RESEARCH SURVEY OF CURRENT WELDING PRACTICES IN SELECTED METAL WELDING INDUSTRIES IN GHANA

By

EMMANUEL ADU

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Faculty of Mechanical and Agricultural Engineering

College of Engineering

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DECLARATION

I hereby declare that this thesis is the result of my own original research work undertaken under the supervision of the undersigned, that all works consulted have been referenced and that no part of the thesis has been presented for another degree in this University or elsewhere.

Emmanuel Adu	………………………	………………………
(Candidate)	Signature	Date

CERTIFICATION

Dr. S. M. Sackey	……………………..	……………………..
(First Supervisor)	Signature	Date
Dr. G. Takyi	……………………..	……………………..
(Second Supervisor)	Signature	Date
Prof. Francis K. Forson	…………………….	……………………..
(Head of Department)	Signature	Date

DEDICATION

This work is dedicated to my lovely Wife,

Mrs. Lorna Bernita Adu

My sweet Mother,

Mad. Florence Adu

And my adorable Daughter,

Catherine Akosua Adu

ACKNOWLEDGEMENT

First and foremost I give thanks and praise to God almighty for giving me life, strength and opportunity to study to this far in my education. I take this opportunity to express my profound gratitude to my supervisors Dr. S. M. Sackey and Dr. G. Takyi. I am highly indebted to them for providing guidance, direction, insightful comments and support throughout the period of this work. Advice given to me by Dr. Cephas Kobina Idan and Dr. L. E. Ansong all of Mechanical Engineering Department, KNUST, was also enormous and I am grateful. I also thank Professor Samuel Kwofie and Mr. Kwesi Amoonu-Otoo all of the Materials Engineering Department, KNUST, for the guidance they offered me in the course of these studies.

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ABSTRACT

Welding is essentially a repair, maintenance, manufacturing and constructional engineering activity. In the last several decades, welding has evolved as an interdisciplinary activity requiring synthesis of knowledge from various disciplines and incorporating the most advanced tools of various basic and applied sciences.

This thesis discusses the current welding practices in some selected metal welding industries in Ghana. It covers, the type of training programmes for welders, categories of welding and welding techniques welders use, quality control methods employed, the type of welding processes used, welder safety issues, challenges facing welders, and welders' knowledge of the technology of welding in the metal joining sector of some Ghanaian industries are investigated using a questionnaire. The questionnaire was administered in two hundred (200) selected industries that practice welding in mostly the Ashanti, Greater Accra and Western regions. The survey reveals that, about eighty eight percent (87.50%) of welders do not go beyond secondary school education. The arc welding process is the most widely used (91%) welding process by industries in Ghana whilst the greatest proportion 86 (43.00%) of these industries use a combination of both arc and gas welding. Sixty-seven percent (67.00%) of welders have high level of knowledge of hazards in industry and 33.00% have low level of knowledge of hazards in industry. About fifty-seven percent (56.50%) of welders are highly prone to hazards in industry and 43.50% of welders are less prone to hazards in industry. It was also found out that sixty percent (60.00%) of welders suffer from various eye problems and about fifty-one percent (50.50%) suffer from various skin diseases likely stemming from long periods of exposure to radiations from the welding arc/flame daily in their work environment.

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ABBREVIATIONS

AC	Alternating Current
ACM	Association for Computing Machinery
AGI	Association of Ghana Industries
AWS	American Welding Society
CC	Pearson's Contingency Coefficient
CE	Carbon Equivalent
DC	Direct Current
DT	Destructive Testing
FZ	Fusion Zone
GMAW	Gas Metal-Arc Welding
GTAW	Gas Tungsten Arc Welding
HAZ	Heat-Affected Zone
IEEE	Institute of Electrical and Electronics Engineers
ISMAR	International Symposium on Mixed and Augmented Reality
MAPP	Methylacetylene-Propadiene
MIG	Metal Inert Gas
MMA	Manual Metal Arc
MoTI	Ministry of Trade and Industry
MSME's	Micro, Small Scale and Medium Enterprises
NBSSI	National Board for Small Scale Industries
NDT	Non-Destructive Testing
NVTI	National Vocational Training Institute
OAW	Oxyacetylene Welding

OFW	Oxy Fuel Gas Welding
OHW	Oxy Hydrogen Welding
PGW	Pressure Gas Welding
PPE	Personal Protective Equipment
RPW	Resistance Projection Welding
RSEW	Resistance Seam Welding
RSW	Resistance Spot Welding
SAW	Submerged Arc Welding
SMAW	Shielded Metal Arc Welding
TIG	Tungsten Inert-Gas
TOR	Tema Oil Refinery
UV	Ultra-Violet

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Welding first evolved as a technique of primary economic importance when the use of iron became widespread, it being required not only in order to make finished products but also as part of the iron- making itself (Lancaster, 1999). Welding consists of fusion or uniting of two or more pieces of materials (metals or plastics) by the application of heat and/or pressure.

Worldwide, welding is a multibillion-dollar fabrication technology used extensively in the construction of buildings and bridges and in the automotive, aircraft, aerospace, energy, shipbuilding, and electronic industries. Perhaps because welding is a construction technique, it is viewed by many as a primitive science. In the last several decades, welding has evolved as an interdisciplinary activity requiring synthesis of knowledge from various disciplines and incorporating the most advanced tools of various basic and applied sciences. Scientists from diverse disciplines such as arc and plasma physics, thermodynamics, high-temperature chemistry, materials science, transport phenomena, mathematical modeling, computer science, robotics, economics, and a variety of engineering fields including mechanical, chemical, and electrical engineering are currently making new contributions (David and DebRoy, 1992). Agarwal and Manghnani, (1992) in their book titled, “Welding Engineering” also stated that, “welding involves more sciences and variables than any other industrial process. The principal sciences involved in welding are Physics, Chemistry and Metallurgy”.

In some industries, notably automotive, welding is done primarily by robots or automated machinery. In many industries such as shipbuilding, heavy equipment production, and small parts fabrication, welding is still largely a manual process done by human operators.

Kenneth et al (2004) in their research "Virtual Training for Welding" reported at the Proceedings of the Third Institute of Electrical and Electronics Engineers (IEEE) and Association for Computing Machinery (ACM) International Symposium on Mixed and Augmented Reality (ISMAR 2004) that, "training of new welders is a significant activity both for industry and for the vocational education community. Training is especially important for welders working on critical items such as pressure vessels, nuclear piping, and naval ships, where welds are carefully inspected. It is estimated that the combined welder training costs for all U.S. shipyards is in excess of $5 million per year. There is therefore an active interest among naval shipbuilders in reducing welder training costs".

Welding as a joining process has its own advantages and drawbacks. The most obvious advantage is that: Welding is usually the most economical way of joining components in terms of material usage and fabrication costs. Alternative mechanical methods of assembly require more complex shape description (for example drilling of holes and addition of fasteners for example rivets and bolts). The resulting mechanical assembly is usually heavier than the corresponding weldment. Some of the draw backs are that, most welding operations are performed manually and are expensive in terms of labor cost; many welding operations are considered skilled trades, and the labor to perform these operations may be scarce. Most welding processes, involving the use of high energy, are inherently dangerous and the welded joint can suffer from certain quality defects that reduce the strength of the joint. (Groover, 2002).

1.1.1 State of Welding in Industries in Ghana

In Ghana welding is extensively used in the manufacturing industry for producing agricultural processing machinery, vehicle body structures and seat frames, burglary-protection shields, compressed gas cylinders, metal containers etc. In the construction industry it is used for constructing bridges, buildings, billboards, railroad rolling stock, electric metal poles, telecommunication antennas etc, and in carrying out maintenance and repair in the mining industry, refineries, and in the automotive industry.

Perhaps the most commonly used welding processes in Ghana are the shielded metal arc welding (SMAW) in the electric arc welding group and oxyfuel gas welding. A few industries also use the gas tungsten arc welding (GTAW) process. A greater number of welders in the welding industry in Ghana operate as micro, small scale and medium enterprises located in industrial areas in cities like Kumasi, Accra, Tema and Takoradi and also in the villages. Most of the welders acquire the welding trade from apprenticeship training from experienced welders without attending any formal welding schools. Most of them appear to be school dropouts who did not complete Senior Secondary School (SSS).

The limitation of welding practices in Ghana to the shielded metal arc welding (SMAW) process and in a few cases to the gas tungsten arc welding (GTAW) process reduces the advantages obtained from the other welding processes and hence limits severely the advantages that welding offers in the joining process during manufacturing.

When welding, the welder and his environment are exposed to a variety of fumes and gases related to the welding process. In most countries there are rules that may limit the exposure of personnel to welding fumes and gases. Some countries, however, do not have any rules. It is important for mankind to realize what kind of problems may occur during welding and how to prevent physical contact with welding fumes and gases.

Kumah et al (2011) in their study, "Radiation-related eye diseases among welders of Suame magazine in the Kumasi metropolis" concluded that the ocular symptoms and ailments prevalent among the welders were most likely due to the radiations they are exposed to in their work environment.

1.2 Problem Statement

A contributing factor to the low status of manufacturing in Ghana may be the fact that manufacturing engineering activities such as welding practices have not been developed to the level that they should be.

A visit to the Ashanti Regional Offices of the Ministry of Trade and Industry (MoTI), revealed that, data on the type of training programmes for welders, the category of welding and welding technique the welders practice, type of welding processes the welders use, safety practices of the welders, needs and challenges of these welders and the general technology of welding in the country is not readily available. Lack of statistical data of these welding practices of the local welding industry hamper the development of this sector. Lack of technical knowhow leads to the common welding problems associated with welded joints such as, lack of penetration, lack of fusion, undercut, overlap, cold lap, slag traps, porosity and blowholes, under fill and rough appearance as well as health hazards to the welder.

A visit taken to some industrial estates in Ghana such as "Suame Magazine", in Kumasi, "Kokompe", in Accra and in most villages in Ghana reveal thousands of welders busy at work in the construction and fabrication industries in the country. The visual appearance of most of the locally welded materials compared to the weldments on some imported machinery and cars shows that the weldments on the imported machinery and cars look much smoother and neater than the local ones. The adequacy of training and knowledge of our local welders cannot be ascertained.

It is also not certain that important welding engineering procedures such as weld design, material preparation, test methods for evaluating welded joints, proper cooling mechanism, proper safety precautions, etc. which must be carried out to ensure defect free welded components and parts and safety in the welding industry are carried out by local welders.

1.3 Goal

The main objective of this thesis work is to conduct a survey of current welding practices, i.e. the type of training programmes for welders, the category of welding and welding techniques the welders use, type of welding processes the welders use, safety of the welders, needs and challenges of these welders and the welders knowledge of the technology of welding in the metal joining sector of some Ghanaian industries and propose improvements of engineering nature where applicable.

1.3.1 Specific Objectives

The specific objectives of this thesis are:

- to investigate the welding practices (i.e. welding processes and techniques, quality control, design and planning considerations, etc.) of some Ghanaian industries that use welding as a maintenance and repair, manufacturing and constructional activity.
- to identify the needs, challenges and safety practices (i.e. hazards, availability of safety equipment, etc.) of some Ghanaian industries in the metal welding fabrications sector.

- to identify problems, which hamper the application of welding in the metal joining sector of the Ghanaian industry.
- to recommend effective policies and measures for improvement and development of welding and training for welders in Ghana.

1.4 Scope of Research

- The scope of the research work is to conduct a survey of current welding practices in the metal joining sector of some Ghanaian industries. The research survey shall include the following specific areas:
    - ➢ Educational background and welding training programmes for welders in Ghana.
    - ➢ The type of welding processes the welders practice.
    - ➢ Quality control mechanisms employed by the welders, inspection and testing methods of welded joints and common causes of failure in welded joints.
    - ➢ Design and planning considerations before welding.
    - ➢ Needs, challenges and safety practices of welders and the welding industry.
- The research shall cover industries that use welding, as a maintenance and repair activity, and for manufacturing and constructional works in Ghana. The research covers industries such as:

1. Maintenance and Repair Industries
    - ➢ Micro, small scale and Medium Enterprises (MSME's) such as welding industries and garages in "Suame Magazine", "Asafo", in Kumasi, "Kokompe", in Accra, "light industrial area" in Tema and Takoradi involved in maintenance and repair.

- Mining industries such as AngloGold Ashanti Limited, Ghana Bauxite Co. Ltd and Tarkwa Gold Mines.
- Refineries such as Tema Oil Refinery (TOR).

2. Manufacturing and construction Industries
    - Micro, small scale and Medium Enterprises (MSME's) such as welding industries and garages in "Suame Magazine", "Asafo", in Kumasi, "Kokompe", in Accra, and "light industrial area" in Tema and Takoradi involved in the manufacturing and construction of products
    - Gratis foundation, Tema-Heavy Industrial Area.
    - Great Kosa Company Ltd, Mpota-Winneba.
    - Motor Vehicle and Equipment manufacturers such as Japan Motors Trading Company Ltd., Mechanical Lloyd Company Ltd., Adum- Kumasi.
    - A. J. Fanj Construction and Industrial Engineering Ltd, construction and fabrication of structural steel for bridges, billboards and buildings, Asokwa-Kumasi.

- Because of time and financial limitations, the survey will be mostly concentrated in the Ashanti, Greater Accra and Western regions; the three major industrial regions in Ghana, with little concentration on the other regions.

1.5 Justification

If a developing nation like Ghana, is to be successful in a global competitive market, it is essential for her to engage in appropriate manufacturing engineering activities such as good welding practices to have the best welding industry. Welding has become complex and technical. It requires considerable knowledge to select the proper welding process for critical work. Our local welders, weld different components and products such as industrial machinery, vehicle body structures and seat frames, bridge construction, railroad rolling stock, etc. and failure on their part to produce a flawless and sound welds, can have serious repercussions on industry and human life.

Losses of life and property due to catastrophic failure of structures are often traced to bad welding practices and hence defective welds. (David and DebRoy, 1992).

An industry survey of Ghanaian industries engaged in welding in the metal fabrications sector would help expose the extent to which this important support function is being performed in that sub-sector, as well as identify weaknesses and other inherent problems of the sector. The research can reveal the personnel, organizational and technical weaknesses in the welding sector and thus help to plan adequately for proper training of welders in the country. The data gathered from this research can be used as a guide for improving the welding practices and to determine the short and long term needs of the welding industry and how various support groups such as education providers, economic policy developers and others could work in better collaboration with industry.

1.6 Methodology

The following methodology was adopted:

- Review of literature on the best modern welding practices in the metal joining sector relevant to the study.
- Study visits to some industries that use welding as a maintenance and repair, manufacturing and constructional activity in Kumasi, Accra, Tema and Takoradi.
- Preparation and distribution of questionnaires and interviewing of industries and MSMEs that practice welding.
- Collection of data, and analysis of data using an appropriate computer software package.

- Conclusions and recommendations for improving the practice of welding in the metal welding joining sector of the Ghanaian industry.

1.7 Structure of Thesis

The thesis has been structured into six chapters. Chapter one has the introduction, which is made up of: background of welding, the state of welding in Ghana, problem statement, goal and objectives of the research, scope of the research, justification or significance of the study, the methodology adopted and a section outlining the structure of the thesis. Chapter two has the literature review, which reviews different literature relevant to the study. Chapter three comprises the research design and methodology, which elaborates in details how the research was carried out and the methodology used. Chapter four is made up of data analysis. Chapter five, results and discussions, shows the results obtained from the data analysis and the ensuing discussions. Chapter six comprises the conclusions and recommendations.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Welding Processes and Their Sub-divisions

The official listing of welding processes and their grouping is shown by figure 2.1, courtesy of the American Welding Society (AWS) Master Chart of Welding and Allied Processes. The AWS definition for a welding process is "a materials joining process which produces coalescence of materials by heating them to suitable temperatures with or without the application of pressure or by the application of pressure alone and with or without the use of filler material." AWS has grouped the processes together according to the "mode of energy transfer" as the primary consideration.

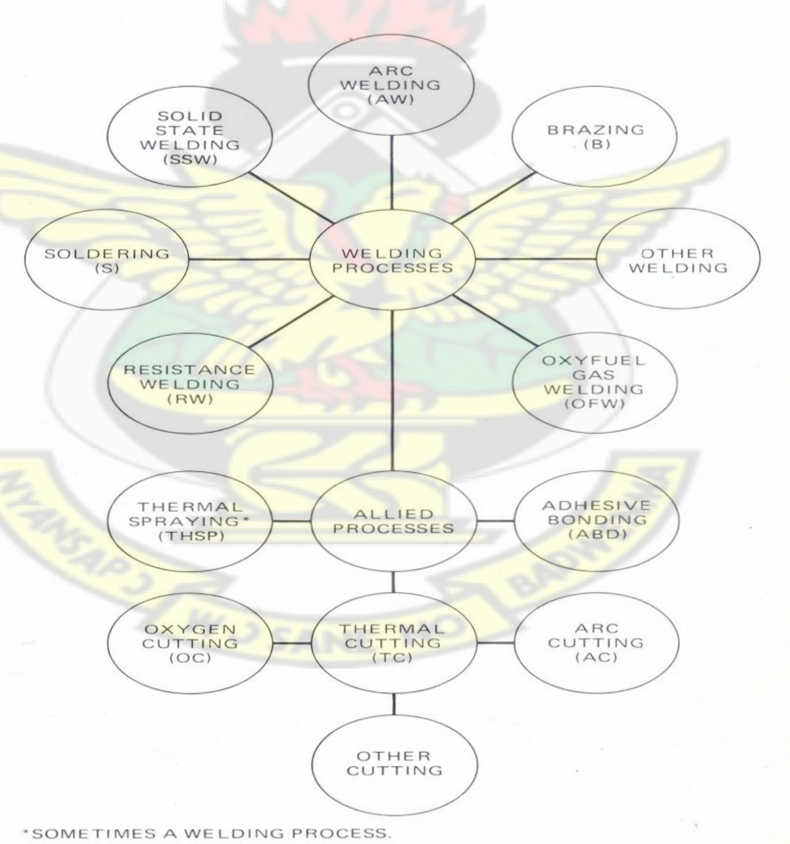


Figure 2.1 AWS master chart of welding and allied processes (http://www.arconweld.com/welding)

2.2. The Arc-Welding Processes: Consumable Electrode

In *arc welding*, the heat required is obtained through electrical energy. Through the use of either a *consumable* or *nonconsumable electrode* (rod or wire), an arc is produced between the tip of the electrode and the parts to be welded, using ac or dc power supplies.

2.2.1. Shielded Metal Arc-Welding Process Overview

Shielded metal arc welding (SMAW) or manual metal arc (MMA) welding is a process that uses covered electrode. The electrodes are in the shape of thin, long sticks; hence, this process is also known as **stick welding**.

An electric arc is formed when an electric current passes between two electrodes separated by a short distance from each other. In arc welding, using direct-current, one electrode is the welding rod or wire, while the other is the plate to be welded. The electrode and plate are connected to the supply, one to the +ve pole and one to the -ve pole. The arc is started by momentarily touching the electrode on to the plate and then withdrawing it to about 3 to 4mm from the plate. When the electrode touches the plate, current flows, and as it is withdrawn from the plate the current continues to flow in the form of a 'spark' across the very small gap first formed. This causes the air gap to become ionized or made conducting, and as a result the current is able to flow across the gap, even when it is quite wide, in the form of an arc. The electrode must always be touched on to the plate before the arc can be started, since the smallest air gap will not conduct a current (at the voltages used in welding) unless the air gap is first ionized or made conducting. The thicker the electrode used, the more heat is required to melt it, and thus the more current is required: The welding current may vary from 20 to 600A in manual metal arc welding (Davies A. C., 2004).

When alternating current is used, heat is developed equally at plate and rod, since the electrode and plate are changing polarity at the frequency of the supply.

If a bare wire is used as the electrode it is found that the arc is difficult to control, the arc stream wandering hither and thither over the molten pool. The globules are being exposed to the atmosphere in their travel from the rod to the pool and absorption of oxygen and nitrogen takes place even when a short arc is held. The result is that the weld tends to be porous and brittle.

The arc can be rendered easy to control and the absorption of atmospheric gases reduced to a minimum by 'shielding' the arc. This is done by the flux covering the electrode, and as a result gases such as hydrogen and carbon dioxide are released from the covering as it melts and form an envelope around the arc and molten pool, excluding the atmosphere with its harmful effects on the weld metal. Under the heat of the arc chemical compounds in the electrode covering also react to form a slag which is liquid and lighter than the molten metal. It rises to the surface, cools and solidifies, forming a protective covering over the hot metal while cooling and protecting it from atmospheric effects, and also slows down the cooling rate of the weld. Some slags are self-removing while others have to be lightly chipped (see figure 2.2).

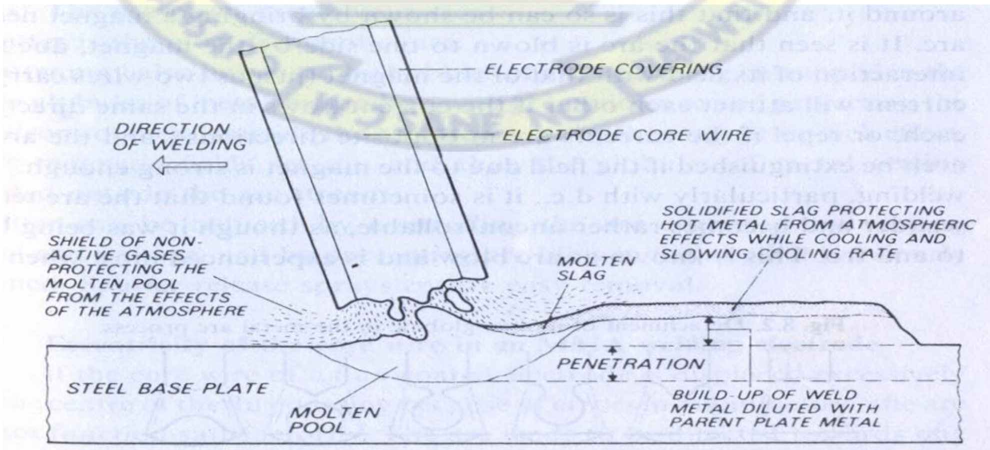


Figure 2.2 The shielded arc weld on steel base plate with a covered electrode (Davies A. C., 2004)

Figure 2.3 shows the essential components of the shielded metal arc welding circuit: Source of energy, welding plant or set, welding lead, electrode holder, electrode, the arc and work (metal to be welded).

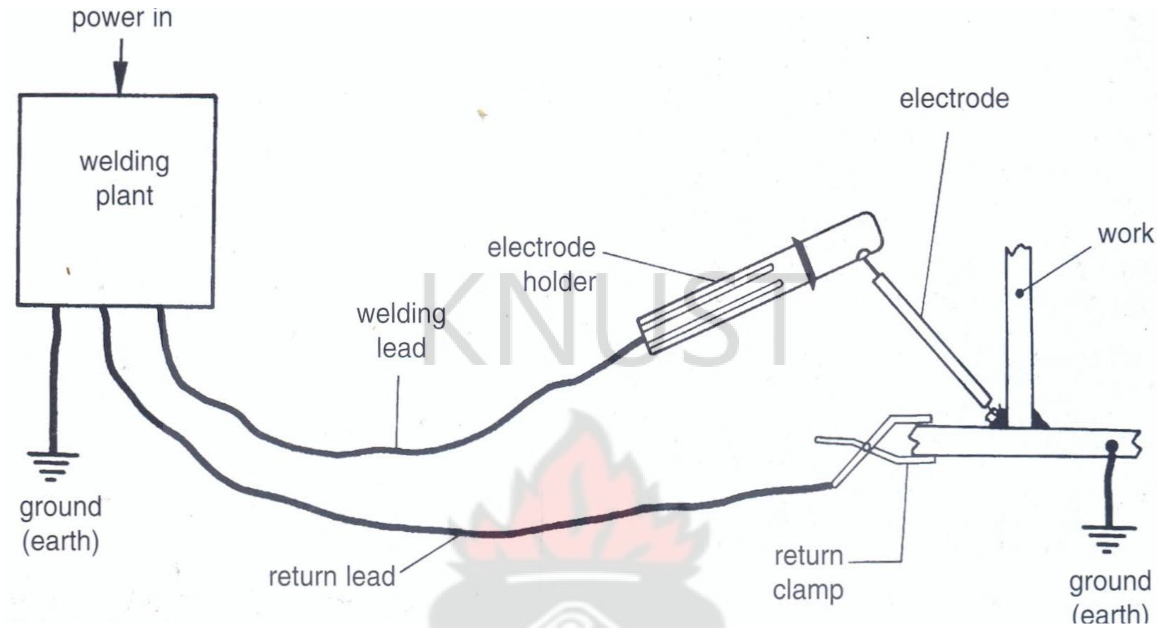


Figure 2.3 The SMAW circuit (Pritchard, 2001)

Arc energy is usually expressed in kilojoules per millimetre length of the weld (kJ/mm) and

$$\text{Arc energy (kJ/mm)} = \frac{\text{voltage } \times \text{welding current}}{\text{welding speed (mm/s) x 1000}'}$$

The welding set must be capable of supplying a continuous current, which can be adjusted to suit various sizes of electrode, at an open circuit voltage of between 50V and 100V. There are a number of types available, which vary in their energy requirement, type and amount of current delivered, open circuit voltage, duty cycle, and cooling mechanism (Pritchard, 2001).

2.2.2. Submerged Arc Welding Process Overview

Characteristics of submerged arc welding (SAW); *Type of operation:* Mechanised; *Heat source:* Arc; *Shielding:* Granular flux; *Current range:* 350 to 2000 A; *Heat input:* 9 to 80 *kJ/s;*

Mode of operation: An arc is maintained between the end of a bare wire electrode and the parent metal. The current is controlled by the power-supply unit. As the electrode is melted, it is fed into the arc by a servo-controlled motor. This matches the electrode feed rate to the speed at which the electrode is melting, thus keeping the arc length constant. The electrode and drive assembly is moved along the joint line by a mechanised traverse system. The arc operates under a layer of granular flux (hence 'submerged' arc). Some of the flux melts to provide a protective blanket over the weld pool. Unmelted flux is recovered and re-used. (Gourd L. M. 1995)

Typical applications: Joints in thick plate in pressure vessels, bridges, ships, structural work, welded pipe. Figure 2.4 and 2.5 shows a schematic diagram and equipment respectively for submerged-arc welding process.

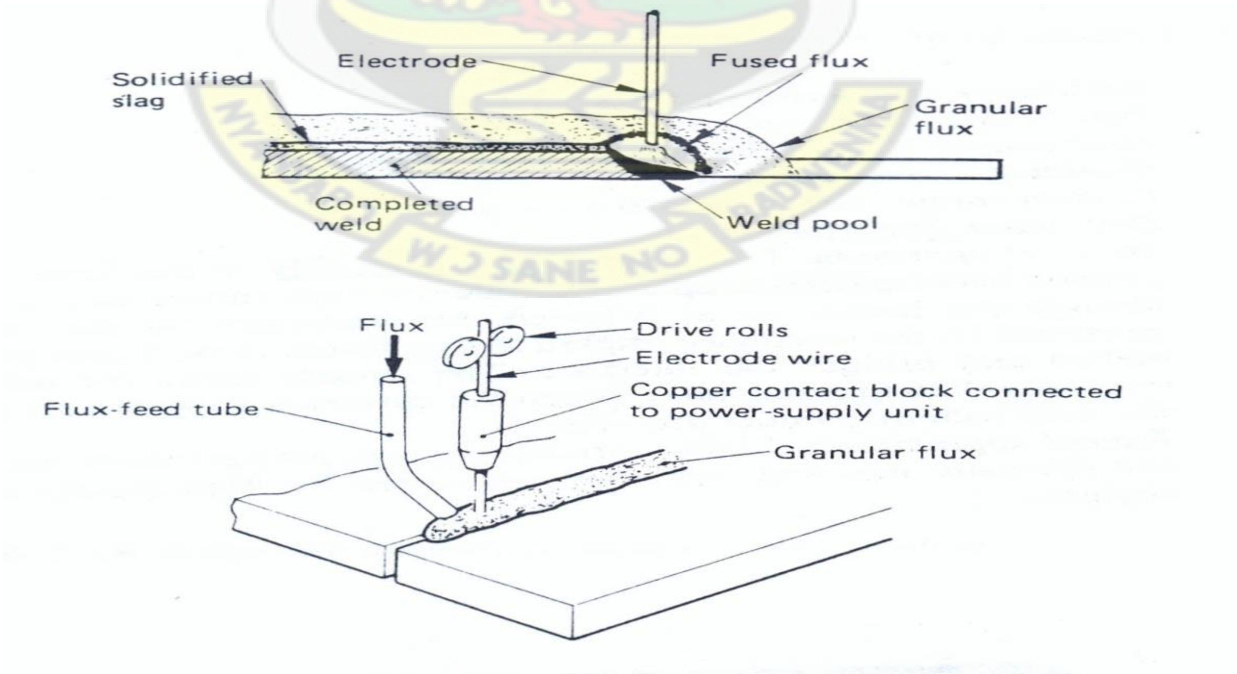


Figure 2.4 Schematic diagram of submerged-arc welding (Gourd L. M. 1995)

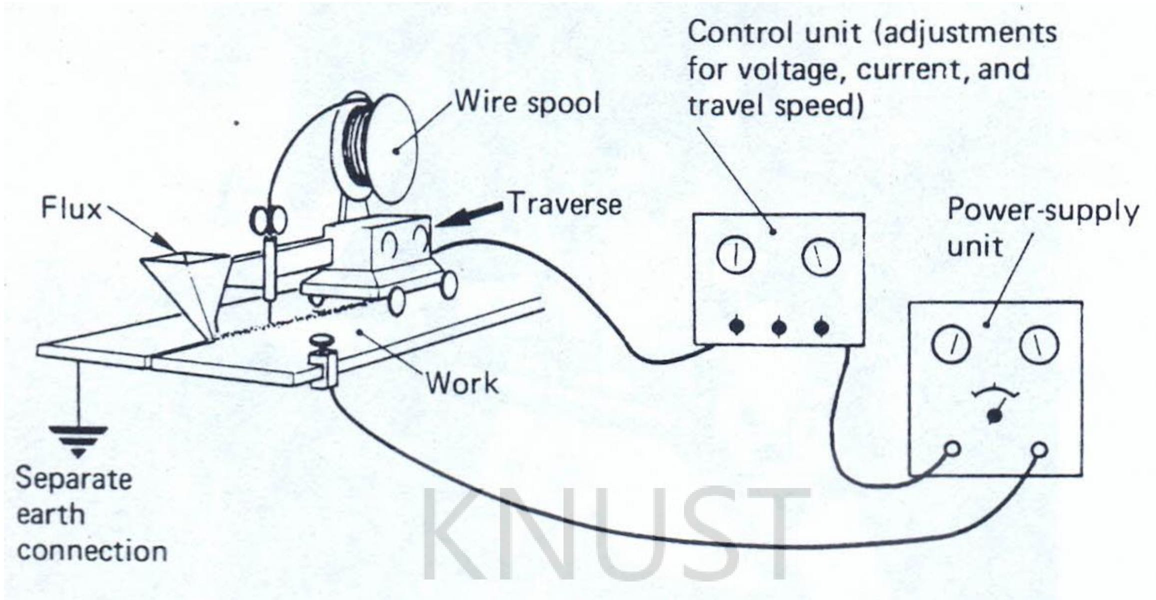


Figure 2.5 Equipment for submerged-arc welding (note that other types of traverse mechanism can be used) (Gourd L. M. 1995)

2.2.3. Gas Metal-Arc Welding Process Overview

In gas metal-arc welding (GMAW), also called MIG welding (for metal inert gas), the weld area is shielded by an external source, such as argon, helium, carbon dioxide, or various other gas mixtures (Fig.2.6a). In addition, deoxidizers are usually present in the electrode metal itself, in order to prevent oxidation of the molten weld puddle. The consumable bare wire is fed automatically through a nozzle into the weld arc (Fig.2.6b), and multiple weld layers can be deposited at the joint. This process, developed in the 1950s, is suitable for a variety of ferrous and nonferrous metals and is used extensively in the metal-fabrication industry. The process is rapid, versatile, and economical; its welding productivity is double that of the SMAW process and it can easily be automated and lends itself readily to robotics and flexible manufacturing systems. (Kalpakjian and Schmid, 2008)

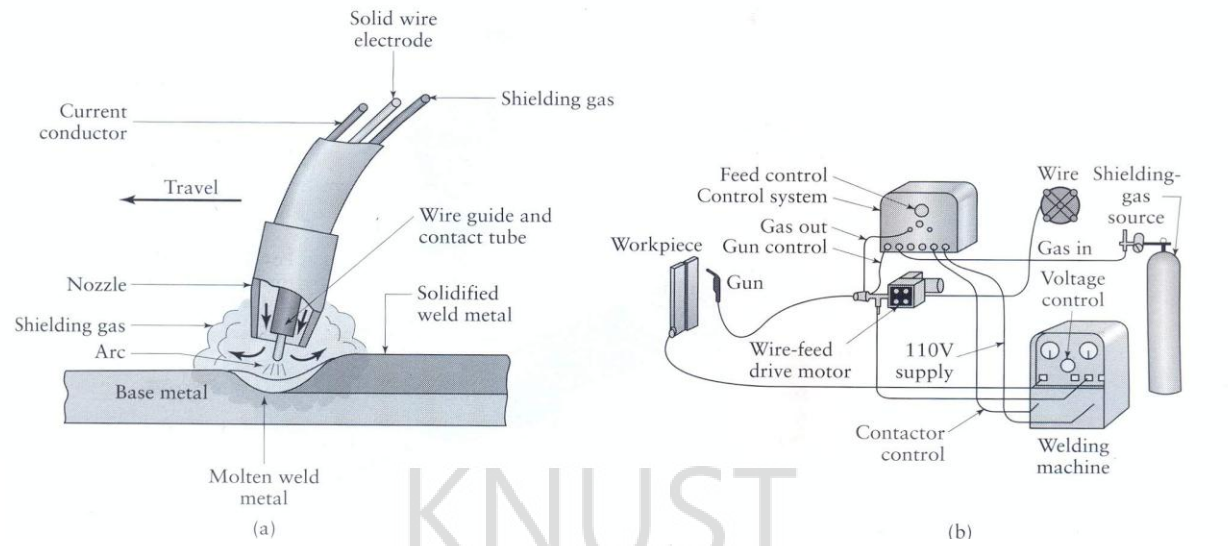


Figure 2.6 (a) Gas metal welding process (b) Basic equipment used in gas metal-arc-welding operations. (Kalpakjian and Schmid, 2008)

2.2.4. Flux Core Welding Overview

According to Wikipedia, flux core welding is a semi-automatic or automatic welding process. This means that the welder needs a way to continuously feed a tubular electrode (consumable) that has flux with a constant voltage. Sometimes the welder may use a shielding gas but it is not necessary; the flux will protect the process from contamination. Because this is a process that is quick, it is used in construction. It is also a portable process.

There are basically two types of flux core welding overview that are used: one type uses a shielding gas and the other one does not. With the first type a shielding gas is not used because the flux already has characteristics to resolve a contamination problem so it acts as its own shield. Most welders prefer this type because it penetrates well with the base metal and because it is portable. The second type uses an outside source for its shielding gas and generally is used to weld different steels together. This type of welding process is used when you have very thick metals to join together or when you have metals that are out of position for some reason. One has to be wary of outside air conditions when using this one because too much wind could make slag on your metal. (Ivan Irons, Welding Basics 1)

2.3 The Arc-Welding Processes: Nonconsumable Electrode

Unlike the arc-welding processes that use consumable electrodes, described in the previous section, nonconsumable-electrode arc-welding processes typically use a **tungsten electrode**. As one pole of the arc, the electrode generates the heat required for welding; a shielding gas is supplied from an external source.

2.3.1. Gas Tungsten Arc Welding Overview

Characteristics of gas tungsten arc welding (GTAW); *Alternative name:* Tungsten inert-gas (TIG) welding; *Type of operation:* Manual; *Heat source:* Arc; *Shielding:* Inert gas; *Current range:* 10 to 300 A; *Heat input:* 0.2 to 8kJ/s. *Mode of operation:* An arc is established between the end of a tungsten electrode and the parent metal at the joint line. The electrode is not melted and the welder keeps the arc gap constant. The current is controlled by the power-supply unit. Filler metal, usually available in 1 m lengths of wire, is added to the leading edge of the pool as required. The molten pool is shielded by an inert gas which replaces the air in the arc area. Argon is the most commonly used shielding gas. *Typical applications:* High-quality welds in metals such as aluminium, stainless steels, Nimonic alloys, and copper in chemical plant; sheet work in aircraft engines and structures. (Gourd L. M. 1995).

Tarng, et al (1999) in their study “Modeling, optimization and classification of weld quality in tungsten inert gas welding of thin aluminum plates” observed that, the quality of TIG welds ranks higher than that of any of the arc-welding processes, due to the reliability, clearance and strength of the weld. The quality of TIG welds is greatly dependent on the selection of process parameters such as arc gap, inert gas flow rate, welding current, welding speed and cleaning percentage. Figure 2.7 and 2.8 shows a schematic diagram and equipment respectively for GTAW process.

The cost of the inert gas makes this process more expensive than SMAW, but it provides welds with very high quality and surface finish. (Kalpakjian and Schmid, 2008).

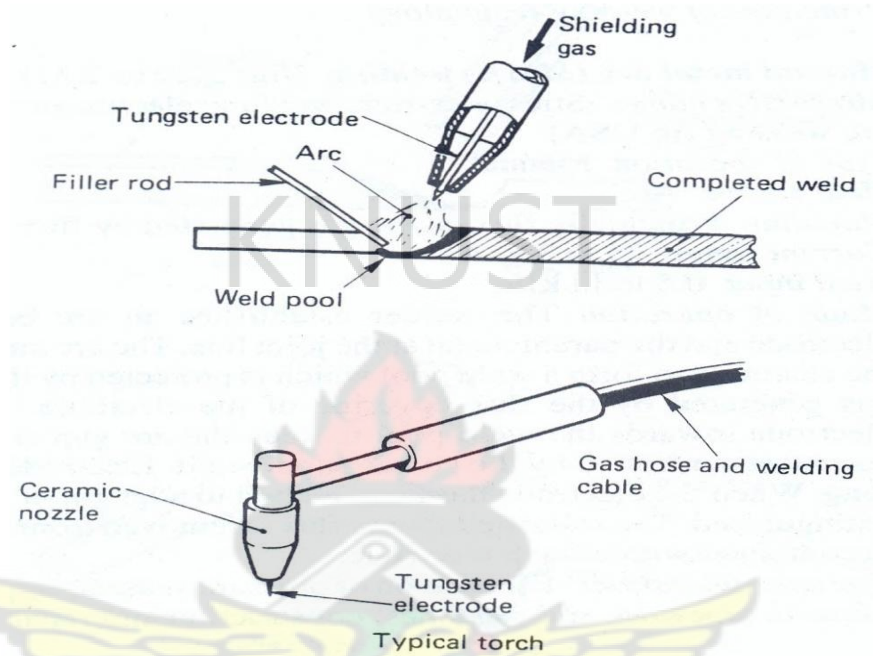


Figure 2.7 Schematic diagram of GTAW welding. (Gourd L. M. 1995).

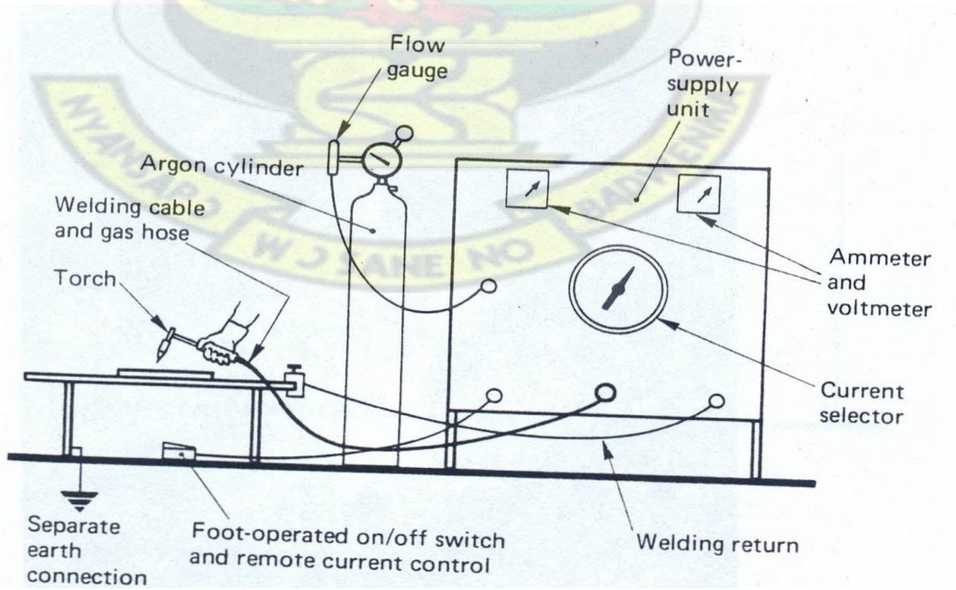


Figure 2.8 Equipment for GTAW welding (Gourd L. M. 1995).

2.4 Resistance Welding

Resistance welding depends on the heating effect of a current flowing through an interface between two overlapping sheets (see figure 2.9). The interface offers a resistance to the flow of the current, and the energy expended is converted to heat. Applying Ohm's law, the voltage (V) required for a current flow (I) is given by V = IR,

where R is the resistance of the interface.

The total energy for a current flow lasting t seconds is expressed as

$H = IVt = I(IR)t = I^2Rt$ joules·

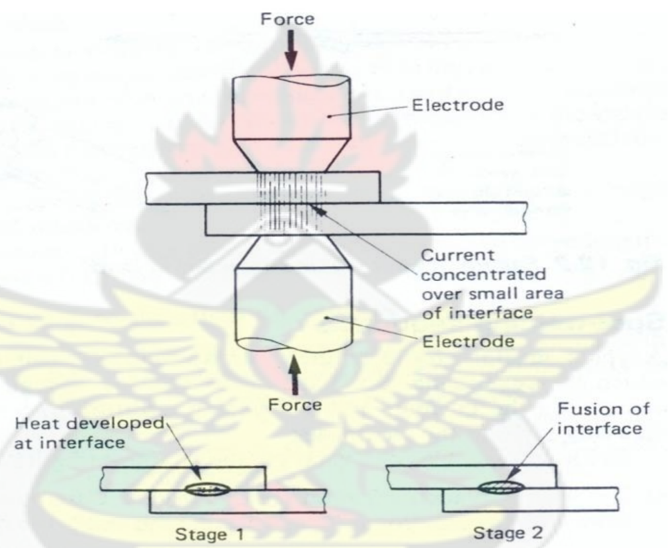


Figure 2.9 Principles of resistance welding. (Gourd L. M. 1995).

The time to make a single resistance weld is usually less than one second. (Connor L. P., 1989)

2.4.1. Resistance Spot Welding (RSW)

Resistance spot welding (RSW) emerged in the 1950s, and is nowadays the predominant assembly technique in the automotive industry. The vehicle components (body in white (BIW), cradle, doors, etc.) are made of thin metal sheets that are connected through spot-welded joints (or simply spot welds). To create a spot weld, two or more metal sheets are pressed together by electrodes, and an electric current is passed through.

The resistance of the metal generates heat, and the sheets are welded together by means of local metal fusion: a spot weld has been created. No welding material is added in this process. Three regions are identified in a spot weld. They are: a weld nugget with cylindrical shape, a heat-affected zone (HAZ) and the base material sheets (Donders et al, 2006) see figure 2.10. These regions have different material properties. For example, the yield stress in the nugget is up to three times higher than in the base material. (Chao Y., 2003)

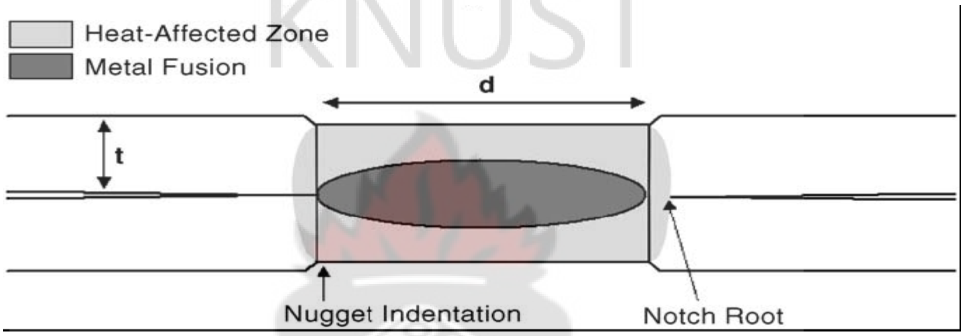


Figure 2.10 Spot weld layout and dimensions. (Donders et al, 2006)

Due to the applied pressure by the electrodes during the welding, the thickness of the nugget is often less than the thickness of the two metal sheets. This so-called nugget indentation is typically not significant for plate thickness up to 1 mm, but is more pronounced when thick plates are assembled. Stress concentration may occur at the indentation edges where a change of thickness takes place or at the notch root; this may result in crack initiation (Chao Y., 2003).

The machines used for spot welding can be either stationary or portable. These machines includes a rocker-arm and larger spot welders with hydraulic or pneumatic cylinders, and portable spot welding guns; widely used in the car industry, (Gourd L. M. 1995) see figure 2.11a, 2.11b and 2.11c.

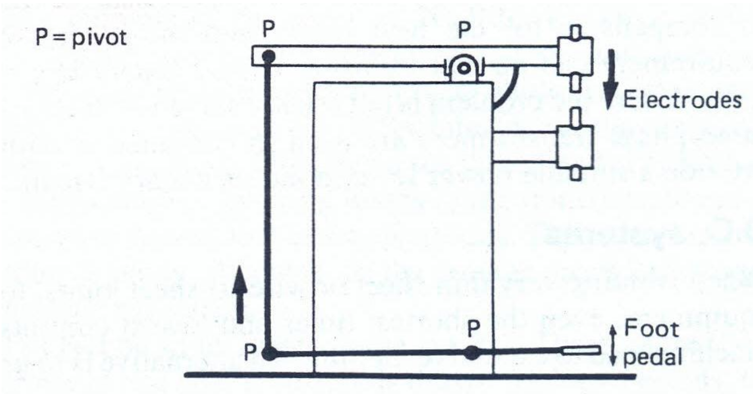


Figure 2.11 (a) rocker-arm spot welding machine (Gourd L. M. 1995)

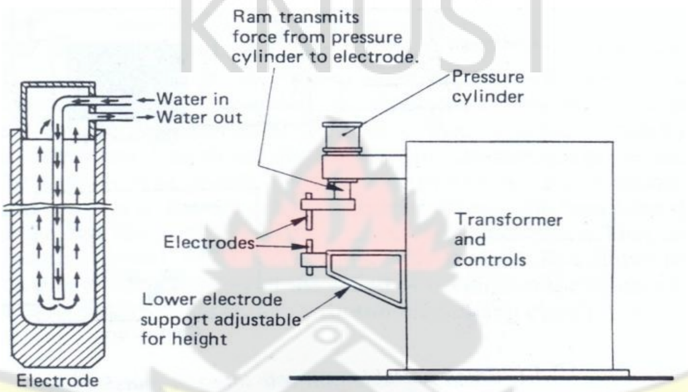


Figure 2.11 (b) larger spot welder with hydraulic pressure cylinder (Gourd L. M. 1995)

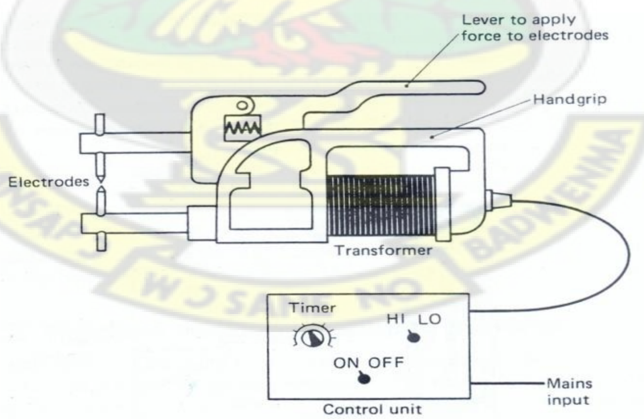


Figure 2.11 (c) small portable spot welding gun with integral transformer (Gourd L. M. 1995)

2.4.2 Resistance Seam Welding (RSEW)

Resistance seam welding is a modification of resistance spot welding wherein the electrodes are replaced by rotating wheels or rollers, as shown in figure 2.12a, and a series of overlapping spot welds are made along the lap joint (Fig.2.12b). With intermittent application of current to the rollers, a series of spot welds at various intervals can be made along the length of the seam (Fig. 2.12c), a procedure called roll spot welding (Kalpakjian and Schmid, 2008). The process is capable of producing air-tight joints, and its industrial application include the production of gasoline tanks, automobile mufflers, and various other fabricated sheet metal containers. Technically, RSEW is the same as spot welding, except that the wheel electrodes introduce certain complexities. (Groover, 2002).

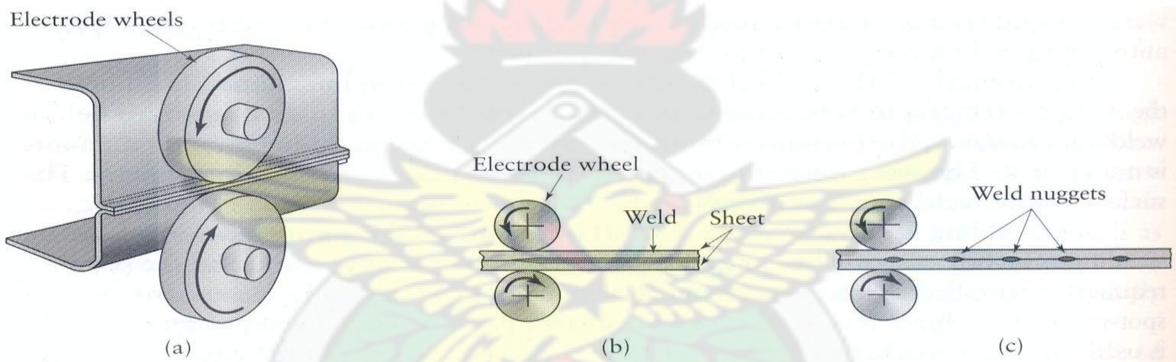


Figure 2.12 (a) Resistance seam welding process with rolls acting as electrodes.
(b) Overlapping spots in seam welds. (c) Roll spot welds. (Kalpakjian and Schmid, 2008).

2.4.3. Resistance Projection Welding (RPW)

In resistance projection welding coalescence occurs at one or more relatively small contact points on the parts. These contact points are determined by the design of the parts to be joined, and may consist of projections, embossments, or localized intersections of the parts. A typical case in which two sheet-metal parts are welded together is described in figure 2.13. The part on top has been fabricated with two embossed points to contact the other at the start of the process. It might be argued that the embossing operation increases the cost of the part, but this increase may be more than offset by savings in welding cost. (Groover, 2002).

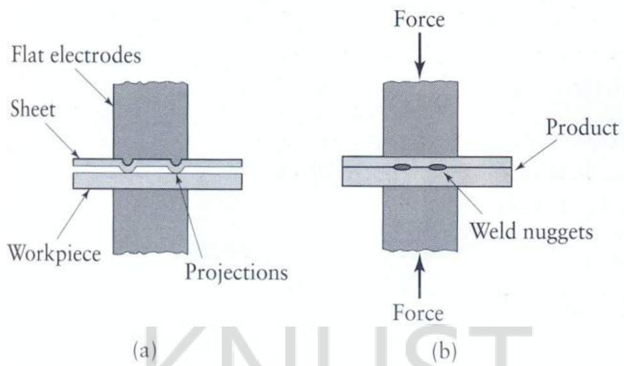


Figure 2.13 RPW (a) before and (b) after, weld nugget formed at the projections (Groover, 2002).

Although embossing workpieces is an added expense, this process produces a number of welds in one stroke, extends electrode life, and is capable of welding metals with different thicknesses. Nuts and bolts are also welded to sheet and plate by this process, with projections that may be produced by machining or forging. The process used for joining a network of wires, such as metal baskets, grills, oven racks, and shopping carts, is considered as resistance projection welding as well, because of the small contact area between crossing wires (grids). (Kalpakjian and Schmid, 2008)

2.5. Oxy Fuel Gas Welding (OFW)

Oxy fuel gas welding is a group of welding processes which produce coalescence by heating materials with a fuel gas flame or flames with or without the application of pressure and with or without the use of filler metal. There are three major processes within this group: oxyacetylene welding, oxyhydrogen welding, and pressure gas welding. There is one process of minor industrial significance, known as air acetylene welding, in which heat is obtained from the combustion of acetylene with air (Cary, 1997)

2.5.1. Oxyacetylene Welding (OAW)

The oxyacetylene welding process shown by figure 2.14, consists of a high-temperature flame produced by the combustion of acetylene with oxygen and directed by a torch. Filler metal is added to fill gaps or grooves. As the flame moves along the joint the melted base metal and filler metal solidify to produce the weld. (Cary, 1997). When acetylene is mixed with oxygen in the correct proportions, this gas burns with a flame temperature of about 3100°C, which is adequate for many welding applications (Gourd L. M. 1995).

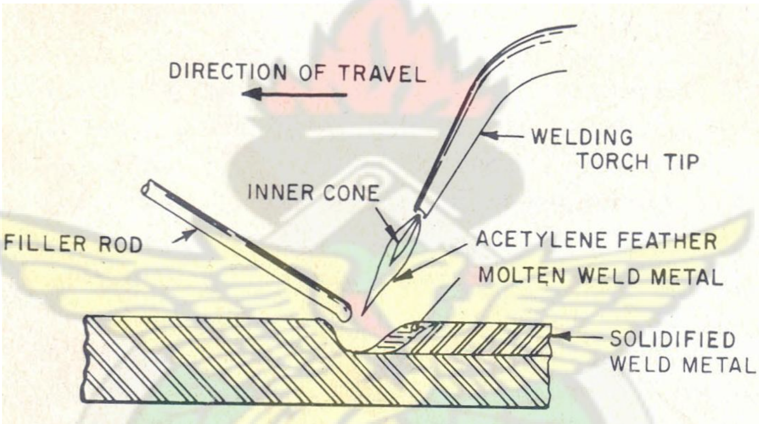


Figure 2.14 Oxyacetylene welding process diagram. (Cary, 1997)

The temperature of the oxyacetylene flame is not uniform throughout its length and the combustion is also different in different parts of the flame. Figure 2.15 shows the relationship between temperature and the flame and the composition of the gases in different portions of the flame. The temperature is the highest just beyond the end of the inner cone and decreases gradually toward the end of the flame.

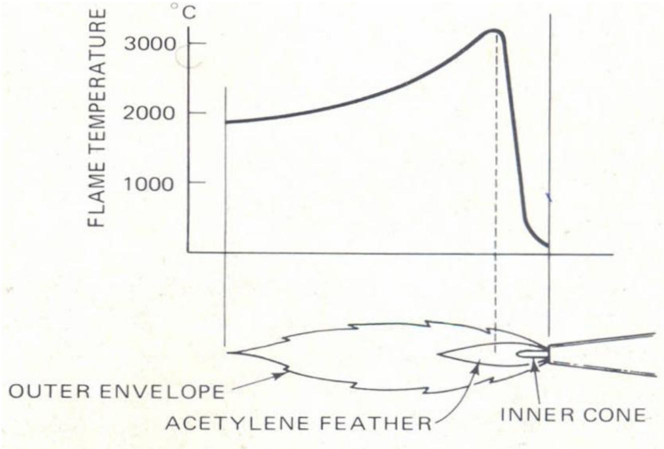


Figure 2.15 The temperature of oxyacetylene flame (Cary, 1997)

The flame in OAW is produced by the chemical reaction of a one-to-one ratio of acetylene and oxygen in two stages. The first stage is defined by the reaction,

$C_2H_2 + O_2 = 2CO + H_2 + Heat$;

the products of which are both combustible, which leads to the second-stage reaction:

$2CO + H_2 + 1.50_2 = 2C0_2 + H_20 + Heat$

The two stages of combustion are visible in the oxyacetylene flame emitted from the torch. (Groover, 2002)

There are three basic types of flame: neutral (or balanced), excess acetylene (carborizing), and excess oxygen (oxidizing). These three flames are shown by figure 2.16.

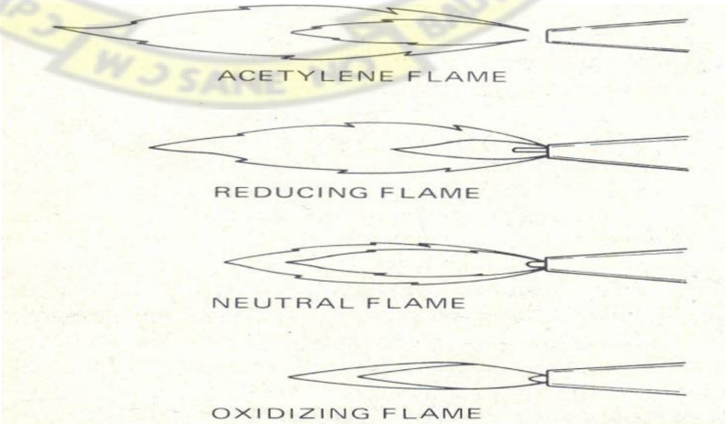


Figure 2.16 The three types of flame. (Cary, 1997)

The neutral flame has a one-to-one ratio of acetylene and oxygen. It obtains additional oxygen from the air and provides complete combustion. It is generally preferred for welding. The neutral flame has a clear, well-defined, or luminous cone indicating that combustion is complete.

For quality welding it is absolutely essential that this neutral flame is achieved (Pritchard, 2001). The carborizing flame has excess acetylene. This is indicated in the flame when the inner cone has a feathery edge extending beyond it. This white feather is called the acetylene feather. If the acetylene feather is twice as long as the inner cone it is known as a *2X* flame which is a way of expressing the amount of excess acetylene. The carborizing flame may add carbon to the weld metal. The oxidizing flame which has an excess of oxygen has a shorter envelope and a small pointed white cone. The reduction in length of the inner core is a measure of excess oxygen. This flame tends to oxidize the weld metal and/is used only for welding specific metals. Most welding procedures, utilizing oxyacetylene welding, use the neutral flame. The welder soon learns proper flame adjustment (Cary, 1997).

Advantages and Major Uses

The oxyacetylene welding process has the following advantages. The equipment is very portable. It is relatively inexpensive, it can be used in all welding positions and the puddle is visible to the welder. The equipment is versatile. It can be used for welding, brazing, soldering, and with proper equipment, for flame cutting. It can also be used as a source of heat for bending, forming, straightening, hardening, etc. The oxyacetylene welding process is normally used as a manual process. It can be mechanized, but this is not too common. It is rarely used for semiautomatic applications. OAW is used for welding most of the common metals as shown by Table 2.1.

Table 2.1 Base metals weldable by the oxyacetylene process. (Cary, 1997)

Base Metal	Filler Metal Type	Flame Type	Flux Type
Aluminums	Match base metal	Slightly reducing	Al. flux
Brasses	Navy brass	Slightly oxidizing	Borax flux
Bronzes	Copper tin	Slightly oxidizing	Borax flux
Copper	Copper	Neutral	None
Copper nickel	Copper nickel	Reducing	None
Inconel	Match base metal	Slightly reducing	Fluoride flux
Iron, cast	Cast iron	Neutral	Borax flux
Iron, wrought	Steel	Neutral	None
Lead	Lead	Slightly reducing	None
Monel	Match base metal	Slightly reducing	Monel flux
Nickel	Nickel	Slightly reducing	None
Nickel silver	Nickel silver	Reducing	None
Steel, low alloy	Steel	Slightly reducing	None
Steel, high carbon	Steel	Reducing	None
Steel, low carbon	Steel	Neutral	None
Steel, medium carbon	Steel	Slightly reducing	None
Steel, stainless	Match base metal	Slightly reducing	SS flux

When welding any metal, the appropriate filler material must be selected and used. The filler metal must match the composition of the base metal to be welded and normally contains deoxidizers to aid in producing sound welds. Flux is also required for welding certain materials. The oxyacetylene welding process is normally used for welding thinner materials up to 1/4 in. (6.4 mm) thick. It can be used for welding heavier material but it is rarely used for thick metals. Its major industrial applications are in the field of maintenance and repair, the welding of small diameter pipe, and for light manufacturing.

Welding Apparatus

The apparatus and equipment employed for oxyacetylene welding are shown by figure 2.17. This diagram shows the (1) welding torch and tips, (2) oxygen and acetylene hose, (3) oxygen and acetylene regulators, (4) oxygen cylinder, and (5) acetylene cylinder. A spark lighter is normally used. The welding torch, sometimes called a *blow pipe*, is the major piece of equipment for this process. It performs the function of mixing the fuel gas with oxygen and provides the required type of flame, which is directed as desired.

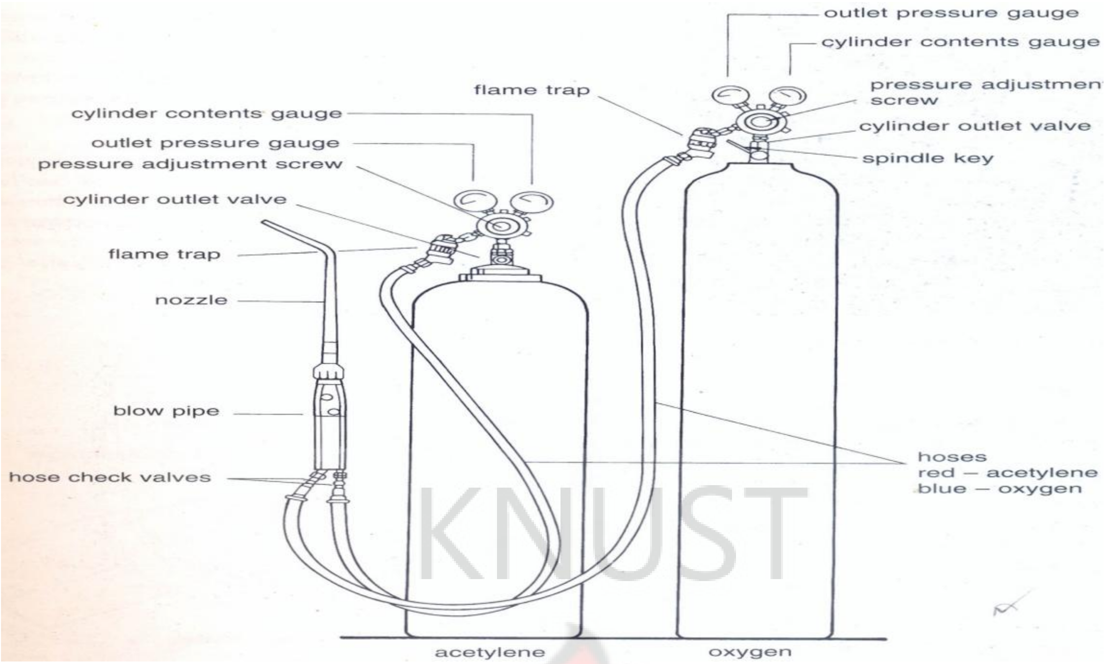


Figure 2.17 The apparatus required for welding with OAW (Pritchard, 2001).

2.5.2. Alternative Gases for Oxy Fuel Welding

According to Groover (2002), several members of the OFW group are based on gases other than acetylene. Most of the alternative fuels are listed in Table 2.2, together with their burning temperatures and combustion heats.

Table 2.2 Gases used in oxyfuel welding and/or cutting, with flame temperatures and heats of combustion.

	Temperature		Heat of Combustion	
Fuel	^{0}C	(^{0}F)	MJ/m^3	(Btu/ft^3)
Acetylene (C_2H_2)	3087	(5589)	54.8	(1470)
*MAPP (C_3H_4)	2927	(5301)	91.7	(2460)
Hydrogen (H_2)	2660	(4820)	12.1	(325)
Propylene (C_3H_6)	2900	(5250)	89.4	(2400)
Propane (C_3H_8)	2526	(4579)	93.1	(2498)
Natural gas	2538	(4600)	37.3	(1000)

Compiled from (Groover, 2002), page 714.
*MAPP is commercial abbreviation for methylacetylene-propadiene.

For comparison, acetylene is included in the list. Although oxyacetylene is the most common OFW fuel: each of the other gases can be used in certain applications-typically limited to welding of sheet metal and metals with low melting temperatures, and brazing. In addition, some users prefer these alternative gases for safety reasons.

The fuel that competes most closely with acetylene in burning temperature and heating value is methylacetylene-propadiene. MAPP (C_3H_4) has heating characteristics similar to acetylene and can be stored under pressure as a liquid, thus avoiding the special storage problems associated with C_2H_2.

When hydrogen is burned with oxygen as the fuel, the process is called ***oxyhydrogen welding*** (OHW). As shown in Table 2.2 the welding temperature in OHW is below that possible in oxyacetylene welding. In addition, the color of the flame is not affected by differences in the mixture of hydrogen and Oxygen, and therefore it is more difficult for the welder to adjust the torch.

Other fuels used in OFW include propane and natural gas. Propane (C_3H_8) is more closely associated with brazing, soldering, and cutting operations than with welding. Natural gas consists mostly of ethane (C_2H_6) and methane (CH_4). When mixed with oxygen it achieves a high temperature flame and is becoming more common in small welding shops.

2.6 Filler Metals and Materials for Welding

There are many types of materials used to produce welds. These welding materials are generally categorized under the term **filler metals,** defined as "the metal to be added in making a welded, brazed, or soldered joint." The filler metals are used or consumed and become a part of the finished weld. The definition has been expanded and now includes electrodes normally considered nonconsumable such as tungsten and carbon electrodes, fluxes for brazing, submerged arc welding, electroslag welding, etc.

Filler metals can be classified into four basic categories. These are: Covered electrodes, Solid (bare) electrode wire or rod, Fabricated (tubular or cored) electrode wire, Fluxes for welding. Included in materials for welding, but a material that cannot be considered a filler metal, would be the gases used in welding. The gases include oxygen and fuel gases for gas welding and cutting and shielding gases for the gas shielded arc welding processes.

2.6.1. Covered Electrodes

The covered electrode is the most popular type of filler metal used in arc welding. The composition of the covering or coating on the electrode determines the usability of the electrode, the composition of the deposited weld metal, and the specification of the electrode.

The original purpose of the coating was to shield the arc from the oxygen and nitrogen in the atmosphere. It was subsequently found that ionizing agents could be added to the coating which helped stabilize the arc and made electrodes suitable for alternating current welding. It was found that silicates and metal oxides helped form slag, which would improve the weld bead shape because of the reaction at the surface of the weld metal. The deposited weld metal was further refined and its quality improved by the addition of deoxidizers in the coating. In addition, alloying elements were added to improve the strength and provide specific weld metal deposit composition. Finally, iron powder has been added to the coating to improve the deposition rate. (Cary, 1997)

According to Gourd (1995), there are four main groups of electrodes used in MMA welding of steels. They are distinguished by the major constituents of the flux covering which determine their operating characteristics.

Acid coverings: Acid coverings are composed mainly of oxides and silicates and have high oxygen content. They give smooth weld profiles with a tendency to concavity.

Cellulosic coverings: Cellulosic coverings have large quantities of organic material containing cellulose. Flour and wood pulp are common constituents. The organic compounds decompose in the arc to generate hydrogen which replaces air in the arc column. The presence of hydrogen increases the voltage across the arc and makes it more penetrating.

Rutile coverings: Rutile coverings are based on titanium oxide. This compound has good slag forming characteristics and produces a stable easy-to-use arc. Rutile electrodes are widely used and fulfill a general-purpose role in the fabricating industry. The deposits have medium oxygen content; hence surface profiles are acceptable, and slag detachability is good.

Basic coverings: Basic coverings mainly contain calcium compounds such as calcium fluoride and calcium carbonate. The term 'basic' refers to the chemical behaviour of the flux. It does not mean that the electrodes are simple or easy to use. They are sometimes called 'lime-coated' or low hydrogen electrodes and are used principally for the welding of high-strength steels.

The low hydrogen content of the weld metal results in a weld that is resistant to solidification cracking and to a high sulphur content in the steel. Because there are no organic or hydrated materials in the covering the electrodes can be baked at high temperature giving a low level of hydrogen in the weld metal and reducing the danger of cold cracking, particularly in highly restrained joints and thick sections. Because of the relatively small gas shield, a short arc should be used and the electrodes are suitable for a.c. or d.c. electrode +ve. They should be stored under warm dry conditions and preferably baked before use (Davies A. C., 2004).

Iron-powder additions: Iron-powder additions are sometimes made to the flux covering to increase the electrode efficiency. This is defined as the mass of metal deposited as a percentage of the mass of core wire melted:

$$\text{electrode efficiency } \% = \frac{\text{mass of metal deposited}}{\text{mass of core wire melted}} \times 100\%$$

With ordinary electrodes the efficiency varies from 75 % to 95 % but with electrodes containing metallic components in the covering the efficiency can approach 200 % (e.g. electrodes containing iron powder). (Davies A. C., 2004).

2.6.2. Nonconsumable Electrodes

There are two types of *nonconsumable electrodes.* The carbon electrode is a non filler metal electrode used in arc welding or cutting, consisting of a carbon graphite rod which may or may not be coated with copper or other coatings. The second is the tungsten electrode, defined as a non filler metal electrode used in arc welding or cutting made principally of tungsten. These electrodes are used for gas tungsten arc welding, plasma arc welding, and atomic hydrogen arc welding.

2.6.3. Fluxes for Welding

Welding flux is required to maintain cleanliness of the base metal, at the welding area, and to help remove the oxide film on the surface of the metal. Flux for fusion welding comes in powder form, of varying colour and density, and is selected to suit the type of metal being welded. Its function is to prevent oxidation of the weld area, break down any oxide which does form, and also to combine with any other impurities present. The addition of flux makes the weld pool appear cleaner and brighter, and makes it flow better; the absence of these signs indicates that more flux should be added (Pritchard, 2001).

Modenesi, et al (2000) in their study, "TIG welding with single-component fluxes" stated that, the use of a flux, even of extremely simple formulation, can greatly increase (up to around 300%) the weld penetration in TIG welding. It was possible to obtain full penetration welds in 5mm thick plates of austenitic stainless steel with no preparation and currents of about 230A.

The method of flux application differs for each process. The delivery techniques include (1) pouring granular flux onto the welding operation, (2) using a stick electrode coated with flux material in which the coating melts during welding to cover the operation, and (3) using tubular electrodes in which flux is contained in the core and released as the electrode is consumed. (Groover, 2002)

2.6.4 Shielding Gases Used in Welding

When any of the welding processes are used, the molten puddle should be shielded from the air in order to obtain a high quality weld deposit. In the submerged arc and electroslag welding process, the molten metal is shielded from the air by a flux. In the shielded metal arc welding process, shielding from the air is accomplished by gases produced by the disintegration of the coating in the arc. In carbon arc welding, the slow burning away of the carbon electrode produces an atmosphere of carbon monoxide and carbon dioxide which shields the molten metal.· In the gas welding processes and in torch brazing the products of combustion of fuel gas with oxygen shields the molten metal from the atmosphere. As the fuel gas burns, the products of primary combustion are carbon monoxide and hydrogen. The gas flame envelops the welding area, the air is excluded, and the molten metal is exposed only to these two gases. These are reducing gases. The products of secondary combustion, which is the reaction of' the carbon monoxide and the hydrogen with air, are carbon dioxide and water vapor. These processes could be considered gas shielded processes.

Gases for Shielding

Various gases are used for arc shielding. These can be inert gases such as helium or argon, or they can be mixtures of these and other gases. All gases have different properties and must be selected for shielding based on the particular metal to be welded, the type of the metal transfer required, and the economics involved. Inert gases will not combine chemically with other elements. There are six truly inert gases: argon, helium, neon, krypton, xenon, and radon. All of these except helium and argon are much too rare and expensive to use for gas shielded welding. The most commonly used active gas for shielding is carbon dioxide. CO_2 is used when welding steels using the gas metal arc process. It is not an inert gas and compensation must be made for its oxidizing tendencies (Cary, 1997).

Modenesi, et al (2000) stated that, usually, in the TIG welding of stainless steels with argon shielding, full penetration welding is restricted to joints of a maximum thickness of 3mm and to relatively low welding speed. Although the welding speed can be increased substantially (up to 160%) when helium or hydrogen is used as part of the shielding gas mixture, bead penetration can only be increased slightly (1–2mm). The capacity to improve the penetration by the selection of the shielding mixture is further limited by the need to use inert or slightly reducing gases, restricting this selection basically to argon and helium mixtures.

2.7 The Metallurgy of Welding

The weldment is divided into three distinct regions (see figure 2.18): the fusion zone (FZ), which undergoes melting and solidification, the heat-affected zone, adjacent to the FZ that often experiences solid-state phase changes but no melting, and the unaffected base material. The integrity of welded joints depends on the weldment microstructure and properties. Rapid heating, cooling, and local structural changes cause significant spatial variations in the composition, microstructure, and residual stress in the fusion and heat-affected zones (David and DebRoy, 1992).

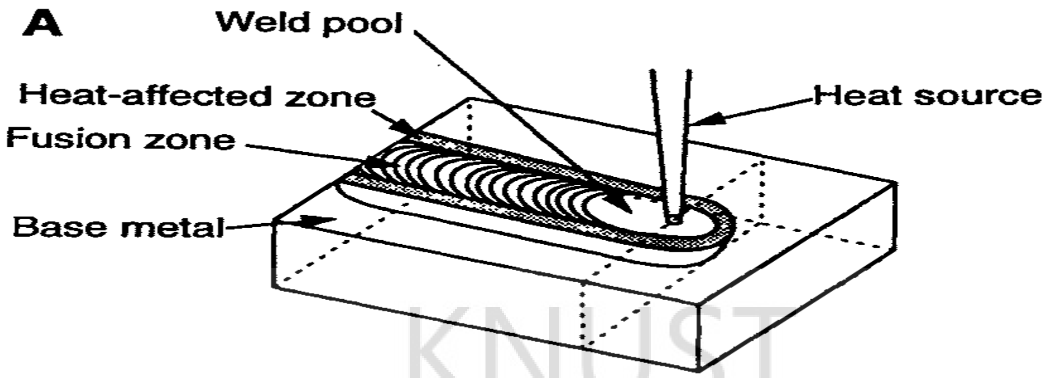


Figure 2.18 Three distinct regions in the weldment: the fusion zone, the heat-affected zone, and the base metal. (David and DebRoy, 1992).

According to Connor L. P. (1989), the width of the heat-affected zone and the widths of each region in the heat-affected zone are controlled by the welding heat input. High heat inputs result in slow cooling rates, and therefore, the heat input may determine the final transformation products. The hardness of a weld heat-affected zone is a function of the base metal carbon content. Figure 2.19 shows the heat-affected zone and the corresponding phase diagram for 0.30% carbon steel.

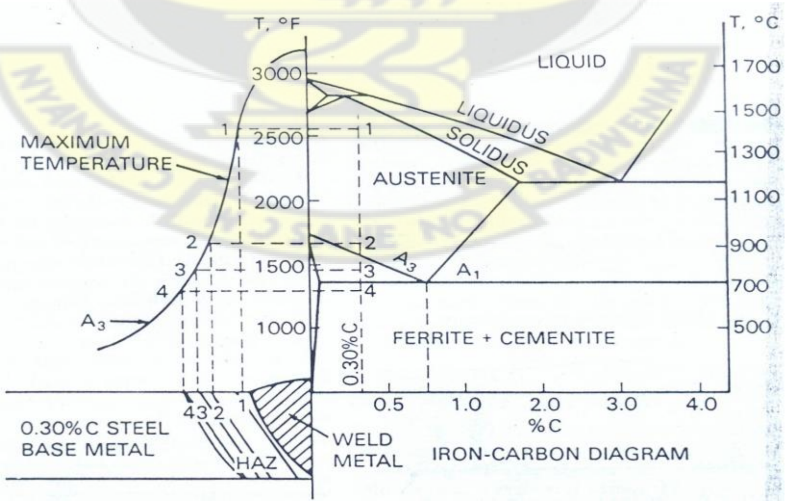


Figure 2.19 Schematic illustration of various regions in a fusion-weld zone and the corresponding phase diagram for 0.30% C steel (Connor L. P., 1989).

2.7.1 Weldability

The characteristic of a metal to be welded without losing desirable properties is called weldability (Connor L. P., 1989).

The two factors most important to weldability are hardenability and the susceptibility of the hardened structure to cracking. Both are increased by using a higher carbon or higher alloy content in the base metal. Certain alloying elements increase hardenability without a significant increase in the susceptibility to cracking. In this regard the carbon equivalent of the base metal becomes important. The carbon equivalent (CE) formula is as follows (Cary, 1997):

$$CE = \%C + \frac{\%Mn}{6} + \frac{\%Mo}{4} + \frac{\%Cr}{5} + \frac{\%Ni + \%Cu}{15} + \frac{\%P}{3}$$

Nobutaka Yurioka (2001) reviewed many carbon equivalents with different coefficients that have been proposed and found that weldability of steel is represented by carbon equivalency. However, carbon equivalent of a simple summation form cannot evaluate weldability of steels from conventional one to carbon-reduced one because the HAZ hardness is interactively determined by carbon content and hardenability.

Zhou et al (2000), stated that, Al and brass are relatively easier to resistance weld compared with Cu because of their relatively higher electrical resistance and lower thermal conductivity. It was found that resistance weldability of sheet metals is not only determined by resistivity (or thermal conductivity) but also affected by other physical properties (such as melting point, latent heat of fusion and specific heat).

The following list briefly summarizes, in alphabetic order, the general weldability of specific metals. The weldability of these materials can vary significantly, with some requiring special welding techniques and good control of processing parameters. (Kalpakjian and Schmid, 2008).

1. *Aluminum alloys:* weldable at a high rate of heat input; aluminum alloys containing zinc or copper generally are considered unweldable.
2. *Cast irons:* generally weldable.
3. *Copper alloys:* similar to that of aluminum alloys.
4. *Lead:* easy to weld.
5. *Magnesium alloys:* weldable with the use of protective shielding gas and fluxes.
6. *Molybdenum:* weldable under well-controlled conditions.
7. *Nickel alloys:* weldable by various processes.
8. *Niobium (columbium):* weldable under well-controlled conditions.
9. *Stainless steels:* weldable by various processes.
10. *Steels, galvanized and prelubricated:* The presence of zinc coating and lubricant layer adversely affects weldability.
11. *Steels, high-alloy:* generally good weldability under well-controlled conditions.
12. *Steels, low-alloy:* fair to good weldability.
13. *Steels, plain-carbon:* excellent weldability for low-carbon steels; fair to good weldability for medium-carbon steels; poor weldability for high-carbon steels. In structural steels, CE values range from 0.35% to 0.5% (Gourd L. M. 1995).
14. *Tantalum:* weldable under well-controlled conditions.
15. *Tin:* easy to weld.
16. *Titanium alloys:* weldable with the use of proper shielding gases.
17. *Tungsten:* weldable under well-controlled conditions.
18. *Zinc:* difficult to weld; soldering preferred.
19. *Zirconium:* weldable with the use of proper shielding gases.

2.7.2. Weld Quality

Because of a history of thermal cycling and attendant micro structural changes, a welded joint may develop discontinuities. Welding discontinuities can also be caused by inadequate or careless application of established welding technologies or sub-standard operator training. The major discontinuities (see figure 2.20) that affect weld quality are described as follows (Pritchard, 2001)

Lack of Penetration: The weld fails to fuse fully into the root of a fillet or through a butt joint. Probable causes:

1. More heat is required - use a larger flame or higher current setting.

2. Less filler is needed - use a smaller electrode, lower wire feed speed, or in gas/TIG welding, feed less in.

3. The joint gap is too small or the angle is too acute.

Over-Penetration: The weld metal protrudes excessively through a butt or breaks through the other side of fillets. The causes are the opposite of those listed above for lack of penetration.

Lack of Fusion: The weld metal fails to fuse at the interface. This has the same causes as lack of penetration and can be avoided by using more heat/less filler.

Undercut: The metal has melted away but has not been filled in, leaving a 'notch' at the side of the weld. Undercut on one side only indicates that the angle of tilt (of the torch/gun) did not bisect the joint angle. If it appears on both sides then the ratio of heat to filler must be reduced, that is, less heat or more filler is needed.

Overlap: Not common, this is where weld metal spills over the plate surface without having fused to it. When this occurs on one side only, a change in tilt angle is needed, but if it happens on both sides then more heat or less filler is required.

Cold Lap: This is a term applied to MIG welding only but actually means lack of fusion/overlap. It is very difficult to eliminate completely, at restarts generally and at those in aluminium in particular. Higher voltage/wire settings are required or less wire/more voltage.

Slag Traps: These occur in MMA welding only and are voids in the weld metal occupied by slag. The causes are numerous and include a low current setting, acute preparation angle, steep electrode slope angle, or welding over slag or heavy scale.

Porosity: Gas entrapment is rarely evident on the weld surface, but the traps' spherical form appears as light circles on an X-ray. This problem is caused in stick welding by damp electrode coatings (hydrogen) or in MIG/TIG welding by lack of gas shielding, or from contaminants such as oil and oxide scale.

Blowholes: These are gas holes large enough to appear on the weld surface and may be due to extreme porosity, or in braze welding occur as a result of too little oxygen in the flame.

Underfill: Part of a butt weld is below the plate surface, causing it to fail any welding test. More filler/passes are required.

Spatter: Particles of weld thrown out on the plate surface, caused by high welding currents, long arcs and damp electrodes in MMA welding, and by too little inductance/too much CO_2 in the shielding gas in MIG welding.

Rough Appearance: Erratic arc length, long arcs and shallow slopes give rise to rough welds, as do damp electrodes and surface contamination.

Cracks: Cracks are mostly related to the composition of the material being welded and temperature gradients that cause thermal stresses in the weld zone. The risk of their formation is an important element in the concept of weldability.

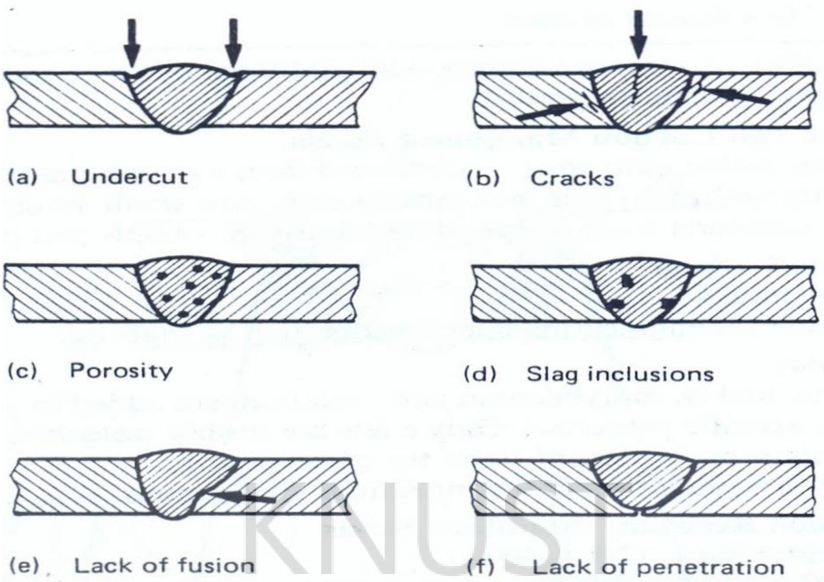


Figure 2.20 Cross-sections of welds containing typical defects (Gourd L. M. 1995).

Terashita and Tatsumi (2003), in their report describing the analysis results of the forms and causes of damaged rail welds in Japan from 1985 to 2001 reported that, "in thermite welds, welding discontinuities, that cause transverse fissures in the rail base, are mainly *lack of fusion* and *centerline shrinkage*. On the other hand, most of transverse fissures in the rail web are caused by *solder cracks.* The enclosed arc welds are damaged by fatigue failure. Initiation of fatigue cracks is *liquation cracks* and *lack of fusion*. On the other hand, all transverse fissures in the rail base are initiated by *lack of fusion.*"

2.8 Methods for Testing of Welded Joints

All types of welded structures—from steel bridges to jet components—serve a function. Likewise, the welded joints in these structures and components are designed for service-related capabilities and properties. Predicting service performance on the basis of laboratory testing presents a complex problem because weld size, configuration, and the environment as well as the types of loading to which weldments are subjected differ from structure to structure. This complexity is further increased because welded joints—consisting of unaffected base metal, weld metal, and a heat-affected zone (HAZ)—are metallurgically and chemically heterogeneous. In turn, each of these regions is composed of many different metallurgical structures as well as chemical heterogeneities. Testing is usually performed to ensure that welded joints can fulfill their intended function. (www.ihs.com, 2001).

A great variety of methods of testing welds are now available and, for convenience, we can divide them into two classes: (1) non-destructive, (2) destructive. Visual inspection falls under the heading of non-destructive tests (Davies A. C. 2004).

2.8.1 Visual Inspection; is no doubt the most widely used inspection method. An inspector visually examines the weldment for (1) conformance to dimensional specifications on the part drawing, (2) warpage, and (3) cracks, cavities, incomplete fusion, and other defects. The welding inspector also determines if additional tests are warranted, usually in the nondestructive category. The limitation of visual inspection is that only surface defects are detectable; internal defects cannot be discovered by visual methods.

2.8.2 Nondestructive Evaluation; the nondestructive inspection group includes a variety of inspection methods that do not damage the specimen being evaluated. *Dye-penetrant* and *fluorescent-penetrant tests* are methods for detecting small defects such as cracks and cavities that are open to the surface. Fluorescent penetrants are highly visible when exposed to ultraviolet light. Their use is therefore a more sensitive technique than dyes.

Magnetic particle testing is limited to ferromagnetic materials. A magnetic field is established in the subject part, and magnetic particles (e.g., iron fillings) are sprinkled on the surface. Subsurface defects such as cracks and inclusions reveal themselves by distorting the magnetic field, causing the particles to be concentrated in certain regions on the surface.

Ultrasonic testing involves the use of high-frequency sound waves (over 20 kHz) directed through the specimen. Discontinuities (e.g., cracks, inclusions, porosity) are detected by losses in sound transmission. *Radiographic testing* uses X-rays or gamma radiation to detect flaws internal to the weld metal. It provides a photographic film record of any defects.

2.8.3 Destructive Testing; these are methods in which the weld is destroyed either during the test or to prepare the test specimen. They include mechanical and metallurgical tests. *Mechanical tests* are similar in purpose to the conventional testing methods such as tensile tests and shear tests. The difference is that the test specimen is a weld joint. *Metallurgical tests* involve the preparation of metallurgical specimens of the weldment to examine such features as metallic structure, defects, extent and condition of heat affected zone, presence of other elements, and similar phenomena (Groover, 2002).

2.9 Designs for Welding

2.9.1 Design Considerations in Welding

As in all manufacturing processes, the optimum choice in welding is the one that satisfies all design and service requirements at minimum cost. General design guidelines for welding may be summarized as follows (Bralla, 1999):

1. Product design should minimize the number of welds, as welding can be costly when it is not automated.
2. The weld location should be selected to avoid excessive stresses or stress concentrations in the welded structure, as well as for appearance.
3. The weld location should be selected so as not to interfere with subsequent processing of the part or with its intended use and appearance.
4. Parts should fit properly before welding; the method employed to produce the edges (sawing, machining, shearing, and flame cutting) can affect weld quality.

5. Modification of the design may avoid the need for edge preparation.
6. Weld-bead size should be kept to a minimum to conserve weld metal.
7. Mating surfaces for some processes may require uniform cross-sections at the joint.

2.9.2 Welding Positions, Joints, Welds, and Weld Joints

Welding Positions

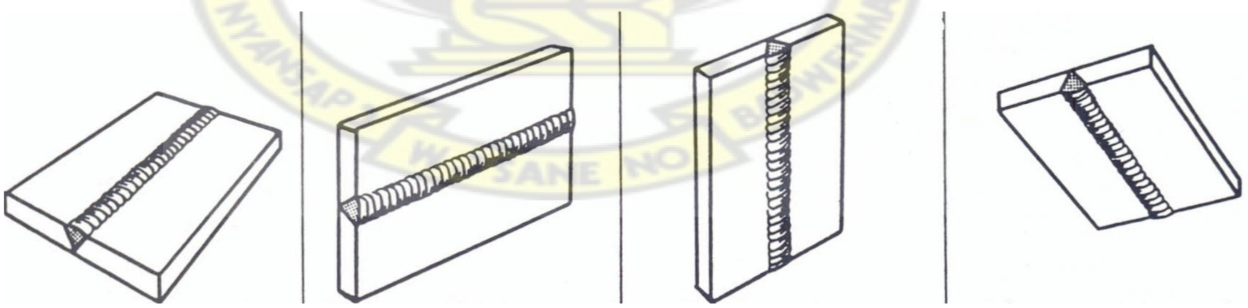
The American Welding Society has defined the four basic welding positions as follows: (see figure 2.21).

Flat; "When welding is performed from the upper side of the joint and the face of the weld is approximately horizontal."

Horizontal; "The axis of the weld is approximately horizontal, but the type of the weld dictates the complete definition. For a fillet weld, welding is performed on the upper side of an approximately horizontal surface and against an approximately vertical surface. For a groove weld the face of the weld lies in an approximately vertical plane."

Vertical: "The axis of the weld is approximately vertical."

Overhead: "When welding is performed from the underside of the joint."



(a) (b) (c) (d)

Figure 2.21 Welding positions (defined here for groove welds): (a) flat, (b) horizontal, (c) vertical, and (d) overhead. (Cary, 1997)

The weld joint

Welding produces a solid connection between two pieces, called a weld joint. A weld joint is the junction of the edges or surfaces of parts that have been joined by welding.

Types of joints: There are five basic types of joints for bringing two parts together for joining (see figure 2.22). The five joint types can be defined as follows:

(a) *Butt joint.* In this joint type the parts lie in the same plane and are joined at their edges.

(b) *Corner joint.* The parts in a corner joint form a right angle and are joined at the corner of the angle.

(c) *Lap joint.* This joint type consists of two overlapping parts.

(d) *Tee joint.* In the tee joint, one part is perpendicular to the other in the approximate shape of the letter T.

(e) *Edge joint.* The parts in an edge joint are parallel with at least one of their edges in common and the joint is made at the common edge(s).

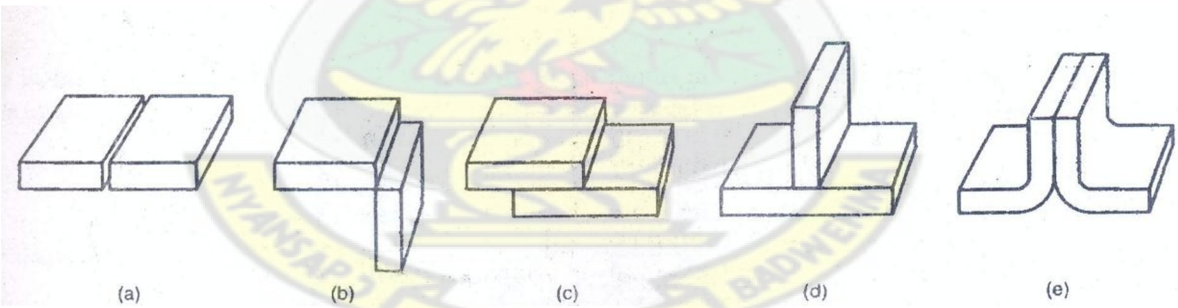


Figure 2.22 Five basic types of joints: (a) butt, (b) corner, (c) lap, (d) tee, and (e) edge. (Groover, 2002)

Types of Welds

There is a distinction between the joint type and the way in which it is welded-the weld type (see figure 2.23). The differences among weld types are in geometry (joint type) and welding process (Groover, 2002).

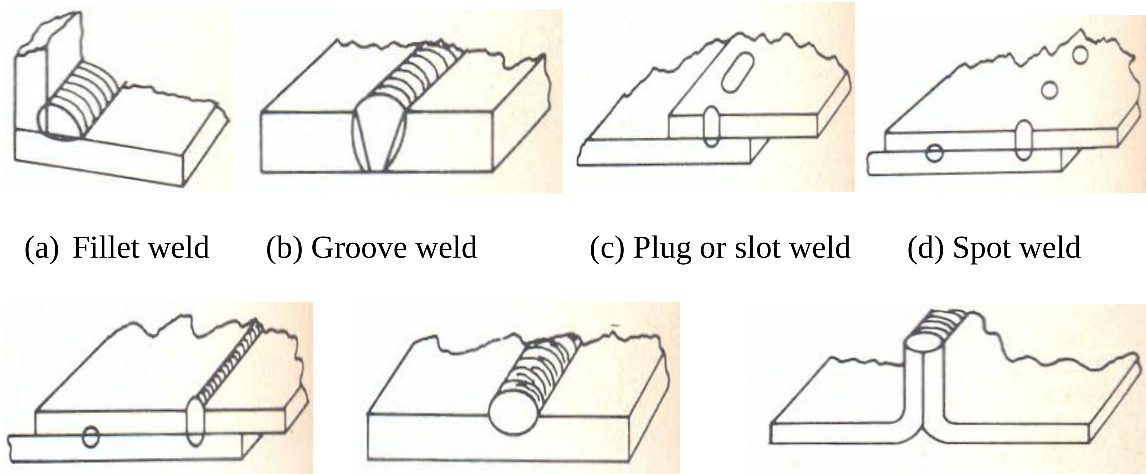
Fillet weld: is used to fill in the edges of plates created by comer, lap, and tee joints. Fillet welds may be single or double.

Groove welds: usually require that the edges of the parts be shaped into a groove to facilitate weld penetration. The grooved shapes include square, bevel, V, U, and J, in single or double sides.

Plug welds and slot welds: are used for attaching flat plates. It is prepared by using one or more holes or slots in the top part and then filling with filler metal to fuse the two parts together.

Spot welds and seam welds, used for lap joints. A *spot weld* is a small fused section between the surfaces of two sheets or plates. Multiple spot welds are typically required to join the parts. It is most closely associated with resistance welding. A *seam weld* is similar to a spot weld except it consists of a more or less continuously fused section between the two sheets or plates.

Flange welds and surfacing welds. *A flange weld* is made on the edges at two (or more) parts, usually sheet metal or thin plate at least one of the parts being flanged as in figure 2.23 (g). *A surfacing weld* is not used to join parts but rather to deposit filler metal onto the surface of a base part in one or more weld beads.



(a) Fillet weld (b) Groove weld (c) Plug or slot weld (d) Spot weld

(e) Seam weld (f) Surfacing weld (g) Flange weld

Figure 2.23 Basic types of welds (Cary, 1997)

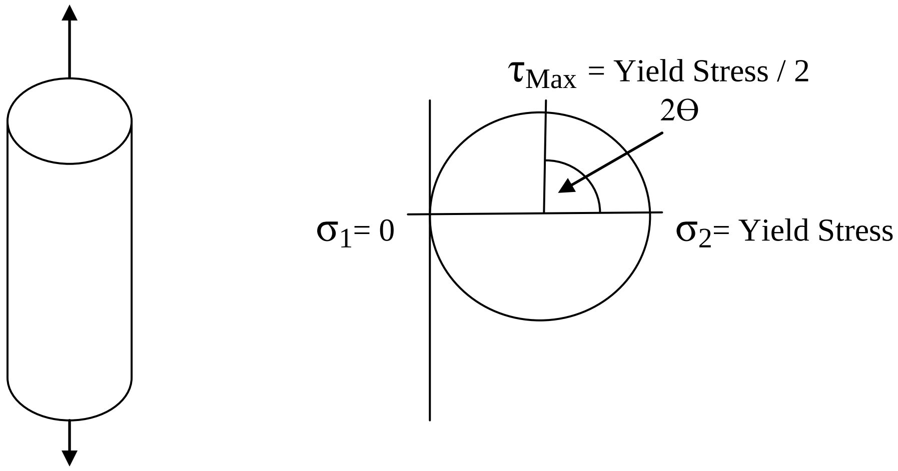
2.9.3 Welded Joint Design

The purpose of the weld joint is to transfer the stresses between the members and throughout the weldment. Forces and loads are introduced at different points and are transmitted to different areas throughout the weldment. The amount of stress to be transferred across the joint is estimated using calculations, experience, and so on (www.gowelding.com).

Welding Calculations

Design Rules for calculating the strength of butt and fillet welded joints subject to Direct, Bending and Torsional loadings.

Consider a tensile test. If Mohr's circle is used to analyse the stresses in the tensile specimen, the first principal stress is zero and the second is equal to the yield stress. The maximum shear stress is therefore half the yield stress and acts on a plane inclined at $\Theta = 45^o$ to the plane of principal stress. Angles represented by Mohr's circle are doubled.



Using Mohr's circle for a simple tensile test, the formula for the principal stresses are;

$$\sigma_{1,2} = \frac{1}{2}\left(\sigma_x + \sigma_y\right) \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}{}^2}$$

which can be simplified when only one direct stress is involved as above.

$$\sigma_2 = \frac{1}{2}\left(\sigma_x \pm \sqrt{\sigma_x{}^2 + 4\tau^2}\right)$$

For a single stress system, stress levels must be kept below the yield stress, however for more complex stress systems when stress's become three dimensional their combined effect must also be considered. As failure of a ductile material normally occurs when the maximum shear stress is exceeded:

Maximum Shear Stress = The greatest difference between Principal Stresses / 2

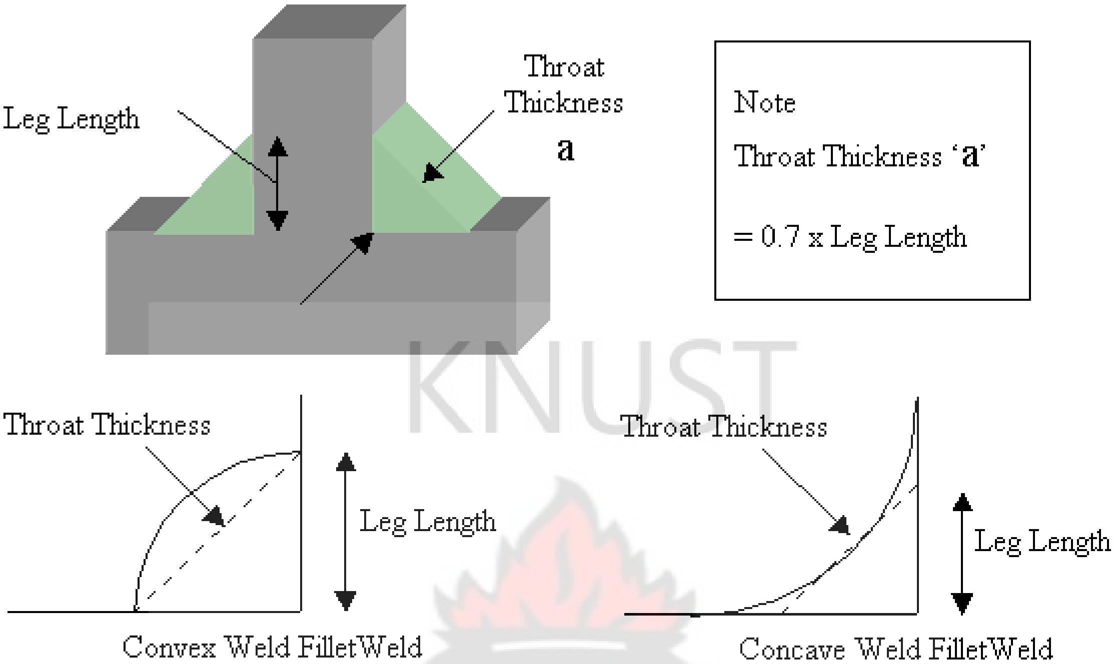
If the principal stresses in a three dimensional stress system are $\sigma_1 > \sigma_2 > \sigma_3$ then:

$\tau_{Max} = (\sigma_1 - \sigma_3) / 2$ and hence yield stress should not exceed $(\sigma_1 - \sigma_3)$ this is known as the Tresca yield criterion.

Basic Weld Design

Short welds should be avoided as weld stop and starts can be a source of defects. As a rule of thumb length of fillet welds should be longer than 8 times the throat thickness 'a' e.g. throat thickness of 5mm gives a minimum weld length of 40mm. Also discounting the first and last 12mm of weld length from stress calculation can also improve reliability.

When calculating the strength of fillet weld the throat thickness should always be used and the weld treated as if it was a perfect triangle.



Before applying the various design formulas, the problem itself must be analyzed and clearly stated. This is not always obvious, and trying to solve the wrong problem can quickly lead to insufficient design stresses which can lead to failure of the weldment. When a load is placed on a member, stress and strain result. Stress is the internal resistance to the applied force. Strain is the amount of deformation caused by the stress, such as deflection in bending, elongation in tension, contraction in compression, and angular twist in torsion. (www.gowelding.com)

Chao (2003) in his study observed that while spot weld in a lap-shear test sample is subjected to a global shear load the failure mechanism of the weld at the microstructure level is in fact tensile. On the other hand, while the spot weld in a cross tension sample is subjected to *normal* load the failure mechanism of the weld is shear. These failure mechanisms help us to develop the applied load-stress relations.

2.9.4 Welding Symbols

A beginner welder may find it difficult to understand welding symbols. However, if he thinks of this as a system of codes or shorthand that tells him different information about the weld that needs to be done, these welding symbols will be easier to read. The symbols tell the welder the type of weld to do, the size of the weld he should do and other information about how he will process it or finish the job. Typical weld symbols set up by American and British standards are shown in appendix A.

2.10 Safety in the Welding Industry

2.10.1 Hazards Welders Encounter and Safety Precautionary Measures

Welding is a very difficult and dangerous profession so it is important for welders to follow general safety guidelines. In this way, they can insure not only their safety but the safety of others around them. Some of the hazards a welder may encounter and safety precautionary measures are as follows (Balchin and Castner, 1993):

Explosion Risks; Explosions can occur when acetylene gas is present in air in any proportion between 2 and 82%. Acetylene is also liable to explode when under excessive pressure, even in the absence of air. The first essential requirements are, therefore, adequate and proper ventilation, and the examination of the installation to ensure that it is free from leaks.

Fire Risks: The risk of any welding or cutting operation starting a fire is considerable. However, there is one risk special to oxyfuel gas welding, and particularly to gas cutting. If the oxygen content is increased, burning intensity and speed is increased, normally non-flammable materials may burn, and oil or grease may catch fire spontaneously. Oxygen may be released into the air by leaks in equipment, by supplies being left on, or by excessive purging. In the normal operation of the flame cutting process about 30% of the oxygen supplied is released unconsumed to the atmosphere: oxyfuel gas cutting should never be undertaken in a confined space without proper ventilation arrangements. Sparks and spatter from arc welding are always liable to ignite any flammable material in the vicinity. Care should therefore be taken to make sure that the workplace and the surrounding area are clear of anything which may catch fire.

Eye Injuries and Burns: During welding and cutting operations precautions must be taken to prevent burns of the eyes and exposed parts of the body which may occur as the result of spattering of incandescent metal particles and from flying slag particles.

Buonanno et al (2011) in their study observed that particle concentration characterization, along with air exchange ratio measurements in the body shop, showed that the indoor concentrations and, hence, worker particle exposure can be reduced through the use of local exhaust ventilation.

If the eyes are exposed to the light of the arc, even for quite short periods, arc eye may develop. Therefore, helmets or hand-held shields with appropriate filter lenses and cover plates must be used by welders and nearby personnel when viewing the arc. Burns are almost invariably caused through lack of care, or through failure to wear protective clothing. Operators should make sure that their clothing is free from oil or grease, and that their workplace is tidy and not encumbered by any inflammable material which may be ignited by sparks or spatter. They should also avoid working with sleeves rolled up and hands and forearms unprotected by suitable gloves or sleeves. In overhead welding, a protective cape is a useful addition to equipment.

Kumah et al (2011) in their study stated that the commonest radiation-related ocular eye diseases among welders at the Suame magazine were pterygium (56.6%), photoconjunctivitis (22.6%) and cataract (5.1%) where as in the control group the commonest conditions were pterygium (6.2%), pinguecula (2.2%) and cataract (1.3%). There was a small number of retinopathies associated with radiation (4.0%). Most (60.0%) of the welders used electricity (arc welding) and the remaining (40.0%) used carbide (oxy-acetylene flame).

Fume Risks: Good ventilation must always be provided for oxyfuel gas welding. The heat produced by prolonged contact of the acetylene flame with a large mass of metal leads to the formation of oxides of nitrogen, and in confined spaces special ventilation or breathing equipment is necessary. The fumes given off when welding and cutting parts which have been galvanized, lead-coated, or otherwise treated may be injurious to the operator and special precautions must be taken. The powder cutting process used to cut stainless steel and non-ferrous metals also requires special precautions. The ultraviolet light from the arc, particularly the gas shielded arc, may form ozone from the air or phosgene from solvents. Shielding gases are released into the atmosphere, and may build up where ventilation is restricted, or even in open topped tanks, as they are generally heavier than air. In the above operations the operator should guard against the possibility of inhaling toxic fumes, for example, by wearing a suitable respirator.

Electric Shock: Under normal industrial conditions a supply of no more than 120V has been used to obtain an adequate measure of safety against electric shock. Any exposed metal part of a portable control device that operates above 50 volts must be grounded. Welders are liable to come into contact with live conductors in the welding circuit in the course of their work. As the risk of shock from 80 V is normally low, welders may come to regard this as safe and become careless. When work is carried out in hot or damp surroundings, the risk of a fatal shock may be significantly increased (Balchin and Castner, 1993).

2.10.2 Welding Gear and Personal Protective Equipment (PPE)

There are varieties of PPE'S that are important to safety. Some of these PPE'S are as follows: *Gloves;* are used to protect the hands from sparks, burns and electric shock. *Hats or doo rags;* a welding hat or doo rag is worn to absorb sweat and resist sparks from the welding work. Most hats protect the ears as well as the head. *Helmets;* a welding helmet protects the head and face from sparks and provides protection to the eyes from the flash and intense heat of the flame. It also protects the welder from breathing in the fumes. The cover plate on the outside has to be made of plastic that is polycarbonate because this is the only type of plastic that will protect from UV rays. The helmet should have a lens filter that is glass that has a filler that protects from the light that goes through the eyes (Ivan Irons, Welding Basics 2).

Protective clothing; should be of a design with inside seams which will not be burned by spatter, and which will reduce the possibility of snagging on edges of the work; it should also be reasonably comfortable to wear, not restricting movement too much, as is compatible with giving adequate protection. The welder's normal workwear, for example coveralls, trousers, shirts and jackets, should be of material which will not burn or melt easily. Woolen clothing is more fire resistant than cotton. *Hand shield;* The hand-shield protects one hand as well as the face but gives the least protection to the head. *Goggles;* goggles can protect the eyes from the heat and light radiated by the work. *Dust respirator;* If the fume from welding operations cannot be removed from the atmosphere before it reaches the welder, an alternative is to filter it from the air breathed with a dust respirator. (Balchin and Castner, 1993).

2.11 Welding Training Programmes

Training for welding, soldering, and brazing workers can range from a few weeks of school or on-the-job training for low-skilled positions to several years of combined school and on-the-job training for highly skilled jobs.

2.11.1 Education and Training for Welders

Formal training is available in high schools and postsecondary institutions, such as vocational-technical institutes, community colleges, and private welding schools. The U.S. Armed Forces operate welding schools as well. Although some employers provide training, they prefer to hire workers who already have experience or formal training. Courses in blueprint reading, shop mathematics, mechanical drawing, physics, chemistry, and metallurgy are helpful. An understanding of electricity also is very helpful, and knowledge of computers is gaining importance, especially for welding, soldering, and brazing machine operators, who are becoming more responsible for the programming of robots and other computer-controlled machines. Since understanding the welding process and inspecting welds is important for both welders and welding machine operators, companies hiring machine operators prefer workers with a background in welding. Employment of welding, soldering, and brazing workers is expected to grow more slowly than average. They will have excellent job opportunities as some welding employers report difficulty finding trained welders. (USA Bureau of Labour Statistics, Occupational Outlook Handbook, 2008-09)

2.11.2 Certification and other Qualifications for Welders

Some welding positions require general certifications in welding or certifications in specific skills such as inspection or robotic welding. The American Welding Society certification courses are offered at many welding schools. Some employers have developed their own internal certification tests. (Occupational Outlook Handbook, 2008-09)

According to the wall street journal, in an article in 2006, all types of welders whether they specialize in welding, brazing or soldering are in demand because of all the construction that continues to grow at least until 2014; in fact the need for new skilled welders is said to increase but the supply hasn't met the demand (Ivan Irons, Welding Basics 1).

Some of the skills needed to be a good welder and get a good job include (Ivan Irons, Welding Basics 1):

- Blueprint reading- the welder has to be able to read a blueprint very quickly and know exactly what he needs to do in the job.
- Safety-the welder has to know the safety rules and how it affects him, other people and the equipment he uses. The welder has to be sure to help people to stay safe.
- Ability to sustain concentration-the welder has to be able to focus on the job for long periods of time and not get distracted.
- Be able to serve customers-although one may not think this is something that would be included in welding, it means that the welder needs to be able to get along with customers and other staff.
- A welder must have good eyesight and be detail oriented.

2.11.3 Advancement for Welders

Welders can advance to more skilled welding jobs with additional training and experience. For example, they may become welding technicians, supervisors, inspectors, or instructors. Some experienced welders open their own repair shops. Other welders, especially those who obtain a bachelor's degree, become welding engineers. (USA Bureau of Labour Statistics, Occupational Outlook Handbook, 2008-09).

2.12 Hypotheses

1. There is no significant relationship between the age of welders and their level of knowledge of the causes of weld failure.
2. There is no significant relationship between the education of welders and their level of knowledge of the causes of weld failure.
3. There is no significant relationship between the training the welders go through and their level of knowledge of the causes of weld failure.
4. There is no significant relationship between the number of years the welder has been welding after qualification as a welder and their level of knowledge of the causes of weld failure
5. There is no significant relationship between the age of welders and their practices before they plan to weld.
6. There is no significant relationship between the education of welders and their practices before they plan to weld.
7. There is no significant relationship between the training the welders go through and their practices before they plan to weld.
8. There is no significant relationship between the number of years the welder has been welding after qualification as a welder and their practices before they plan to weld.
9. There is no significant relationship between the age of welders and their level of knowledge of hazards in industry.
10. There is no significant relationship between the education of welders and their level of knowledge of hazards in industry.
11. There is no significant relationship between the training the welders go through and their level of knowledge of hazards in industry.

12. There is no significant relationship between the number of years the welder has been welding after qualification as a welder and their level of knowledge of hazards in industry.
13. There is no significant relationship between the age of welders and their proneness to hazards in industry.
14. There is no significant relationship between the education of welders and their proneness to hazards in industry.
15. There is no significant relationship between the training the welders go through and their proneness to hazards in industry.
16. There is no significant relationship between the number of years the welder has been welding after qualification as a welder and their proneness to hazards in industry.
17. There is no significant relationship between the number of years the industry has been welding and the level of availability of safety or personal protective equipment in industry.

CHAPTER THREE

3.0 METHODOLOGY AND QUESTIONNAIRE DESIGN

3.1 Introduction

This chapter describes the methodology and work plan used in executing the research work and the challenges encountered. The questionnaire survey method was used to elicit information on the current welding practices in selected metal welding industries in Ghana.

3.2 Sample Size Selection

The research involves population proportions; that is, deciding on the number in the population of industries that practice welding. The sample size was therefore decided based on a confidence level of 95% and an error of 0.06. The number required is given as:

$$n = \frac{1}{4}\left[\frac{z_{\alpha/2}}{d}\right]^2$$ (McClave and Sincich, 2000)

Where n = number required

$z_{\alpha/2}$ = 1.65 (from the standard normal probability tables) for a confidence interval of 95% and the error d given as 0.06. Substituting these values in the above Equation n is obtained as 189. A total round value of n = 200 was therefore chosen for the research.

A total of 200 engineering firms, companies and institutions and wayside welding enterprises mostly concentrated in the Ashanti, Greater Accra and Western Regions, that practice welding were selected using 'Stratified Random Sampling' based on the scope of work. Stratified Random Sampling is used to select samples in situations where the population is heterogeneous but has definite strata or classes which are homogenous (Ferguson and Takane, 1989). Hence these firms were put into three categories; firms that use welding as: (1) maintenance and repair activity; (2) for manufacturing (example, manufacturers of classroom metal desks, metal gate, block making machines, metal containers, coal pot etc.), and (3) constructional works (includes companies that build tunnels, subways, structural steel for bridges and buildings, metal bill board and sign board construction, etc.) in Ghana.

3.3 Pilot Survey

A pilot survey was conducted for five (5) engineering firms and welding firms in the Kumasi metropolis for purposes of testing the effectiveness and reliability of the survey instrument. Two field officers personally administered the questionnaire during the pilot survey. The pilot survey guided the researcher to get the final questionnaire.

3.4 Questionnaire Development and Administration

Questionnaires were developed and used to elicit information from welders in engineering firms, companies and institutions and wayside welding firms during the survey. Both open-ended and closed-ended questions were included in the questionnaire used to collect information on the survey. The open-ended questions were such that respondents were free to use their own words to elaborate on and organize information and give their views on the subject matter, whereas the close-ended questions assisted the respondents in choosing from possible answers given in the questionnaire.

The attitudes and opinions of respondents were studied. Open-ended questions were formulated to elicit awareness of the issue in question and general attitudes towards it. A closed-ended question follows to capture information on specific attitudes to the subject. An open-ended question is placed next to explore the participants' justifications for their attitudes. This is followed by closed-ended question to tap the intensity with which they hold such attitudes. The closed-ended questions are typically of the multiple choice type. This kind of question structuring was first introduced by Gallup in 1947. (Marshall, 1997).

The survey instrument consists of five main sections. Personal information data could be found in section A (from 1 to 7) of the questionnaire. Section A elicits information on the demographic characteristics of the welders. Section B of the questionnaire elicits information on the work and industry background; i.e. type of ownership, number of years industry has been welding, etc. and covers questions 8 to 14. Questions on production issues; i.e. type of welding process employed, products or items welded, quality control mechanisms employed, etc. are found from 15 to 31. Design and planning for welding questions; i.e. welders knowledge of type of joints and welds, factors welders consider before planning to weld, etc. are found from 32 to 39. Questions on safety; i.e. welders' knowledge of welding hazards in industry, availability of safety equipment in industry, etc. are found from 40 to 44. Lastly, question 45, an open-ended question, elicits information on the challenges the welders go through in industry.

Most of the questions in all the sections are a combination of both close and open ended questions. Responses had little or no prompting from the interviewer. The advantage of this was that interviewee responses were not restricted or biased (as would occur with multiple choices). The disadvantage was that responses to the open-ended questions were not easily quantifiable. In some cases, common responses were grouped for the purpose of displaying results. The final form of the survey instrument is shown in appendix B.

3.5 Field Work

Questionnaire used for the field work were personally administered by field officers. Field officers booked appointments with all the selected firms and the welders to send the questionnaire to them and agree on the day and time of subsequent meeting. This prior notice was very important because it gave the respondents ample time to study and understand the questionnaire and got them prepared. Field work was conducted in engineering firms both in the formal and informal sector. For the entire research survey, 250 questionnaires were administered and 200 responded and retrieved from firms both in the formal and informal sector. For the firms in the formal sector, 68 firms responded. From the Ashanti region, 29 responded, Greater Accra 19 (Accra 7, Tema 12), Western region 8, Eastern region 7, Brong Ahafo region 3, Upper East region 1 and Central region 1. No questionnaires were administered in the Volta, Northern and Upper west regions. For the engineering firms in the informal sector (wayside welding industries), out of the 250 questionnaires administered in the entire research, 132 were retrieved. Majority of the questionnaires in the informal sector were administered in the Ashanti region, with about 57 retrieved from respondents at the Suame Magazine in Kumasi.

Field officers visited the engineering firms at their places and assisted them in filling the questionnaire. Questions on the questionnaire which were not clear to respondents were clarified. Questions asked ranged from personal data, work background, production issues, design for welding to perceptions of respondents about safety issues and any challenges encountered. Each respondent spent about an hour during the administration of the questionnaire.

The survey approach of using personal interviews by a single data collector questionnaire ensured consistency of interpretation of the questions. It also enabled the adaption of the survey questions to meet the goal of exposing and exploring issues of most relevance to this research.

3.6 Survey Distribution

Finding engineering firms or industries especially those in the formal sector that practice heavy welding was not a simple task. These engineering firms were selected from the Association of Ghana Industries (AGI) database, National Board for Small Scale

Industries (NBSSI) records, firms suggested by interviewees, website pages and telephone directory. AGI and NBSSI are categories of associations and organization of small to very large industries. This was done to have a broad base spectrum of metal joining industries to investigate the practices of welding engineering which is common to all categories of industries.

NBSSI has its own categories for establishing the size of industries. The categories are designated as Micro, Small, Medium and Large. These designations are based on staff strength. The determination of NBSSI categories are:

- Those with less than 6 employees are designated micro industry
- Those with between 6 and 29 employees are designated small industry
- Those with 30 to 49 employees are designated medium industry
- Those with more than 50 employees are designated large industry

Interviewees especially in the formal sector were selected to be fairly representative of the regions in the country which have industries (Ashanti region, Greater Accra, Western region, Eastern region, Brong Ahafo region, Upper East region and Central region) and of some key maintenance, manufacturing and construction welding industries.

3.7 Challenges Encountered During Survey

Though the survey was conducted successfully by the field officers, some challenges were encountered. Main highlights of the challenges are presented as follows:

- **Identification of Key Maintenance, Manufacturing and Constructional Engineering Firms.**

It was difficult identifying key engineering firms that practice welding especially those in the formal sector during the survey. This is because there is limited information in the database of the relevant institutions such as AGI, and even the

Ministry of Trade and Industry (MoTI). Though the information on the firms was available, the difficulty was how to identify those firms that practice heavy welding.

- **Postponement of Appointment and Busy Schedule of Respondents**

Most of the firms postponed appointments already booked with them; with their reason being that they had a lot of work on their hands at the appointment time. For other welders, due to their busy schedule, having enough time to go through the questionnaire was a difficulty. Taking an hour off their busy schedule was something most of them were not comfortable with; thus causing extra delays in time spent than originally planned.

- **Unwillingness to Provide some Information and Camera Allergies**

Most respondents were skeptical in providing some information especially those in the formal sector in the area of some technical details; with the fear that field officers will steal their technology. Notable amongst such were firms owned by private individuals. Other firms were unwilling to provide the information with the excuse that they have responded to a lot of such questionnaires in the past and are yet to see the benefits and therefore considered the exercise as a waste of their time.

Some of the firms, both in the formal and informal sectors did not allow field officers to take camera photos as it was explained to be against company policy.

- **Respondents Lack of Understanding of Questionnaire**

Most of the welders interviewed especially those in the informal sector, although had experience in welding, could not read to understand the questionnaire in the English language. In this way field officers had to engage them in the local dialect (Twi) which was more comfortable to them.

In some instances, field officers had to observe the welding processes the welders practice and fill the questionnaires appropriately for them.

- **Financial Challenges**

Financing the research was a challenge. The research was solely financed by the researcher. The cost of transportation, accommodation and food was very high. The money available was not enough to foot all the bills and this was a major challenge during the period of administering and retrieving the questionnaires.

CHAPTER FOUR

4.0 DATA PRESENTATION AND ANALYSES

4.1 Introduction

This chapter presents the data collected from the research and the analyses of the data. The data gathered in this study were analyzed using Stata 10 statistical tool. The results are presented in sections according to major attributes of this study interest. The instrument of data collection was divided into sections and subsection containing related research items. The data gathered from the study are treated based on the variable information required.

4.2 Demographic Characteristics of Respondent Welders

This section presents the demographic characteristics of the welders under study. As shown in Table 4.1, the age group of welders used in this study is between 18 – 70 years among which 18 - 30 years account for 63 (31.50%), 31 - 49 years were 100 (50.00%) while 50-70 years were 37 (18.50%). The research did not capture any welder less than 18 and above 70 years. The research captured 200 (100%) male welders and no female welders. The educational level of the welders revealed that 59 (29.50%) completed primary school, 47 (23.50%) completed secondary school, 25 (12.50%) completed tertiary institution, 59 (29.50%) completed vocational/technical school. Those without formal education were 10 (5.00%). The respondents were of age and had good understanding of the topic of interest. Thus the data gathered from the field are accurate, valid and useful for this research work.

Table 4.1: Demographic Information

Welders Age Group in Years	**Frequency**	**Percent (%)**
18-30	63	31.50
31-49	100	50.00
50-70	37	18.50
Gender		
Male	200	100
Female	Nil	Nil
Educational Level		
Primary completed	59	29.50
Secondary completed	47	23.50
Tertiary completed	25	12.50
Vocational/Technical	59	29.50
No formal education	10	5.00

4.3 Training, Certification and Qualification and Rank of Respondents in Industry

Of interest to this study, was to elicit information on how respondents attained their welding training, whether the welders had any certificate after training, the type of certificate, the number of years of practicing welding after qualification and their rank or grade in industry. As shown in Table 4.2, the analyses of the training background of the welders under study revealed that 100 (50.0%) went through apprenticeship to a master, 64 (32%) welding craft practice from a technical institute and 36 (18%) through apprenticeship to a master and welding craft practice from a technical institute.

A total of 112 (56%) had certificates after training and 88 (44%) had no any certificate after training.

Table 4.2: Training, Certification and Qualification and Rank of Respondents in industry

Welding training	Frequency	Percent (%)
A. Through apprenticeship to a master	100	50.00
B. Welding craft practice from a technical institute	64	32.00
C. Both apprenticeship and technical institute	36	18.00
Any certificate after Training?		
Welders with Certificate	112	56.00
Welders without Certificate	88	44.00
Type of certificate		
Intermediate certificate in welding	45	40.18
Advanced certificate in welding	29	25.89
National Vocational Training Institute (NVTI) cert I	11	9.82
National Vocational Training Institute (NVTI) cert II	11	9.82
Others (testimonial & short courses)	14	12.50
Did not respond	2	1.79
Years of practicing welding after qualification		
less than 1yr	1	0.50
1-5	36	18.00
6-10	66	33.00
11-15	27	13.50
16-20	22	11.00
21-25	15	7.50
26-30	20	10.00
above 30	13	6.50
Rank or Grade of welders		
Welding technician grade I	28	41.18
Welding technician grade II	13	19.12
Senior welding technician	10	14.71
Welding supervisors	7	10.29
Welding instructor	2	2.94
Did not respond	8	11.76
Employee/Private Ownership of Industry		
Employee in an industry	68	34.00
Private/Informal	132	66.00

The type of certificate analyses shows 45 (40.18%) had intermediate certificate in welding, 29 (25.89%) advanced certificate in welding, 11 (9.82%) NVTI cert I, 11 (9.82%) NVTI cert II, 14 (12.50%) others while 2 (1.79%) did not respond.

The number of year groups of welders under this study for practicing welding after their qualification shows less than 1 year were 1 (0.50%), 1-5 years account for 36 (18.00%), 6-10 years were 66 (33.00%), 11-15 years were 27 (13.50%), 16-20 years were 22(11.00%), 21-25 years were 15 (7.50%), 26-30 years were 20 (10.00%) while respondents welding above 30 years were 13 (6.50%).

Out of the 200 industries surveyed, 132 (66.00%) are qualified welders operating as informal/private industries. The rest 68 (34.00%) are qualified welders operating in the formal sector/employees in industry. The ranked status of those in the formal sector revealed that 28 (41.18%) of the respondents are graded Welding Technician grade I, 13 (19.12%) are graded as Welding Technician grade II, 10 (14.71%) are graded Senior Welding Technician, 7 (10.29%) are graded Welding Supervisors, 2 (2.94%) are graded Welding Instructors, 8 (11.76%) did not respond.

Tables 4.3 - 4.5 show the classification of respondents' training programmes, type of certificate in welding and rank or grade in industry according to educational level. Table 4.6 show the classification of respondents rank or grade in industry according to the type of certificate held.

Table 4.3: Classification of Welders Training Programmes According to Educational Level

Educational Level		Welding Training			Total
		Apprenticeship to master	Technical Institute	Both	
Primary completed	Count	51	1	7	59
	Percent %	51.00	1.56	19.44	29.50
Secondary completed	Count	31	5	11	47
	Percent %	31.00	7.81	30.56	23.50
Tertiary completed	Count	6	18	1	25
	Percent %	6.00	28.l3	2.78	12.50
Vocational/tech.	Count	4	40	15	59
	Percent %	4.00	62.50	41.67	29.50
No formal educ.	Count	8	0	2	10
	Percent %	8.00	0.00	5.56	5.00
Total		100	64	36	200
		100.00	100.00	100.00	100.00

Table 4.4: Classification of Respondents Type of Certificate in Welding According to Educational Level

Educational Level		Type of Certificate in Welding						Total
		Intermediate	Advance	NVTI Cert. I	NVTI Cert. II	*Others (Testimonial)	No response	
Primary completed	Count	4	0	2	2	4	0	12
	Percent %	8.89	0.00	18.18	18.18	28.57	0.00	10.71
Secondary completed	Count	9	1	3	3	5	0	21
	Percent %	20.00	3.45	27.27	27.27	35.71	0.00	18.75
Tertiary completed	Count	2	15	0	0	2	0	19
	Percent %	4.44	51.72	0.00	0.00	14.29	0.00	16.96
Vocational/tech.	Count	30	12	6	5	1	2	56
	Percent %	66.67	41.38	54.55	45.45	7.14	100.00	50.00
No formal educ.	Count	0	1	0	1	2	0	4
	Percent %	0.00	3.45	0.00	9.09	14.29	0.00	3.57
Total		45	29	11	11	14	2	112
		100.00	100.00	100.00	100.00	100.00	100.00	100.00

*Others (certificates and testimonials issued by private weilding companies)

Table 4.5: Classification of Respondents Rank or Grade in Industry According to Educational Level

Educational Level		Rank or Grade in Industry						Total
		Technician Grade I	Technic. Grade II	Senior Welding Technic.	Welding Supervisor	Welding Instructor	No Respo-nse	
Primary completed	Count Percent	2 7.14	0 0.00	0 0.00	1 14.29	0 0.00	2 25.00	5 7.35
Secondary completed	Count Percent	0 0.00	2 15.38	1 10.00	0 0.00	0 0.00	2 25.00	5 7.35
Tertiary completed	Count Percent	9 32.14	2 15.38	7 70.00	2 28.57	0 0.00	1 12.50	21 30.88
Vocational/tech.	Count Percent	17 60.71	8 61.54	1 10.00	4 57.14	2 100.00	3 37.50	35 51.47
No formal educ.	Count Percent	0 0.00	1 7.69	1 10.00	0 0.00	0 0.00	0 0.00	2 2.94
Total		28 100.00	13 100.00	10 100.00	7 100.00	2 100.00	8 100.00	68 100.00

Table 4.6: Classification of Respondents Rank or Grade in Industry According to Type of Certificate Held

Type of Certificate Held		Rank or Grade in Industry						Total
		Technician Grade I	Technic. Grade II	Senior Welding Technic.	Welding Supervisor	Welding Instructor	No Response	
Intermediate Certificate	Count	13	5	0	0	0	3	21
	Percent	50.00	38.46	0.00	0.00	0.00	42.86	32.81
Advance Certificate	Count	9	4	6	4	1	3	27
	Percent	34.62	30.77	66.67	57.14	50.00	42.86	42.19
NVTI Cert. I	Count	3	2	1	0	0	0	6
	Percent	11.54	15.38	11.11	0.00	0.00	0.00	9.38
NVTI Cert. II	Count	0	1	0	2	1	1	5
	Percent	0.00	7.69	0.00	28.57	50.00	14.29	7.81
Others	Count	1	1	2	0	0	0	4
	Percent	3.85	7.69	22.22	0.00	0.00	0.00	6.25
No Response	Count	0	0	0	1	0	0	1
	Percent	0.00	0.00	0.00	14.29	0.00	0.00	1.56
Total		26	13	9	7	2	7	64
		100.00	100.00	100.00	100.00	100.00	100.00	100.00

4.4 Welding Practices in Industry

The surveyed industries range from refineries, research and educational institutes, motor vehicle and equipment, mining, food processing, wood processing, construction and metal fabrication industries. The results of some of the responses of their welding practices are presented in the remaining part of this section.

4.4.1 Number of Years Firm has been Practicing Welding

The ranges of years industries under study have been practicing welding: 1-10 years are 66 (33.00%), 11-20 years are 54 (27.00%), 21-30 years are 40 (20.00%), 31-40 years are 18 (9.00%), 41-50 years are 11 (5.50%) and above 50 years are 11 (5.50%). In percentage terms, the ranges of years are shown in Figure 4.1.

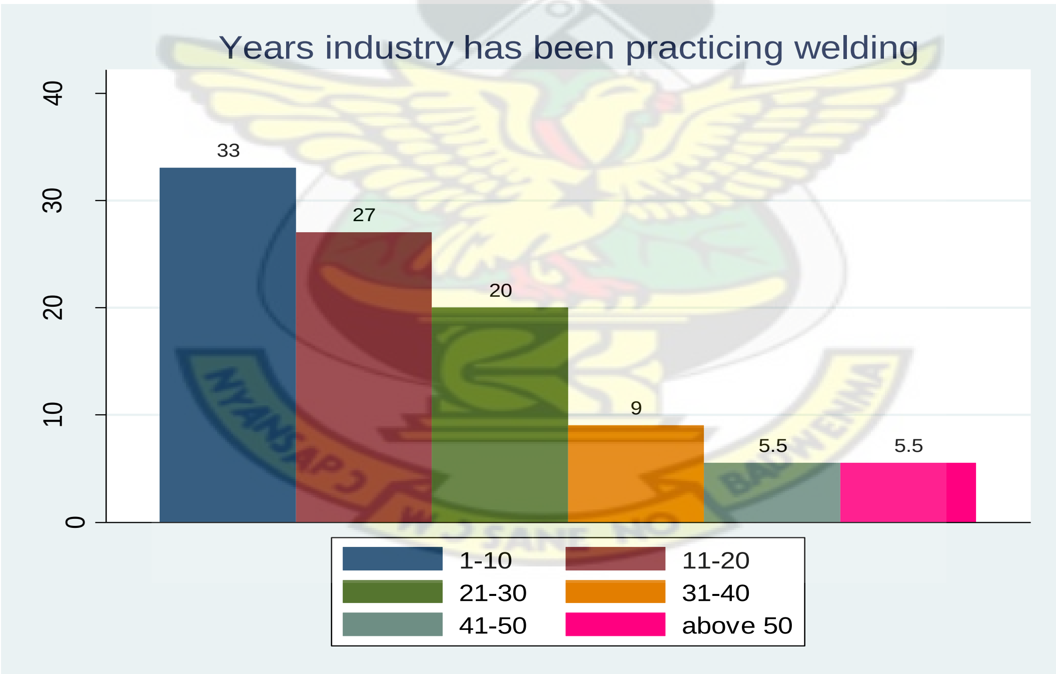


Figure 4.1: Percentage count of industry against the ranges of year's industry practice welding.

4.4.2 Proportions of Welders Employed by Different Industry Groups

The proportions of welders employed by different industry groups under this study shows that the largest number of welders 129 (64.50%) in one group is employed by the "Fabricated Metal Products" group. A total of 35 (17.50%) is employed by the group known as "Machinery", 3 (1.50%) is employed by the "construction" industry, the "Motor Vehicle and Equipment and Auto Repair" group employ 31 (15.50%) while the "Primary Metal Industry" employs 2 (1.00%). Figure 4.2 is a histogram of the percentages of welders employed by the different industry groups.

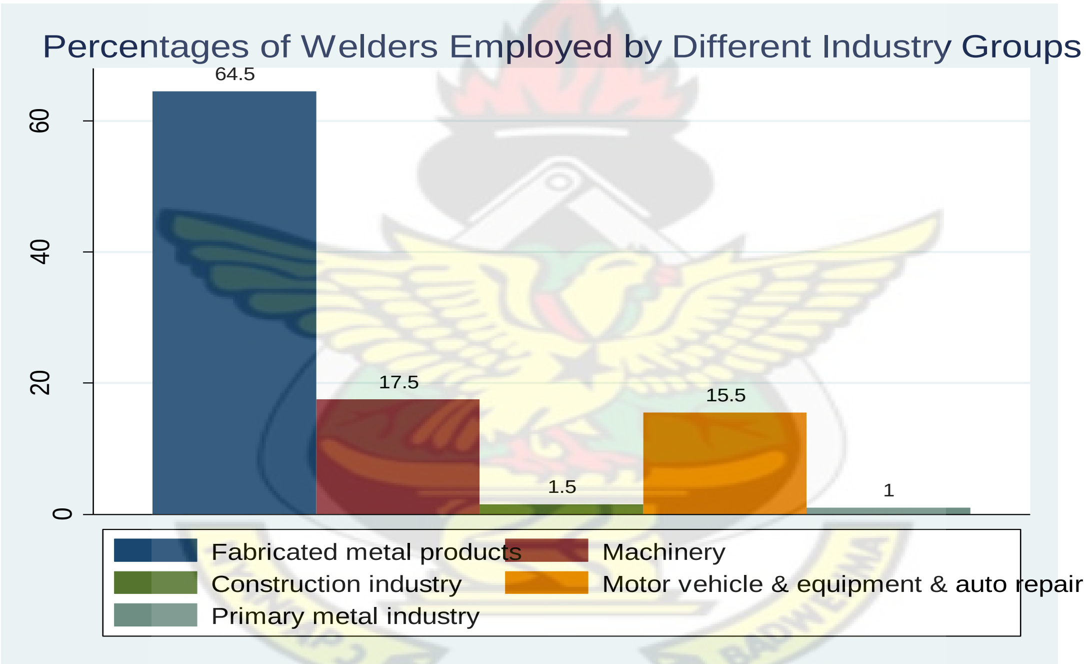


Figure 4.2: The percentages of welders employed by the different industry groups.

4.4.3 Proportions of Welders/Industry Involved in Different Areas of Application of Welding.

The proportions of welders or industry involved in different areas of application of welding under this study shows that repair and maintenance welding, account for 80 (40.00%), constructional welding 10 (5.00%), manufacturing 9 (4.50%), maintenance and manufacturing 50 (25.00%), maintenance and construction 25 (12.50%), manufacturing and construction 2 (1.00%) while welders and industry that practice all three categories constitute 24 (12.00%). Figure 4.3 shows the various categories of the welding practiced by the welders and industry under study.

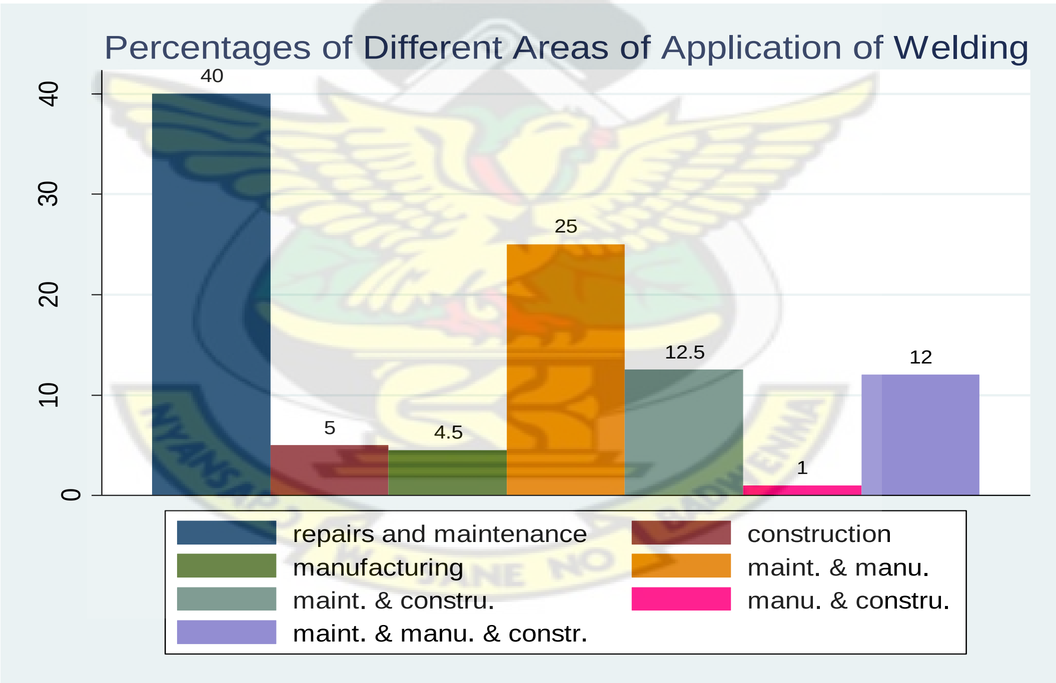


Figure 4.3: Percentages of different areas of application of welding by welders

4.4.4 Type of Welding Technique/Procedure Practiced in Industry

Responses to the type of welding technique practiced in industry revealed that majority 180 (90.00%) practice manual welding only**,** machine welding only 2 (1.00%), automatic welding only 1 (0.50%), manual and machine 15 (7.50%), manual and automatic 1 (0.50%) while industries that use manual, machine and automatic were 1 (0.50%). None of the industries

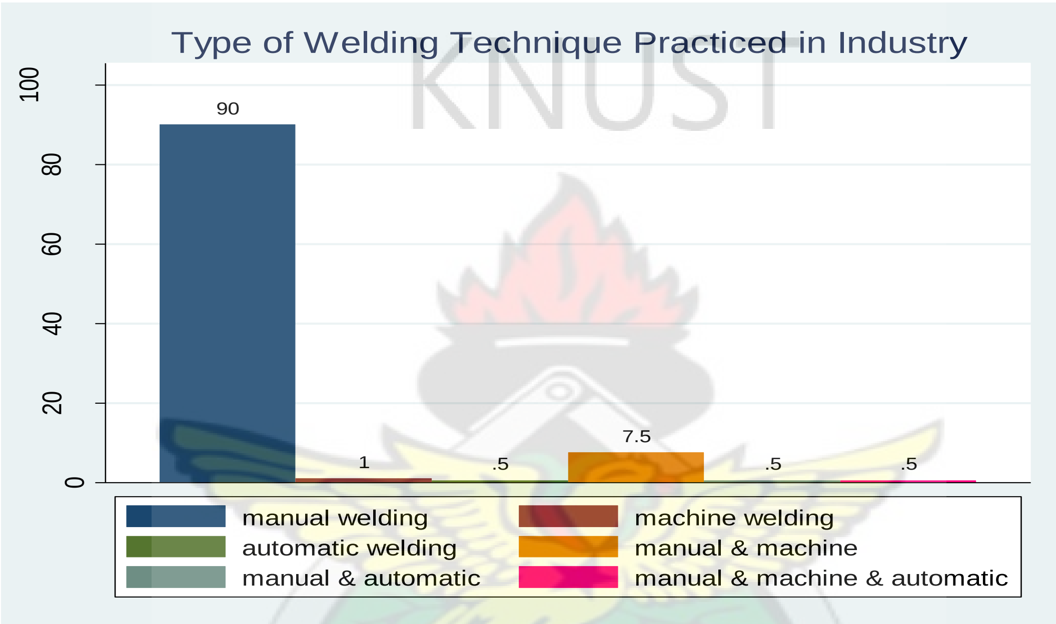


Figure 4.4: Type of welding technique practiced in industry

surveyed practice the robotic welding technique. Figure 4.4 shows type of welding technique practiced in industry.

4.4.5 Type of Welding Process Used

A total of 80 (40.00%) use only the arc welding process, 19 (9.50%) use only gas welding, no industry use only resistance, 86 (43.00%) use arc and gas, 1 (0.50%) use arc and resistance and 14 (7.00%) use all three. Figure 4.5 shows the distribution of type of welding process used in industry by percentages.

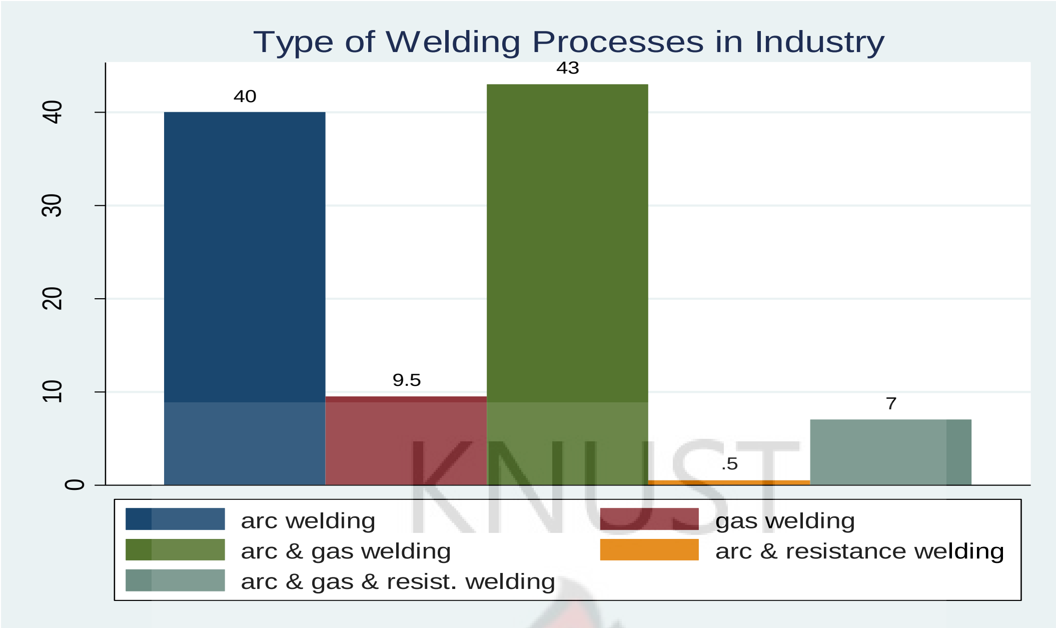


Figure 4.5: Distribution of type of welding process used in industry by percentages.

From the above analyses of the type of welding process, the total count of industries that use arc welding is 181. The distribution of the types of arc welding processes used in industry in terms of percentages is as shown in figure 4.6.

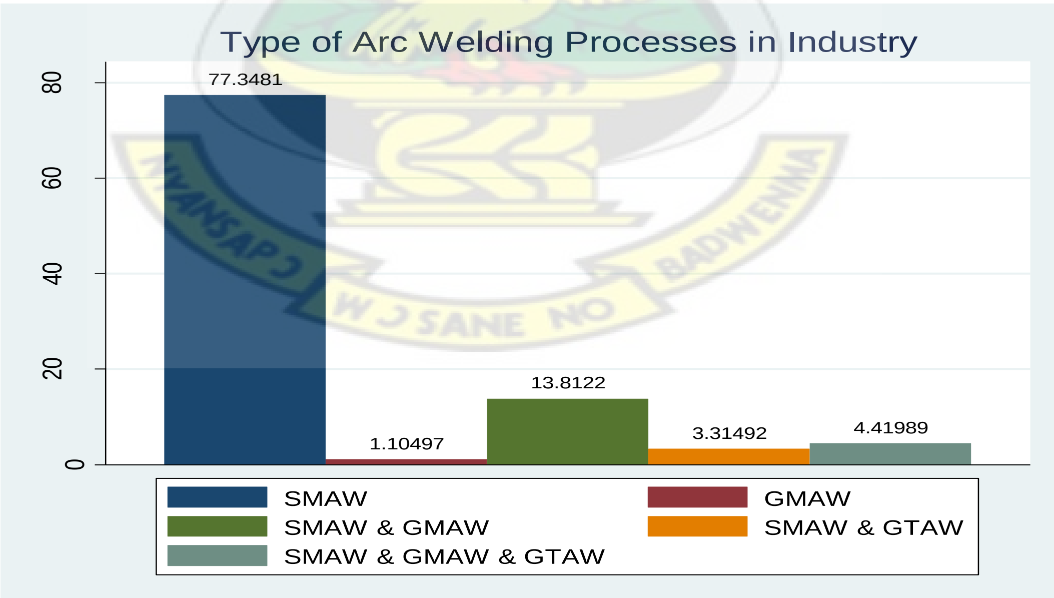


Figure 4.6: Distribution of type of arc welding processes used in industry by percentages

The analyses of gas welding showed that the total count of industries that use gas is 119. The distribution of the types of gas welding processes used in industry in terms of percentages is as shown in figure 4.7.

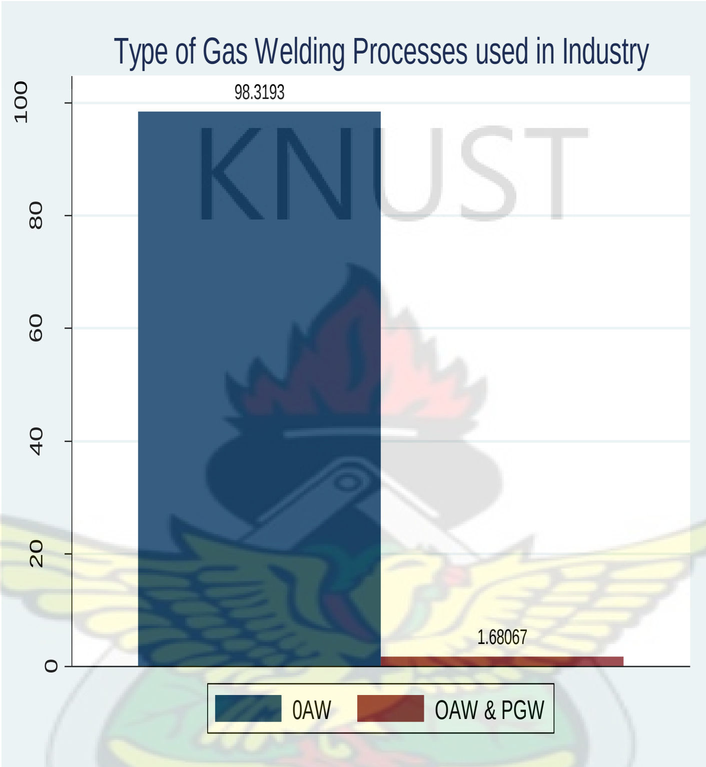


Figure 4.7: Distribution of type of gas welding processes used in industry by percentages

The analyses of the resistance welding processes also revealed that the total count of industries that use resistance is 15. The distribution of the types of resistance welding processes used in industry in terms of percentages is as shown in figure 4.8.

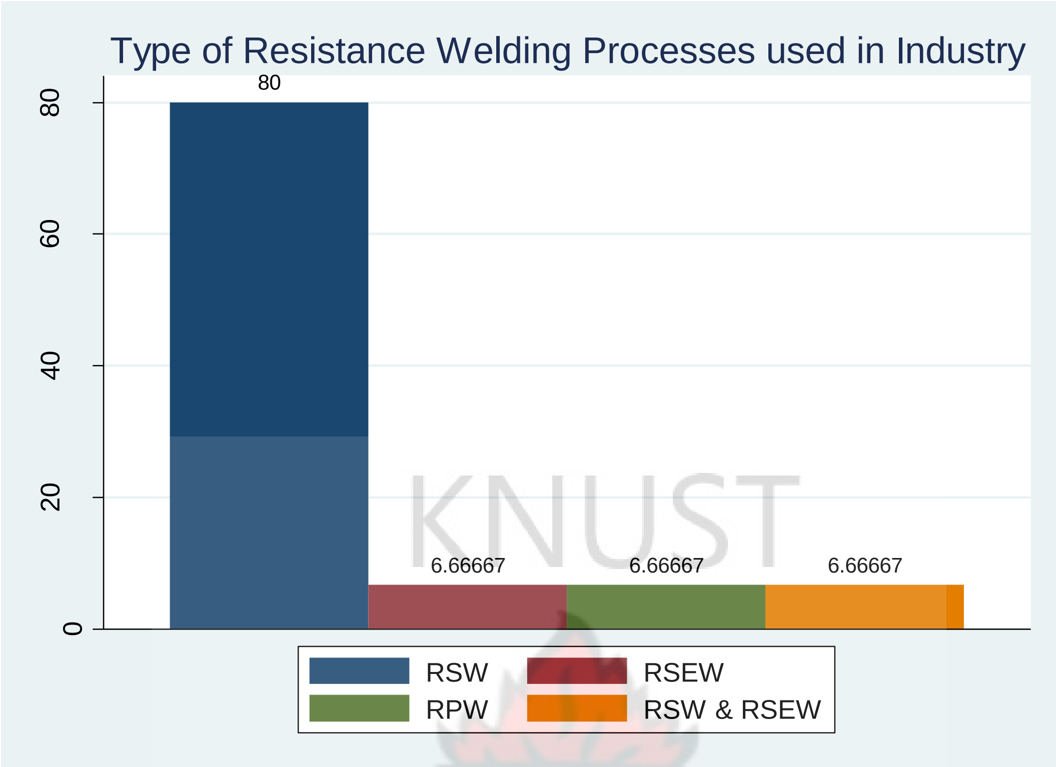


Figure 4.8: Distribution of type of resistance welding processes used in industry by percentages

4.4.6 Quality Control Mechanisms for Testing Welds

One fifty nine, 159 (79.50%) of the 200 respondents said they do not use any quality control mechanism for testing of welds but employ just visual inspection. The remaining 41 (20.50%) firms responded they use quality control mechanism for testing of welds. A total of 15 (7.50%) out of the 41 (20.50%) said they employ destructive testing, 10 (5.00%) nondestructive testing, 2 (1.00%) destructive and nondestructive and 14 (7.00%) said they employ other methods. Figure 4.9 and 4.10 below shows the percentages count of industry the responses received.

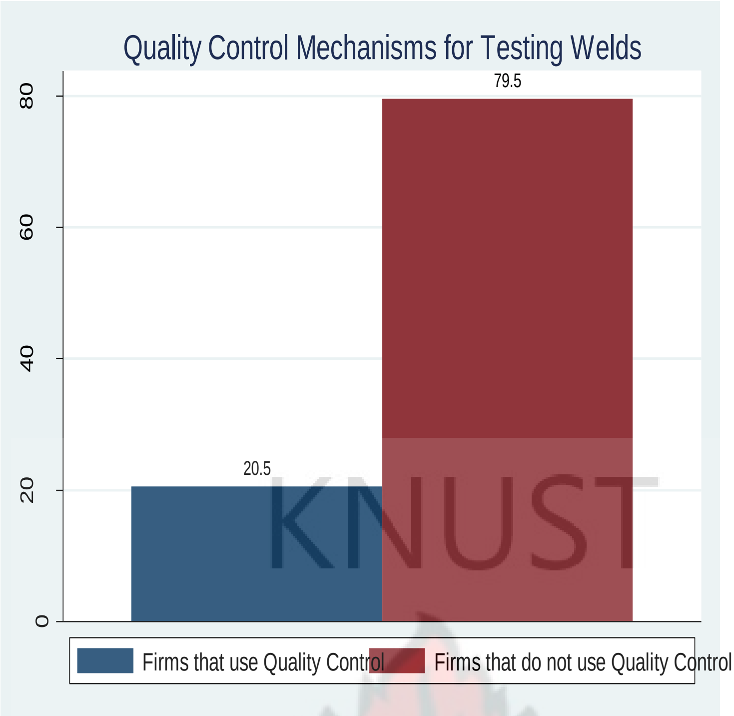


Figure 4.9: The application of quality control mechanisms in industry

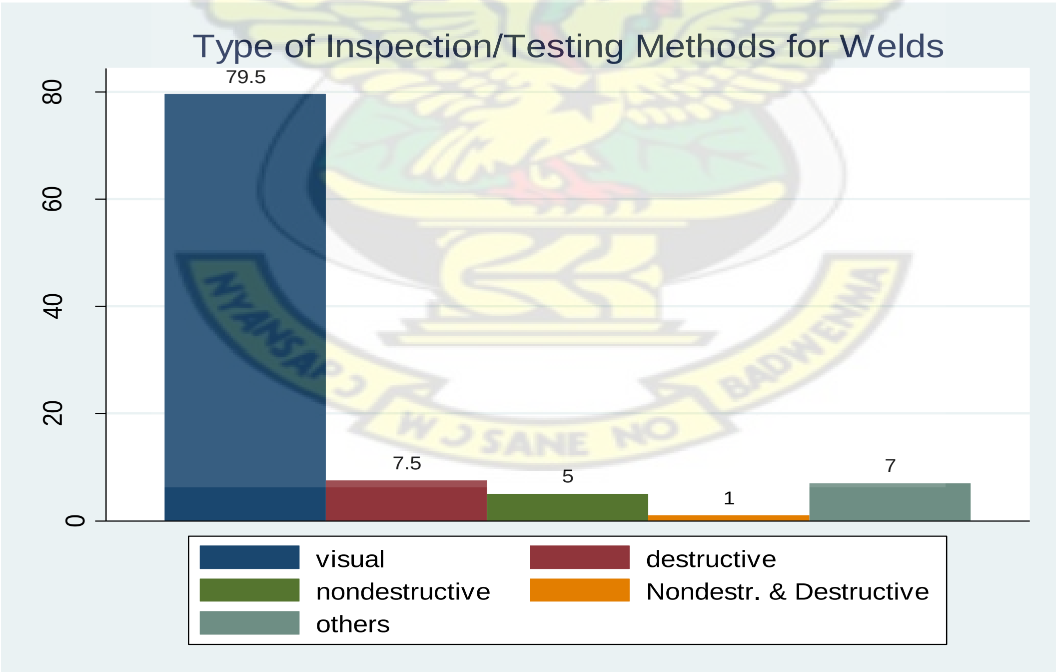


Figure 4.10: Distribution of quality control mechanisms inspection methods employed in industry

4.5 Analysis of Opinion, Knowledge, and Practices of Respondents on Some Welding Topics

This section analyses the opinion, knowledge and practices of the welders which is of interest to this study; i.e. respondents opinion on the cause of a weld failure, knowledge of the causes of weld failure, knowledge of the type of joints and type of welds and practices or preparation they undertake before planning to weld two pieces of metal together.

The response options of the research items were scaled and given one-point weight for every correct response. This enabled the researcher to generate quantitative data from the various responses by total point score of each respondent. The descriptive analysis of the data set (Table 4.8) provides the maximum score, the minimum score, the mean score, and standard deviation of the scores. The mean value, served as a cut-off point for dichotomous classification of the respondents into categories of interest to this study (high knowledgeable, less knowledgeable, good practice and poor practice).

4.5.1 Analysis of Opinion on Welded Joint Failure Immediately after Being Welded

The response to the research item "have you ever experienced failure in your welded joint immediately after being welded?", 74 (37.00%) of the welders indicated experiencing weld failure, 103 (51.50%) had no experience while 23 (11.50%) were not aware (Table 4.7). Out of the 74 (37.00%) that responded experiencing weld failure, 26 (35.14%) said the failure is the fault of the welder, 27 (36.49%) said they believe the failure was as a result of a problem of welding technique while 21 (28.38%) thought it was as a result of both fault of the welder and problem of welding technique. Figure 4.11 shows in percentages count of welders the responses received.

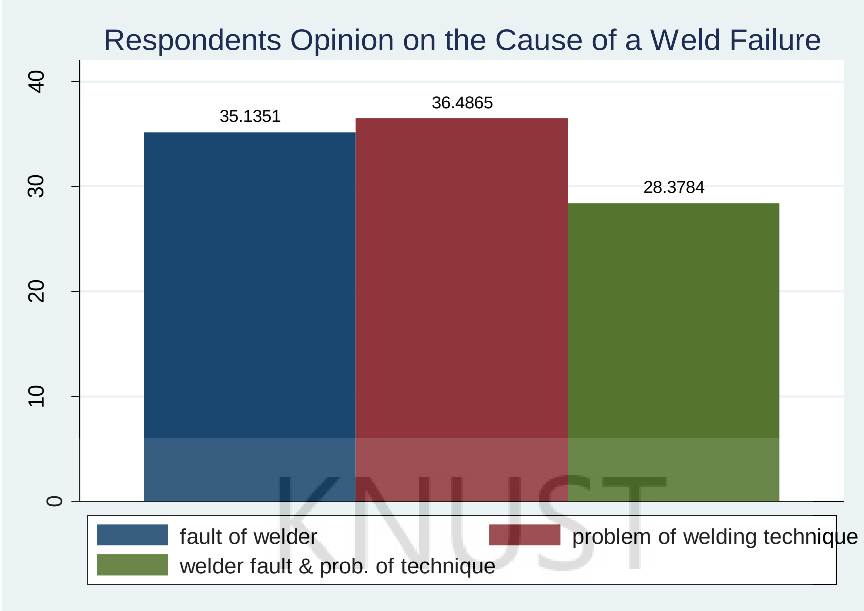


Figure 4.11: Respondents opinion on the cause of a failure in a welded joint immediately after being welded.

4.5.2 Knowledge of Causes of Weld Failure

The responses obtained on the knowledge of welders in this study on the causes of weld failure are presented in Table 4.7. This descriptive analysis outlined above explores the respondents understanding of the causes of weld failure. Based on the gathered data, 195 (97.50%) of the welders think incorrect electrode/filler rod chosen by the welder can cause weld failure while 5 (2.50%) do not think it can cause weld failure, 91 (45.50%) think high restraint of joint by the welder can cause weld failure while 109 (54.50%) do not, 147 (73.50%) think rapid cooling of weld such as water quenching of cast iron weld can cause weld failure while 53 (26.50%) do not. A total of 121 (60.50%) think improper joint preparation by the welder before welding can cause weld failure while 79 (39.50%) do not, 132 (66.00%) think welds too small for size of parts joined can cause weld failure while 68 (34.00%) do not, 136 (68.00%) think welding over foreign material on surface such as rust, oil, moisture, paint, etc. can cause weld failure while 64 (32.00%) do not think welding over foreign material can cause weld failure.

Table 4.7: Distribution of Welders Awareness of Causes of Weld Failure

Research Items	**Frequency Distribution of Responses**	
	Yes	**No**
29) Have you ever experienced failure in your welded joint immediately after being welded or in service?	74 (37.00%)	103 (51.50%)
31a) Do you think Incorrect electrode/filler rod chosen by the welder can cause weld failure?	195 (97.50%)	5 (2.50%)
31b) Do you think High restraint of joint or highly stressed joint by the welder can cause weld failure?	91 (45.50%)	109 (54.50%)
31c) Do you think Rapid cooling of weld such as water quenching of cast iron weld can cause weld failure?	147 (73.50%)	53 (26.50%)
31d) Do you think Improper joint preparation by the welder before welding can cause weld failure?	121 (60.50%)	79 (39.50%)
31e) Do you think Welds too small for size of parts joined can cause weld failure?	132 (66.00%)	68 (34.00%)
31f) Do you think Welding over foreign material on surface such as rust, oil, moisture, paint, etc. can cause weld failure?	136 (68.00%)	64 (32.00%)
31g) Do you think Unsteady current/voltage or inappropriate gas mixtures can cause weld failure?	184 (92.00%)	16 (8.00%)
31h) Do you think Welding speed too fast can cause weld failure?	126 (63.00%)	74 (37.00%)
31i) Do you think Welding speed too slow can cause weld failure?	99 (49.50%)	101 (50.50%)

A total of 184 (92.00%) think unsteady current/voltage or inappropriate gas mixtures can cause weld failure while 16 (8.00%) do not and 126 (63.00%) think welding speed too fast can cause weld failure while 74 (37.00%) do not. Lastly the analysis further shows that the percentage of welders 99 (49.50%) who think too slow a welding speed can cause weld failure are about the same as those 101 (50.50%) who think too slow a welding speed can not cause weld failure.

Table 4.8: Descriptive Statistics of Overall Response

Section of Questionnaire	Research Items	Number of Respondents	Minimum Score	Maximum Score	Mean of Scores	Standard Deviation of Scores
Question 31	Knowledge of Welders on Causes of Weld Failure	200	1.00	9.00	6.135	2.024169
Question 32	Knowledge of Welders on Types of Joints	200	1.00	5.00	4.295	1.202165
Question 34	Knowledge of Welders on Types of Welds	200	1.00	6.00	3.665	1.654224
Question 39	Practices of Welders Before Planning to Weld	200	1.00	9.00	6.02	1.938657
Question 40	Knowledge of Welders on Accidents/Hazards in Industry	200	1.00	6.00	4.77	1.325096
Question 41	Accidents/Hazards Prone Level of Welders in Industry	200	0.00	5.00	2.77	1.343924
Question 42	Safety/Personal Protective Equipment Availability	200	1.00	8.00	5.11	2.066215
	Valid Number	200				

From Table 4.8, the maximum score for Question 31 of Table 4.7 is 9 and the minimum score is 1 with a mean of 6.135. Scores from 6 – 9 were taken as high knowledgeable and scores from 5 and below taken as low knowledgeable. Based on the classification criteria, the result shows two levels of the respondents' knowledge as presented in Table 4.9.

Table 4.9: Distribution of Respondents' Level of Knowledge of Causes of Weld Failure

Knowledge Level	Causes of Weld Failure	
	Frequency	Percent (%)
Low	77	38.50
High	123	61.50
Total	200	100.00

A total of 123 (61.50%) of the welders have high level of awareness of the causes of weld failure while 77 (38.50%) do not have considerable awareness of causes of weld failure.

4.5.3 Knowledge of the type of joints and type of welds

From Table 4.8 the responses obtained on the knowledge of welders on the type of joints and type of welds shows that the maximum score of Question 32 on knowledge of type of joints is five (5) and minimum is one (1) with a mean of 4.295. Scores from 4-5 were taken as high knowledge and score from 3 and below were taken as low level of knowledge. Also the maximum score of Question 34 on knowledge of type of welds is six (6) and minimum is one (1) with a mean of 3.665. Scores from 4-6 were taken as high knowledge and score from 3 and below were taken as low level of knowledge. The results of the knowledge of welders on the type of joints and type of welds are compared in Table 4.10.

Table 4.10: Distribution of Respondents' Level of Knowledge of the Type of Joints and Type of Welds

Knowledge Level	Type of Joints		Type of Welds	
	Frequency	Percent (%)	Frequency	Percent (%)
Low	41	20.50	109	54.50
High	159	79.50	91	45.50
Total	200	100	200	100

The analysis of the level of awareness on the type of joints shows that 159 (79.50%) of the welders under study have high level of knowledge while 41 (20.50%) have low knowledge. That on the level of awareness on the type of welds revealed, a smaller percentage 91 (45.50%) have high knowledge while a greater percentage 109 (54.50%) have low knowledge.

4.5.4 Practices of Welders before Planning to Weld

The responses obtained from Question 39 of the questionnaire are presented in Table 4.11. This question elicits information on general practices before planning to weld. Based on the data gathered, on joint preparation, 147 (73.50%) of the welders indicated they do joint preparation before welding while 53 (26.50%) do not do joint preparation. On the thickness of the metal, 182 (91.00%) said they consider the thickness before planning to weld while 18 (9.00%) said they do not consider the thickness. Coincidentally, equal proportion 112 (56.00%) responded that they consider the type of joint or welding position before planning to weld while 88 (44.00%) equal proportion do not consider the type of joint or welding position. About 98 (49.00%) responded they consider the speed of welding before planning to weld while 102 (51.00%) said they do not.

Table 4.11: Distribution of Welder Practices before Planning to Weld

Research Items	Frequency Distribution of Responses	
	Yes	No
What factors do you consider before planning to weld?		
(a) Joint preparation	147 (73.50%)	53 (26.50%)
(b) The thickness of the metal	182 (91.00%)	18 (9.00%)
(c) The type of joint	112 (56.00%)	88 (44.00%)
(d) The welding position	112 (56.00%)	88 (44.00%)
(e) The speed of welding	98 (49.00%)	102 (51.00%)
(f) The type of electrode/filler rod	194 (97.00%)	6 (3.00%)
(g) The electrode/Filler wire size	120 (60.00%)	80 (40.00%)
(h) The thermal conductivity of the metal to be welded	39 (19.50%)	161 (80.50%)
(i) The type of metal	197 (98.50%)	3 (1.50%)

On the type of electrode/filler rod, 194 (97.00%) said they consider the type of electrode/filler rod before planning to weld while 6 (3.00%) said they do not consider the type of electrode/filler rod. On the electrode/Filler wire size, 120 (60.00%) responded that they consider the electrode/Filler wire size or diameter before planning to weld while 80 (40.00%) said they do not. On the thermal conductivity of the metal, 39 (19.50%) do consider the thermal conductivity of the metal while 161 (80.50%) do not. A great majority, 197 (98.50%) of the welders in this research responded that they consider the type of metal before planning to weld while a smaller proportion 3 (1.50%) responded they do not consider the type of metal before planning to weld.

From Table 4.8, the maximum score for Question 39 of Table 4.11 is 9 and the minimum score is 1 with a mean of 6.02. Scores from 6 – 9 were taken as good practice and scores from 5 and below were taken as poor practice. Based on the classification criteria, the result shows two levels of the respondents' practices before planning to weld as presented in Table 4.12.

Table 4.12: Distribution of Respondents' Practices before Planning to Weld

Practices	Practices before Planning to Weld	
	Frequency	Percent (%)
Poor practice	84	42.00
Good practice	116	58.00
Total	200	100.00

Table 4.12 shows that a total of 116 (58.00%) of the welders demonstrate good practices before planning to weld while 84 (42.00%) do not.

Tables 4.13 - 4.16 show the classification of the respondents' knowledge of causes of weld failure according to age, education, welding training and number of years of welding after qualification as welder.

Tables 4.17 - 4.20 show the classification of the respondents' practices before planning to weld according to age, education, welding training and number of years of welding after qualification as welder.

Table 4.13: Classification of Respondents' Knowledge of Causes of Weld Failure According to Age

Age in Years		Classification of Respondents' Knowledge of Causes of Weld Failure		Total
		Not Knowledgeable	Knowledgeable	
18-30	Count Percentage %	27 42.86	36 57.14	63 100.00
31-49	Count Percentage %	40 40.00	60 60.00	100 100.00
50-70	Count Percentage %	10 27.03	27 72.97	37 100.00
Total		77 38.50	123 61.50	200 100.00

Table 4.14: Classification of Respondents' Knowledge of Causes of Weld Failure According to Educational Level

Educational Level		Classification of Respondents' Knowledge of Causes of Weld Failure		Total
		Not Knowledgeable	Knowledgeable	
Primary completed	Count Percentage %	15 25.42	44 74.58	59 100.00
Secondary completed	Count Percentage %	20 42.55	27 57.45	47 100.00
Tertiary completed	Count Percentage %	10 40.00	15 60.00	25 100.00
Vocational/tech.	Count Percentage %	27 45.76	32 54.24	59 100.00
No formal educ.	Count Percentage %	5 50.00	5 50.00	10 100.00
Total		77 38.50	123 61.50	200 100.00

Table 4.15: Classification of Respondents' Knowledge of Causes of Weld Failure According to Welding Training

Welding Training		Classification of Respondents' Knowledge of Causes of Weld Failure		Total
		Not Knowledgeable	Knowledgeable	
A. Apprenticeship to master	Count Percentage %	32 32.00	68 68.00	100 100.00
B. Technical institute	Count Percentage %	27 42.19	37 57.81	64 100.00
C. Both A & B	Count Percentage %	18 50.00	18 50.00	36 100.00
Total		77 38.50	123 61.50	200 100.00

Table 4.16: Classification of Respondents' Knowledge of Causes of Weld Failure According to Number of Years of Welding after Qualification

Number of Years of Welding after Qualification		Classification of Respondents' Knowledge of Causes of Weld Failure		Total
		Not Knowledgeable	Knowledgeable	
Less than 1 Year	Count Percentage %	0 0.00	1 100.00	1 100.00
1-5	Count Percentage %	17 47.22	19 52.78	36 100.00
6-10	Count Percentage %	27 40.91	39 59.09	66 100.00
11-15	Count Percentage %	10 37.04	17 62.96	27 100.00
16-20	Count Percentage %	7 31.82	15 68.18	22 100.00
21-25	Count Percentage %	7 46.67	8 53.33	15 100.00
26-30	Count Percentage %	5 25.00	15 75.00	20 100.00
Above 30	Count Percentage %	4 30.77	9 69.23	13 100.00
Total		77 38.50	123 61.50	200 100.00

Table 4.17: Classification of Respondents' Practices before Planning to Weld According to Age

Age in Years		Classification of Respondents' Practices before Planning to Weld		Total
		Poor Practice	Good Practice	
18-30	Count Percentage %	33 52.38	30 47.62	63 100.00
31-49	Count Percentage %	40 40.00	60 60.00	100 100.00
50-70	Count Percentage %	11 29.73	26 70.27	37 100.00
Total		84 42.00	116 58.00	200 100.00

Table 4.18: Classification of Respondents' Practices before Planning to Weld According to Educational Level

Educational Level		Classification of Respondents' Practices before Planning to Weld		Total
		Poor Practice	Good Practice	
Primary completed	Count Percentage %	36 61.02	23 38.98	59 100.00
Secondary completed	Count Percentage %	16 34.04	31 65.96	47 100.00
Tertiary completed	Count Percentage %	6 24.00	19 76.00	25 100.00
Vocational/tech.	Count Percentage %	23 38.98	36 61.02	59 100.00
No formal educ.	Count Percentage %	3 30.00	7 70.00	10 100.00
Total		84 42.00	116 58.00	200 100.00

Table 4.19: Classification of Respondents' Practices before Planning to Weld According to Welding Training

Welding Training		Classification of Respondents' Practices before Planning to Weld		Total
		Poor Practice	Good Practice	
A. Apprenticeship to master	Count Percentage %	47 47.00	53 53.00	100 100.00
B. Technical institute	Count Percentage %	24 37.50	40 62.50	64 100.00
C. Both A & B	Count Percentage %	13 36.11	23 63.89	36 100.00
Total		84 42.00	116 58.00	200 100.00

Table 4.20: Classification of Respondents' Practices before Planning to Weld According to Number of Years of Welding after Qualification

Number of Years of Welding after Qualification		Classification of Respondents' Practices before Planning to Weld		Total
		Poor Practice	Good Practice	
Less than 1 Year	Count Percentage %	1 100.00	0 0.00	1 100.00
1-5	Count Percentage %	15 41.67	21 58.33	36 100.00
6-10	Count Percentage %	33 50.00	33 50.00	66 100.00
11-15	Count Percentage %	9 33.33	18 66.67	27 100.00
16-20	Count Percentage %	10 45.45	12 54.55	22 100.00
21-25	Count Percentage %	6 40.00	9 60.00	15 100.00
26-30	Count Percentage %	7 35.00	13 65.00	20 100.00
Above 30	Count Percentage %	3 23.08	10 76.92	13 100.00
Total		84 42.00	116 58.00	200 100.00

4.6 Safety of Welders in Industry

The responses obtained from **section E (Safety issues)** of the questionnaire is presented in this section. Of interest to this study was respondents' knowledge of hazards in industry, the welders' proneness to hazards in industry, availability or requirements of safety or protective equipment in industry, exposure time to arc/flame duration and insurance for welders in industry.

4.6.1 Analysis of Safety

The response options of the research items in this section were scaled and given one-point weight for every correct response. This enabled the researcher to generate quantitative data from the various responses by total point score of each respondent. The mean value, served as a cut-off point for dichotomous classification of the respondents into categories of interest to this study.

Question 40 elicits information on the general knowledge of welders on hazards in industry as a result of lack of safety measures. For this part of the analysis, since electrical hazards/shock is associated with arc/resistance welding and cylinder explosions/flashback is associated with gas welding, correct response of any of the two or all two options were scaled and given one point weight. From Table 4.8 the responses obtained on knowledge of welders on hazards shows that the maximum score is six (6) and minimum score is one (1) with a mean of 4.77. Score from 5-6 were taken as high knowledge and scores from 4 and below taken as low knowledge.

Question 41 was used to measure the welders' proneness to hazards in industry and the responses obtained are presented in Table 4.21. Based on the data collated, a total of 172 (86.00%) do often encounter burns while 28 (14.00%) do not. A total of 155 (77.50%) encounter electric shock while 45 (22.50%) do not. A total of 120 (60.00%) have eye related problems or diseases while 80 (40.00%) responded not having any eye problems or diseases. A total of 40 (20.00%) responded to have ever encountered explosion of cylinders/flashback while 160 (80.00%) said they have never encountered explosion of cylinders/flashback. A total of 121 (60.50%) responded they have been experiencing respiratory diseases or headache which they believe is as a result of the fumes from the welding they do while 79 (39.50%) responded they do not experience respiratory diseases or headache. A total of 101 (50.50%) of the respondents said they do have skin diseases while an almost equal proportion 99 (49.50%) responded they do not have skin diseases. A total of 39 (19.50%) said ever experienced fire outbreak while 161 (80.50%) said they have never experienced fire outbreak.

The proportions of the degree of hazards is also shown in Table 4.21

Table 4.21: Distribution of Respondents Proneness to Hazards in Industry

Research Items	Frequency Distribution of Responses		Degree of Hazards	
	Yes	No	Severe	Less Severe
What are some of the accidents/hazards you often encounter in the welding industry or shop?				
a) Fire outbreak	39 (19.50%)	161 (80.50%)	35 (89.74%)	4 (10.25%)
b) Explosion of cylinders/Flashback	40 (20.00%)	160 (80.00%)	40 (100%)	0 (0.00%)
c) Electric shock	155 (77.50%)	45 (22.50%)	146 (94.19%)	9 (5.81%)
d) Burns	172(86.00%)	28 (14.00%)	123 (71.51%)	49 (28.49%)
e) Inhalation of welding fumes leading to respiratory diseases or headache	121 (60.50%)	79 (39.50%)	118 (97.52%)	3 (2.48%)
f) Skin diseases from ultraviolet light/infra-red when welding	101 (50.50%)	99 (49.50%)	96 (95.05%)	5 (4.95%)
g) Eye damage/problems	120 (60.00%)	80 (40.00%)	119 (99.17%)	1 (0.83%)

From Table 4.8 the responses obtained on the hazards proneness of welders in industry shows that the maximum score is five (5) and minimum score is zero (0) with a mean of 2.77. Score 3-5 were taken as highly prone and 2 and below were taken as less prone. Since this research cut across arc, gas and resistance welders, this classification of respondents was done without electric shock and explosion of cylinders/flashback. This is because electric shock is associated with arc/resistance welding and cylinder explosions/flashback is associated with gas welding but the rest of the hazards can be said to be common to all the welder groups. This made sure the analysis of their responses was not biased towards one group but unbiased to all the welders.

Question 42 was used to investigate the availability of safety or personal protective equipment used by welders in industry. The responses obtained are presented in Table 4.22.

Table 4.22: Distribution of Availability of Safety/Personal Protective Equipment

Research Items	**Frequency Distribution of Responses**	
	Yes	**No**
What safety design mechanisms do you have in the industry or welding shop?		
(a) Fire extinguishers	107 (53.50%)	93 (46.50%)
(b) First aid box	93 (46.50%)	107 (53.50%)
(c) Respirators	88 (44.00%)	112 (56.00%)
(d) Welding goggles	188 (94.00%)	12 (6.00%)
(e) Welding gloves	167 (83.50%)	33 (16.50%)
(f) Welding screens/shield	177 (88.50%)	23 (11.50%)
(g) Welding aprons and welding jackets	114 (57.00%)	86 (43.00%)
(h) Safety boots	91 (45.50%)	109 (54.50%)

The responses revealed that 107 (53.50%) of the industries had fire extinguishers while 93 (46.50%) do not have, 93 (46.50%) have first aid box while 107 (53.50%) do not have. A total of 88 (44.00%) use respirators while 112 (56.00%) do not have and therefore do not use them, 188 (94.00%) have proper welding goggles while 12 (6.00%) do not have proper welding goggles. A total of 167 (83.50%) have welding gloves while 33 (16.50%) do not have. A total of 177 (88.50%) have welding screens or shield while 23 (11.50%) do not use. A total of 114 (57.00%) have welding aprons and welding jackets while 86 (43.00%) do not have. Lastly, a total of 91 (45.50%) have safety boots while 109 (54.50%) do not have.

From Table 4.8 the responses obtained on availability of safety or personal protective equipment in industry shows that the maximum score is eight (8) and the minimum score is one (1) with a mean of 5.11. Score from 5-8 were taken as high availability of safety equipment and 4 and below were taken as less availability of safety equipment.

Table 4.23 compares the responses presented above in section E of the questionnaire, on the general knowledge of welders on hazards in industry, the welders proneness to hazards in industry and the availability of safety or personal protective equipment.

Table 4.23: Distribution of Respondents Knowledge of Hazards in Industry, Proneness to Hazards in Industry and the Availability of Safety or Personal Protective Equipment

Safety Analysis Response	**Knowledge of Welders on Hazards in Industry**		**Welders Proneness to Hazards in Industry**		**Availability of Safety or Personal Protective Equipment**	
	Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)
Less	66	33.00	87	43.50	80	40.00
High	134	67.00	113	56.50	120	60.00
Total	200	100	200	100	200	100

The analysis revealed that 134 (67.00%) of the welders under this study have high knowledge of hazards in industry while 66 (33.00%) have low knowledge of hazards in industry. A total of 113 (56.50%) are highly prone to hazards in industry while 87 (43.50%) are less prone to hazards in industry. On the availability of safety or personal protective equipment in industry or for use by welders, 120 (60.00%) have high availability of safety or personal protective equipment and 80 (40.00%) have less availability of safety or personal protective equipment.

Tables 4.24 - 4.27 show the classification of the respondents' knowledge of hazards in industry according to age, education, welding training and number of years of welding after qualification as welder.

Table 4.24: Classification of Respondents' Knowledge of Hazards in Industry According to Age

Age in Years		Classification of Respondents' Knowledge of Hazards in Industry		Total
		Not Knowledgeable	Knowledgeable	
18-30	Count Percentage %	24 38.10	39 61.90	63 100.00
31-49	Count Percentage %	33 33.00	67 67.00	100 100.00
50-70	Count Percentage %	9 24.32	28 75.68	37 100.00
Total		66 33.00	134 67.00	200 100.00

Table 4.25: Classification of Respondents' Knowledge of Hazards in Industry According to Educational Level

Educational Level		Classification of Respondents' Knowledge of Hazards in Industry		Total
		Not Knowledgeable	Knowledgeable	
Primary completed	Count Percentage %	28 47.46	31 52.54	59 100.00
Secondary completed	Count Percentage %	9 19.15	38 80.85	47 100.00
Tertiary completed	Count Percentage %	7 28.00	18 72.00	25 100.00
Vocational/tech.	Count Percentage %	19 32.20	40 67.80	59 100.00
No formal educ.	Count Percentage %	3 30.00	7 70.00	10 100.00
Total		66 33.00	134 67.00	200 100.00

Table 4.26: Classification of Respondents' Knowledge of Hazards in Industry According to Welding Training

Welding Training		Classification of Respondents' Knowledge of Hazards in Industry		Total
		Not Knowledgeable	Knowledgeable	
A. Apprenticeship to master	Count Percentage %	32 32.00	68 68.00	100 100.00
B. Technical institute	Count Percentage %	23 35.94	41 64.06	64 100.00
C. Both A & B	Count Percentage %	11 30.56	25 69.44	36 100.00
Total		66 33.00	134 67.00	200 100.00

Table 4.27: Classification of Respondents' Knowledge of Hazards in Industry According to Number of Years of Welding after Qualification

Number of Years of Welding after Qualification		Classification of Respondents' Knowledge of Hazards in Industry		Total
		Not Knowledgeable	Knowledgeable	
Less than 1 Year	Count Percentage %	1 100.00	0 0.00	1 100.00
1-5	Count Percentage %	13 36.11	23 63.89	36 100.00
6-10	Count Percentage %	25 37.88	41 62.12	66 100.00
11-15	Count Percentage %	8 29.63	19 70.37	27 100.00
16-20	Count Percentage %	5 22.73	17 77.27	22 100.00
21-25	Count Percentage %	5 33.33	10 66.67	15 100.00
26-30	Count Percentage %	8 40.00	12 60.00	20 100.00
Above 30	Count Percentage %	1 7.69	12 92.31	13 100.00
Total		66 33.00	134 67.00	200 100.00

Tables 4.28 - 4.31 show the classification of the respondents' proneness to hazards in industry according to age, education, welding training and number of years of welding after qualification as welder.

Table 4.28: Classification of Respondents' Proneness to Hazards in Industry According to Age

Age in Years		Classification of Respondents' Proneness to Hazards in Industry		Total
		Less Prone	Highly Prone	
18-30	Count Percentage %	29 46.03	34 53.97	63 100.00
31-49	Count Percentage %	43 43.00	57 57.00	100 100.00
50-70	Count Percentage %	15 40.54	22 59.46	37 100.00
Total		87 43.50	113 56.50	200 100.00

Table 4.29: Classification of Respondents' Proneness to Hazards in Industry According to Educational Level

Educational Level		Classification of Respondents' Proneness to Hazards in Industry		Total
		Less Prone	Highly Prone	
Primary completed	Count Percentage %	21 35.59	38 64.41	59 100.00
Secondary completed	Count Percentage %	18 38.30	29 61.70	47 100.00
Tertiary completed	Count Percentage %	15 60.00	10 40.00	25 100.00
Vocational/tech.	Count Percentage %	29 49.15	30 50.85	59 100.00
No formal educ.	Count Percentage %	4 40.00	6 60.00	10 100.00
Total		87 43.50	113 56.50	200 100.00

Table 4.30: Classification of Respondents' Proneness to Hazards in Industry According to Welding Training

Welding Training		Classification of Respondents' Proneness to Hazards in Industry		Total
		Less Prone	Highly Prone	
A. Apprenticeship to master	Count Percentage %	36 36.00	64 64.00	100 100.00
B. Technical institute	Count Percentage %	30 46.88	34 53.13	64 100.00
C. Both A & B	Count Percentage %	21 58.33	15 41.67	36 100.00
Total		87 43.50	113 56.50	200 100.00

Table 4.31: Classification of Respondents' Proneness to Hazards in Industry According to Number of Years of Welding after Qualification

Number of Years of Welding after Qualification		Classification of Respondents' Proneness to Hazards in Industry		Total
		Less Prone	Highly Prone	
Less than 1 Year	Count Percentage %	1 100.00	0 0.00	1 100.00
1-5	Count Percentage %	14 38.89	22 61.11	36 100.00
6-10	Count Percentage %	29 43.94	37 56.06	66 100.00
11-15	Count Percentage %	15 55.56	12 44.44	27 100.00
16-20	Count Percentage %	8 36.36	14 63.64	22 100.00
21-25	Count Percentage %	7 46.67	8 53.33	15 100.00
26-30	Count Percentage %	9 45.00	11 55.00	20 100.00
Above 30	Count Percentage %	4 30.77	9 69.23	13 100.00
Total		87 43.50	113 56.50	200 100.00

Table 4.32 show the classification of the availability of safety or personal protective equipment in industry according to number of years firm has been practicing welding.

Table 4.32: Classification of the Availability of Safety or Personal Protective Equipment in Industry According to Number of Years Firm has been Practicing Welding.

Number of Years Industry has been Welding		Classification of the Availability of Safety or Personal Protective Equipment		Total
		Less Availability	High Availability	
1-10	Count Percentage %	39 59.09	27 40.91	66 100.00
11-20	Count Percentage %	19 35.19	35 64.81	54 100.00
21-30	Count Percentage %	14 35.00	26 65.00	40 100.00
31-40	Count Percentage %	5 27.78	13 72.22	18 100.00
41-50	Count Percentage %	2 18.18	9 81.82	11 100.00
Above 50	Count Percentage %	1 9.09	10 90.91	11 100.00
Total		80 40.00	120 60.00	200 100.00

4.6.2 Exposure Time to Arc/Flame

The response to the research item, "how long are you exposed to arc/flame daily" revealed that 29 (14.50%) of the welders in this study are exposed for less than an hour to arc or flame, 27 (13.50%) for between an hour and two hours and a great proportion of the welders 144 (72.00%) are exposed in the work to arc or flame for above two hours. Figure 4.12 shows the exposure time to arc/flame daily against percentage count of welders.

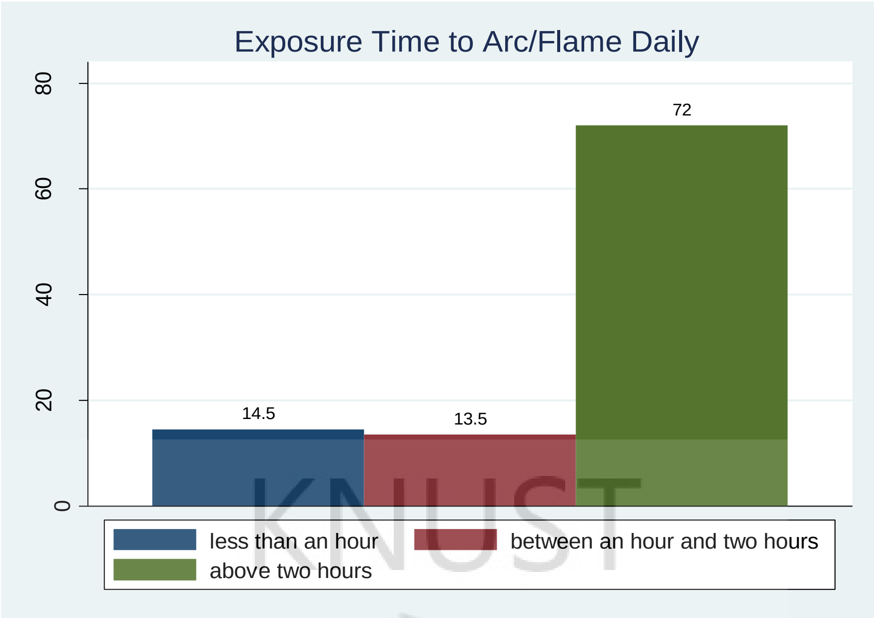


Figure 4.12: Exposure time to arc/flame daily

4.6.3 Insurance for Welders

Out of the 200 industries surveyed, 63 (31.50%) of the firms responded that they have insurance for their welders. The remaining 137 (68.50%) responded they do not have insurance for the welders. Figure 4.13 shows the distribution of the responses received.

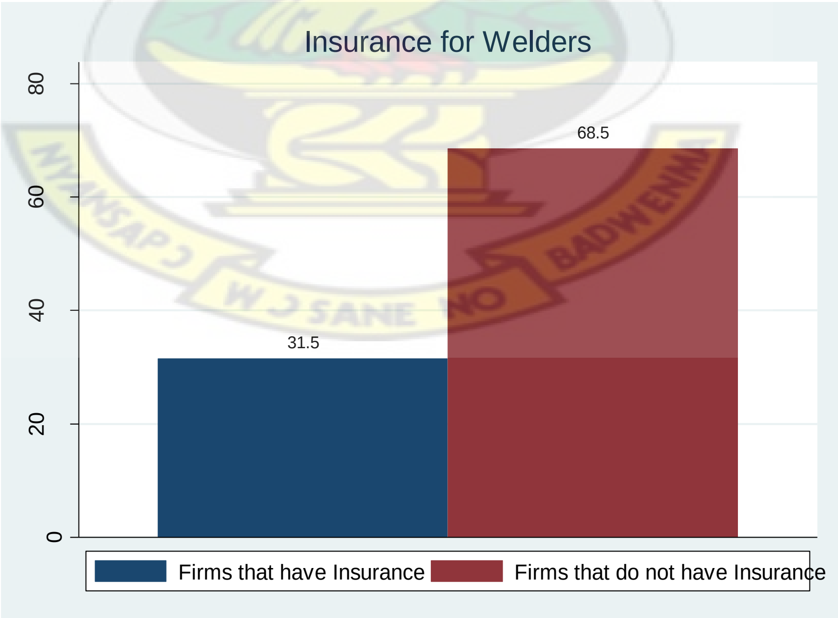


Figure 4.13: Distribution of Insurance for Welders in Industry

4.7 Some Challenges Facing Welders

Table 4.33 presents a summary of some of the challenges respondents face in their chosen profession and in industry.

Table 4.33 Summary of the Challenges Respondents Face in their Practice

Respondents Response to what are some of the Challenges you go through as a Welder	**Frequency of Response**
1) Lack of recognition of academic qualification for welders in industry as compared to electrical and mechanical qualification and low ratings among electricians, fitters, etc.	6
2) Most industries in the country do not have any ladder of progression for welders. The Ministry of Education does not have any course higher than advanced certificate for welders.	2
3) Difficulty in interpreting drawings and blue print.	1
4) Difficulty in acquiring welding training in Ghana and certification.	2
5) Lack of proper welding machines and materials such as guillotine machines, forming machines, bending machines, fixtures, grips, electrodes, welding shield, welding transformer machines and heat treatment furnaces and safety tools in industry and for practical work in welding training schools.	69
6) Shortage of carbide (oxy-acetylene gas) at supply stations which reduce productivity.	10
7) High cost of welding materials and equipment such as acetylene gas, iron rods etc.	14
8) Frequent power failure or fluctuations affect work schedule and hence productivity.	25
9) Industry does not organize any workshop training programmes or refresher courses for welders to update on new technology in welding and no special treatment incase of accidents due to poor safety management in industry.	3
10) Lack of proper welding materials on the market such as contaminated electrodes as a result of oxidation, rusting and/or over aged electrodes.	9
11) Lack of capital to expand.	45
12) Lack of government support especially to the small scale welding industries to grow.	9
13) High interest rate on loans from banks.	13
14) Stealing by robbers at night.	2

4.8 Hypotheses Testing

The hypotheses raised in this study were tested using chi-square X^2 test statistic because the tables built in this study are an r x c contingency tables and satisfies the requirements for use of the chi-square X^2 distribution for contingency table tests of hypothesis. This section presents the stated hypotheses, the chi-square results, degree of freedom and the Pearson's Contingency Coefficient (CC) tested at 5% two-tail test level of significance. The X^2 is calculated using

$$X^2 = \sum_{i=1}^{r}\sum_{j=1}^{c}\frac{\left(O_{ij} - E_{ij}\right)^2}{E_{ij}} \text{ where}$$

O_{ij} = observed frequency for the cell at row i and column j
E_{ij} = expected frequency for the cell at row i and column j

The number of degrees of freedom (df) in a two- variable contingency table equals the number of rows r minus one (i.e., r - 1) times the number of columns c minus one (i.e., c - 1).

df = (r - 1) (c - 1).

The Pearson's Contingency Coefficient; a measure of the association for X^2, is calculated as

$$CC = \frac{\sqrt{\frac{X^2}{(N+X^2)}}}{\sqrt{\frac{(L-1)}{L}}}$$

Where, X^2= value obtained from analysis
N= total number of observations in the r x c table
L= the smaller of the value of r x c (Runyon P. et al. 1996)

According to Montgomery and Runger (1994), the hypothesis is rejected if the observed value (calculated value) of the test statistic exceeds the critical values from the chi-square distribution table.

The results of the tests are shown in Table 4.34.

Table 4.34: Hypotheses Test Results

Stated Hypotheses	**Degree of Freedom**	**Chi-square Test Value Calculated**	**Chi-square Critical Value (From Tables)**	**CC-value**	***Hypothesis* Accepted or Rejected**
1) There is no significant relationship between the age of welders and their level of knowledge of the causes of weld failure.	2	2.6571	5.9915	0.1619	Accepted
2) There is no significant relationship between the education of welders and their level of knowledge of the causes of weld failure.	4	6.4823	9.4877	0.2506	Accepted
3) There is no significant relationship between the training the welders go through and their level of knowledge of the causes of weld failure.	2	4.1626	5.9915	0.2020	Accepted
4) There is no significant relationship between the number of years the welder has been welding after qualification as a welder and their level of knowledge of the causes of weld failure.	6	4.0501	12.5916	0.1993	Accepted
5) There is no significant relationship between the age of welders and their practices before they plan to weld.	2	5.2381	5.9915	0.2260	Accepted
6) There is no significant relationship between the education of welders and their practices before they plan to weld.	4	14.1176	9.4877	0.3632	Rejected
7) There is no significant relationship between the training the welders go through and their practices before they plan to weld.	2	2.0707	5.9915	0.1431	Accepted
8) There is no significant relationship between the number of years the welder has been welding after qualification as a welder and their practices before they plan to weld.	6	5.0140	12.5916	0.2212	Accepted

9) There is no significant relationship between the age of welders and their level of knowledge of hazards in industry.	2	1.9993	5.9915	0.1407	Accepted
10) There is no significant relationship between the education of welders and their level of knowledge of hazards in industry.	4	9.9963	9.4877	0.3086	Rejected
11) There is no significant relationship between the training the welders go through and their level of knowledge of hazards in industry.	2	0.3922	5.9915	0.0625	Accepted
12) There is no significant relationship between the number of years the welder has been welding after qualification as a welder and their level of knowledge of hazards in industry.	6	6.2398	12.5916	0.2459	Accepted
13) There is no significant relationship between the age of welders and their proneness to hazards in industry.	2	0.3063	5.9915	0.0553	Accepted
14) There is no significant relationship between the education of welders and their proneness to hazards in industry.	4	5.6024	9.4877	0.2335	Accepted
15) There is no significant relationship between the training the welders go through and their proneness to hazards in industry.	2	5.8082	5.9915	0.2376	Accepted
16) There is no significant relationship between the number of years the welder has been welding after qualification as a welder and their proneness to hazards in industry.	6	3.3045	12.5916	0.1803	Accepted
17) There is no significant relationship between the number of years the industry has been welding and the level of availability of safety or personal protective equipment in industry.	5	18.642	11.0705	0.4130	Rejected

CHAPTER FIVE

5.0 DISCUSSION OF RESPONSES

5.1 Introduction

This chapter presents the discussion of responses of the administered questionnaires. The result of the research is discussed under four main headings:

- Educational background and welding training programmes of welders in Ghana
- Welding practices in Ghanaian industry.
- Knowledge of respondents on some relevant welding topics.
- Safety issues in welding.

5.2 Education Background and Welding Training Programmes of Welders in Ghana

5.2.1 Education and Training

The research has revealed that 59 (29.50%) of the welders completed primary school, 47 (23.50%) secondary with most of them dropping at the junior high school or middle school level and 10 (5.00%) with no formal education. Fifty nine 59 (29.50%) completed vocational or technical and 25 (12.50%) completed tertiary with most of them coming from the polytechnics. This indicates that majority of the welders do not go beyond the secondary school level.

From Table 4.2, 100 (50.00%) of the welders acquired their welding trade through apprenticeship, 64 (32.00%) from a technical institute and 36 (18.00) went through apprenticeship and have gone through a few weeks of trade test from the National Vocational Training Institute (NVTI). This is an indication that most of the welders acquire the welding trade through apprenticeship training from experienced welders without attending any formal welding schools.

5.2.2 Certification and Qualification and Rank of Welders in Industry

Welder qualification means "the demonstration of a welder's ability to produce welds meeting prescribed standards (i.e. welding codes and specifications written to provide a minimum set of rules for the construction of weldments that will protect public life and property)". *Welder certification* means "certification in writing that a welder has produced welds meeting prescribed standards (welding codes and specifications)."

The research revealed that, although all the welders interviewed from the 200 industries had qualified from one training programme or another i.e. through apprenticeship to a master, formal training from a technical institute or both training programmes, only 112 (56.00%) had certification. The highest among the certificates welders held is advanced certificate in welding with 29 (25.89%) out of the 112 having this advanced certificate. This significantly indicates that welding standards are not regulated among the welders. Establishing standards (welding codes and specifications) will ensure product uniformity.

A total of 68 (34.00%) of the welders were employees in industries. Their rank status revealed that 7 (10.29%) are graded welding supervisors, 2 (2.94%) are graded welding instructors, and 51 (75.00%) of the welders being welding technicians (28 (41.18%) are graded welding technician grade one, 13 (19.12%) are graded as welding technician grade two whilst 10 (14.71%) are graded senior welding technician). A total of 8 (11.76%) of the respondents did not respond.

From the classification of welders training programmes according to educational level (Table 4.3), for welders who went through the apprenticeship trade out of 100, 51 (51.00%) had primary education, 31 (31.00%) had secondary education, 6 (6.00%) had tertiary (most polytechnic graduates) education, 4 (4.00%) completed vocational/technical institute, and 8 (8.00%) had no formal education. For welders who went through a technical institute training out of 64, 1 (1.56%) had primary education, 5 (7.81%) had secondary education, 18 (28.l3%) had tertiary education, 40 (62.50%) completed vocational/technical institute, and 0 (0.00%) had no formal education. This indicates that, a greater majority of the welders with low educational background who did not go past the secondary school level goes through the apprenticeship training while greater majority who completed vocational/technical institute acquire their welding training from a technical institute.

The classification of respondents' type of certificate in welding according to educational level (Table 4.4) shows that for the different levels of education of the welders, majority of those with vocational/technical education hold certificates. For those with intermediate certificate in welding, out of 45, greater percentage 30 (66.67%) have vocational/technical education. For those who hold advance certificate, out of 29, majority i.e. 15 (51.72%) and 12 (41.38%) have tertiary education and vocational/technical education respectively. For those who hold the national vocational training institute (NVTI) Cert. I, out of 11, majority of 6 (54.55%) have vocational/technical education. For those who hold national vocational training institute (NVTI) Cert. II, out of 11, 5 (45.55%) have vocational/technical education. This indicates that welders who have vocational/technical education hold majority of the certificates. Also, welders with tertiary and vocational/technical education have the highest certificates of the advance certificates.

Table 4.5 of this research shows that for the different levels of education of the welders in Ghana, majority of those with tertiary and vocational/technical education hold majority of the welding positions in industry. For those graded technician grade I, out of 28, majority 17 (60.71%) have vocational/technical education. For those graded technician grade II, out of 13, majority, 8 (61.54%) have vocational/technical education. For those graded as senior welding technicians, out of 10, majority, 7 (70.00%) have tertiary education. For those graded as welding supervisors, out of 7, majority, 4 (57.14) have vocational/technical education. For those graded as welding instructors, out of 2, all 2 (100%) have vocational/technical education. This is an indication that welders with tertiary and vocational/technical education hold majority of the welding positions in industries in the country.

Table 4.6 shows that welders holding higher positions such as welding supervisors 1 (50.00%) and welding instructors 1 (50.00%) have the highest certificates; advance certificates and NVTI cert. II. However, a careful look at the table shows that, for those graded as technician grade I, out of 26, 9 (34.62%) had the advance certificate. This was not expected, as one will expect that a welder with a higher certificate should have a higher position. This may confirm the response made by some of the welders in section 4.7 of chapter 4, as one of the challenges they encounter in industry that, there is lack of recognition of academic qualification for welders compared to electrical and mechanical qualification and low ratings among electricians, fitters, etc. and also the lack of a clear proper organizational progression for welders in industry.

5.3 Welding Practices in Industries in Ghana

5.3.1 Number of Years Firm has been Practicing Welding

Today, welding is an important manufacturing, maintenance and constructional joining process taking its place with the metal working operations to help bring us quality metal products at economical prices. From section 4.4.1, a greater percentage count 66 (33.00%) of the welding firms have been welding for between 1-10 years and the smaller percentage 11 (5.50%) of the firms have been welding for above 50 years. This suggests that firms practicing welding for longer number of years are few as compared to the recent firms in operation. This important engineering sector needs to be developed rapidly up to best modern practices.

5.3.2 Category of Welding and Proportions of Welders Employed by Different Industrial Groups

The welding process finds widespread application in almost all branches of industry. From section 4.4.3 of the research, it has revealed that, some of the welders and firms employ a combination of the category of welding (repair and maintenance, manufacturing and constructional welding) practices. However, the largest number of welders and firms employs welding for repair and maintenance, the second largest number of welders and industries employs welding for manufacturing (example, manufacturers of classroom metal desks, metal gate, block making machines, metal containers, coal pot etc.) and the third largest number of welders and industries employs welding for construction (includes construction of tunnels, subways, structural steel for bridges and buildings, metal bill board and sign board construction, etc.) in Ghana.

Section 4.4.2 of this research provides categories of the number of welders employed by different industry groups. From the research it can therefore be said that:

The single largest number of welders 129 (64.50%) in one group is employed by the "Fabricated Metal Products" sub-sector. This industry group includes manufacturers of classroom metal desks, metal gate, block making machines, metal containers, coal pot, burglar protection shield, fabrication of agro-processing, environment and sanitation equipment, ice breaker machines, metal storage tanks, platforms, hoists stands, concrete mixers, corn shearer, etc.

The second largest number of welders 35 (17.50%) is employed by the group known as "Machinery". This group includes manufacturers and repair and maintenance of refinery machinery such as crude oil large diameter pipes, sterilizer, chimney, cyclone, elevator bucket, pipe manifold system, steam coils and so on, mining machinery such as elbows, cylinder tanks for mineral processing, trash screens, chutes, mill hoppers, etc., electrical machinery such as turbines, electrical generators, transformers, electric motors and etc., construction machinery such as chipping spreader, bulldozers, cranes and etc., food processing/brewery machinery, farm machinery, woodworking machinery, as well as paper-making machinery.

The third largest number of welders is employed by the “Motor Vehicle and Equipment and Auto Repair” which employs 31 (15.50%) of the welders. This group includes manufacturers and repair and maintenance of automobiles, buses, tipper trucks, repair and building of trailers and heavy duty vehicles, vehicle chassis and exhaust welding, welding repair shops and garages, etc.

The fourth largest number of welders 3 (1.50%) is employed by the “Construction” industry. This industry group includes companies that build tunnels, subways, structural steel for bridges and buildings, metal bill board and sign board construction, etc.

The remaining 2 (1.00%) of the welders are employed by the “Primary Metal Industry”. These industries include steel mills and companies that produce structural shape sheet metals.

5.3.3 Type of Welding Technique/Procedure Practiced in Industry

A very few of the firms practice welding using a combination of techniques (manual, machine or automatic). A total of 180 (90.00%) of the firms practice only manual welding. This significantly indicates that little automation in welding is being practiced in industries in Ghana.

Because of the hazards of manual welding and to increase productivity, and improve product quality, various forms of mechanization and automation have been developed such as machine welding, automatic welding, and robotic welding (Groover, 2002). However, relatively short runs, constant changes in the position of welding, movement across the shop floor from one fabrication to another, and a mix of different types of work or joint all encourage the use of manual welding, since the welder's skill can be deployed to the best advantage in coping with the varying requirements. On the other hand, some fabrications, especially where long joints are involved, could be designed to take advantage of higher speeds of welding or greater deposition rates by automation than those obtainable with manual techniques.

5.3.4 Type of Welding Process Used

Section 4.4.5 of this report, shows that one hundred and eighty one or approximately ninety-one percent 181 (91%) of the firms were found to use arc welding process. In addition 119 (60%) of the firms use gas welding process while only 15 (8%) use resistance welding. However, the greatest percentage of the firms 86 (43.00%) use a combination of arc and gas welding processes. This is an indication that arc welding process is the most widely used welding process practiced by industries in Ghana whilst a greater proportion of industries use the combination of both arc and gas.

The research also shows that in the arc welding group the greater majority of the firms 140 (77.35%) that use arc welding use the shielded metal arc welding (SMAW) only with just a few using a combination of SMAW, GTAW or GMAW. Within the gas welding group, the largest percentage of the firms 117 (98.32%) of the 119 firms use the oxyacetylene welding (OAW) only with just a few using a combination of OAW and pressure gas welding (PGW). Whilst within the resistance welding group, the largest percentage of the firms 12 (80.00%) of the 15 firms use the resistance spot welding (RSW) process only with just a few using a combination of the RSW, resistance seam welding (RSEW) or resistance projection welding (RPW).

According to Gourd, (1995) “it would be easy to say that the process chosen should provide the required quality at the lowest cost: While this must always be the aim, there are usually constraints which make this decision a compromise. In making a choice between processes, quality must be considered in terms of the skill of the welders available to do the job. Similarly, availability of equipment contributes an important restraint - the volume of work may not justify investment in new plant or retraining labour, and existing welding sets are often used even though the apparent cost may be higher” (Gourd, 1995).

From the above discourse, a series of questions can be raised as to why many of our local fabricators choose the SMAW process which is most suitable for welding steel plates and just a few of them use the more specialized welding techniques such as the GTAW process which has more attributes for welding in the aero-engine industry and the RSW process which is always the first choice for the car-body manufacturer. This significantly indicates that as a country, we need to equip these welders with the requisite skill and equipment to handle the more specialized welding techniques to produce more technological products in order to catch up with the more developed nations.

5.3.5 Quality Control Mechanisms for Testing Welds

Testing is usually performed to ensure that welded joints can fulfill their intended function. In fact the basis of a specification for weld quality is frequently an assessment of the number and size of the defects which can be present in a weld before it is considered to be defective and therefore rejectable. From section 4.4.6, 159 (79.50%) of the 200 firms said they use only visual inspection to ascertain the quality of the welded joint, which is usually the first means of assessing quality. This figure is very high and of concern since visual inspection may not be good enough especially for critical components such as in welded parts in automobiles, refinery pipes, chemical storage tanks or cylinders, etc.

which most of our local welders work on. Even with good lighting, it is often difficult to detect cracks by visual inspection. The effectiveness and indeed the speed of the examination is improved if the presence of a crack is highlighted by the use of nondestructive testing (NDT) such as say dye penetrant or magnetic particle techniques etc. and the use of destructive testing such as microscopic test or bending test etc. Surprisingly, for both nondestructive testing and destructive testing (DT) only 27 (13.50%) of the firms use these methods. The remaining 14 (7.00%) responded that they use other methods such as using chipping hammer to remove carbon from the surface of the welded area to reveal cracks and other defects. To obtain quality products, and a fairly proper assessment of the number and size of the defects which can be present in a weld, assisted visual inspection such as NDT and DT should be of prime interest to industries that practice welding in Ghana.

5.4 Knowledge of Respondents on some Welding Topics

5.4.1 Knowledge of Respondents on Causes of Weld Failure

From Table 4.7 of the analysis (chapter 4), 74 (37.00%) of the respondents have experienced failure of their welded joint immediately after being welded or in service. Out of this percentage, almost the same proportion of the welders i.e. 26 (35.14%) and 27 (36.49%) thought the failure was as a result of fault of the welder and a problem of the welding technique respectively. The rest 21 (28.38%) responded that the cause was due to both. In this analysis, it can be concluded that the welder and the welding technique such as current/voltage settings, electrode specification, how the joint was allowed to cool, are ultimately responsible for possible causes of any cracking or failure in the joint.

From Table 4.13 of the analysis (chapter 4), within the age group of 18-30 years, 36 (57.14%) out of 63 have high level of knowledge of the causes of weld failure. Within the age group of 31-49, 60 (60.00%) out of 100 have high level of knowledge of the causes of weld failure and within the age group of 50-70, 27 (72.97%) out of 37 have high level of knowledge. Comparing the three age groups it appears that 50-70 age group is more knowledgeable than either of the two. However, such a conclusion cannot be drawn because the numbers sampled are not comparable. A test of hypothesis is rather used to find out whether age group has any influence on the level of knowledge of welders on the causes of weld failure. Because the data are the frequency of specific categories, the chi-square is used.

In terms of education (Table 4.14, chapter 4) 15 (60.00%) out of 25 with tertiary education have high level of knowledge. Twenty-seven 27 (57.45%) out of 47 of those with secondary education have high level of knowledge of the causes of weld failure, 32 (54.24%) out of 59 of those with vocational/technical education have high level of knowledge and for those with no formal education 5 (50.00%) out of 10 have high level of knowledge of the causes of weld failure. This is expected as the level of education influences assimilation of information. For those with primary education 44 (74.58%) out of 59 have high level of knowledge. This percentage is higher than all the levels of education discussed so far but one cannot draw the conclusion that those with primary education are more informed than all the rest of educational levels because the numbers sampled are not comparable. Also length of practice is an important factor to be considered. However it is clear from Table 4.14 that the numbers sampled for those with primary and vocational/technical education are comparable. For this reason, a chi-square test was used to find out whether education really has any influence on the level of knowledge of welders on the causes of weld failure.

In terms of welding training gone through, (Table 4.15, chapter 4) 68 (68.00%) out of 100 who went through the apprenticeship trade have high level of knowledge on the causes of weld failure, 37 (57.81%) out of 64 who went to a technical institute to acquire their welding trade have high level of knowledge whilst 18 (50.00%) out of 36 who through both i.e. apprenticeship and technical institute, have high level of knowledge on the causes of weld failure. Again comparing the percentages, one cannot draw a valid conclusion from the research data that, welders who went through the apprenticeship trade are more knowledgeable than those who went to a technical institute or those who went to both apprenticeship and technical institute because the numbers sampled are not comparable. A chi-square test was used to find out whether there is any relationship between the level of knowledge of the causes of weld failure and the three welding training programmes in the sample space.

From Table 4.16 (chapter 4), for welders who have been welding for less than 1 year after qualification as a welder, 1 (100.00%) out of 1 have high level of knowledge of the causes of weld failure. For the year group 1-5 years, 19 (52.78%) out of 36 have high level of knowledge, for the year group 6-10 years, 39 (59.09%) out of 66 have high level of knowledge, for the year group 11-15 years, 17 (62.96%) out of 27 have high level of knowledge, for the year group 16-20 years, 15 (68.18%) out of 22 have high level of knowledge, for the year group 21-25 years, 8 (53.33%) out of 15 have high level of knowledge, for the year group 26-30 years, 15 (75.00%) out of 20 have high level of knowledge whilst welders who have been welding for above 30 years, 9 (69.23%) out of 13 have high level of knowledge of the causes of weld failure. Because the data are the frequency of specific categories, a chi-square test was used to find out whether the length of period of welding really has any influence on the level of knowledge of welders on the causes of weld failure. Those who have been welding for less than 1 year were too few (only 1) to be included in a valid chi-square test.

This study (Table 4.9) has revealed that only 61.50% of the welders have high level of knowledge of the causes of weld failure. A look at Table 4.7, shows that the only well known areas that the welders think can cause weld failure are through incorrect electrode/filler rod chosen by the welder 195 (97.50%) and unsteady current/voltage or inappropriate gas mixtures 184 (92.00%). From Table 4.7, the percentage ignorance ranges from 2.50% to 54.50%. At 95% confidence interval these figures translate to ranges of 0.5%-4.50% and 47.50%-61.50%. That is among the welders surveyed between 0.5% and 61.50% are ignorant in many areas of the causes of weld failure.

5.4.2 Knowledge of Practices of Welders before Planning to Weld

Factors welders consider before welding two pieces of metal together such as joint preparation, the thickness of the metal, the type of joint etc. as shown in Table 4.11 was used to classify the welders into two groups; welders of good practice and poor practice (Table 4.12).

Tables 4.17 - 4.20 show the classification of the welders' practices before planning to weld according to age, education, welding training and number of years of welding after qualification as welder respectively.

In the age group (Table 4.17 chapter 4), 18-30, 30 (47.62%) out of 63 observe good practices before planning to weld. In the age group, 31-49, 60 (60.00%) out of 100 observe good practices and for those within 50-70, 26 (70.27%) out of 37 observe good practices. It appears that those within the age group 50-70 observe very good practices before planning to weld. Because the data are the frequency of specific categories, a chi-square test was used to find out if age had any influence on the practices of welders before planning to weld.

In terms of education (Table 4.18 chapter 4), 23 (38.98%) out of 59 with primary education observe good practices before planning to weld. A total of 31 (65.96%) out of 47 with secondary education observe good practices. A total of 36 (61.02%) out of 59 with vocational/ technical education observe good practices and 19 (76.00%) out of 25 with tertiary education observe good practices. An interesting outcome is the percentage for those without formal education 7 (70.00%) out of 10 observe good practices. Because the numbers sampled are not comparable one cannot arrive at a valid conclusion. A chi-square test was used to find out whether education had any influence on the practices of welders before planning to weld.

In terms of welding training gone through, (Table 4.19, chapter 4), 53 (53.00%) out of 100 who went through the apprentice trade observe good practices before planning to weld, 40 (62.50%) out of 64 who went to a technical institute observe good practices and 23 (63.89%) out of 36 went through both i.e. apprenticeship and technical institute observe good practices before they weld. It appears those who went through both training observe very good practices before planning to weld. A chi-square test was used to find out whether there is any relationship between practices of welders before planning to weld and the welding training programmes.

For the classification of respondents practices before planning to weld according to the number of years of welding after qualification, (Table 4.20 chapter 4), for the year group less than one year no welder, 0 (0.00%) out of 1 observe good practices, welders within the year group 1-5 years 21 (58.33%) out of 36 observe good practices. Within 6-10 years 33 (50.00%) out of 66 observe good practices, within 11-15 years 18 (66.67%) out of 27 observe good practices, within 16-20 years 12 (54.55%) out of 22 observe good practices, within 21- 25 years 9 (60.00%) out of 15 observe good practices, within 26-30 years 13 (65.00%) out of 20 observe good practices and for welders who have been welding for above 30 years after qualification as a welder, 10 (76.92%) out of 13 observe good practices before planning to weld. A chi-square test is used to find out whether the length of period of welding after qualification really has any influence on the practices of the welders before they plan to weld. Those welding for less than 1 year were not included.

The study (Table 4.12) has revealed that only 58.00% of the welders demonstrate good practices before planning to weld. A look at Table 4.11, shows that the only well known factors that the welders consider before planning to weld are the thickness of the metal 182 (91.00%), the type of electrode/filler rod 194 (97.00%) and the type of metal 197 (98.50%).

5.5 General Safety of Welders in Industry

The safety of welders in industry was studied in three sections; the general knowledge of welders on hazards in industry, the welders proneness to hazards in industry and the availability of safety or personal protective equipment in industry. The overall results of the three sets are summarized in Table 4.23, chapter 4, where on the knowledge of welders on hazards in industry 67.00% had high knowledge and 33.00% had low knowledge. On the welders' proneness to hazards in industry, 56.50% are highly prone and 43.50% are less prone. On the availability of safety or personal protective equipment in industry, only 60.00% had high availability and 40.00% had less availability. The figures give a course for concern because having a very high knowledge of the hazards in industry and a very high availability of safety or protective equipment will help to a large extend reduce the proneness to hazards in industry.

5.5.1 Knowledge of Welders on Hazards in Industry

Tables 4.24 - 4.27, chapter 4 show the classification of the respondents' knowledge of hazards in industry according to age, education, welding training and number of years of welding after qualification as welder.

In the age group (Table 4.24, chapter 4) 18-30, 39 (61.90%) out of 63 have high knowledge of hazards in industry, in the age group 31-49, 67 (67.00%) out of 100 have high level of knowledge of hazards in industry and in the age group 50-70, 28 (75.68%) out of 37 have high level of knowledge of hazards in industry. Because the data are the frequency of specific categories, the chi-square is used. A chi-square test was used to find out if age had any influence on the level of knowledge of welders on hazards in industry.

In terms of education (Table 4.25, chapter 4), 31 (52.54%) out of 59 with primary education have high knowledge of hazards in industry, 38 (80.85%) out of 47 with secondary education have high knowledge of hazards in industry, 40 (67.80%) out of 59 with vocational/technical education have high knowledge of hazards in industry, 18 (72.00%) out of 25 with tertiary education have high knowledge of hazards in industry and 7 (70.00%) out of 10 with no formal education have high knowledge of hazards in industry. A chi-square test was used to find out whether education had any influence on level of knowledge of welders on hazards in industry.

In terms of welding training (Table 4.26 chapter 4), 68 (68.00%) out of 100 who went through the apprenticeship to master training programme have high knowledge of hazards in industry, 41 (64.06%) out of 64 who went through the technical institute training programme have high knowledge of hazards in industry and 25 (69.44%) out of 36 who went through both training programmes have high knowledge of hazards in industry. A chi-square test was used to find out whether the welding training programmes they go through had any influence on the level of knowledge of welders on hazards in industry.

In terms of the number of years of welding after qualification (Table 4.27 chapter 4), for the year group less than one year, no welder 0 (0.00%) out of 1 has knowledge of hazards in industry. For the year group 1-5, 23 (63.89%) out of 36 have high knowledge of hazards in industry. For the year group 6-10, 41 (62.12%) out of 66 have high knowledge of hazards in industry. For the year group 11-15, 19 (70.37%) out of 27 have high knowledge of hazards in industry. For the year group 16-20, 17 (77.27%) out of 22 have high knowledge of hazards in industry. For the year group 21-25, 10 (66.67%) out of 15 have high knowledge of hazards in industry. For the year group 26-30, 12 (60.00%) out of 20 have high knowledge of hazards in industry and for those who have been welding after qualification for above 30 years, 12 (92.31%) out of 13 have high knowledge of hazards in industry. It appears those who have been welding after qualification for above 30 years are more knowledgeable. However the numbers sampled are not comparable. A chi-square test is used to find out whether the length of period of welding after qualification really has any influence on the level of knowledge of hazards in industry. Those welding for less than 1 year were not included.

The study (Table 4.23) has revealed that only 67.00% have high level of knowledge of hazards in industry. The percentage of 33.00% having low level of knowledge at 95% confidence interval translates to 26%-40% of the welders surveyed in the various industries having low level of knowledge of the hazards that can arise as a result of the lack of observing proper safety measures.

5.5.2 Proneness of Welders to Hazards in Industry

Tables 4.28 - 4.31, in chapter 4, show the classification of the respondents' proneness to hazards in industry according to age, education, welding training and number of years of welding after qualification as welder.

In the age group (Table 4.28 chapter 4) 18-30, 34 (53.97%) out of 63 are highly prone to hazards in industry, in the age group 31-49, 57 (57.00%) out of 100 are highly prone to hazards in industry and in the age group 50-70, 22 (59.46%) out of 37 are highly prone to hazards in industry. It appears the age group 50-70, are more highly prone to hazards in industry than the other age groups. However such a conclusion cannot be drawn because the sample space is not the same. A chi-square test was used to find out if age had any influence on the prone levels to hazards in industry.

In terms of education (Table 4.29 chapter 4), 38 (64.41%) out of 59 with primary education are highly prone to hazards in industry, 29 (61.70%) out of 47 with secondary education are highly prone to hazards in industry, 30 (50.85%) out of 59 with vocational/technical education are highly prone to hazards in industry, 10 (40.00%) out of 25 with tertiary education are highly prone to hazards in industry and 6 (60.00%) out of 10 with no formal education are highly prone to hazards in industry. A chi-square test was used to find out whether education of the welders had any influence on their prone levels to hazards in industry.

In terms of welding training gone through (Table 4.30 chapter 4), 64 (64.00%) out of 100 who went through the apprenticeship to master training programme are highly prone to hazards in industry, 34 (53.13%) out of 64 who went through the technical institute training programme are highly prone to hazards in industry and 15 (41.67%) out of 36 who went through both training programmes; that is, apprenticeship and technical institute training programs are highly prone to hazards in industry. It appears the welders who went through the apprenticeship to master training programme are more highly prone to hazards in industry than the other groups. A chi-square test was used to find out whether the welding training programmes the welders go through had any influence on their prone levels to hazards in industry.

In terms of the number of years of welding after qualification (Table 4.31 chapter 4), for the year group less than one year, no welder 0 (0.00%) out of 1 are highly prone to hazards in industry. For the year group 1-5, 22 (61.11%) out of 36 are highly prone to hazards in industry. For the year group 6-10, 37 (56.06%) out of 66 are highly prone to hazards in industry. For the year group 11-15, 12 (44.44%) out of 27 are highly prone to hazards in industry. For the year group 16-20, 14 (63.64%) out of 22 are highly prone to hazards in industry. For the year group 21-25, 8 (53.33%) out of 15 are highly prone to hazards in industry. For the year group 26-30, 11 (55.00%) out of 20 are highly prone to hazards in industry and for those who have been welding after qualification for above 30 years, 9 (69.23%) out of 13 are highly prone to hazards in industry. These percentages are obtained under different sample spaces of the year groups and so a clear conclusion cannot be drawn. A chi-square test is used to find out whether the length of period of welding after qualification really has any influence on the welders prone levels to hazards in industry. Those welding for less than 1 year were few (1), hence were not included in the chi-square test.

These demographic classifications can help in planning effective interventions when and where necessary.

The study (Table 4.23) has revealed that only 43.50% of the total welders surveyed are less prone to hazards in industry. A look at Table 4.21 shows that, the only areas of the hazards that the welders are very less prone are explosions/flashback 160 (80.00%) and fire outbreak 161 (80.50%). From Table 4.21, the percentage of highly prone levels of the various hazards studied ranges from 19.50% to 86.00%. At 95% confidence interval these figures translate to ranges of 13.50%-25.50% and 81.00%-91.00%. That is among the welders surveyed, between 13.50% and 91.00% are highly prone in many areas of hazards in industry.

5.5.3 Availability of Safety or Personal Protective Equipment in Industry

Table 4.32, chapter 4 shows the classification of the availability of safety or personal protective equipment in industry according to number of years industry has been practicing welding.

For industries practicing welding between 1-10 years, 27 (40.91%) out of 66 have high availability of safety or personal protective equipment. For industries practicing welding between 11-20 years, 35 (64.81%) out of 54 have high availability of safety or personal protective equipment. For industries practicing welding between 21-30 years, 26 (65.00%) out of 40 have high availability of safety or personal protective equipment. For industries practicing welding between 31-40 years, 13 (72.22%) out of 18 have high availability of safety or personal protective equipment. For industries practicing welding between 41-50 years, 9 (81.82%) out of 11 have high availability of safety or personal protective equipment. For industries practicing welding above 50 years, 10 (90.91%) out of 11 have high availability of safety or personal protective equipment. Comparing the year groups it appears that as the industries are practicing welding for longer periods, they tend to have high availability of safety or personal protective equipment in terms of percentages. However, such a conclusion cannot be drawn because the numbers sampled are not comparable. A chi-square test is used to find out whether the length of period industry has been practicing welding really has any influence on the availability of safety or personal protective equipment in industry.

The study (Table 4.23) has revealed that only 60.00% of the industries surveyed have high availability of safety or personal protective equipment. From the answers to the individual questions in the test of the availability of safety or personal protective equipment (Table 4.22), the only safety or personal protective equipment that are of very high availability in the industries are welding goggles 188 (94.00%), welding gloves 167 (83.50%) and welding shields 177 (88.50%). For the items that are mostly lacking; about 46.50% of the industries have no fire extinguishers, 53.50% of the industries have no first aid box, 56.00% of the industries have no respirators, only 6.00% of the industries have no welding goggles, 16.50% of the industries have no welding gloves, only 11.50% of the industries have no welding shield, 43.00% of the industries have no welding aprons and jackets, and about 54.50% of the industries and for that matter the welders have no or do not use safety boots.

The above percentages of lack of availability of safety or personal protective equipment are quite high and give course for concern. The percentage lack ranges from 6.00% to 56.00%. At 95% confidence interval these figures translate to ranges of 3.00%-9.00% and 49.00%-63.00%. That is among the industries surveyed between 3.00% and 63.00% lack in many areas of safety protective equipment.

5.5.4 Exposure to Arc/Flame Duration

From section 4.6.2 chapter 4, about 72.00% of the welders surveyed are exposed to arc/flame radiation for at least two hours daily. Although exposure of the body to radiations from the arc/flame as a welder is inevitable, very long periods of exposure without proper precautionary measures could be dangerous to parts of the body. The arc/flame emits ultra-violet and infra-red radiation. Ultra-violet radiation is damaging to both eyes and skin. Exposure of the tissue of the eyeball to ultra-violet radiation will produce a condition known as 'arc-eye'. At the same time, attention must be paid to the effect of ultra-violet radiation on the skin. Small amounts of radiation simply result in a suntan effect, but prolonged exposure causes severe burning, and the welder should wear suitable protective clothing to cover any areas of skin which might be exposed to the arc. Also specific forms of cataract of the eye have been attributed to the effect of regular exposure to infra-red radiation. From this research it has been established that among the industries surveyed between 3.00% and 63.00% lack in many areas of safety protective equipment. This indicates that the welders long periods of exposure to arc/flame has to some extend a causative influence on the percentages of eye problems (60.00%) and skin diseases (50.50%) realized in this study.

5.5.5 Insurance for Welders

From section 4.6.3, 68.50% of the welders do not have any life insurance policy. Since welders are exposed to a lot of risks such as the dangerous high temperatures of molten metals, fire hazards, hazards of electrical shock, hazards of explosions or flashback, etc one would have expected that most of these welders will be insured in case of accidents. Without any insurance policy for these welders, they will be responsible for their own care in case of an accident. A life insurance will give the welders some claim for their care in the event of an accident in the course of their work.

5.6 Test of Hypothesis

From Table 4.34, the following conclusions regarding the hypotheses tested are:

Hypothesis 1: We accept the null hypothesis that there is no significant relationship between the age of welders and their level of knowledge of the causes of weld failure.

Hypothesis 2: We accept the null hypothesis that there is no significant relationship between the education of welders and their level of knowledge of the causes of weld failure.

Hypothesis 3: We accept the null hypothesis that there is no significant relationship between the training the welders go through and their level of knowledge of the causes of weld failure.

Hypothesis 4: We accept the null hypothesis that there is no significant relationship between the number of years the welders have been welding after qualification as welders and their level of knowledge of the causes of weld failure.

Hypothesis 5: We accept the null hypothesis that there is no significant relationship between the age of welders and their practices before they plan to weld.

Hypothesis 6: We reject the null hypothesis and conclude that there is significant relationship between education of the welders and their practices before they plan to weld.

Hypothesis 7: We accept the null hypothesis that there is no significant relationship between the training the welders go through and their practices before they plan to weld.

Hypothesis 8: We accept the null hypothesis that there is no significant relationship between the number of years the welders have been welding after qualification as welders and their practices before they plan to weld.

Hypothesis 9: We accept the null hypothesis that there is no significant relationship between the age of welders and their level of knowledge of hazards in industry.

Hypothesis 10: We reject the null hypothesis and conclude that there is significant relationship between the education of welders and their level of knowledge of hazards in industry.

Hypothesis 11: We accept the null hypothesis that there is no significant relationship between the training the welders go through and their level of knowledge of hazards in industry.

Hypothesis 12: We accept the null hypothesis that there is no significant relationship between the number of years the welders have been welding after qualification as welders and their level of knowledge of hazards in industry.

Hypothesis 13: We accept the null hypothesis that there is no significant relationship between the age of welders and their proneness to hazards in industry.

Hypothesis 14: We accept the null hypothesis that there is no significant relationship between the education of welders and their proneness to hazards in industry.

Hypothesis 15: We accept the null hypothesis that there is no significant relationship between the training the welders go through and their proneness to hazards in industry.

Hypothesis 16: We accept the null hypothesis that there is no significant relationship between the number of years the welders have been welding after qualification as welders and their proneness to hazards in industry.

Hypothesis 17: We reject the null hypothesis and conclude that there is significant relationship between the number of years the industry has been welding and the level of availability of safety or personal protective equipment in industry.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The objective of this thesis work was to conduct a survey of current welding practices, i.e. the type of training programmes for welders, the category of welding and welding technique the welders use, type of welding processes the welders use, safety of the welders, needs and challenges of these welders and the welders knowledge of the technology of welding in the metal joining sector of some Ghanaian industries and propose effective policies and improvements of engineering nature where applicable.

The study has indicated that:

Conclusions on the educational background and welding training programmes of welders in Ghana

1. About eighty eight percent (87.50%) of the welders do not go beyond secondary school education and the majority in this group attains their welding training through apprenticeship.
2. Fifty percent 100 (50.00%) of the welders acquired their welding trade through apprenticeship, 64 (32.00%) from a technical institute and 36 (18.00) went through apprenticeship and have gone through a few weeks of trade test from the National Vocational Training Institute (NVTI).
3. Only 56.00% of the welders have certification and the highest certification is the advanced certificate in welding issued by the polytechnics. The National Vocational Training Institute (NVTI) also issues NVTI I and NVTI II certificate.
4. Welders with tertiary and vocational/technical education hold majority of the welding positions in industries in the country such as technicians, senior welding technicians, welding supervisors and welding instructors.

5. There is not a clear proper grading system of positions for welders and organizational progression in industry.

Conclusions on welding practices in the Ghanaian industry

6. The largest number of welders and industries practices repair and maintenance welding, the second largest number of welders and industries practices manufacturing welding and the third largest number of welders and industries practices constructional welding.
7. Among the categories of the number of welders employed by the different industry groups, the single largest number of welders 64.50% in one group is employed by the "Fabricated Metal Products" group.
8. Little automation in welding is being practiced in industries in Ghana with 90.00% of the industries practicing manual welding only.
9. One hundred and eighty one or approximately ninety-one percent 181 (91%) of the firms use the arc welding process. In addition 119 (60%) of the firms use the gas welding process while only 15 (8%) of the firms use resistance welding. However, the greatest percentage of the combination of welding process 86 (43.00%) use by the firms is the arc and gas welding process. This is an indication that the arc welding process is the most (91%) widely used welding process practiced by industries in Ghana whilst the greatest proportion 86 (43.00%) of these industries use the combination of both arc and gas.
10. Within the arc welding group, the largest percentage of about seventy-seven percent (77.35%) of the firms uses the shielded metal arc welding (SMAW) only.
11. Within the gas welding group, the largest percentage of about ninety-eight percent (98.32%) of the firms uses the oxyacetylene welding (OAW) only.

12. Within the resistance welding group, the largest percentage of eighty percent (80.00%) of the firms use the resistance spot welding (RSW) process only.
13. About eighty percent (79.50%) of the industries use only visual inspection to ascertain the quality of welded joint with only about fourteen percent (13.50%) of the firms using nondestructive testing (NDT) and destructive testing (DT) methods.

Conclusions on the knowledge of respondents on some relevant welding topics

14. About sixty-two percent (61.50%) of the welders have high level of knowledge of the causes of weld failure and 38.50% have low level of knowledge of the causes of weld failure.
15. The age, education, training the welders go through and the numbers of years the welders have been welding after qualification as welders does not influence their level of knowledge of the causes of weld failure.
16. About eighty percent (79.50%) of the welders have high level of knowledge of the types of joints and 20.50% have low level of knowledge of the types of joints.
17. About forty-six percent (45.50%) of the welders have high level of knowledge of the type of welds and 54.50% have low level of knowledge of the type of welds.
18. Fifty-eight percent (58.00%) of the welders demonstrate good practices before planning to weld and 42.00% demonstrate poor practices before planning to weld.
19. The education of the welders has an influence on their practices before planning to weld but their age, training the welders go through and the numbers of years the welders have been welding after qualification as welders does not influence their practices before planning to weld.

Conclusions on safety issues in welding

20. Sixty-seven percent (67.00%) of the welders have high level of knowledge of hazards in industry and 33.00% have low level of knowledge of hazards in industry.
21. The education of the welders has an influence on their level of knowledge of hazards in industry but the age, training the welders go through and the numbers of years the welders have been welding after qualification as welders does not influence their level of knowledge of hazards in industry.
22. About fifty-seven percent (56.50%) of the welders are highly prone to hazards in industry and 43.50% of the welders are less prone to hazards in industry.
23. The age, education of the welders, training the welders go through and the numbers of years the welders have been welding after qualification as welders, all, does not influence their proneness to hazards in industry.
24. Sixty percent (60.00%) of the industries have high availability of safety or personal protective equipment and 40.00% have less availability of safety or personal protective equipment.
25. The number of years the industry has been welding has an influence on the level of availability of safety or personal protective equipment in industry.
26. Sixty percent (60.00%) of the welders suffer from various eye problems and about fifty-one percent (50.50%) suffer from various skin diseases and these diseases are most likely due to the long period of time they are exposed to radiations daily in their work environment.
27. About thirty-two percent (31.50%) of the firms have insurance policies for their welders and 68.50% of the firms do not have any insurance policies for their welders.

6.2 Recommendations

On the basis of this research work the following recommendations are made:

1. Considering that most welders in industry have low educational background and their level of ignorance in some of the aspects of welding practices as reported in this study, gives cause for worry, industries, the universities, polytechnics, the national vocational training institutes in Ghana, etc. should institute regular training programmes and/or refresher courses for the welders in all aspects of welding and fabrication to improve industrial welding practices.
2. An attempt should be made as a country to equip welders with the requisite skill and equipment to diversify into most of the more specialized welding techniques and processes.
3. The universities, polytechnics, and other technical institutions should also mount higher and professional courses in welding and fabrication leading to awards higher than the advanced certificate in welding as this study has revealed, such as the award of higher national diploma and degrees in welding.
4. General safety practices in welding such as hazards in welding, importance of having and using safety and personal protective equipment when welding should be part of the training for the welders and in the technical institutions.
5. Industries that practice welding in Ghana must institute some form of insurance policies for the industry and the welders.
6. Since welding is an important manufacturing, maintenance and construction engineering activity, the government should take a critical look at the activities of especially the small scale welding industries by coordinating their operations under one industrial estate and giving them support in terms of land and space, training, welding equipment, low interest loans, etc., to improve their rate of

productivity and also encourage manufacturing and innovations in different products in the country.

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APPENDICES

APPENDIX A: BASIC WELD SYMBOLS

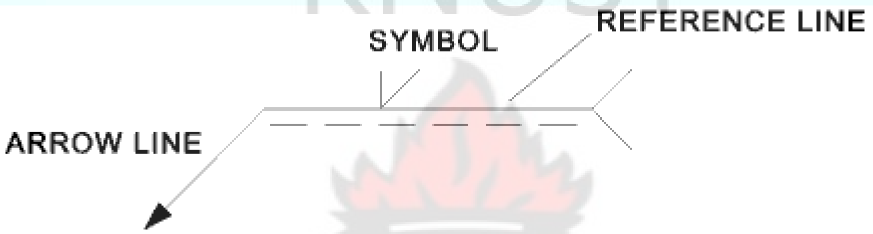
Standards

The British Standard for weld symbols is BS EN 22553. When identification of the weld process is required as part of the weld symbol the relevant weld process code is listed in BS EN ISO 4063.

Basic Weld Symbol

The weld symbol always includes

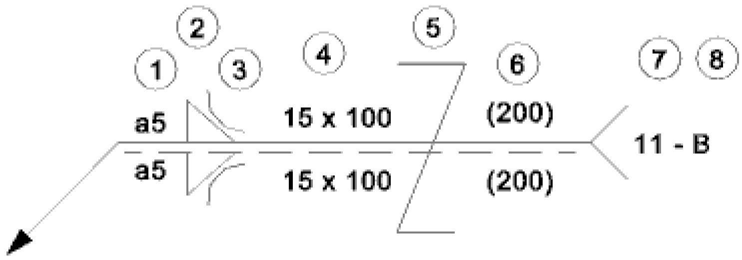
1. An arrow line
2. A reference line
3. A symbol



Note: Weld symbols on the full reference line relates to welds on the near side of the plate being welded. Weld symbols on the dashed line relates to weld on the far side of the plate. If the welds are symmetrical on both sides of the plate the dashed line is omitted. If the dashed line is above the full line then the symbol for the nearside weld is drawn below the reference line and the symbol for the farside weld is above the dashed line

Figure A-1 Basic Weld Symbol

More Detailed Symbolic Representation of Weld

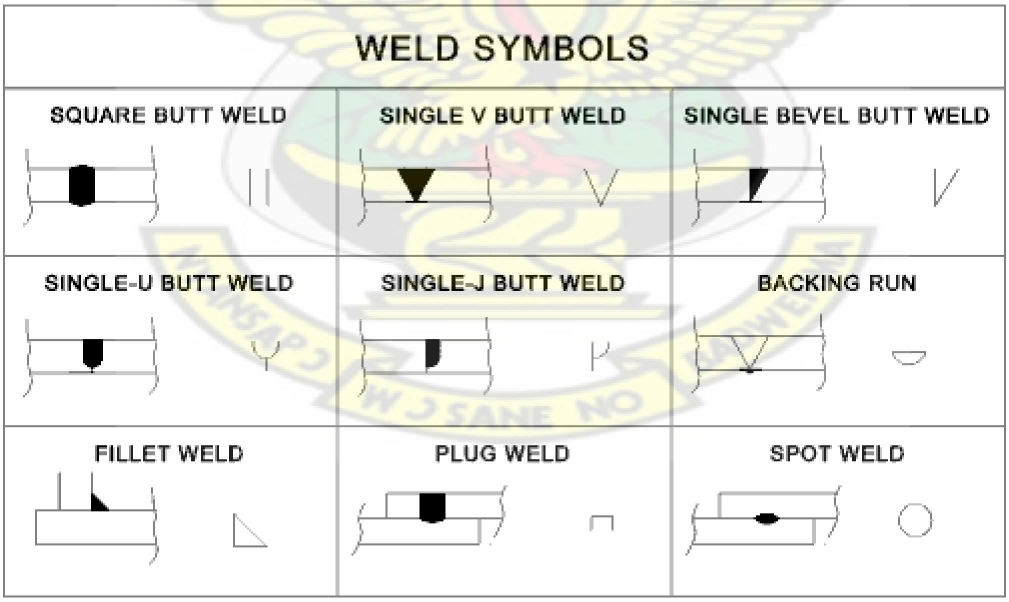


Information above reference line identifies weld on same side as symbolic representation
Information below reference line identifies weld on opposite side to symbolic representation.

1) Dimension referring to cross section of weld
2) Weld Symbol
3) Supplementary symbol
4) Number of weld elements x length of weld element
5) Symbol for staggered intermittent weld
6) Distance between weld elements
7) Welding process reference
8) Welding class

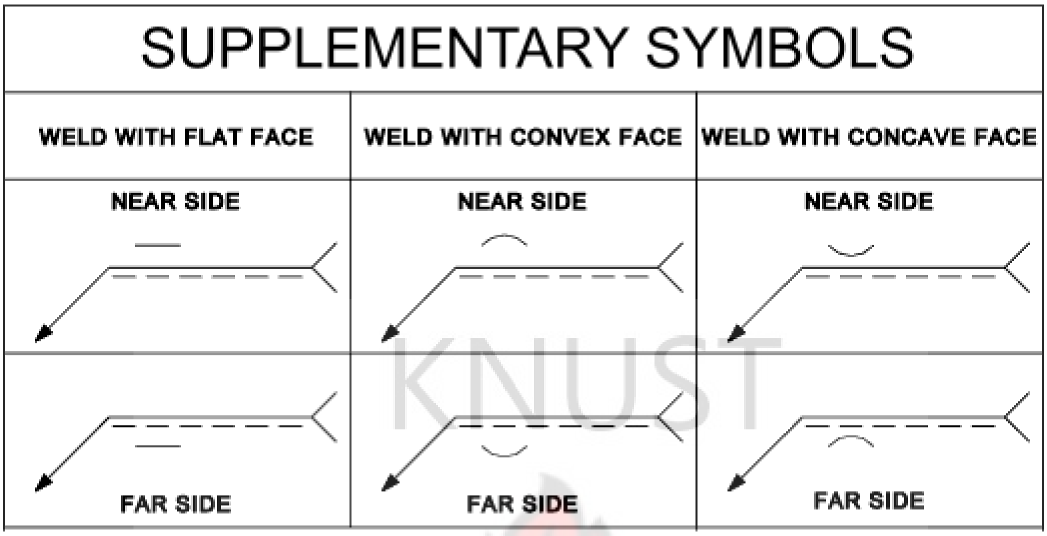
Figure A-2 Detailed Symbolic Representation of Weld

Table A-1 Table of Weld Symbols

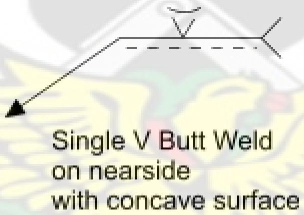


Supplementary Symbols

The weld symbols below are used in addition to the primary weld symbols as shown above. They are not used on their own.



Below is an example of the application of this symbol.



Complementary Indication

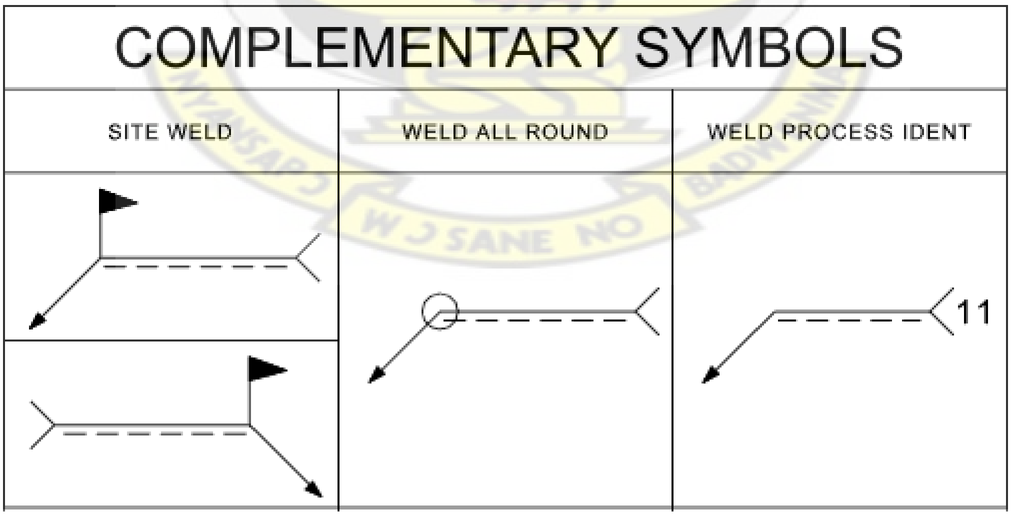


Figure A-3 Supplementary and Complementary Weld Symbols

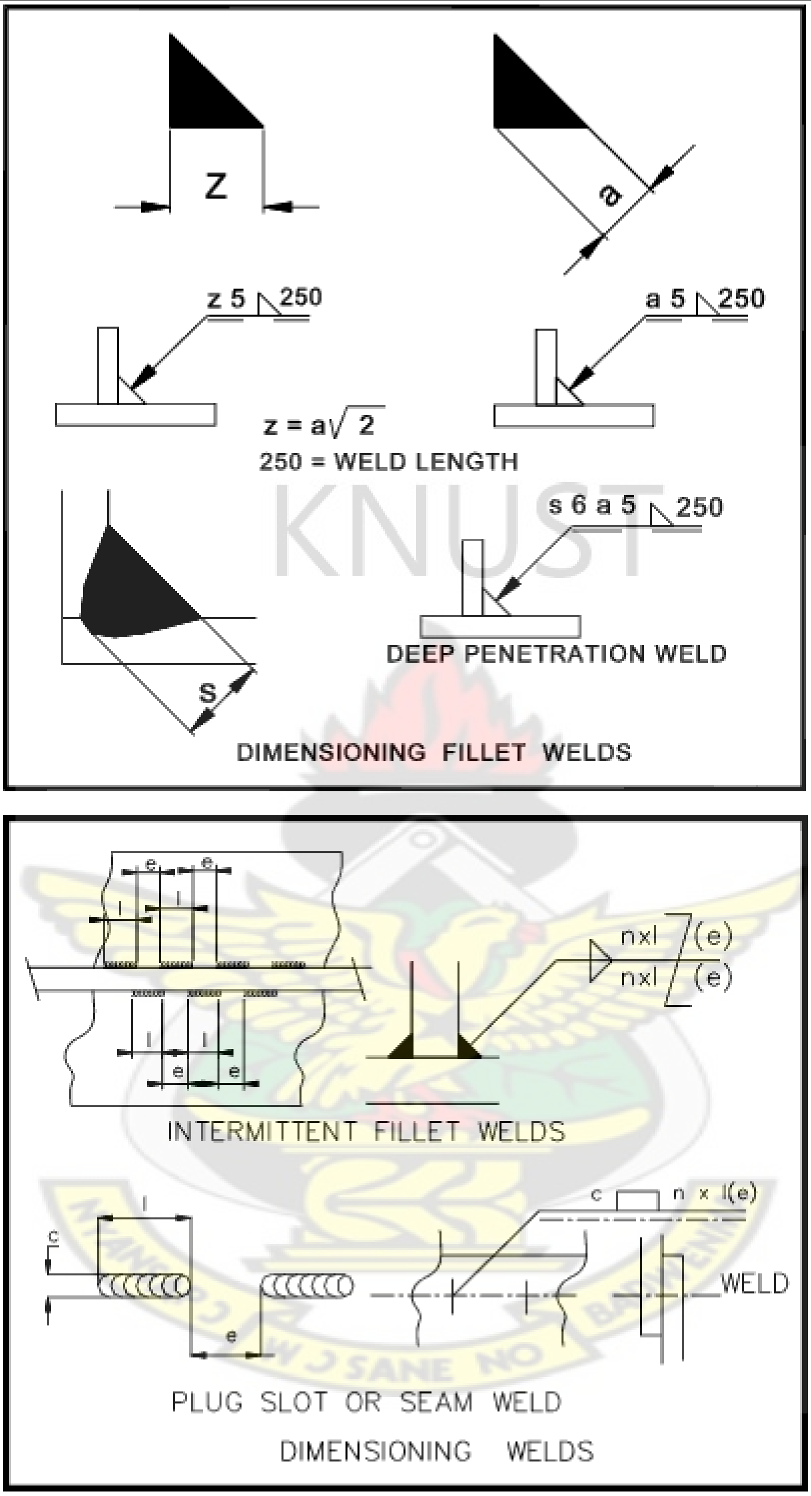


Figure A-4 Dimensioning Welds

APPENDIX B

QUESTIONNAIRE

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF MECHANICAL ENGINEERING

TOPIC: RESEARCH SURVEY OF CURRENT WELDING PRACTICES IN SELECTED METAL WELDING INDUSTRIES/ENGINEERING FIRMS IN GHANA

Dear respondent,

I am a postgraduate student of the Department of Mechanical Engineering, Kwame Nkrumah University of Science and Technology, Kumasi. This questionnaire is to obtain information about the welding practices, needs, challenges and safety practices of some Ghanaian industries in the metal welding fabrications sector. The information supplied will be the basis for coming out with a statistical data that can be used as a guide for improving the welding practices and to determine the short and long term needs of the welding industry and how various support groups such as educational providers, economic policy developers and others could work in better collaboration with the industries. Kindly supply honest information.

Please provide answers or tick (√) as appropriate

A. PERSONAL INFORMATION

1. Gender: (a) Male ( ) (b) Female ( )
2. Age
   (a) Less than 18 ( )
   (b) 18-30 ( )
   (c) 31-49 ( )
   (d) 50-70 ( )
   (e) above 70 ( )
3. Educational level
   (a) Primary completed ( )
   (b) Secondary completed ( )
   (c) Tertiary completed ( )
   (d) Vocational/Technical ( )
   (e) No formal education ( )

4. How did you receive your welding training?
   (a) Through apprenticeship to a master ( )
   (b) Welding craft practice from a technical institute such as KTI, Tamale Technical Institute, etc. ( )
   (c) Others, specify……………………………………………………………………
   ……………………………………………………………………………………
5. Did you obtain any certificate after training?
   (a) Yes ( )
   (b) No ( )
6. If yes, what type of certificate?
   (a) Intermediate certificate in welding ( )
   (b) Advanced certificate in welding ( )
   (c) Others, specify…………………………………………………………………...
   ………………………………………………………………………………………
7. For how many years have you been welding after qualification?
   (a) Less than 1 year ( )
   (b) 1-5 years ( )
   (c) 6-10 years ( )
   (d) 11-15 years ( )
   (e) 16-20 years ( )
   (f) 21-25 years ( )
   (g) 26-30 years ( )
   (h) Above 30 years ( )

B. WORK BACKGROUND

8. Name of industry/shop…………………………………………………………………
9. Location of industry / shop…………………………………………………………..
10. Do you work
    (a) In an industry/Formal ( )
    (b) As private/Informal ( )
11. Are you
    (a) A master ( )
    (b) A worker or an employee in an industry/institution ( )
12. If working or employed by an industry/institution, what is your rank?
    (a) Welding technician Grade I ( )
    (b) Welding technician Grade II ( )
    (c) Others, specify……………………………………………………………………
13. How many years has the industry / shop been practicing welding?
    (a) 1-10 yrs ( )
    (b) 11-20 yrs ( )
    (c) 21-30 yrs ( )
    (d) 31-40 yrs ( )

(e) 41-50 yrs ( )
(f) Above 50 yrs ( )

14. What category of welding do your industry / shop do?
    (a) Repairs and maintenance ( )
    (b) Construction ( )
    (c) Manufacturing ( )
    (d) Others specify…………………………………………………………………….

C. PRODUCTION ISSUES

15. What type of welding technique/procedure do you practice?
    (a) Manual welding ( )
    (b) Machine welding ( )
    (c) Automatic welding ( )
    (d) Robotic welding ( )
16. What type of welding process is used?
    (a) Arc welding ( )
    (b) Gas welding ( )
    (c) Resistance welding ( )
    (d) Others specify…………………………………………………………………….
17. If arc welding, which of this/these arc welding processes do you use?
    (a) Shielded metal arc welding (SMAW) ( )
    (b) Gas metal arc welding(GMAW) ( )
    (c) Gas tungsten arc welding (GTAW) ( )
    (d) Submerged arc welding (SAW) ( )
    (e) Others, specify……………………………………………………
18. If gas welding, which of this/these gas welding processes do you use?
    (a) Oxyacetylene welding (OAW) ( )
    (b) Oxyhydrogen welding (OHW) ( )
    (c) Pressure gas welding (PGW) ( )
    (d) Others specify……………………………………………
19. If resistance welding, which of this/these resistance welding processes do you use?
    (a) Resistance Spot Welding (RSW) ( )
    (b) Resistance Seam Welding (RSEW) ( )
    (c) Resistance Projection Welding (RPW) ( )
    (d) Others specify…………………………………………………………………….
20. What is the main factor why you select to use gas/arc/resistance welding?
    (a) Low cost of equipment ( )
    (b) Ease in using technology ( )
    (c) Potentially safe to use ( )
    (d) Type / design of work ( )
    (e) Others specify…………………………………………………………………

21. What are the products you manufacture / construct?

………………………………………………………………………………………

………………………………………………………………………………………

22. If your industry / shop do repair and maintenance what items are welded?

(a) Large diameter pipes ( )

(b) Structural steel for bridges and buildings ( )

(c) Construction of flat trailers ( )

(d) Car seats ( )

(e) Mining machinery ( )

(f) Agricultural machinery ( )

(g) Others specify

………………………………………………………………………………………

………………………………………………………………………………………

23. What welding accessories or equipment are available?

(a) Power source available

(i)Electricity ( ) (ii) Gas cylinder ( )

(b) (i) Chipping hammer and brushes ( )

(ii) Welding fixtures and positioners ( )

(iii) Welding carts ( )

(iv) Welding table ( )

(v) Welding transformer machine ( )

(vi) Plasma cutting machine ( )

(vii) Others, specify……………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

24. What mechanism is applied in cooling weld?

(a) Water ( )

(b) Oil ( )

(c) Air ( )

(d) Furnace ( )

(e) Soil ( )

(f) Others specify…………………………………………………………………

25. Do you have any quality control mechanisms you use to ascertain the quality of your welded joints?

(a) Yes ( )

(b) No ( )

26. If yes, what do you do?

………………………………………………………………………………………

………………………………………………………………………………………

27. What tests or inspections are employed after welding?

(a) Visual inspection ( )

(b) Destructive testing ( )

(c) Non destructive testing ( )

(d) No testing ( )

28. What are some of the common welding problems/defects you encounter with your welded joints?
   (a) Porosity ( )
   (b) Weld cracks ( )
   (c) Poor penetration ( )
   (d) Undercutting ( )
   (e) Slag inclusions ( )
   (f) Rough appearances ( )
   (g) Others, specify…………………………………………………………………..
29. Have you ever experienced failure in your welded joint immediately after being welded or in service?
   (a) Yes ( )
   (b) No ( )
30. If yes, what do you think were the cause(s)?
   (a) Fault of the welder ( )
   (b) A problem of welding technique ( )
   (c) Others, specify
   ………………………………………………………………………………………
   ………………………………………………………………………………………
31. Which of this/these do you think can cause weld failure?
   (a) Incorrect electrode/filler rod chosen by the welder ( )
   (b) High restraint of joint or highly stressed joint by the welder ( )
   (c) Rapid cooling of weld such as water quenching of cast iron weld ( )
   (d) Improper joint preparation by the welder before welding ( )
   (e) Welds too small for size of parts joined ( )
   (f) Welding over foreign material on surface such as rust, oil, moisture, paint, etc. ( )
   (g) Unsteady current/voltage or inappropriate gas mixtures ( )
   (h) Welding speed too fast ( )
   (i) Welding speed too slow ( )
   (j) Not aware ( )
   (k) Others, specify…………………………………………………………………………
   ………………………………………………………………………………………

D. DESIGN AND PLANNING FOR WELDING

32. How many of the following types of joint(s) are you aware of?
   (a) Butt ( )
   (b) Corner ( )
   (c) Lap ( )
   (d) Tee ( )
   (e) Edge ( )

33. Which of this/these types of joint(s) do you mainly use?
   (a) Butt ( )
   (b) Corner ( )
   (c) Lap ( )
   (d) Tee ( )
   (e) Edge ( )
34. How many of the following types of weld(s) are you aware of?
   (a) fillet welds ( )
   (b) groove welds ( )
   (c) flange welds ( )
   (d) plug welds or slot welds ( )
   (e) seam welds ( )
   (f) spot or projection welds ( )
35. Which of this/these types of weld(s) do you mainly use?
   (a) fillet welds ( )
   (b) groove welds ( )
   (c) flange welds ( )
   (d) plug welds or slot welds ( )
   (e) seam welds ( )
   (f) spot or projection welds ( )
36. Which metal(s) do you mostly weld?
   (a) Alloy steel ( )
   (b) Aluminum alloys ( )
   (c) Cast iron ( )
   (d) Mild steel ( )
   (e) Nickel ( )
   (f) Others specify…………………………………………………………………………
37. Which common electrodes are you aware are on the market?
   (a) Nickel base electrode ( )
   (b) Nickel alloy electrode ( )
   (c) Stainless steel electrode ( )
   (d) Low carbon steel electrode ( )
   (e) Cast iron electrodes ( )
   (f) Others, specify…………………………………………………………………………
   ………………………………………………………………………………………
38. Which electrodes do you often use?
   (a) Nickel base electrode ( )
   (b) Nickel alloy electrode ( )
   (c) Stainless steel electrode ( )
   (d) Low carbon steel electrode ( )
   (e) Cast iron electrodes ( )
   (f) Others, specify…………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………

39. What factors do you consider before planning to weld?
(a) Joint preparation ( )
(b) The thickness of the metal ( )
(c) The type of joint ( )
(d) The welding position ( )
(e) The speed of welding ( )
(f) The type of electrode/filler rod ( )
(g) Electrode/Filler wire size ( )
(h) The thermal conductivity of the metals to be welded ( )
(i) The type of metal
(g) None ( )
(j) Others, specify…………………………………………………………………………
…………………………………………………………………………………………….

E. SAFETY ISSUES

40. What do you think the lack of safety measures in the welding shop could cause?
(a) Burns ( )
(b) Electric shock ( )
(c) Eye damage/problems ( )
(d) Explosion of cylinders/Flashback ( )
(e) Inhalation of welding fumes leading to respiratory diseases or headache ( )
(f) Skin diseases from ultraviolet light/infra-red when welding ( )
(g) Fire outbreak ( )
(h) Others, specify…………………………………………………………………………
…………………………………………………………………………………………

41. What are some of the accidents/hazards you often encounter in the welding shop?
(a) Burns ( ) Degree: Severe ( ) Less severe ( )
(b) Electric shock ( ) Degree: Severe ( ) Less severe ( )
(c) Eye damage/problems ( ) Degree: Severe ( ) Less severe ( )
(d) Explosion of cylinders/Flashback ( ) Degree: Severe ( ) Less severe ( )
(e) Inhalation of welding fumes leading to respiratory diseases or headache ( )
Degree: Severe ( ) Less severe ( )
(f) Skin diseases from ultraviolet light/infra-red when welding ( )
Degree: Severe ( ) Less severe ( )
(g) Fire outbreak ( ) Degree: Severe ( ) Less severe ( )
(h) Others, specify…………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………….

42. What safety design mechanisms do you have in the welding shop?
   (i) Fire extinguishers ( )
   (j) First aid box ( )
   (k) Respirators ( )
   (l) Welding goggles ( )
   (m) Welding gloves ( )
   (n) Welding screens/shield ( )
   (o) Welding aprons and welding jackets ( )
   (p) Safety boots ( )
   (q) Others, specify…………………………………………………………………
43. How long are you exposed to arc/flame daily?
   (a) Less than an hour ( )
   (b) Between an hour and two hours ( )
   (c) Above two hours ( )
44. Is your life insured in case of accidents?
   (a) Yes ( )
   (b) No ( )
45. What are some of the challenges you go through as a welder?
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………