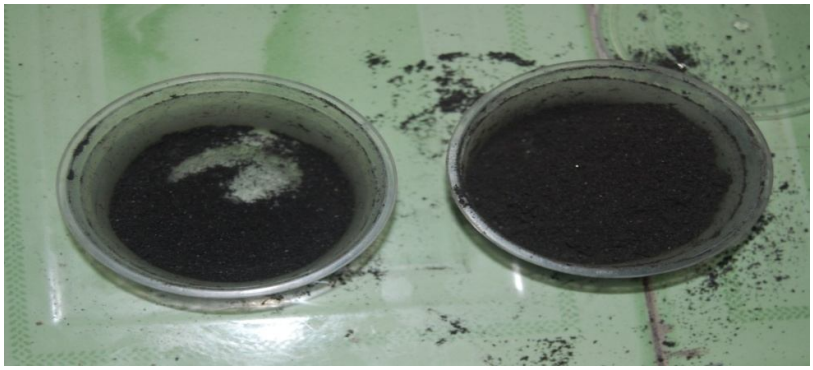
- X-ray florescence machine
- Arc welding machine (180 ampere)
- Oven
- Sieve with 90microns aperture
- Hounsfield tensometer
- Identec universal hardness testing machine
- Photographic and visual metallurgical microscope

- Pulverizer.
- Izod impact testing machine.

3.4 Experimental Procedure

Different materials have been used by many researchers in the formulation of flux for electrode coating. There are more than hundred different raw materials that can go in to the production of arc welding electrodes (Dave, 1986) even though less than hundred materials may be included in a specific coating of an electrode. The strength of the weld in which these researchers intend to achieve is the basis in which they formulate and develop their own flux composition mixture. Thus selecting materials for electrode covering, researchers have to take into consideration the application of such electrodes as different electrodes have different properties. It is well known that the mechanical properties and performance of a weld metal depend upon the properties of the coatings which are further depended upon the chemical composition of the flux and as a result of this, several theories and models have been used for the formation and development of fluxes, which include the Hadamard multivariate analysis (Achebo and Ibhadode, 2008). The statistical model (Achebo, 2009) which is based on expert evaluation method and the Taguchi method. In this research, a two level multivariate resolution (IV) Hadamard matrix design model was adopted in the formulation of flux. The model was used to generate twelve different flux compositions. However, of the twelve different compositions mixture generated, the first four was chosen to produce electrodes. Table 3.1shows the matrix layout of the Hadamard resolution (IV) multivariate design of seven variables (variables here are the materials used for flux coating). This design produces twelve flux compositions. Table 3.2 shows the composition ranges used in the entire experiment which is a guide or the control composition ranges used for the generation of the twelve flux compositions. The composition ranges were based on previous work done by researchers in the formulation of flux composition mixture. The high value was taken to be

positive(+) sign while the low value was attributed to be negative sign (-). In the production of arc welding electrodes, coating on an electrode is formulated to satisfy three major objectives and these are: to form fusible slags, to stabilize the arc and to produce an inert gas for shielding molten metal (Ugoamadi, 2010). Plate VI shows the homogenous mixture of the flux composition for electrode type E6020 and E6027.



Plate; VI: Flux composition mixture.

Table 3.1: Hadamard matrix layout

Trial	0	X1	X2	X3	X4	X5	X6	X7
1	+	+	-	-	+	+	-	+
2	+	+	+	-	-	-	+	+
3	+	+	+	+	+	-	-	-
4	+	-	+	+	-	+	-	+
5	+	+	-	+	-	+	+	-
6	+	-	+	-	+	+	+	-
7	+	-	-	+	+	-	+	+
8	+	-	-	-	-	-	-	-

(Source: Achebo and Ibhadode, 2008)

Table 3.2: Proposed chemical composition ranges for the newly developed flux composition.

Constituent elements	Composition ranges (%)
Mill scales	35≤X1≤40
Sodium silicate	25≤X2≤30
Calcium carbonate	10≤X3≤15
Manganese oxide	8≤X4≤10
Calcium fluoride	3≤X5≤5
Silica	3≤X6≤5
Feldspar	2 ≤X7≤4

Where X_1= Mill scale, X_2= Sodium silicate, X_3= Calcium carbonate, X_4=Manganese dioxide, X_5=Calcium fluoride, X_6=Silica, X_7=Feldspar.

3.4.1 Chemical composition formulation process

Tables 3.3-3.9 show the steps involved in arriving at the twelve flux compositions. The composition ranges in Table 3.2 were used for these steps. The matrices of variables X_1, X_2, X_3, X_4, X_5, X_6, X_7 were extracted from the Hadamard matrix layout (Table 3.1) and the composition ranges in Table 3.2 were used to fill the matrices of the extracted variables bearing in mind that(+) signifies high value and (-) signifies a low value of the composition ranges. X_7 is being considered first in the formulation process. The other variables X_1-X_6 are filled and X_7 is left blank. Since the condition of this formulation process states that each composition or trial must add up to hundred percent by weight to make a complete composition. Then the variables X_1-X_6 are added up and the remaining value to sum it up to hundred percent by weight would be entered in the X_7 column. If the value falls within the

range or limits set for variable X_7 as specify in Table 3.2, but if the value is above, equal or below the range, it was skipped, and this was repeated till Table 3.9.

Table 3.3: Feldspar, two-four percent of flux composition ranges (%)

¤ Trial	X_1	X_2	X_3	X_4	X_5	X_6	X_7
1	40	25	10	10	5	3	-
2	40	30	10	8	3	5	4
3	40	30	15	10	3	3	-
4	35	30	15	8	5	3	4
5	40	25	15	8	5	5	2
6	35	30	10	10	5	5	-
7	35	25	15	10	3	5	-
8	35	25	10	8	3	3	-

Table 3.4: Silica, three-five percent of flux composition ranges (%)

Trial	X_1	X_2	X_3	X_4	X_5	X_6	X_7
1	40	25	10	10	5	-	4
2	40	30	10	8	3	5	4
3	40	30	15	10	3	-	2
4	35	30	15	8	5	3	4
5	40	25	15	8	5	5	2
6	35	30	10	10	5	-	2
7	35	25	15	10	3	-	4
8	35	25	10	8	3	-	2

Table 3.5: Calcium fluoride, three-five percent of flux composition ranges (%)

Trial	X_1	X_2	X_3	X_4	X_5	X_6	X_7
1	40	25	10	10	-	3	4
2	40	30	10	8	3	5	4
3	40	30	15	10	-	3	2
4	35	30	15	8	5	3	4
5	40	25	15	8	5	5	2
6	35	30	10	10	-	5	2
7	35	25	15	10	-	5	4
8	35	25	10	8	-	3	2

Table 3.6: Manganese oxide, eight-ten percent of flux composition ranges (%)

Trial	X_1	X_2	X_3	X_4	X_5	X_6	X_7
1	40	25	10	-	5	3	4
2	40	30	10	8	3	5	4
3	40	30	15	-	3	3	2
4	35	30	15	8	5	3	4
5	40	25	15	8	5	5	2
6	35	30	10	-	5	5	2
7	35	25	15	-	3	5	4
8	35	25	10	-	3	3	2

Table 3.7: Calcium carbonate, ten-fifteen percent of flux composition ranges (%)

Trial	X_1	X_2	X_3	X_4	X_5	X_6	X_7
1	40	25	13	10	5	3	4
2	40	30	10	8	3	5	4
3	40	30	12	10	3	3	2
4	35	30	15	8	5	3	4
5	40	25	15	8	5	5	2
6	35	30	13	10	5	5	2
7	35	25	-	10	3	5	4
8	35	25	-	8	3	3	2

Table 3.8: Sodium silicate, twenty five-thirty percent of flux composition ranges (%)

Trial	X_1	X_2	X_3	X_4	X_5	X_6	X_7
1	40	28	10	10	5	3	4
2	40	30	10	8	3	5	4
3	40	27	15	10	3	3	2
4	35	30	15	8	5	3	4
5	40	25	15	8	5	5	2
6	35	-	10	10	5	5	2
7	35	28	15	10	3	5	4
8	35	-	10	8	3	3	2

Table 3.9: Mill scales, thirty five-fortypercent of flux composition ranges (%)

Trial	X_1	X_2	X_3	X_4	X_5	X_6	X_7
1	-	28	10	10	5	3	4
2	40	30	10	8	3	5	4
3	37	27	15	10	3	3	2
4	35	30	15	8	5	3	4
5	40	25	15	8	5	5	2
6	38	30	10	10	5	5	2
7	38	28	15	10	3	5	4
8	-	25	10	8	3	3	2

Table 3.10: The twelve newly formulated flux compositions in percentage by weight (%)

X_1	X_2	X_3	X_4	X_5	X_6	X_7
40	30	10	8	3	5	4
35	30	15	8	5	3	4
40	25	15	8	5	5	2
40	25	13	10	5	3	4
40	30	12	10	3	3	2
35	30	13	10	5	5	2
40	28	10	10	5	3	4
40	27	15	10	3	3	2
35	28	15	10	3	5	4
37	30	15	10	3	3	2
38	30	10	10	5	5	2
38	25	15	10	3	5	4

Table 3.11: Four flux compositions that were used in the production of electrodes (%).

X_1	X_2	X_3	X_4	X_5	X_6	X_7
40	30	10	8	3	5	4
35	30	15	8	5	3	4
40	25	15	8	5	5	2
40	25	13	10	5	3	4

Table 3.10 presents the twelve flux composition mixture that was generated using the Hadamard multivariate chemical composition model, while Table 3.11 shows the four flux compositions that were used in the production of electrodes.

3.4.2 Production process

Each of these minerals, Mill scales, Sodium silicate, Calcium carbonate, Manganese dioxide, Silica, Calcium fluoride and Feldspar were sieved with a ninety micron aperture sieve so as to ensure uniformity of particle size for all these minerals. Thereafter these minerals were then weighed and mixed thoroughly for about fifteen minutes in a particular proportion as indicated in Table 3.11 until an homogenous mixture was obtained. A measured quantity of sodium silicate which acts as binder was added to the homogenous dry mixture and thoroughly mixed for another five minutes until a thick paste was formed. The thick paste that was formed was coated on a mild steel core wire of 2.4mm diameter manually by means of a wooden mould. Generally, there are two main ways of coating core wire with fluxing materials. The most important thing to consider is to ensure that the coating does not flake off.

1. Dipping: Repeated dipping of the core wire in to the thick paste is used to obtain thick coating, however it must be noted that this process is gradually fading, because it gives non-uniform coating and it also leads to flaking off of the coating.

2.Extrusion: Nowadays this is the most commonly used coating method, it involves forcing the flux in form of a thick paste under pressure round the core wire and hence the thickness of the coating can be more accurately controlled. For the purpose of this research and to ensure a low production cost, the coating was done using a mould. A mould made of wood with a groove in the shape of an electrode was made in the Department of Civil Engineering. However before the coating was applied on the mild steel, a nylon was used to cover the groove and a lubricating oil was applied, so as to ensure easy removal of the electrode to be

produced from the nylon, thereafter the 2.4mm diameter core wire was laid in the groove and the thick paste was applied manually on it and the mould was covered. Pressure was then applied on the mould using the compaction machine in order to force the flux to stick to the core wire and to ensure concentricity of the coating, and it was allowed to cure before the mould was removed from the machine and the mould was split opened. Now an electrode has been formed and the electrode was dried at a well regulated temperature of 60^{oc} in an oven. The drying was done so as to reduce the moisture content of the electrode and while drying the electrodes in the oven adequate care was taken so as not to overheat the electrode to prevent cracking of the coating. After about an hour the electrodes were removed from the oven and stored in a moisture free place. The electric oven that was used for drying the produced the electrodes is shown in Plate VII, while Plate VIII shows the compaction process that was carried out to ensure concentricity of the flux coating.



Plate; VII: Electric Oven



Plate; VIII: compaction process

3.4.3 Mechanical test

The produced electrodes were used to carry out welds on mild steel sections. The mechanical properties of the weld deposits of the electrodes produced and the foreign electrode in the market were subjected to tensile test, hardness test and impact tests. The metallographic examination of the weldments was also examined and the results obtained are reported in the next chapter. The specimen electrodes produced and the foreign electrodes in the market is shown in Plate IX and Plate X shows a professional welder, welding with the produced electrodes while Plate XI shows the same welder welding with a foreign electrode.



Plate; IX: Foreign electrodes and the produced electrodes





Plate; X: Welding with the produced electrodes **Plate; X1: Welding with the foreign electrode**

3.4.4 Production cost determination

Since all the materials used in the production process were sourced locally and besides these materials are relatively available, they are also cheap.Mill scales which is the main raw material is available in abundance as waste in Dana steel rolling mill, Katsina state. Therefore the cost of production is relatively low compared to the foreign electrodes in the market.

3.4.5 Estimated cost for the produced electrodes

The cost of materials, labour and equipment that went in to the production of the electrodes was estimated at seventeen thousand naira as shown in table 3.12.

Table 3.12 Cost estimate for the produced electrodes

Description	Quantity	Amount(#)
Chemicals		
Sodium silicate	4 Ltrs	2500
Calcium carbonate	2 Kg	1000
Manganese dioxide	1 Kg	5000
Silica	2 Kg	1000
Calcium fluoride	2 Kg	500
Feldspar	2 Kg	1000
Materials		
Wooden mould	1	1000
Mild steel wire	16	1000
Equipment		
Oxford 800 XRF machine	-	-
Oven(available)	-	-
Compaction machine	-	-
Labour	-	2000

All the chemicals with the exception of silica and manganese dioxide which were obtained in Lagos were bought in Benin City. The wooden mould was produced in Civil Engineering Department, Ahmadu Bello University, Zaria, and the mild steel core wire was obtained from Dana steel rolling mill in Katsina state.



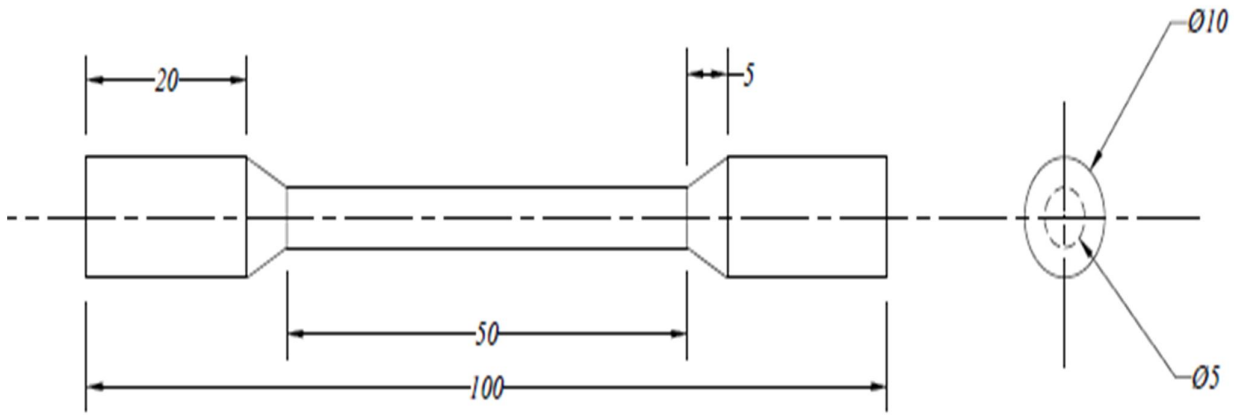
Plate; XII: Tensile test sample preparation on a lathe machine (Mechanical Engineering Department ABU, Zaria)

3.5 Sample Preparation

Twenty test samples were prepared using mild steel and the electrodes produced as well as the foreign electrode was used to carry out weld on the prepared samples. Five of the samples were used for tensile test, five samples were used for hardness test, and another five samples were used for impact test while the last five samples were used for metallographic examination.

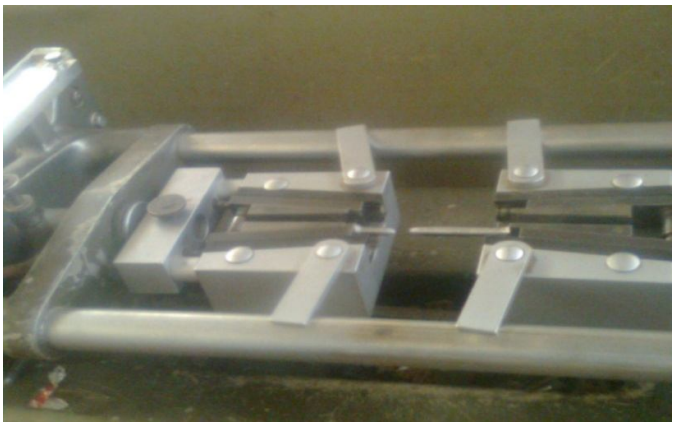
3.5.1 Tensile test samples.

Tensile test is one of the most widely used of the mechanical test, here the mild steel was cut in to 100mm length from a round bar and was machined on a lathemachine in to a dumb-bell shape. A round steel bar undergoing machining on a lathe machine is shown in Plate XII. Fig, 3.1 presents the dimension of the machined specimen which has a central reduced section.



Fig; 3.1: Tensile test specimen

Five of the prepared samples (tensile test specimen) were subjected to tensile test. But before then each of the samples was cut at the Centre and chamfered on a lathe machine. Each of the four produced electrodes was used to weld the specimen at the point of cut and a foreign electrode was used to carry out weld on the last specimen. Thereafter all the specimens were subjected to tensile test. Hounsfield tensometer type 'W' with serial number 9875 was used to perform the test. Here the specimen was gripped in between the chucks of the tensometer, which can apply a measured load of up to 20KN to the specimen held between the chucks. The diameter of all the samples was notedand the autographic recording drum of the machine was covered with a graph sheet and the pointer set at zero before the commencement of the tests. The load was then applied by hand using the load handle until the specimen was pulled to fracture. A fractured tensile test specimen held between the chucks of a tensometer is shown in Plate XIII. The load is measured by the deflection of a spring, which in deflecting causes a mercury piston to displace mercury in to a small bore glass tube adjacent to a graduated scale. The load against extension graph was plotted and traced out on the graph. From the graph the maximum load, the breaking load, strain and the percentage elongation of the specimens were obtained



Plate; XIII: Fractured tensile test specimen held between the chucks of a tensometer (Mechanical Engineering Department, ABU, Zaria).

3.5.2 Hardness test samples

Five samples of mild steel sheet of 5mm thickness, width 10mm and length of 50mm were used for hardness test. These samples were then cut in to two halves using an hacksaw and welded along the cut section using the produced electrodes and the foreign electrode. Identec universal hardness testing machine (Diamond Rockwell) type 8187.5 LKV model B shown in Plate XIV was used to obtain the hardness value of each of the samples welded with the produced electrodes and the sample welded with the foreign electrode. Before subjecting these samples to hardness test, they were grinded and polished first. Minor load of 10kgf and a Major load of 60kgf was used. The scale used was HRA and an Indentor of diamond cone. The readings were obtained directly from the machine



Plate; XIV: Identec universal hardness testing machine type 8187.5 LKV model B (Metallurgical and Materials Engineering Department, ABU, Zaria)

3.5.3 Impact test samples

The reliability of a material can be determined, by measuring its resistance to fracture, either ductile, brittle of fracture toughness (Ives, 2001). Five samples of mild steel sheet of 5mm thickness, width 10mm and length 60mm was used for impact test, these samples were cut in to two halves and welded along the cut section using the produced electrodes and the foreign electrode. A V- notch of 1mm depth was made on the welded section and was tested for toughness using the Izod impact testing machine (the toughness of a material is the amount of energy a material can absorb before fracture) and the results obtained was recorded in joules. Plate XVI shows the Izod impact testing machine used. The capacity of the machine is 120 ft lb and the serial number is E51425/9.

3.5.4 Metallographic examination

Five samples of 5mm thickness, 10mm width and 50mm length was grinded, polished, etched and the photographic views of these samples welded with the produced electrodes and

the foreign electrode were taken. Metallographic examination was done to observe the microstructure of the weld deposit on the prepared samples. After welding with the produced electrodes and the foreign electrode these samples were filed using a flat file so as to remove any welded projections from the surface of these samples. These samples were later subjected to grinding, the grinding process was done using silicon carbide grinding paper of various grit sizes ranging from 120 to 600. The coarsest grit size silicon carbide paper was used first which is 120, followed by 240, 320, 400 and 600. Grinding was done in order to remove any surface imperfection and to smoothen the surface of these samples. During the grinding process, coolant was applied intermittently to the samples so as to avoid temperature rise of the samples which can alter the mechanical properties and to flush away the particles being removed from the surface of the samples. Thereafter the samples were washed so as to avoid the transfer of grit particles to the polishing cloth. These samples were then moved to the polishing machine for polishing. Polishing was done so as to obtain a mirror like surface of the samples which will be suitable for metallographic examination. The polishing was carried out on the polishing wheel made of bronze which was covered with a smooth lint free cloth on which alumina polishing powder was applied. During polishing the samples were held in the direction opposite the rotating polishing wheel. Coolant was also added to prevent rise in temperature of the samples. Now a bright and shiny surface of the samples is obtained. Afterwards the surface of these samples was cleaned to remove traces of polishing powder and the samples were etched. Since these samples are mild steel a 2% Nital etchant was used for etching, the etchant contain 98ml of ethanol and 2ml of nitric acid. After etching swabbing was carried out on the etched surface and the photographic view of the prepared samples was taken using the metallurgical microscope shown in Plate XV.



Plate; XV: Metallurgical microscope (Metallurgical & Materials Engineering Department, ABU, Zaria)



Plate; XVI: Izod impact testing machine (Mechanical Engineering Department, ABU Zaria)

CHAPTER FOUR

4.0 RESULTS

4.1 Introduction

This chapter presents the results of the mechanical tests conducted on the welded joints of on all the samples as well as the microstructural analysis of the weldments and heat affected zone using the produced electrodes and a foreign electrode.

4.2 Results of Mechanical Tests Conducted

Table 4.1: Elemental composition of mill scales using XRF analysis.

Element	Mg0	Al_20_3	$Si0_2$	P_20_5	$S0_3$	Cl	$Ti0_2$	Cr_20_3	Mn_20_3	Fe_20_3	Zn0
Conc (wt %)	0.217	4.178	12.512	0.191	0.341	0.116	0.091	0.089	1.864	80.388	0.013

Table 4.2: Tensile test results.

Electrode Type	Input Voltage (volts)	Current Settings (ampere)	Tensile Strength (N/ $mm^{2)}$	Strain	Percentage Elongation (%)	Remark
E6020	80	180	453.0	0.16	16	Fractured outside the weld
E6024	80	180	413.1	0.08	8	Fractured at the weld
E6027	80	180	434.2	0.12	12	Fractured at the weld
E6030	80	180	344.2	0.04	4	Fractured at the weld
Foreign	80	180	468.3	0.22	22	Fractured outside the weld

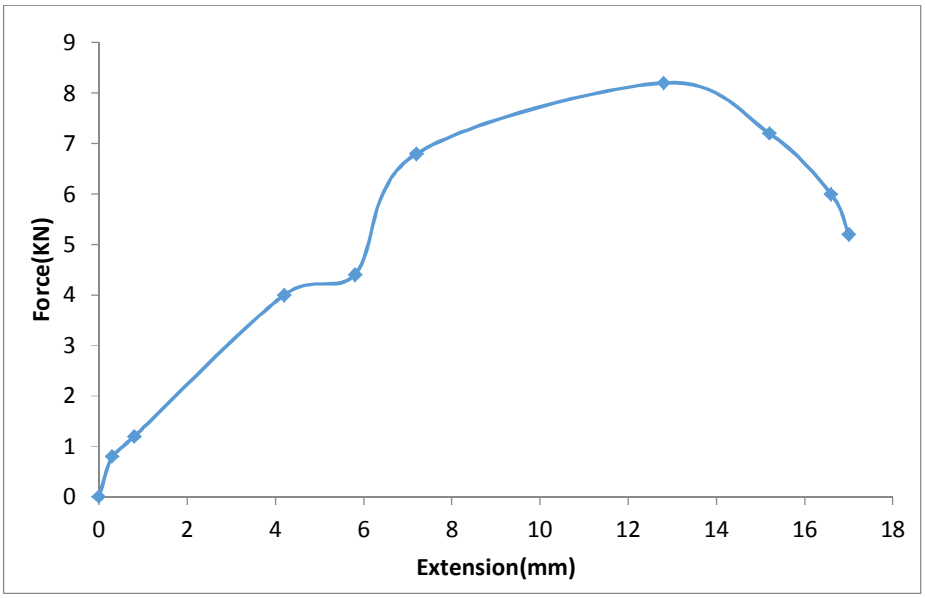
Tensile strength=Maximum load(N)/Cross sectional area of the specimen(mm^2)

Input voltage is the voltage is the voltage supplied to the transformer(arc welding machine)

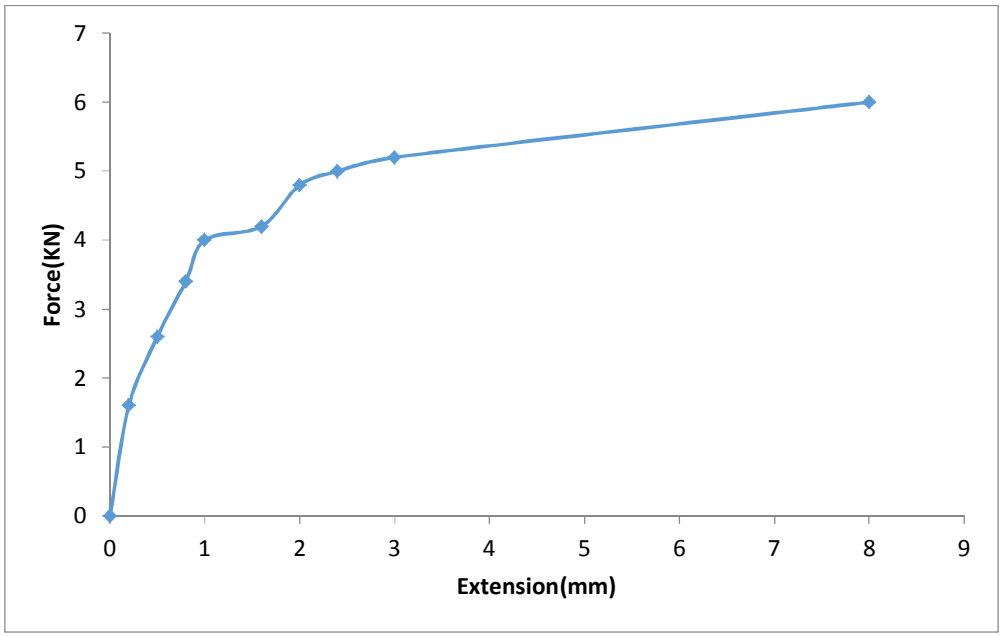
Current setting: This is the current at which the welding was carried out

Strain=Change in length/Gauge length

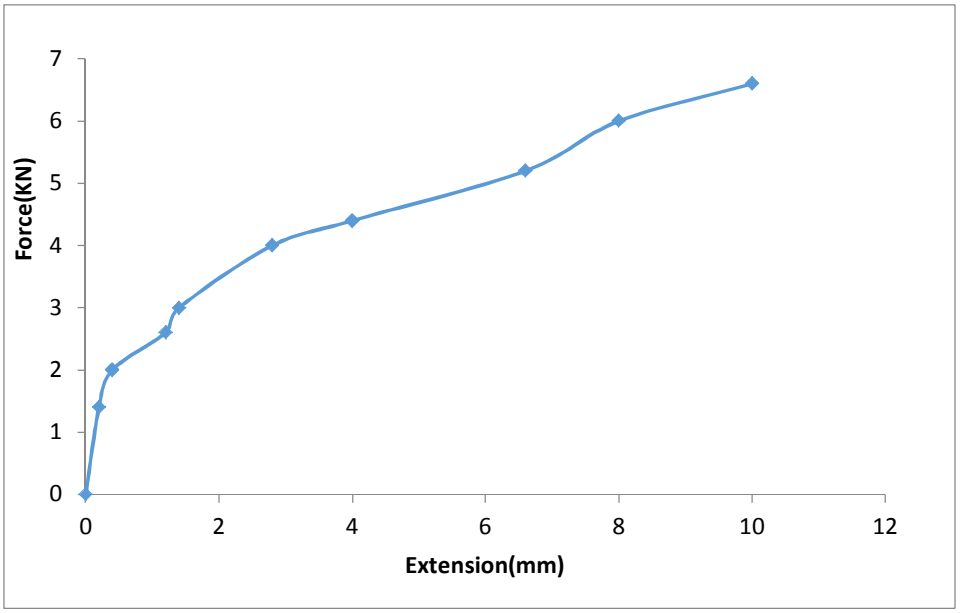
Percentage Elongation: Change in length over Original length X 100



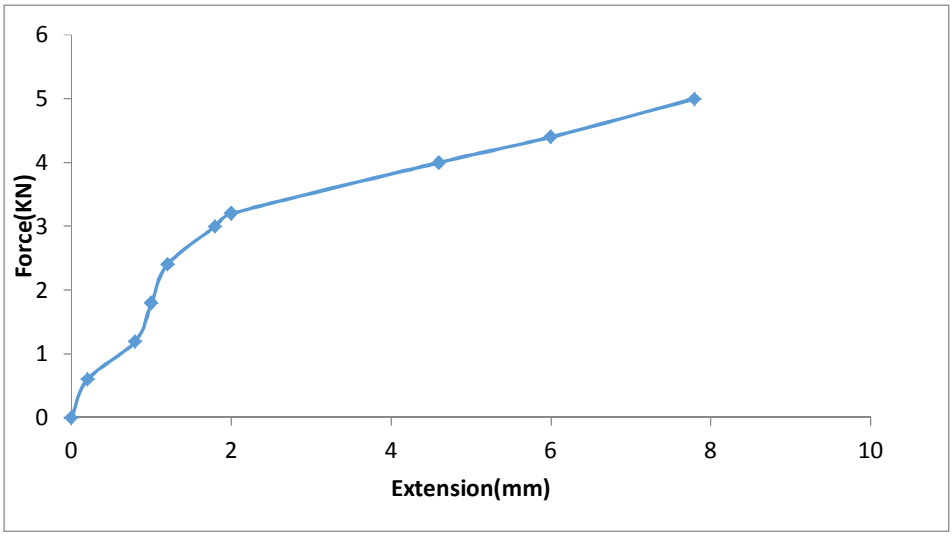
Fig; 4.1: Variation of Load-Extension of tensile test conducted on the specimen welded with electrode type E6020



Fig; 4.2: Variation of Load-Extension of tensile test conducted on the specimen welded with electrode type E6024.

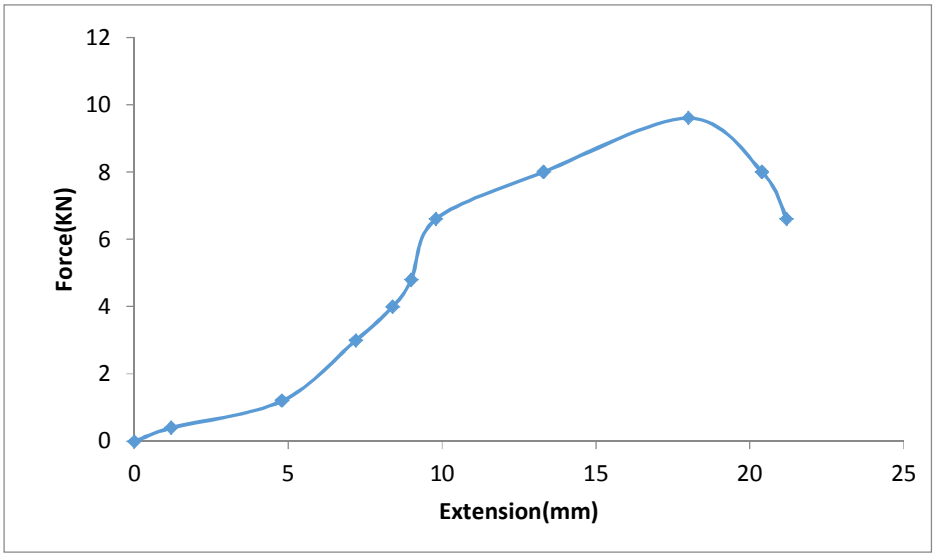


Fig; 4.3:Variation of Load-Extension of tensile test conducted on specimen welded with electrodetype E6027.

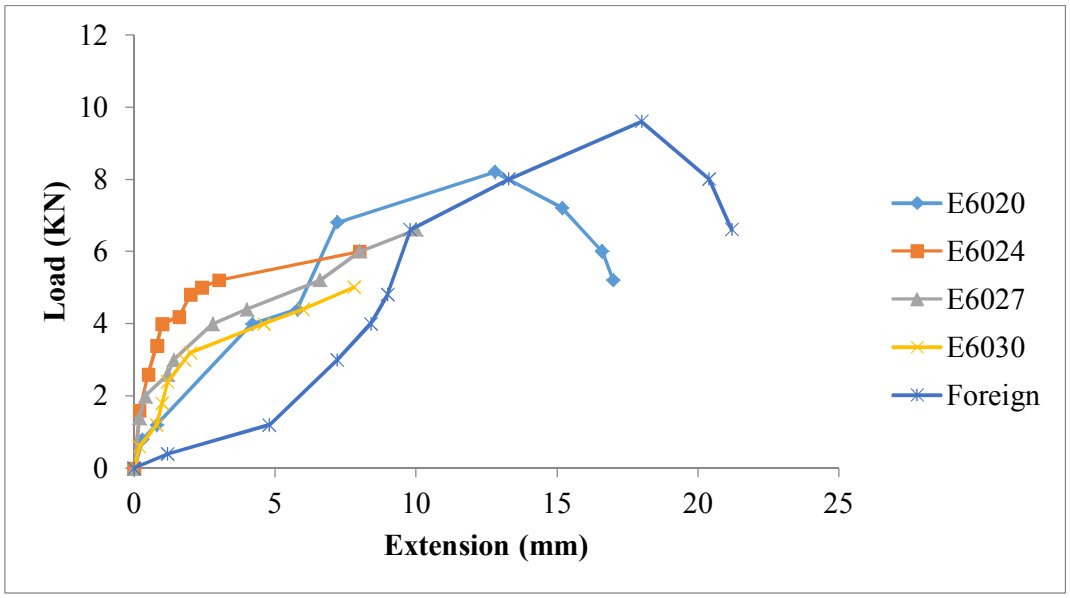


Fig; 4.4: Variation of Load-Extension of tensile test conducted on the specimen welded with electrode type E6030

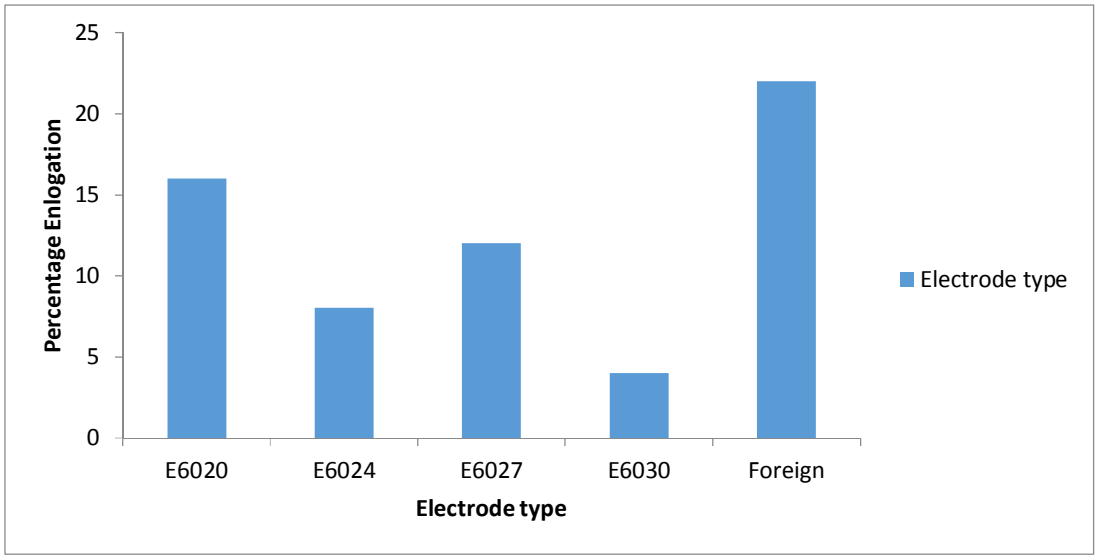
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Fig; 4.5:Variation of Load-Extension of tensile test conducted on specimen welded with a foreign electrode.



Fig; 4.6: Variation of Load-Extension graph for the entire specimen super imposed on each other.



Fig; 4.7: Bar chart of percentage elongation against the electrode type.

Table 4.3: Results of the hardness test carried out on some of the prepared samples using Identec universal testing machine.

Electrode Type	Minor Load(kgf)	Major Load(kgf)	Hardness test value(kgf)	Hardness test value(N)
E6020	10	60	46.6	457.1
E6024	10	60	42.6	417.9
E6027	10	60	44.7	438.5
E6030	10	60	40.7	399.3
Foreign	10	60	47.8	468.9

NB: To convert kilogram-force(kgf) to Newton(N), multiply the readings in kgf by 9.81

Table 4.4: Results of the Izod Impact test conducted.

Electrode Type	Depth of Notch(mm)	Thickness of sample (mm)	Impact Energy (ftlb)	Impact Energy(J)
E6020	1	4.6	43.5	59.0
E6024	1	4.3	64.0	86.8
E6027	1	4.3	70.0	94.9
E6030	1	4.2	44.4	60.2
Foreign	1	4.4	29.5	40.0

NB: To convert foot pounds (ft lb) to joules (J) multiply the readings in ft lb by 1.356

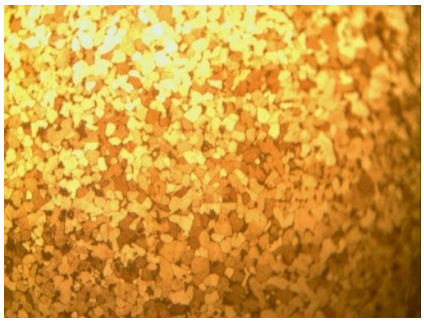


Plate XVII: Microstructure of mild steel in the as-received condition(x200)

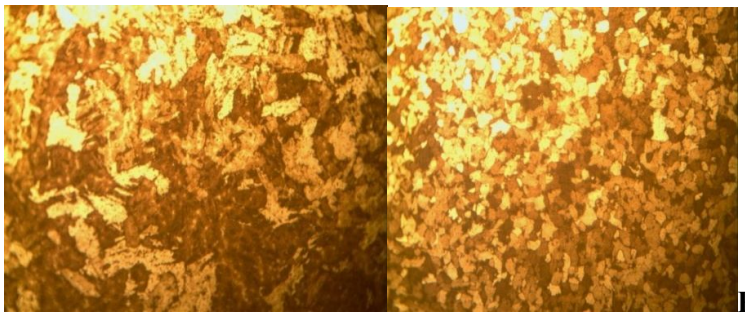


Plate XVIII: Microstructure of weldment(E6024) x200

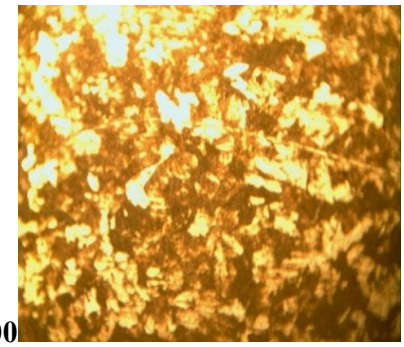


Plate XIX: HAZ(E6024) x200

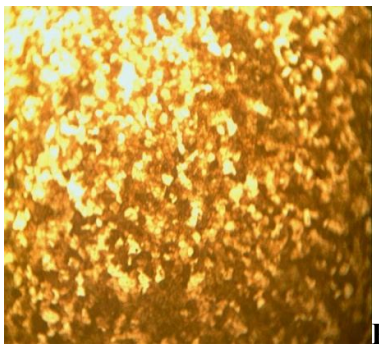


Plate XX: Microstructure of weldment(E6027) x200

Plate XXI: HAZ(E6027) x200

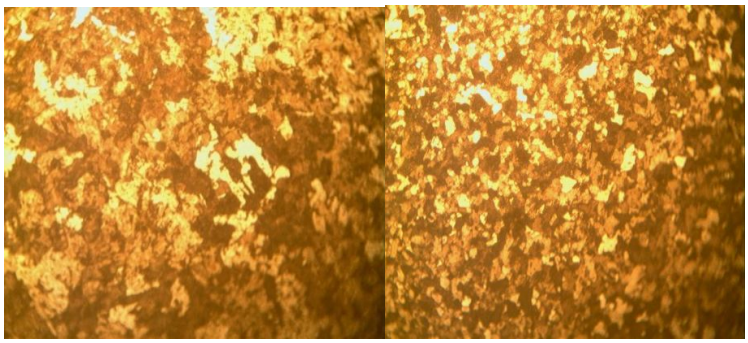
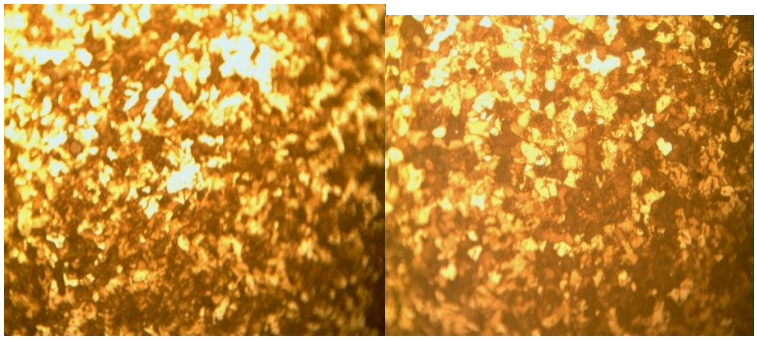


Plate XXII: Microstructure of weldment(E6030) x200 **Plate XXIII: HAZ(E6030) x200**



Plate; XXIV Microstructure of weldment(6020) x200 **Plate XXV: HAZ(E6020) x200**

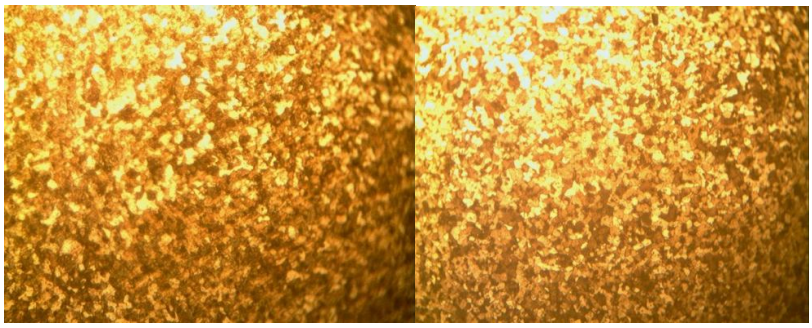


Plate XXVI: Microstructure of weldment(Foreign)x200 **Plate XXVII:HAZ(Foreign)x200**

CHAPTER FIVE

5.0 DISCUSSION OF RESULTS

5.1 Elemental Analysis of Mill Scales

The elemental composition of mill scales, using the modern Oxford 800 X Supreme XRF machine is presented in Table 4.1 and it can be observed that $Si0_2$, Al_20_3 and Fe_20_3 were found to be the major constituent elements, with Fe_20_3 constituting more than 80% of the total constituent element and Fe_20_3 being an important constituent in electrode covering, therefore this suggests that Mill scales can be used in electrode production. Other elements such as Mn_20_3, P_20_5, Mg0 were found to be present in traces.

5.2 Performance Evaluation of the Welded Joints

Table 4.2 shows the results of the tensile test conducted on some welded specimen using the produced electrodes and the foreign electrode under the same welding condition(Input voltage and Current setting). It can be observed that all the produced electrodes with the exception of electrode type E6030 compete well with the foreign electrode. The welded specimen using electrode type E6020 produced the highest tensile strength as the welded joint shows that it can withstand a tensile strength of up to 453.0 N per mm^2. The produced electrodes did not only give a clean and sound weld, the welded joints produced by these electrodes are also defects free. The little difference in the tensile strength of the weld produced by the foreign electrode and the produced electrodes can be attributed to the production process adopted, meanwhile the difference in the tensile strength of the four produced electrodes must have been due to variation in the process parameters

Figure 4.1 is the variation of load against extension of the tensile test of the weld joint using electrode type E6020, it can be observed that with a gradual increase in load, there is a corresponding increase in extension of the specimen, that is the extension produced is directly

proportional to load, this continues until the maximum load is reached. At this point of maximum load, which is 8.2KN a reduction in area of the specimen occurs and small increase in extension also take place and a neck is formed. The reduced area was not able to sustain the load being applied, hence the specimen finally fractured at this new point which is called the breaking load point. For the specimen welded with electrode type E6020, it can be observed that the maximum load is different from the breaking load. The reason for this is that, the specimen did not fractured at the welded point, because the welded joint is stronger than other part of the specimen, hence fracture occurs outside the welded zone. The type of fracture that occurs here is referred to as ductile fracture. This type of fracture is aided by plastic deformation of the specimen and a visual observation of the fractured surface, revealed a fibrous surface, indicating that plastic deformation occurred before the specimen fractured.

Figures 4.2, 4.3, 4.4 present the variation of load against extension of the tensile strength tests of the weld joints using electrode type E6024, E6027 and E6030. It can be observed that there is little elongation and the specimen fractured at the point of maximum load. Here the maximum load is the same as the breaking load, and specimen welded with electrode type E6024, E6027 and E6030 fractured at the welded point. Therefore it can be deduced that the material is stronger than the welded joint. A close examination of the fractured surfaces of each of the specimen shows a crystalline surface, indicating that the specimen was brittle and fracture of the specimen occurred with little plastic deformation.

Figure 4.5, is the variation of the tensile test of the specimen welded with the foreign electrode, from the graph it can be observed that as the applied load increases, extension also increases. Just like what was obtained in Fig 4.1, the specimen did not fractured at the point of maximum load. At maximum load there is increase in extension(elongation of the specimen) and reduction in the area, and with the load concentrated at the reduced area, the specimen finally fractured at this new point called the breaking load point. It can also be said here that

the welded joint is stronger than other part ofthe specimen, and thisexplain the reason why the specimen fractured outside the welded zone, therefore the maximum load is also different from the breaking load. Here also we have ductility fracture, the initiation and initial growth of cracks observed occurred due to plastic deformation.

Figure 4.6 shows the variation of load against extension of the tensile tests conducted on all the specimen welded with the produced electrodes and the foreign electrode super-imposed in each other. It can be observed that the sample welded with the foreign electrode gave the highest yield strength with the highest extension, then followed by the specimen welded with electrode type E6020. The specimen welded with electrode type E6030 produced the lowest yield strength with the lowest extension, this shows that the specimen welded with electrode type E6030 produced the joint that is least ductile when compared to joints produced using the foreign electrode and the other three types of electrodes produced.

Figure 4.7 shows the bar chart of percentage elongation against electrode type, the foreign electrode produced the joint with the highest percentage elongation while the welded joint produced electrode type E6030 gave the lowest percentage elongation as evident in the chart.

From Table 4.3 it can be observed that the foreign electrode (commercial) produced the highest average value of hardness test and of the four different electrodes produced, electrode type E6020 produced the highest average value of hardness test. A similar trend was observed in the result of the hardness test conducted in relation to tensile test result earlier reported. This corroborate what was reported by Ebelebe (2014): that there is a relationship between the hardness value of a material and the tensile strength of a material, that is hardness of a material varies directly with strength of a material.

Table 4.4 shows the results of the impact test conducted on some welded specimen using the produced electrodes and the foreign electrode. The test was carried out using the Izod impact

testing machine, it can be observed that the specimen welded with electrode type E6030, produced the highest impact energy while the foreign electrode gave the lowest impact energy (measure of toughness) as a result of this it can be deduced from this results that as the hardness properties of the specimen welded with the produced electrodes and the foreign electrode increases, the impact energy (measure of toughness) decreases. In other words it could be said that hardness properties varies inversely proportional to impact energy, the harder the joint the less tough it is.

5.3 Micrographsof Weldment and Heat Affected Zone

Plate XVII shows the microstructure of mild steel in the as- received condition, revealing an even distribution of the pearlite (black matrix) in ferrite (white matrix). Etchant; 2% Nital, Mag; x200.

Plate XVIII shows the microstructure of the weldment of electrode type E6024 revealing a coarse structure of pearlite in ferrite matrix, while Plate XIX revealed the heat affected zone having an intermediate grain size. Etchant; 2% Nital, Mag; x200.

Plates XX and XXI are the microstructures of the weldment and heat affected zone of electrode type E6027.The weldment revealed a coarse pearlite and an elongated ferrite matrix, while the heat affected zone shows a fine grain size of both the pearlite and the ferrite grain structure. Etchant; 2% Nital, Mag; x200.

Plate XXII revealed the microstructure of the weldment of electrode type E6030 showing a coarse and dominant pearlite matrix in ferrite matrix, while Plate XXIII shows the heat affected zone with a fine pearlite matrix in ferrite matrix. Etchant; 2% Nital, Mag; x200.

Plate XXIV shows the microstructure of the weld metal using electrode type E6020 revealing coarse pearlite grain matrix in ferrite matrix, while Plate XXV shows the heat affected zone of

the weld metal of electrode type E6020 showing a fine pearlite in ferrite matrix. Etchant; 2% Nital, Mag:x200.

Plate XXVI shows the microstructure of the weldment using the foreign electrode, revealing an intermediate pearlite in ferrite matrix, while Plate; XXVII shows the heat affected zone with fine pearlite and ferrite matrix. In all cases it can be observed that the microstructure of the weldment revealed that it has bigger grain size due to the reason of high heat input at the weld during welding operation and a relatively lower cooling rate. The slow rate of cooling which probably might have been caused by the shielding gas, which insulate the weldment from the atmospheric air and thus reducing the rate of cooling and hence permitting greater grain growth. The heat affected zone has a fine grain size, because of lower heat input and consequently higher cooling rate which resulted in grain refinement.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

In this study Iron oxide based arc welding electrodes were produced using mill scales (an industrial waste). The produced electrodes and a foreign electrode were used in welding, and the mechanical properties of the welded joints were obtained and compared. The metallographic examination of the welded joints was also determined and the following conclusions were drawn from this research.

1 The analyzed mill scales shows the presence of predominantly Iron oxide, and Iron oxide is one of the important constituents of covering on mild steel arc welding electrodes, therefore it can be concluded that mill scales can be used in the production of Iron oxide electrodes such as E6020, E6024, E6027 and E6030.

2 It is an established fact that the mechanical properties and performance of an electrode depends on the coating formulation, as a result of this a new flux, composition was generated by the application of Hadamard multivariate chemical composition model, and it was observed that the newly formulated flux produced a good fusion and it can also be concluded that the newly formulated flux did not only perform well, it also did not produce any weld defect, such as gas porosity and slag inclusion etc.

3 With an appropriate variation in the flux constituent elements different types of electrodes can be produced.

4 The foreign electrode was able to yield the best performance in terms of strength and visual appearance of the welded specimens this is because these electrodes were produced under a more ideal condition.

5 The microstructure analysis of the weldments revealed an acceptable grain structure.

6.2 Recommendations

It is recommended that future research on the production of arc welding electrodes should focus on the following area

1 Extrusion production process should be adopted (use of extruder) so as to have electrodes with improved appearance.

2 Potassium silicate binder should be used, as the binding agent, because research has proved that it is a more efficient binder than Sodium silicate.

3 The assessment of the hardness of the weld, heat affected zone and parent metal.

4 The federal government of Nigeria should encourage local production of electrodes, by making attempt to look for other local substitutes for electrodeproduction as there are more than eighteen materials which can be used in making electrode coating and all these materials can be locally substituted for, by so doing local production of electrodes would not have been on the increase, a new technology would have been developed.

REFERENCES

Achebo, J.I. (2009). Development of composition of aluminum welding fluxes using statistical method. *Preceding's of the international multiconference of engineers and computerscientists,* Hong Kong, ISBN: 987-988-17012-7-5.

Achebo, J.I. and Dagwa, I.M. (2009).Design, manufacture and performance evaluation of welding electrode coating machine. *International journal of applied engineering research*.Vol.4(7).

Achebo, J.I. and Ibhadode, A.O.A. (2008).Development of a new flux for aluminum gas welding.*Advanced materials research,* Switzerland Vol44-46, pp677-684

Achebo, J.I. and Ibhadode, A.O.A. (2009). Determination of optimum Welding flux compositions using the bend strength test technique.*Advanced materials research* Vol62-64 pp393-397.

Adeyeye, D.A. and Oyawale, F.A. (2008). Mixture experiments and their applications in welding flux design. *Journal of the Brazilian society of mechanical sciences andengineering*Rio De Jeneiro Vol. 30 No4.

Armentani, E. Esposito, R. and Sepe, R. (2007). The effects of thermal properties and weld efficiency on residual stresses in welding. *The journal of achievements in materials and manufacturing engineering,* Vol20 Pp 319-322.

Cary, H.B. and Helzer, S.C. (2005*)*. *Modern welding technology*, Pearson Education New Jersey ISBN: 0-13-113029-3

Cary, H.B. (1998*)*. *Modern weldingtechnology*, Forth Edition, published by prentice hall London.

Dave, S. (1986). *Welding skills and technology*, Mc Graw- Hill book Co-Singapore. ISBN: 0-07-000757-8, pp 367.

Davies, A.C. (1994). *Science and practice of welding*, Tenth Edition, Cambridge University press, London, ISBN: 0521567025.

Davies, A.C. (1972). *Science and practice of welding*, Seventh Edition, Cambridge University press, London. pp 55

Ebelebe, G.O. (2014).Development and performance evaluation of a piston made of Al-Cu- Mg/Bagasse Ash particulate composite, *a thesis of masters of science* in Mechanical Engineering, Ahmadu Bello University, Zaria.

Folayan, C.O, Adebisi, O. and Tuleun, L.T. (1992).Production of E6020 arc welding electrodes, *research proposal submitted to raw materials research and development council*.

Gaal, B. (2012). Development of a coating formulation procedure for Ni-base shielded metal arc electrodes with varying core wire composition, *a thesis of masters of science in welding engineering,* Ohio state university.

Hwaiyu, G. (2004). *Manufacturing Engineering handbook published* by McGraw Hill. ISBN 0-07139825-2. Chapter 21 (21.3).

Ibhadode, A.O.A. (2001). *Introduction tomanufacturing technology*, Second Edition, published by Ambik Press, Benin City. ISBN 987-34275-1-2, pp 505-509.

Internet link:http://www.welding.com (Retrieved November 2012) 12.05pm

Internet link: http://www.lincolnelectric.com.(RetrievedNovember 2012) 12.05 pm

Internet link: http//www.efunda.com/process/metals_processing/welding.cfm(Retrieved, January, 2014) 1.20pm

Ives, E. (2001).*A Guide to wood micotermy; making quality microslides of wood section* Ipswich, Suffolk IP8 3 AY, UK.

Jackson, C.E. (1973). Fluxes and slags in welding, *welding research bulletins, no190*

Jain, R.K. (2011). *Production technology*, seventeenth edition, Khanna publishers, New Delhi- 1-10002, ISBN 81-7409-099-1 pp 295.

Jain, R.K. (2008). *Production technology,* Sixteenth Edition, Khanna publishers. New Delhi, India. ISBN 81-7409-099-1, Pp 427-465.

Khurmi, R.S. and Gupta, J.K. (2005).*A textbook of machine design* Second Edition, Eurasia publishing house (PVT.), Ltd, Ram Nagar New Delhi-110 055 Pp 341.

Kay, T. Gao, G. and Naing, T. S. (2010). Current welding technology on Myanmar.*Journal of American science*6(1): Pp 99-204.

Kou, S. (2003).*Welding metallurgy*, Second Edition, A John Willey and Sons Inc; USA pp 13-30

Lancaster, J.F. (1993). *Metallurgy of welding*. Chapman and Hall, London.

Lincoln Electric. (2006).*The procedure hand book of arc welding*. Revised Third Edition Cleaveland press US.

Nwigbo, S.C. andAtuanya, C.U. (2012).Formulation of a metal arc welding flux with a potash enriched sodium silicate binder. *Journal of emerging trends in engineering and appliedsciences.Vol3*(3) pp 497-501.

Parking, N. and Flood, C.R. (1974). *Welding craft practice* part1 Vol 2 Electric arc welding and related studies, Pergamon press, Oxford.

Parma, R.S. (2005). *Welding technology*, Khanna publishers New Delhi India.

Radhakrishnan, V.M. (2005). *Welding Technology and Design* Second Edition, New age Publishers, U.S ISBN-978-81224-1672-5.

Somksy, P. (1986). *Basic welding, The Macmillan press limited, London ISBN 9780333426104*

Ugoamadi, C.C. (2010). Production of arc welding electrodes with local raw materials*Nigerian journal of technology,* Vol.29 No.1.

Weman, K. (2003). *Welding process handbook* CRC Publishers NY, ISBN 0-8493-1773-8.

Oxford Instruments

OPERATOR: INSTRUMENT MANAGER

ANALYSED: 09/04/2013 12:32:30 PM

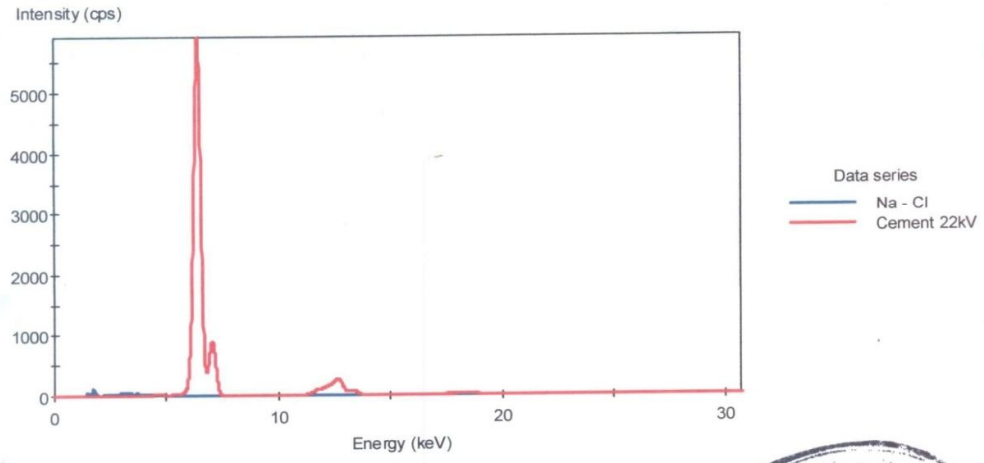
SAMPLE: Iron

Analysis Method: Minerals

Analyte Concentration Table

Element	Concentration
Na2O	0.000 Wt %
MgO	0.217 Wt %
Al2O3	4.178 Wt %
SiO2	12.512 Wt %
P2O5	0.191 Wt %
SO3	0.341 Wt %
Cl	0.116 Wt %
K2O	0.000 Wt %
CaO	0.000 Wt %
TiO2	0.091 Wt %
Cr2O3	0.089 Wt %
Mn2O3	1.864 Wt %
Fe2O3	80.388 Wt %
ZnO	0.013 Wt %
SrO	0.000 Wt %

Spectra for all conditions





APPENDIX B

UNIVERSITY OF BENIN, BENIN CITY, NIGERIA

DEPARTMENT OF PRODUCTION ENGINEERING
FACULTY OF ENGINEERING

OFFICE OF THE HEAD OF DEPARTMENT

P.M.B. 1154,
Cables & Telegrams: Uniben Benin
Telex: 41365 Uniben NG.
E-mail: prodeng@uniben.edu.ng
Telephone: (052) 600546-549
Extension: 2602, 2934.

Our Ref: FE(PE)S.7/04

May 27, 2013.

Your Ref:

Oerlikon Electrode Manufacturing Company,
Sango Otta,
Ogun State, Nigeria.

TO WHOM IT MAY CONCERN

Dear Sir,

LETTER OF INTRODUCTION

I write on behalf of Mr. Owolabi Olawale Aderemi a postgraduate student, who is carrying out a research project on "**Production of arc welding electrodes using mill scales from Katsina rolling mills**".

It would be appreciated if you could give him the necessary assistance he needs for the research project. The confidentiality and anonymity of any piece of information given will be preserved in consonance with research ethics.

Thank you for your cooperation.

Dr. J.O. Osarenmwinda
Ag. Head of Department 27/05/2013

HEAD OF DEPARTMENT
DEPT. OF PRODUCTION ENGINEERING
UNIVERSITY OF BENIN