UNIVERSITY OF EDUCATION, WINNEBA

COLLEGE OF TECNOLOGY EDUCATION - KUMASI

COMPARATIVE STUDY OF PHYSICAL AND MECHANICAL PROPERTIES OF A36 MILD STEEL WELDED JOINTS USING OXYACETYLENE AND SHIELDED METAL ARC WELDING PROCESSES

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FRANK ABOAGYE KESSE

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A Thesis Submitted To The Department Of MECHANICAL AND AUTOMOTIVE TECHNOLOGY EDUCATION, Faculty Of Technical Education Of The School Of Graduate Studies, University Of Education, Winneba, in partial fulfillment Of the requirements for the award of Master Of Philosophy (Mechanical Engineering Technology) degree

BY

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AUGUST, 2021

STUDENT'S DECLARATION

I, Aboagye Frank Kesse, declare that this dissertation is my own work towards the MPhil Mechanical Engineering Technology and that to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the university. All texts and quotations from books. articles, and journals have been duly acknowledged.

Aboagye Frank Kesse ……………………….. ………………………….

(Candidate) Signature Date

Certified by: ………………………….. ………………………….

Ing. Enock Duodu (PhD) Signature Date

(Supervisor)

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This thesis allowed me to better understand the scientific efforts done by people who worked very hard for many years to accomplish the foundation of knowledge demonstrated here. To them I am extremely grateful, but also there are several people who helped me in diverse ways and to whom I demonstrate my entire appreciation.

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DEDICATION

I dedicate this dissertation to my noble and selfless hardworking Supervisor, Ing. Dr. Enock A. Duodu, my darling wife Linda Owireduwaa Boateng, my cherished kids; Kwasi Opoku Kesse, Ofosu Agyei Kesse, Owusuwaa Afriyie Kesse, Kwasi Boadu Kesse and Serwaa Nyarkowaa Kesse.

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ABSTRACT

One of the crucial industrial methods for joining metals has been welding, hence many techniques have been developed to get an efficient and cost-effective process for different kinds of materials. In this study, an attempt was made to investigate the tensile and bending strength of A36 2.5 mm thick mild steel plate welded by the processes of oxyacetylene and shielded metal arc welding (SMAW). The specimen, having been carefully welded to form butt and lap joints were subjected to tensile and bending tests using universal testing machine WAW-1000H. Four test runs were performed for each welded joint. Based on the results obtained from the tensile and bending tests conducted, it was observed that oxyacetylene welded joint produced a stronger joint that could withstand much higher force compared with shielded metal arc welded joint when lap and butt joints were considered. Where in oxyacetylene lap welded joint, an average maximum ultimate tensile strength of 332.75 N/mm^2 under an average force of 83.188 KN was obtained for four sample specimen, shielded metal arc lap welded joint, recorded an average maximum ultimate tensile strength of 288.5 N/mm^2 under an average force of 72.125 KN. For butt joint, oxyacetylene recorded an average tensile strength of 288.75 N/mm^2 under an average load of 72.125 KN as against 256.75 N/mm^2 under an average load of 64.163 KN for shielded metal arc welded joint. However, in considering bending strength of oxyacetylene butt and lap welded joints and shielded metal arc butt and lap welded joints where the joined workpiece might be subjected to bending working conditions, shielded metal arc butt and lap joints recorded bending strength of 6.0 N/mm^2 under an average force of 0.6 KN and 6.50 N/mm^2 under an average force of 0.65 KN for butt and lap joints respectively as against 5.88 N/mm^2 under an average load of 0.59 KN and 6.38 N/mm^2 under an average load of 0.64 KN for oxyacetylene welded butt and lap joints respectively. It is therefore recommended to welding practitioners, engineers and fabricators that, for tensile strength, using 2.5 mm thick mild steel plate, oxyacetylene butt and lap welded joints should be used compared to shielded metal arc butt and lap welded joints as the former could withstand much higher tensile strength than than the later. However, for bending strength, shielded metal arc butt and lap welded joints appears slightly beneficial than the other.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

One of the crucial industrial methods for joining metals has been welding, hence many techniques have been developed to get an efficient and cost-effective process for different kinds of materials, requiring trained and specialized labor (American Welding Society, 2018). In the United States, an employment survey indicated that about 382,730 people were employed as welders, solderers, and brazers in 2016 (United States Department Labor, 2017). Many of the problems that are inherent to welding can be avoided by proper consideration of the particular characteristics and requirements of the process. Proper design of the joint is critical. Selection of the specific process requires an understanding of the large number of available options, the variety of possible joint configurations, and the numerous variables that must be specified for each operation. If the potential benefits of welding are to be obtained and harmful side effects are to be avoided, proper consideration should be given to the selection of the process and the design of the joint. Generally, the quality of a weld joint is strongly influenced by process parameters during the welding process. In order to achieve high quality welds a good selection of the process variables should be utilized, which in turn results in optimizing the bead geometry.

Welding as a process of joining materials, in general, and metals and alloys in particular is a double-edged sword. On one hand, welding offers one of the best joining methods for obtaining joints with such a strength comparable to (or even superior to) the physical element being joined, with lesser weight than mechanical fastening (e.g. bolting and riveting) and a greater environmental durability than adhesive bonding (whether using organic adhesives such as epoxies, or inorganic adhesives such as cement). It offers one of the assured ways of achieving leak tightness against fluids (i.e. gases and liquids), and can be performed indoors or outdoors, manually or automatically (using mechanization or robots) employing a wide variety of process embodiments, and, for better or worse, produces joints that are permanent. On the other hand, the use of welding demands thoughtful structures and joints designs, proper equipment and consumables (e.g. shielded gases or fluxes and fillers), skilled operators, appropriate quality assurance for joint performance demands, and more importantly, an understanding of what it takes to produce a sound weld (Messler, 2019).

Many scholars and dictionaries tend to define welding in a utilitarian sense, appropriately intended for the general public, rather than for engineers, in general, and materials and welding engineers in particular. The Merriam-Webster Dictionary New Edition, (2016) defines welding as "1. To unite (metallic parts) by heating and allowing the metals to flow together or by hammering or compressing with or without previous heat. 2. To unite (plastics) in a similar manner by heating".

According to Messler (2019), in a most general and unambiguous sense, "welding is defined as a process by which materials of the same fundamental class or type are brought together and caused to coalesce through the formation of primary (and occasionally, secondary) chemical bonds under combined action of heat and pressure, with or without any filler". In all situations, welding is a joining process meant to unite parts in order to create a permanent assembly.

A convincing argument can be made that joining by mechanical fastening or design feature interlocking, adhesive bonding, or welding, including brazing and soldering, is the most important process in manufacturing and most construction because it usually occurs after a considerable value has already been added to produce the near-net-shaped detail parts for assembly. As welding is typically the most technically elaborate, requiring the most skilled practitioners, and accounts for about half of all joining, it almost certainly accounts for much more than half of all joining by value. Hence, any problem associated with welding that cannot be avoided or resolved is serious.

Major industrial sectors dependent on welding worldwide, as of 2017, included the following: energy (23%), construction (20.5%), transportation (19.5%), process and others (15%), heavy machinery (11%), ship building (8%), and aerospace and defense (3%) (Ashby, 2018). Major applications include: agricultural equipment, aircraft, airport support equipment, automobiles, bridges, buildings, chemical-processing equipment, earthmoving equipment, food and beverage-processing equipment, gas, oil, and water pipelines, heavy machines, locomotives and railcars, marine power plants, mining equipment, oil and gas drilling and recovery equipment, petroleum-processing equipment, pharmaceutical-processing equipment, power generation equipment, railroad cars and track equipment, ships, trucks, and buses. Although digital electronics has transformed how we live, welding has enabled us to live in our modern world.

The total global market for welding consumables alone (e.g. stick electrodes and solid and flux-cored wires) exceeded $15 billion in 2017 and has been forecast to grow by 1.7 times over the next decade (Ashby, 2018). As the cost of labor far exceeds the cost of consumables in welding, with consumables typically accounting for only around 5% of the total cost, the total annual value of welding is staggering (Messler, 2011).

1.2 Statement of the problem

The use of mild steel is prominent in design and manufacturing of many engineering products. Many of the problems that are inherent in welding can be avoided by proper consideration of the particular characteristics and requirements of the process. Understanding how welding works in terms of various processes and the metallurgy involved is crucial in the bid to obtaining good quality welds. In order to achieve high quality welds a good selection of the right welding process should be utilized. Chen et al. (2017) presented an experimental study of welding effects on tensile characteristics of the T-welds of the high-strength low-alloyed steel. Zhang et al. (2016) conducted experimental investigation of the welding influence on strength of the high performance steels and concluded that welding significantly softened the heat affected zone in the HSLA steel with insignificant effect on the normal strength. Durmusogly, Turker, and Tosun (2015) made an investigative research on gas metal welding (GMA) of the HY-80 steels with application of different welding parameters. They subjected different samples, obtained from the welded joints, to tensile, hardness, and impact toughness tests. Hosseinioun et al. (2017) did a study on the multi-run welding of the HSLA steel plates executed by the MMA procedure. Dundjer et al. (2018) performed a research on the influence of the welding parameters on the HSLA steel and on hardness and impact energy of samples welded at related different welding parameters. Saxena et al. (2018) presented a comparative study of the tensile and impact properties of the multi-pass SMAW Armox 500T steel joints, executed with the two different consumables: austenitic stainless steel and low hydrogen ferritic steel.

Alipooramirabad et al. (2017) opined that one of the important steps in design and fabrication of welded structures is selection of the welding process and the filler consumables. Despite the usual assumption that the welded joints of steels possess long-term reliability, there can be causes of fracture and even crashes of plants due to defective work of bad quality of joints' execution (Otakar et al. 2013). Nový et al. (2019) presented selected experimental results of investigation of the structural steels fatigue resistance.

With all these research works done by renowned researchers to offer an insight into when the use of a particular material with a particular joining process proves to be scientifically resilient for engineering applications, there appears to be a gap in establishing the relationship between when the use of oxyacetylene and shielded metal arc welded joints prove to be mechanically beneficial. In an attempt to address this, the study seeks to make a comparative analysis of mechanical properties of A36 mild steel plate welded joint using oxyacetylene and shielded metal arc welding processes.

1.3 Purpose of the Study

There are many types of welding processes. Some of them are highly specialized and are used only in certain situations and with specific metals. The two most known methods of welding are arc welding and gas welding. Gaining the knowledge and understanding of the underlying issues in welding will make the decision of selecting the appropriate method of welding easier.

The main aim of the study was to conduct an experimental research which seeks to develop and establish the relationship between Oxyacetylene and Shielded Metal Arc welding processes using 2.5 mm thick mild steel plate used to form butt and lap joints. The following are the specific objectives formulated to guide the study;

1. to evaluate the tensile strength of A36 mild steel plate of 2.5mm thick butt and lap joints formed using oxyacetylene and shielded metal arc welding processes.
2. to establish the modulus of elasticity relationship between oxyacetylene and shielded metal arc welded butt and lap joints.
3. to determine the bending strength of A36 mild steel plate of 2.5mm thick butt and lap joints formed using oxyacetylene and shielded metal arc welding processes.

4. to analyze the density of oxyacetylene and shielded metal arc welded butt and lap joints.

1.4 Significance of the Study

The significance of the study include the following;

1. The study seeks to provide the needed guideline information on the type of welding processes which are more appropriate under any circumstance of industrial practices.

2. The results of the study will serve as a reference point for other researchers working on a similar work of this kind.

3. The study will aid prospective fabricators, welding practitioners and engineers in the safe design of light engineering projects where the use of a mild steel plate of 2.5mm thick is crucial.

4. The research findings will add to scholarly knowledge and literature in the academic world to support engineers, researchers and students studying welding and fabrication.

1.5 Organization of the Thesis

This thesis has been organized into five chapters. The First Chapter presents the introduction which comprises the background, the key research problem under investigation, the purpose of the study, the statement of the problem and the significance of the study.

Chapter Two deals with a variety of issues in literature and previous research works which are related to the study. This chapter reviews theoretical and practical information relevant to the study.

Chapter Three describes the materials and methods employed for the experimental research work. This chapter gives the direction as to how the study was conducted. It includes the experimental setup, the type of specimens and how the specimens were prepared for the experiment. It gives a detailed account of how the specimens were joined by means of two welding processes and the standard used. Detailed experimental procedures were explained and ways of getting data were shown.

Chapter Four presents the results and the detailed discussion of the experimental reseach conducted. Chapter Five provides the key summary of findings of the study, conclusion, recommendations and limitations to the study. It gives the outcome of the research findings and identify the areas for further research work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The content of this chapter is an overview of available theoretical literature and practical information needed for the study on the comparative analysis of the mechanical properties of Oxyacetylene and Shielded Metal Arc Welded joints that will ultimately be used as a foundation to build the methodology of the study. It reviews related literature from published books, journals, articles, websites and other relevant information in relation to the topic under study.

2.2 Literature Survey and Fundamental Theories

2.2.1 Literature survey

Welding is one of the most important and versatile means of fabrication employed by many industries. In view if this, a lot of research works are being conducted in this regard.

Chen et al. (2017) presented an experimental study of welding effects on tensile characteristics of the T-welds of the high-strength low-alloyed steel. Zhang et al. (2016) conducted experimental investigation into the welding influence on strength of the high performance steels and concluded that welding significantly softened the heat affected zone in the HSLA steel with insignificant effect on the normal strength. Durmusogly, Turker, and Tosun (2015) made an investigative research on gas metal welding (GMA) of HY-80 steels with application of different welding parameters. They subjected different samples, obtained from the welded joints, to tensile, hardness, and impact toughness tests. Hosseinioun et al (2017) did a study on the multi-run welding of the HSLA steel plates executed by the MMA procedure. Dundjer etal.(2018) performed a research on the influence of the welding parameters on the HSLA steel and on hardness and impact energy of samples welded at related different welding parameters. Saxena et al.(2018) presented a comparative study of the tensile and impact properties of the multi-pass SMAW Armox 500T steel joints, executed with the two different consumables: austenitic stainless steel and low hydrogen ferritic steel.

Alipooramirabad et al. (2017) opined that one of the important steps in design and fabrication of welded structures is selection of the welding process and the filler consumables. Influence of the welded joints' quality on safety and reliability in operation has been studied. Despite the usual assumption that the welded joints of steels possess long-term reliability, they can be causes of fracture and even crashes of plants due to defective work of bad quality of joints' execution (Otakar et al. 2013). Nový et al. (2019) presented selected experimental results of investigation of the structural steels fatigue resistance. The research further establishes the basic qualitative relations between the pre-existing microstructure, relevant micro hardness values, and measured values of the impact toughness. Derived conclusions can be used for both the relevant technology and welding.

2.2.2 Fundamental Theories

Metal transfer plays an important role in ensuring the quality of weld produced. As a result, techniques are continually developed in this regard. The experimental techniques which have been widely used in previous studies of the metal transfer process, include optical methods, sensor measurements, and acoustic detections (Lin, Li and Simpson 2001). In the early 1980's, an optical technique (100-1000 frames per second) was developed at the M.I.T. welding laboratory for viewing metal transfer process with a relatively small aggregate of optical equipment.

As an extension of the static force balance model, Choi et al. (2001) proposed a dynamic force balance model (DFBM) for metal transfer analysis. The dynamic force balance model predicts metal transfer in arc welding by introducing the inertial force in addition to the conventional forces used in the SFBT. The dynamics of a pendent drop are modelled as a second-order mass, spring, and damper system. Although the DFBM shows better agreement with the measured drop size than the SFBT, both models are unable to accurately predict the detached drop size in the high current range.

In 2001, Wang and his associates successfully conducted numerical analysis for the droplet impingement on the weld pool surface and the fluid flow, heat, mass transfer in the weld pool for GMAW. The RIPPLE computer program, which models transient, two-dimensional, incompressible fluid flows with free surfaces by using advanced CFD techniques, was introduced into the study of GMAW. While their study focused on the interaction between the droplet and the weld pool, the droplet growth and detachment process was not included in their paper Previous models for the metal transfer process have been unable to make accurate predictions of the transition between the globular and spray transfer modes.

In the present study, a new transient two-dimensional model is developed on the base of RIPPLE to simulate the droplet formation, detachment and transport in gas metal arc welding (Wang, Huang and. Zhang 2003). The transient shape of the droplet is calculated using the fractional volume of fluid (VOF) method, which is shown to be more flexible and efficient than other methods for treating complicated free-boundary configurations. Gravitational force, surface tension force, and electromagnetic force play fundamental roles in the process of droplet growth and detachment.

The weld bead also plays a crucial role in determining the quality of the weld. Therefore, it is very important to set the proper welding process parameters to get the best bead geometry and Heat Affected Zone (HAZ) width (Montgomery C. et al., 2011). In SAW the weld quality is mainly influenced by independent variables like wire feed rate (Wf), electrode stick out (So) and traverse speed (Ts), and these are also paramount with respect to the strength of weldment (Kiran, et al., 2012). Controlling these input parameters is crucial in order to obtain quality welds. Yang et al (2019) used a regression model to control the process parameters of SAW. Raveendra and Parmaris (2000) applied regression analysis to predict the welding geometry. Sen et al (2014) developed a mathematical model by using a multiple linear regression analysis in MINITAB 13.1 to predict the weld bead geometry for double pulse gas metal arc welding process. Groover, M. P. (2002) developed a mathematical model based on multiple regression analysis (MRA) to correlate the welding process parameters and weld bead geometry and prediction of bead geometry in pulsed GMA welding. But most of the industrial processes are non-linear, complex, and the linear mathematical models are not giving a closer approach to describe the behaviour of the processes. Recently, for observing and controlling the welding processes parameters, many artificial intelligence (AI) methods or technique such as fuzzy logic (FL), artificial neural networks (ANN) Modenesi et al, (2000), artificial neural fuzzy interface system (ANFIS) (Akkas et al, 2013) and expert system have been deployed as key techniques. Ghosh et al (2007), advocating the advantages of the above-mentioned models consideration of simplicity, applicability, powerful tools are reviewed. Nagesh and Datta (2002) reported that artificial networks are powerful tools for analysis and modeling. An ANN model has been developed to establish the relationship between the welding process parameters and the weld bead geometry in laser welding (Sathiya, Panneerselvam and Jaleel, 2012). To predict and optimize the depth of penetration in hybrid CO2 laser–MIG welding, an artificial neural network was used for 5005 AI–Mg alloy (Ghosal and Chaki, 2010). Dhas and Kumanan (2010) present the development of Neuro hybrid model (NHM) to predict weld bead width in SAW.

A comparison of multiple regression analysis (MRA) with artificial neuron network (ANN) was used as methods of predicting the bead geometry and mechanical properties (Acherjee et al. 2011). Xiong et al. (2014) reported that the neural network model has a better performance than regression model for predicting the bead geometry in GMAW process. Kim et al. (2003) studied the back propagation neural network (BPNN) considerably more accurate than multiple regressions (MRA) in modeling bead height in metal arc welding. Moreover, the prediction with ANN is more accurate than that with a regression equation.

2.3 The Fundamentals of the Weld Joint Design

The performance of weld joints is determined not only by the load resisting cross sectional area of joint but also properties of region close to the weld metal i.e. heat affected zone (HAZ). The design engineer must note that heat affected zone (HAZ) can be significantly wider or stronger than weld and so accordingly various parameters of weld joint design should be established.

Weld joints may be subjected to a variety of load conditions ranging from a simple tensile load to the complex combination of torsion, bending and shearing loads depending upon the service conditions. The ability of weld joints to contain a given load emanates from metallic continuity across the members being joined. Mechanical properties of the weld metal and load resisting cross section area of the weld (besides heat affected zone characteristics) are two most essential parameters which need to be established for designing a weld joint.

2.4 Modes of Failure of Weld Joint

A poorly designed weld joint can lead to the failure of an engineering component. These are seen in three ways namely a) elastic deformation (like bending or torsion of shaft and other sophisticated engineering systems like precision measuring instruments and machine tools) of weld joint beyond acceptable limits, b) plastic deformation (change in dimensions beyond acceptable limits as-decided by application) of engineering component across the weld joint and c) fracture of weld joint into two or more pieces under external tensile, shear, compression, impact creep and fatigue loads.

Failure of weld joints, depending upon the application may occur in different ways and therefore different methods are required for designing the weld joints as per application and service requirements.

2.5 Design of Weld Joint and Mechanical Properties

Stiffness and rigidity are essential elements for designing weld joints especially where elastic deformation is to be controlled. In such conditions, weld metal of high modulus of elasticity (E) and rigidity (G) is deposited for producing weld joints besides selecting suitable load resisting cross sectional area. When the failure criterion for a weld joint is the plastic deformation, then weld joints are designed on the basis of yield strength of the weld metal. When the failure criterion for weld joint is to avoid fracture under static loading, then ultimate strength of the weld metal is used as a basis for design. Under simplified conditions, design for fatigue loads is based on endurance limit. Weld joints invariably possess different types of weld discontinuities of varying sizes which can be very crucial in case of critical applications e.g. weld joints used in nuclear reactors, aerospace and space craft components. For instance, weld joints for critical applications are designed using fracture mechanics approach which takes into account the size of discontinuity (in form of crack, porosity or inclusions), applied stresses and weld material properties (yield strength and fracture toughness) in design of weld joints.

2.6 Factors Affecting the Performance of Weld Joint

It is worth noting, that, the mechanical performance of the weld joints is governed by not only mechanical properties of the weld metal and its load resisting cross sectional area (as stated above) but also on the welding procedure used for developing a weld joint which includes the edge preparation, weld joint design, and type of weld, number of passes, preheat and post weld heat treatment, if any, welding process and welding parameters (welding current, arc length, welding speed) and method used for protecting the weld contamination from atmospheric gases. As most of the above mentioned steps of welding procedure influence metallurgical properties and residual stresses in weld joint which invariably affect the mechanical (tensile and fatigue) performance of the weld joint.

2.7 Design of Weld Joints and Loading Conditions

Design of weld joints for static and dynamic loads needs different approaches. This is crucial because for static loads, the direction and magnitude become either constant or changes very slowly while in case of dynamic loads such as impact and fatigue conditions, the rate of loading is usually high. In case of fatigue loading both magnitude and direction of load may fluctuate. Under the static load condition, low rate of loading increases the time available for localized yielding to occur in area of high stress concentration which in turn causes stress relaxation by redistribution of stresses through-out the cross section while under dynamic loading conditions, due to lack of availability of time, yielding across the section of weld doesn't take place and only localized excessive deformation occurs near the site of a high concentration stress which eventually provide an easy site for nucleation and growth of cracks as in case of fatigue loading.

2.8 Principles of Fusion Welding

Full fusion welding, as the name implies, is a thermal joining process in which the edges of the parent metal to be joined are melted and caused to fuse together with or without the use of a filler material. The basic principle of fusion welding is shown in Figure 2.1, which outlines two typical joint configurations: one using a separate filler rod and the other self-supplying and not needing a filler rod. The filler rod is a thin steel rod or wire of similar composition to the parent metals being joined. Filler rods are usually copper plated so that they do not rust. The two basic welding processes as shown in Figure 2.2 and Figure 2.6 are commonly referred to as:

i. Gas-welding (oxy-acetylene welding).

ii. Metal-arc welding (electric), also commonly known as 'stick' welding.

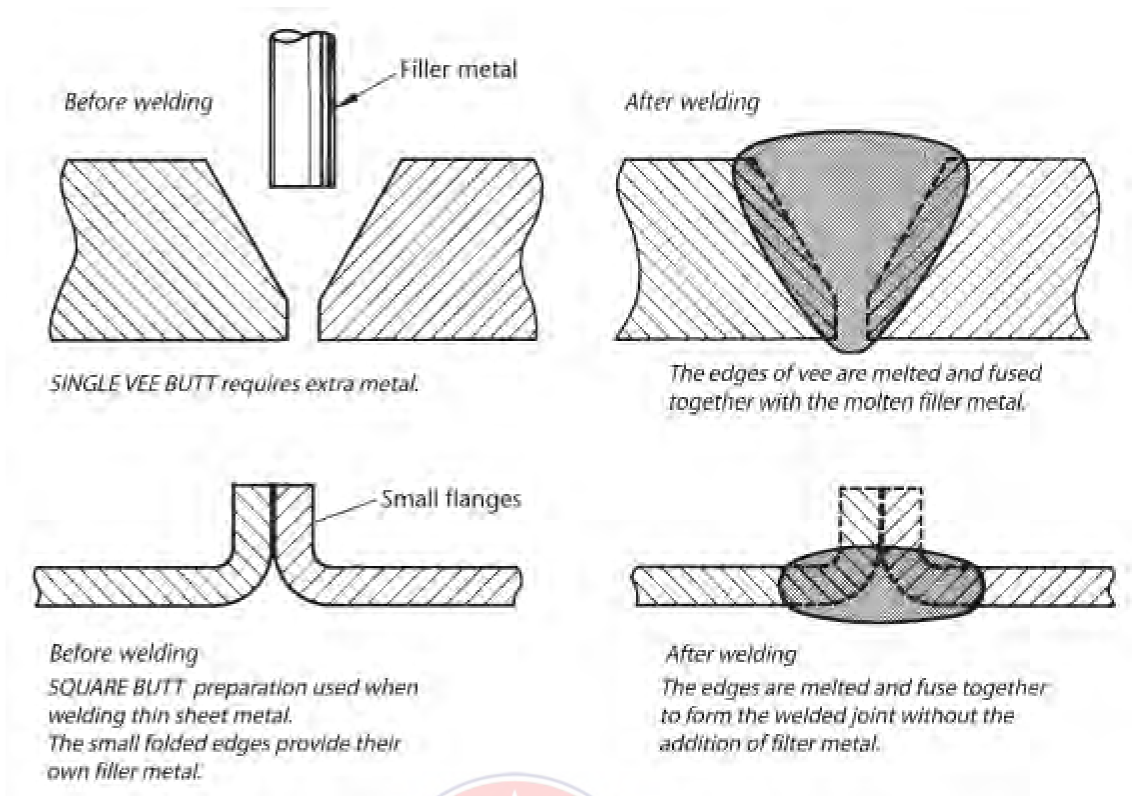


Figure 2.1 Fusion welding with and without the addition of filler metal

2.8.1 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, 2014).

2.8.1.1 Oxyacetylene Welding (OAW)

The oxyacetylene welding process shown by figure 2.2, 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, 2014). 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, 2014).

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 2.4 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.

An oxy-fuel gas flame provides the heat required at a high enough temperature to melt most engineering materials in common use. The fuel-gas most widely used is acetylene and the

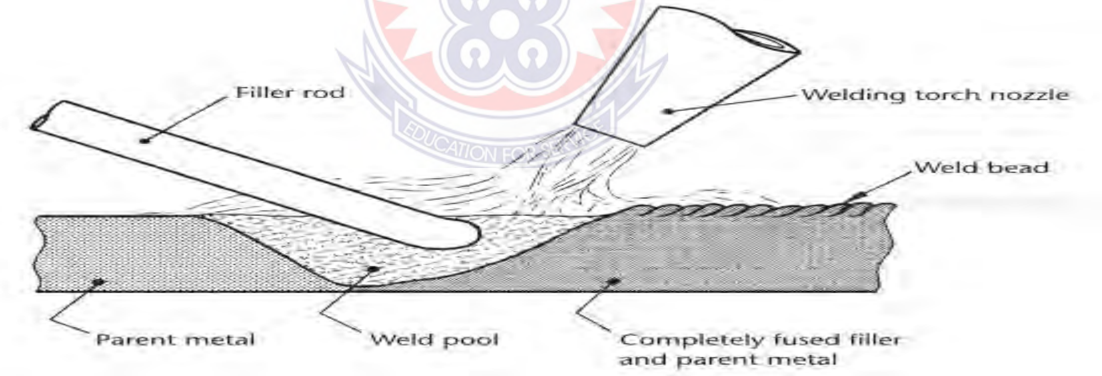


Figure 2.2 Oxy-acetylene welding

process is then referred to as oxy-acetylene welding. Acetylene is the most economical gas to use in conjunction with commercially pure oxygen supplied from high-pressure cylinders to give a flame with a maximum temperature of 3200°C.

The main advantage of the oxyacetylene welding process is that the equipment is simple, portable, and inexpensive. Therefore, it is convenient for maintenance and repair applications. However, due to its limited power density, the welding speed is very low and the total heat input per unit length of the weld is rather high, resulting in large heat-affected zones and severe distortion. The oxyacetylene welding process is not recommended for welding reactive metals such as titanium and zirconium because of its limited protection power. 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, 2014)

Base metal	Filler Metal Type	Flame Type	Flux Type
Aluminum	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 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.

2.8.1.2 Welding Apparatus

The apparatus and equipment employed for oxyacetylene welding are shown by figure 2.3. 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.

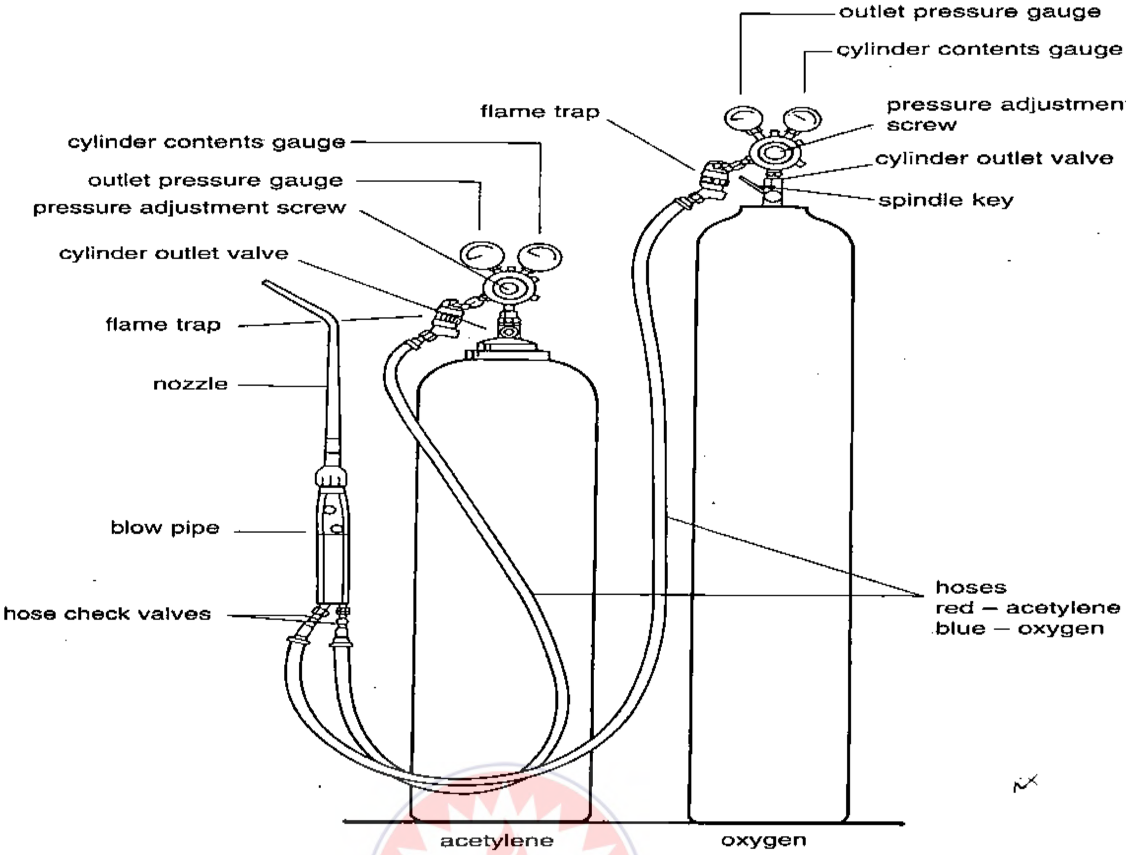


Figure 2.3 the apparatus required for welding with OAW (Pritchard, 2001).

2.8.1.3 Welding Flame

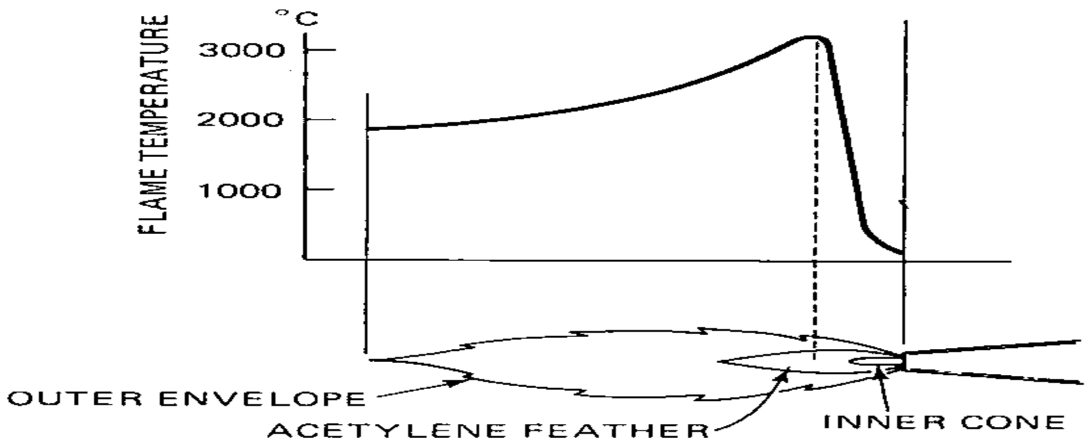


Figure 2.4 characteristics of welding flame

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, C2H2 + O2 = 2CO + H2 + Heat; the products of which are both combustible, which leads to the second-stage reaction: 2CO + H2 + 1.502 = 2C02 + H20 + 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 (carburizing), and excess oxygen (oxidizing).

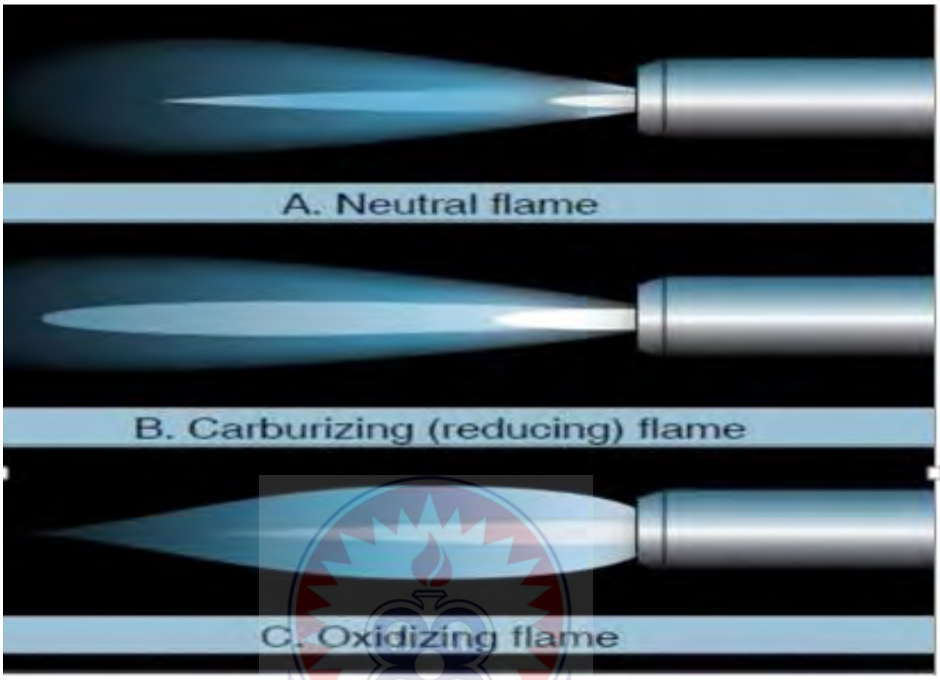


Figure 2.5 The three types of flame. (Cary, 2014)

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 carburizing 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 carburizing 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, 2014).

2.8.1.4 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

Fuel	Temperature		Heat of Combustion	
	°C	°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. 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 colour 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.

2.9 Metal-Arc Welding

Providing access is available to a main supply of electricity, metal-arc welding is very much cheaper than oxy-acetylene welding. It also produces higher temperatures and greater amounts of heat energy, enabling much thicker sections to be welded successfully. For site work, welding generators are required which, although more expensive in initial cost, are still cheaper to run, especially where heavy sections such as girders have to be welded. The ‘arc’ is produced by a low-voltage, high-amperage current jumping the air gap between the electrode and the joint to be welded. The heat of the electric arc is concentrated on the edges of the parent metals that are to be joined, causing the edges of the parent metal to melt.

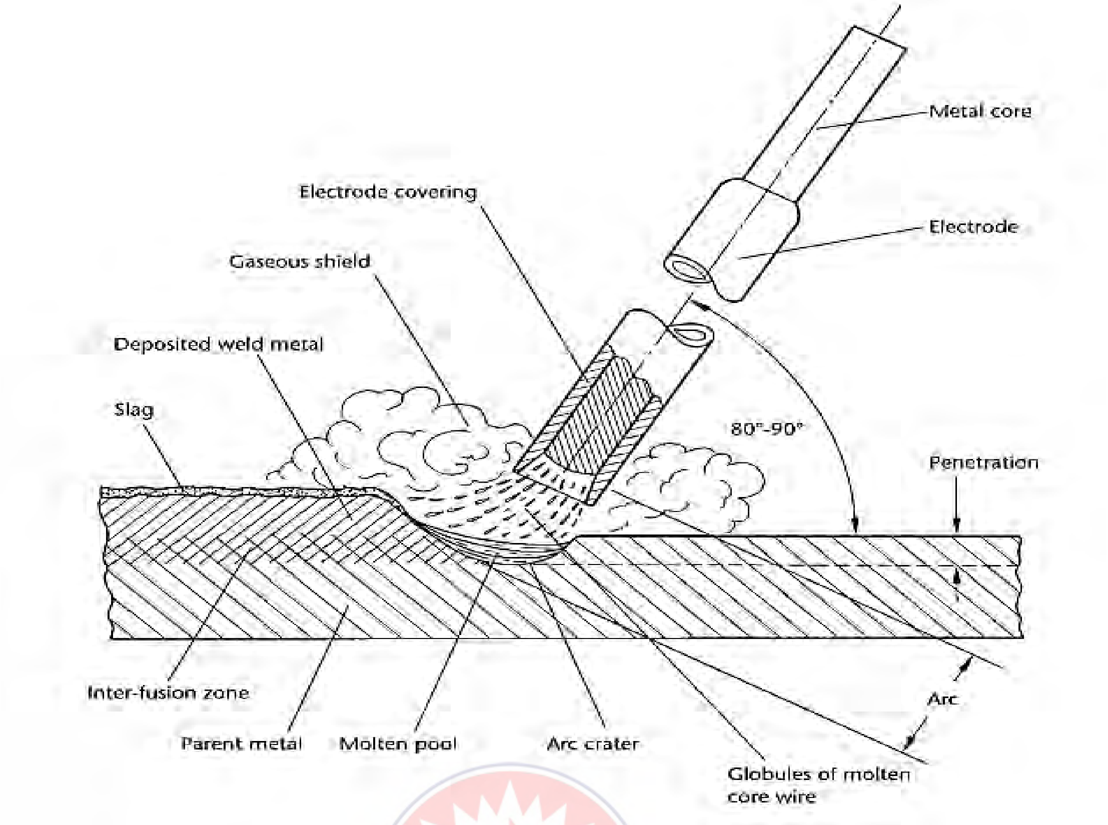


Figure 2.6 metallic arc welding

Whilst these edges are still molten, additional metal in the molten state is transferred across the arc from a suitable electrode. Upon cooling, this molten mass of weld metal solidifies to produce a strong joint. As soon as the arc is struck the tip of the electrode commences to melt, thus increasing the gap between the electrode and the work. Therefore, it is necessary for the operator to advance the electrode continuously towards the joint in order to maintain a constant arc gap (length) of approximately 3 mm during the welding operation. The electrode is also moved along the joint to be welded with a uniform velocity. This requires considerable skill that is only acquired with practice.

2.9.1 Shielded Metal Arc Welding

Shielded metal arc welding (SMAW) is a process that melts and joins metals by heating them with an arc established between a sticklike covered electrode and the metals, as shown in Figure 2.7. It is often called stick welding. The electrode holder is connected through a welding cable to one terminal of the power source and the workpiece is connected through a second cable to the other terminal of the power source (Figure 2.7a). Shielded metal arc welding (SMAW) is the broadly employed, joining process in the field of engineering applications. In fact, it can be utilized in those places where the mechanized process cannot be reached and also more popular due to its economy and portability (Sidhu and Chatha 2012). The core of the covered electrode, the core wire, conducts the electric current to the arc and provides filler metal for the joint. For electrical contact, the top 15mm of the core wire is bare and held by the electrode holder. The electrode holder is essentially a metal clamp with an electrically insulated outside shell for the welder to hold safely. The heat of the arc causes both the core wire and the flux covering at the electrode tip to melt off as droplets (Figure 2.7b). The molten metal collects in the weld pool and solidifies into the weld metal. The lighter molten flux, on the other hand, floats on the pool surface and solidifies into a slag layer at the top of the weld metal.

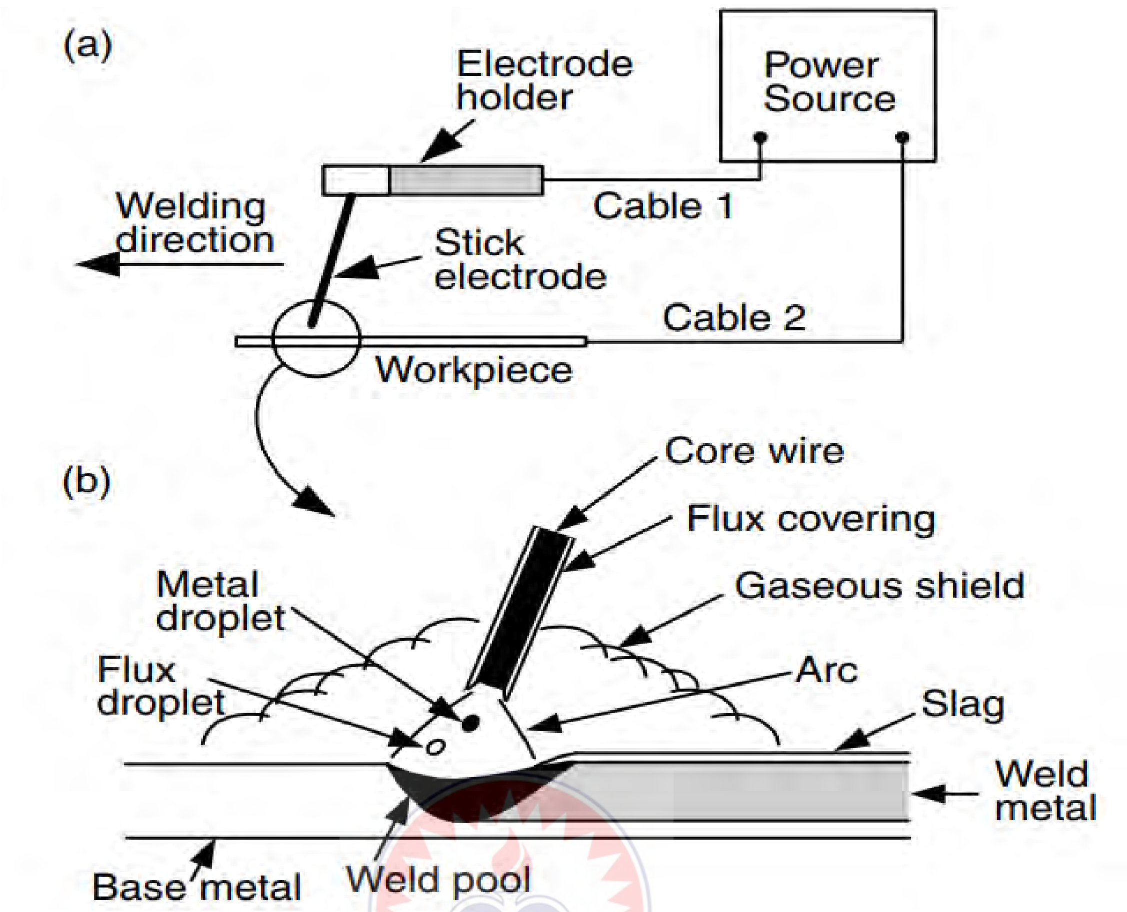


Figure 2.7 Shielded metal arc welding: (a) overall process; (b) welding area enlarged (Gourd, 2014)

The welding equipment is relatively simple, portable, and inexpensive as compared to other arc welding processes. For this reason, SMAW is often used for maintenance, repair, and field construction. However, the gas shield in SMAW is not clean enough for reactive metals such as aluminium and titanium. The deposition rate is limited by the fact that the electrode covering tends to overheat and fall off when excessively high welding currents are used. The limited length of the electrode (about 350 mm) requires electrode changing, and this further reduces the overall production rate. (Gourd, 2014).

2.9.2 Gas–Tungsten Arc Welding

Gas–tungsten arc welding (GTAW) is a process that melts and joins metals by heating them with an arc established between a non-consumable tungsten electrode and the metals, as shown in Figure 2.8. The torch holding the tungsten electrode is connected to a shielding gas cylinder as well as one terminal of the power source, as shown in Figure 2.5a. The tungsten electrode is usually in contact with a water-cooled copper tube, called the contact tube, as shown in Figure 2.8b, which is connected to the welding cable (cable 1) from the terminal. This allows both the welding current from the power source to enter the electrode and the electrode to be cooled to prevent overheating. The workpiece is connected to the other terminal of the power source through a different cable (cable 2). The shielding gas goes through the torch body and is directed by a nozzle toward the weld pool to protect it from the air. Protection from the air is much better in GTAW than in SMAW because an inert gas such as argon or helium is usually used as the shielding gas and because the shielding gas is directed toward the weld pool. For this reason, GTAW is also called tungsten–inert gas (TIG) welding. However, in special occasions a noninert gas can be added in a small quantity to the shielding gas. Therefore, GTAW seems a more appropriate name for this welding process. When a filler rod is needed, for instance, for joining thicker materials, it can be fed either manually or automatically into the arc. (Gourd, 2014).

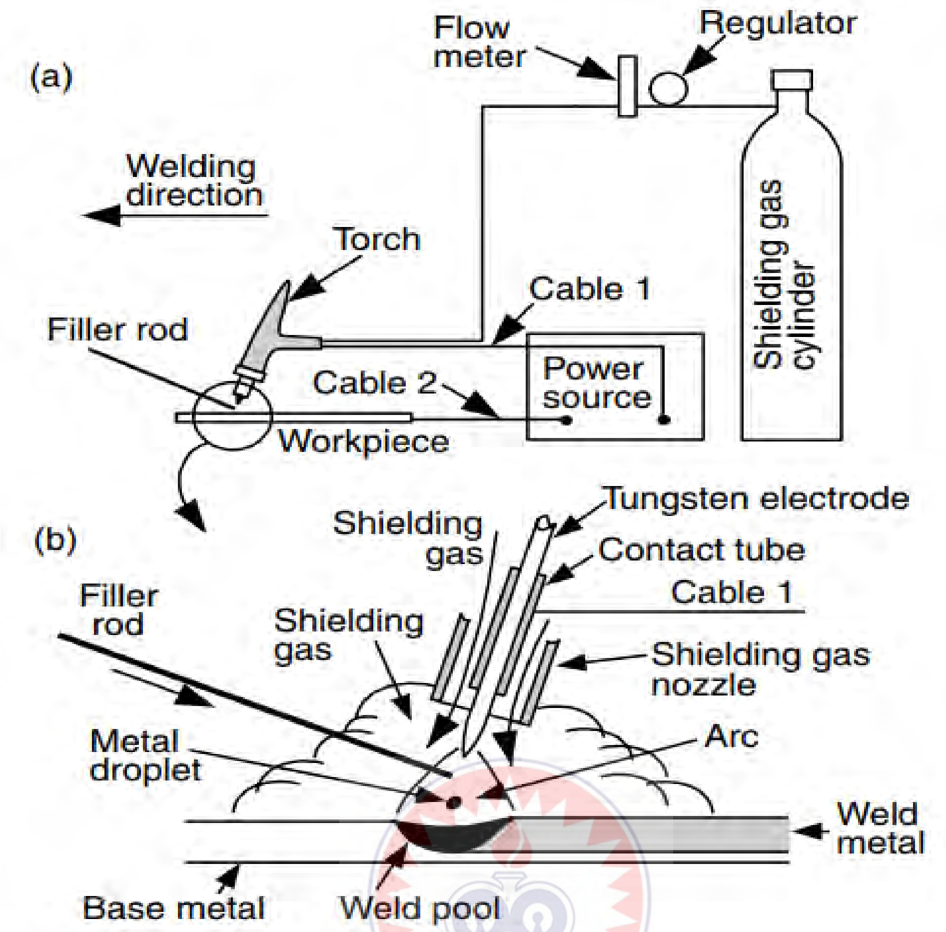


Figure 2.8 Gas–tungsten arc welding: (a) overall process; (b) welding area enlarged

Gas–tungsten arc welding is suitable for joining thin sections because of its limited heat inputs. The feeding rate of the filler metal is somewhat independent of the welding current, thus allowing a variation in the relative amount of the fusion of the base metal and the fusion of the filler metal. Therefore, the control of dilution and energy input to the weld can be achieved without changing the size of the weld. It can also be used to weld butt joints of thin sheets by fusion alone, that is, without the addition of filler metals or autogenous welding. Since the GTAW process is a very clean welding process, it can be used to weld reactive metals, such as titanium and zirconium, aluminium, and magnesium. However, the deposition rate in GTAW is low. Excessive welding currents can cause melting of the tungsten electrode and results in brittle tungsten inclusions in the weld metal. However, by using preheated filler metals, the deposition rate can be improved. In the hot-wire GTAW process, the wire is fed into and in contact with the weld pool so that resistance heating can be obtained by passing an electric current through the wire. (Davies, 2004).

2.9.3 Flux-Core Arc Welding

Flux-core arc welding (FCAW) is similar to GMAW, as shown in Figure 2.6a. However, as shown in Figure 2.9b, the wire electrode is flux cored rather than solid; that is, the electrode is a metal tube with flux wrapped inside. The functions of the flux are similar to those of the electrode covering in SMAW, including protecting the molten metal from air. The use of additional shielding gas is optional. (Blackman and Dorling, 2000).

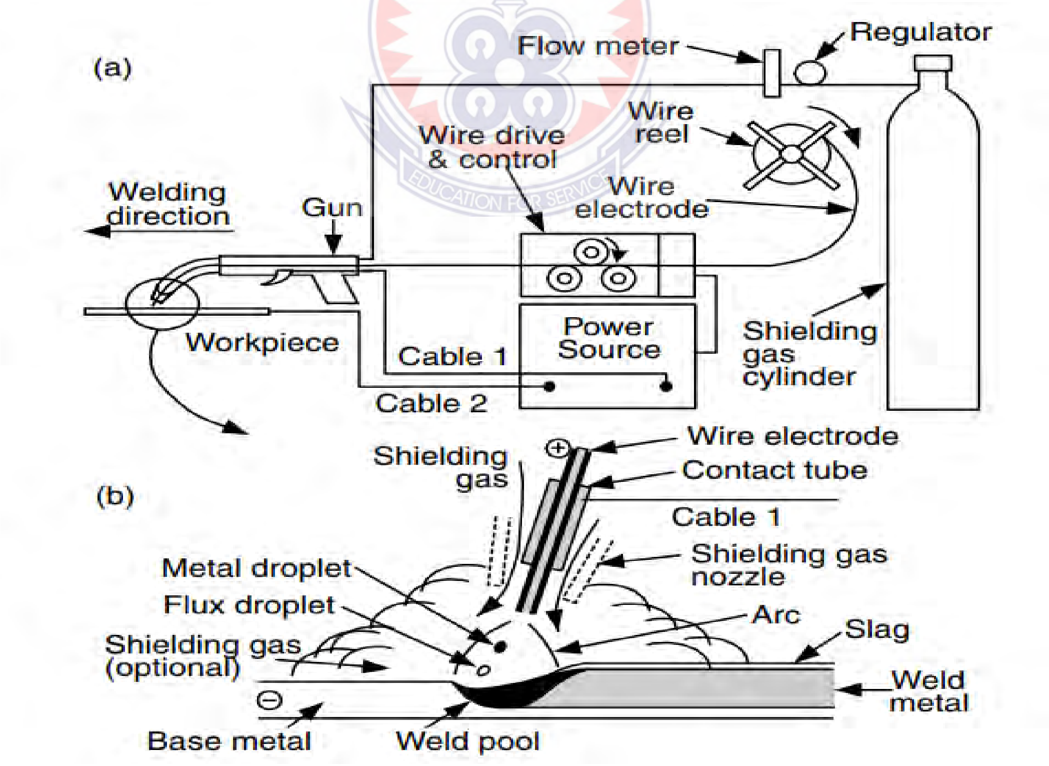


Figure 2.9 Flux-core arc welding: (a) overall process; (b) welding area enlarged.

2.9.4 Gas–Metal Arc Welding

Gas–metal arc welding (GMAW) is a process that melts and joins metals by heating them with an arc established between a continuously fed filler wire electrode and the metals, as shown in Figure 2.10. Shielding of the arc and the molten weld pool is often obtained by using inert gases such as argon and helium, and this is why GMAW is also called the metal–inert gas (MIG) welding process. Since noninert gases, particularly CO2, are also used, GMAW seems a more appropriate name. This is the most widely used arc welding process for aluminium alloys. (Davies, 2004).

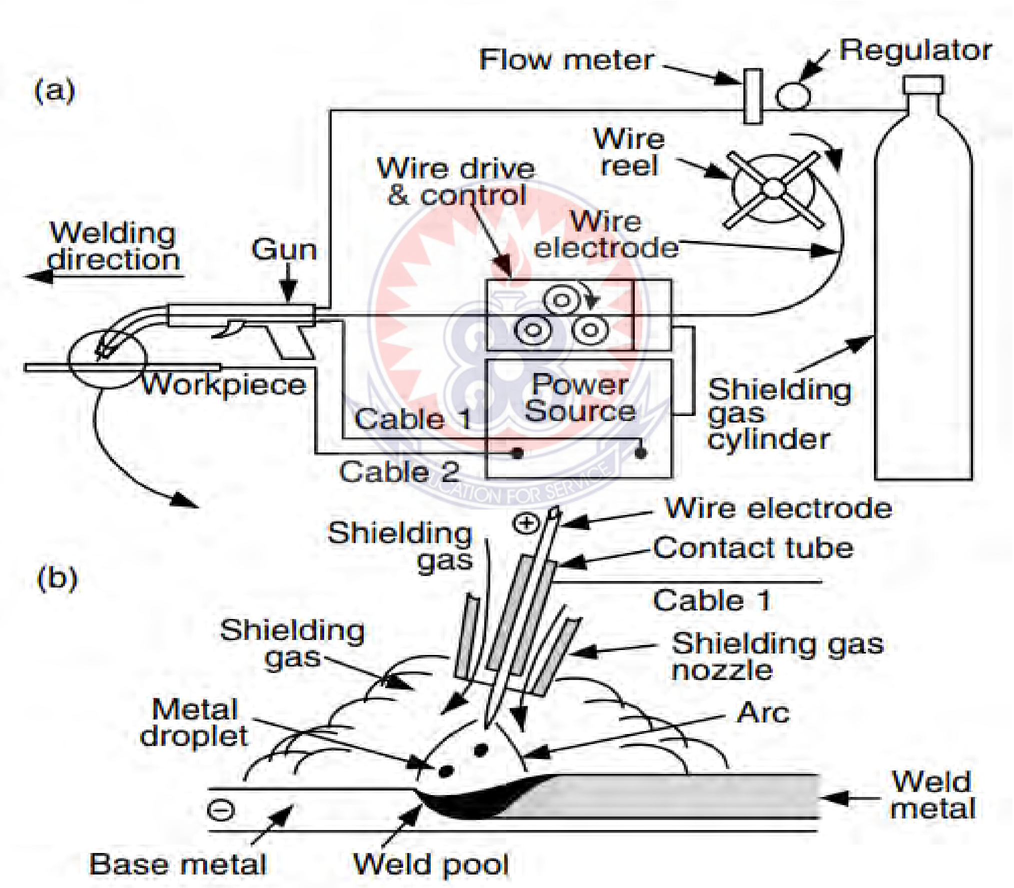


Figure 2.10 Gas–metal arc welding: (a) overall process; (b) welding area enlarged.

Like GTAW, GMAW can be very clean when using an inert shielding gas. The main advantage of GMAW over GTAW is the much higher deposition rate, which allows thicker workpieces to be welded at higher welding speeds. The dual-torch and twinwire processes further increase the deposition rate of GMAW (Blackman and Dorling, 2000). The skill to maintain a very short and yet stable arc in GTAW is not required. However, GMAW guns can be bulky and difficult-to-reach small areas or corners.

2.10 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 non-consumable 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.

2.10.1 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, 2001)

According to Gourd (2014), 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 fulfil 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, 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. 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, 2004).

2.10.2 Non-consumable Electrodes

There are two types of non-consumable 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.

2.10.3 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).

2.10.4 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 electro slag 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 vapour. 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. CO2 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, 2001).

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.

2.11 The Metallurgy of Welding

The weldment is divided into three distinct regions (see Figure 2.11): 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, 2017).

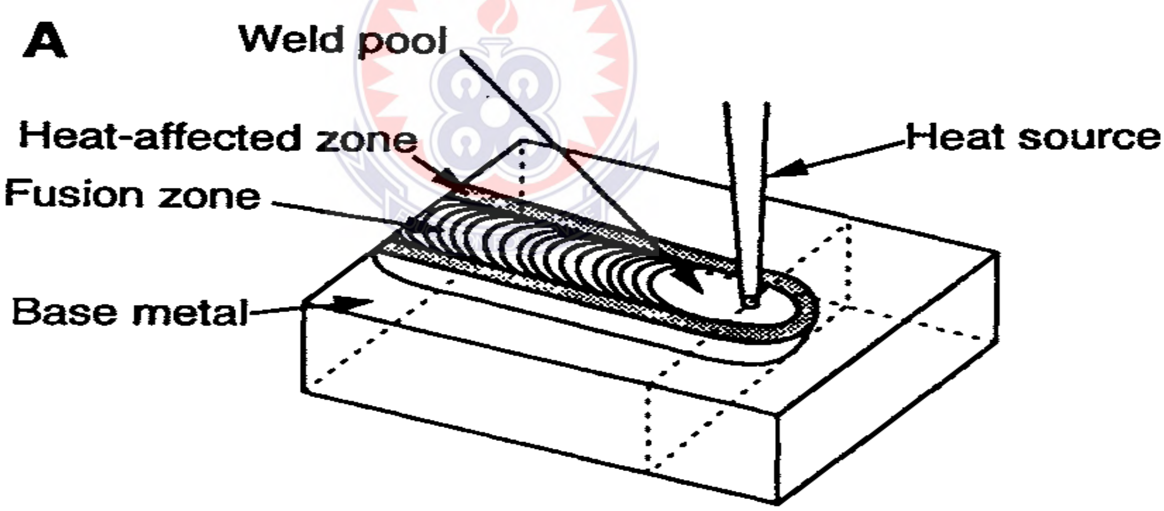


Figure 2.11 Three distinct regions in the weldment: the fusion zone, the heat-affected zone, and the base metal. (David and DebRoy, 2017)

According to Connor, (2013), 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 2.12 shows the heat-affected zone and the corresponding phase diagram for 0.30% carbon steel.

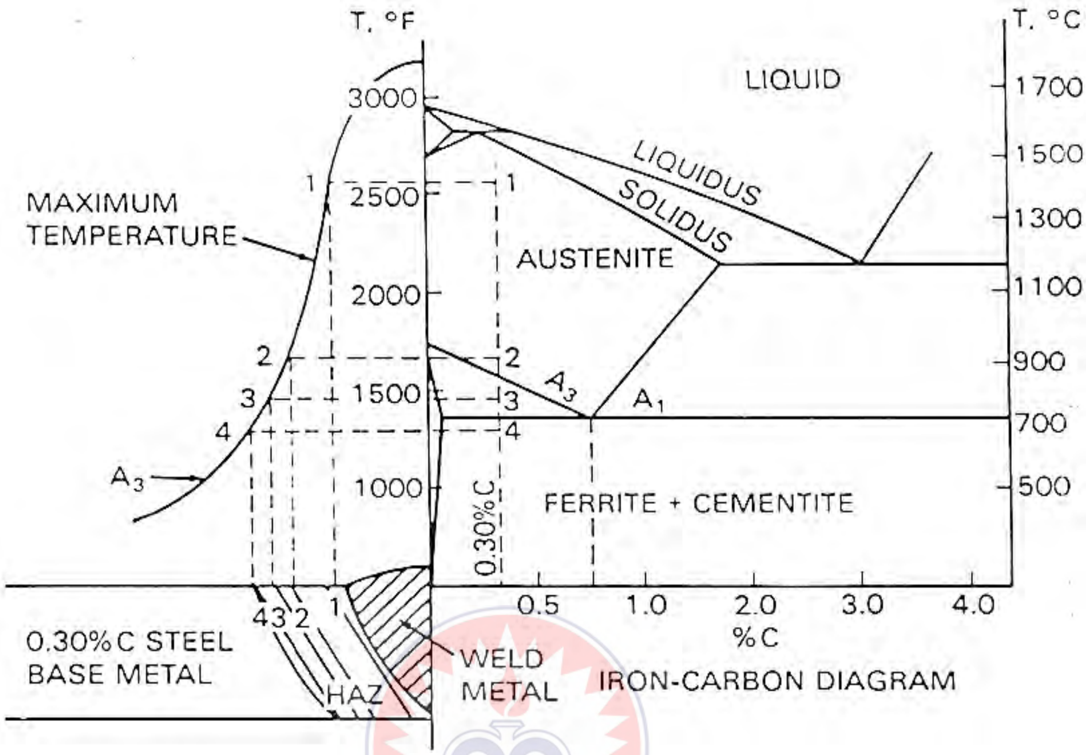


Figure 2.12 Schematic illustration of various regions in a fusion-weld zone and the corresponding phase diagram for 0.30% carbon steel (Connor, 2013).

2.12 Weldability

The characteristic of a metal to be welded without losing desirable properties is called weldability (Connor, 2013). 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, 2001):

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

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).

2.13 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 2.13) 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.

4. 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.
5. 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.
6. 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.
7. 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.
8. 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.
9. 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.
10. 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.

11. 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.
12. Underfill: Part of a butt weld is below the plate surface, causing it to fail any welding test. More filler/passes are required.
13. 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 CO2 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.
14. 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.

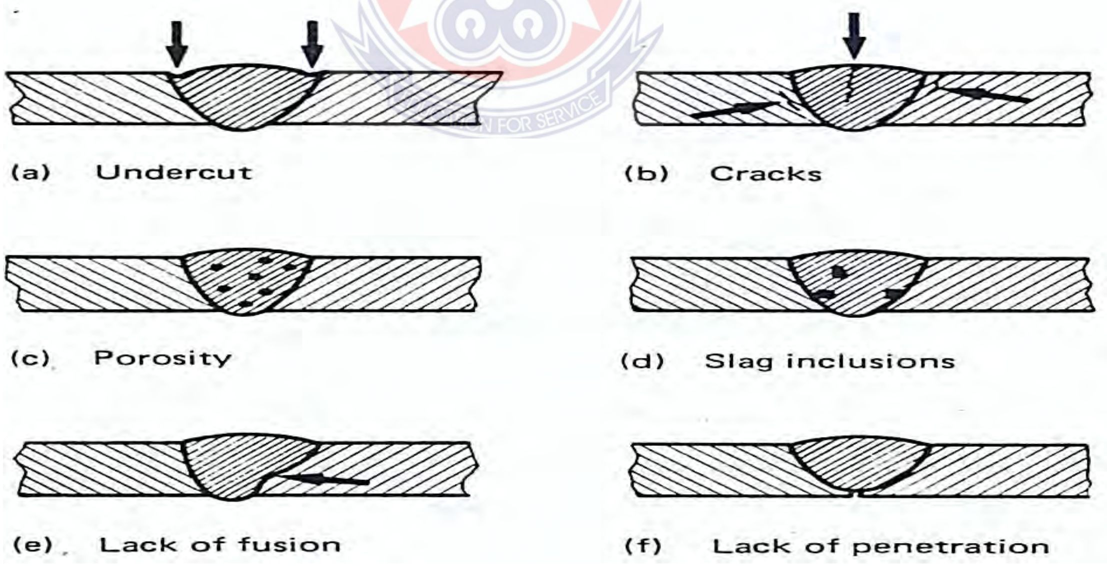


Figure 2.13 Cross-sections of welds containing typical defects (Gourd, 2014).

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.

2.14 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 fulfil 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).

2.14.1 Visual Inspection

It 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 non-destructive category. The limitation of visual inspection is that only surface defects are detectable; internal defects cannot be discovered by visual methods.

2.14.2 Non-destructive Evaluation

The non-destructive 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.

2.9.7.3 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 (Bralla, 2009).

2.15 Designs for Welding

2.15.1 Design Considerations in Welding

1. 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, 2009): 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.

2.15.2 Welding Positions, Joints, Welds, and Weld Joints

Welding Positions, The American Welding Society has defined the four basic welding positions as follows: (see Figure 2.14). 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."

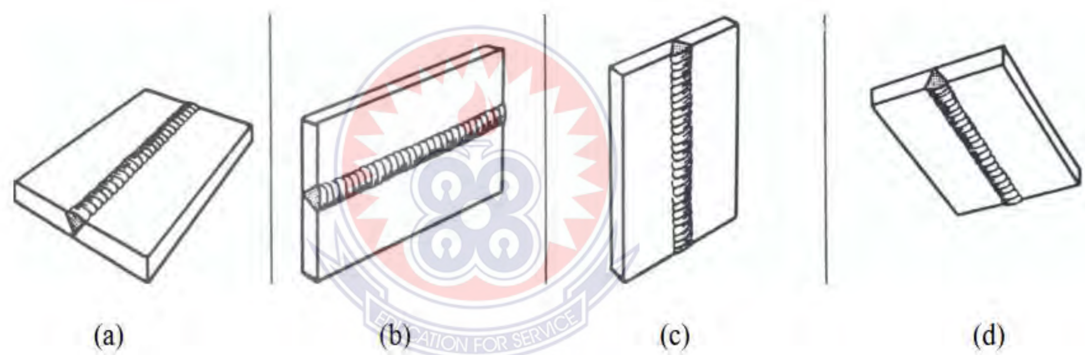


Figure 2.14 Welding positions (defined here for groove welds): (a) flat, (b) horizontal, (c) vertical, and (d) overhead. (Cary, 2001)

2.15.3 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 2.15). 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).

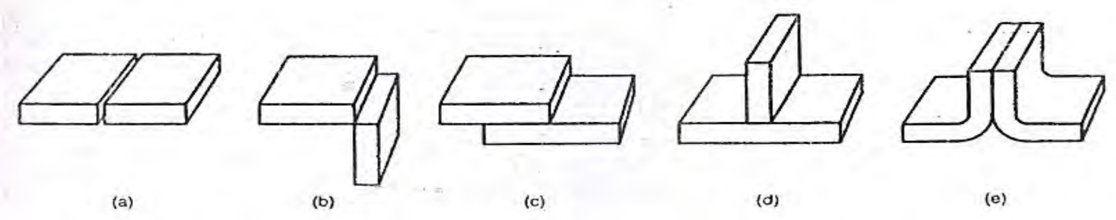


Figure 2.15 Five basic types of joints: (a) butt, (b) corner, (c) lap, (d) tee, and (e) edge. (Groover, 2002)

2.15.4 Types of Welds

There is a distinction between the joint type and the way in which it is welded-the weld type (see Figure 2.15). The differences among weld types are in geometry (joint type) and welding process (Nagesh and Datta 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 2.16 (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.

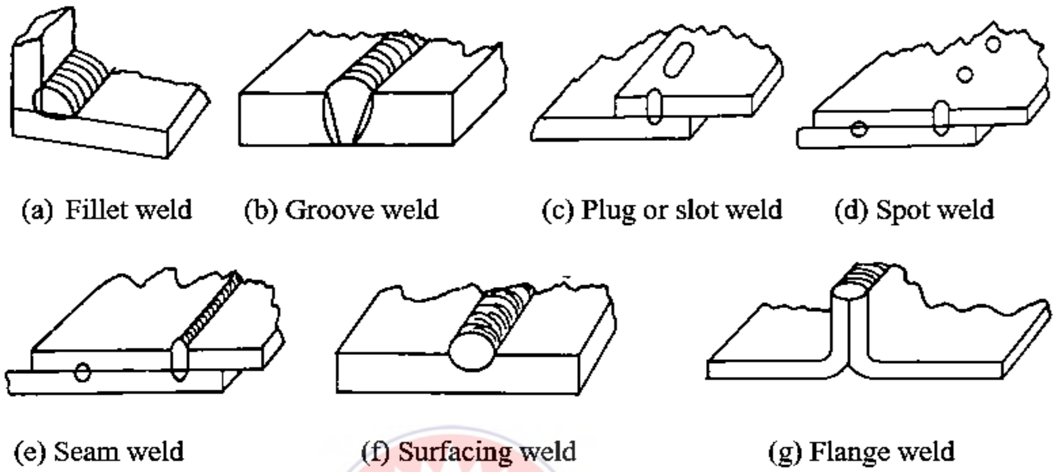


Figure 2.16 types of weld

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter explains how the experimental research was conducted. It includes the experimental setup, the type of specimens and how the specimens were prepared for the experiment. It gives a detailed account of how the specimens were joined by means of two welding processes and the standard used. Detailed experimental procedures were explained and ways of getting data were shown.

3.2 Materials

. Introduction

Manufacturers and engineers are always on the lookout for new materials and improved processes to use in manufacturing better products, and thus maintain their competitive edge and increase their profit margin (Farag, 2008). In recent years, many traditional materials which have served in engineering applications for a long time are being replaced by the so called 'new materials', in order to meet the demand of weight reduction and performance enhancement (Rao, 2008). The available set of materials is rapidly growing both in type and number . It is estimated that there are more than 80,000 materials in the world. It includes metallic alloys and nonmetallic engineering materials such as plastics, ceramics and glasses, composite materials, and semiconductors. This large number of materials, coupled with the complex relationships between the different selection parameters, often make the selection of a materials for a given component a difficult task (Farag, 2002). In selecting materials, designers and engineers have to take into account a large number of factors. These factors for material include mechanical properties (Young's Modulus, strength, yield stress, elasticity, fatigue, creep resistance, ductility, hardness and toughness), physical properties (crystal structure, density, melting point, vapor pressure, viscosity, porosity,permeability,reflectivity,transparency,optical properties, dimensional stability), magnetic properties, electrical (resistivity, permittivity, dielectric strength), thermal and radiation (specific heat, conductivity, expansively, diffusivity, transmissivity, reflectivity, emissivity), surface (texture, corrosivity, wear resist), manufacturing properties (machinability, formability, weld ability, cast ability, heat treatability, etc.), material cost, reliability, durability, recycle ability, material impact on environment, performance characteristics, availability, fashion, market trends, cultural aspects, aesthetics, etc. Figure 3.1 shows a material selection chart developed by Ashby M. F. with focus on strength and density.

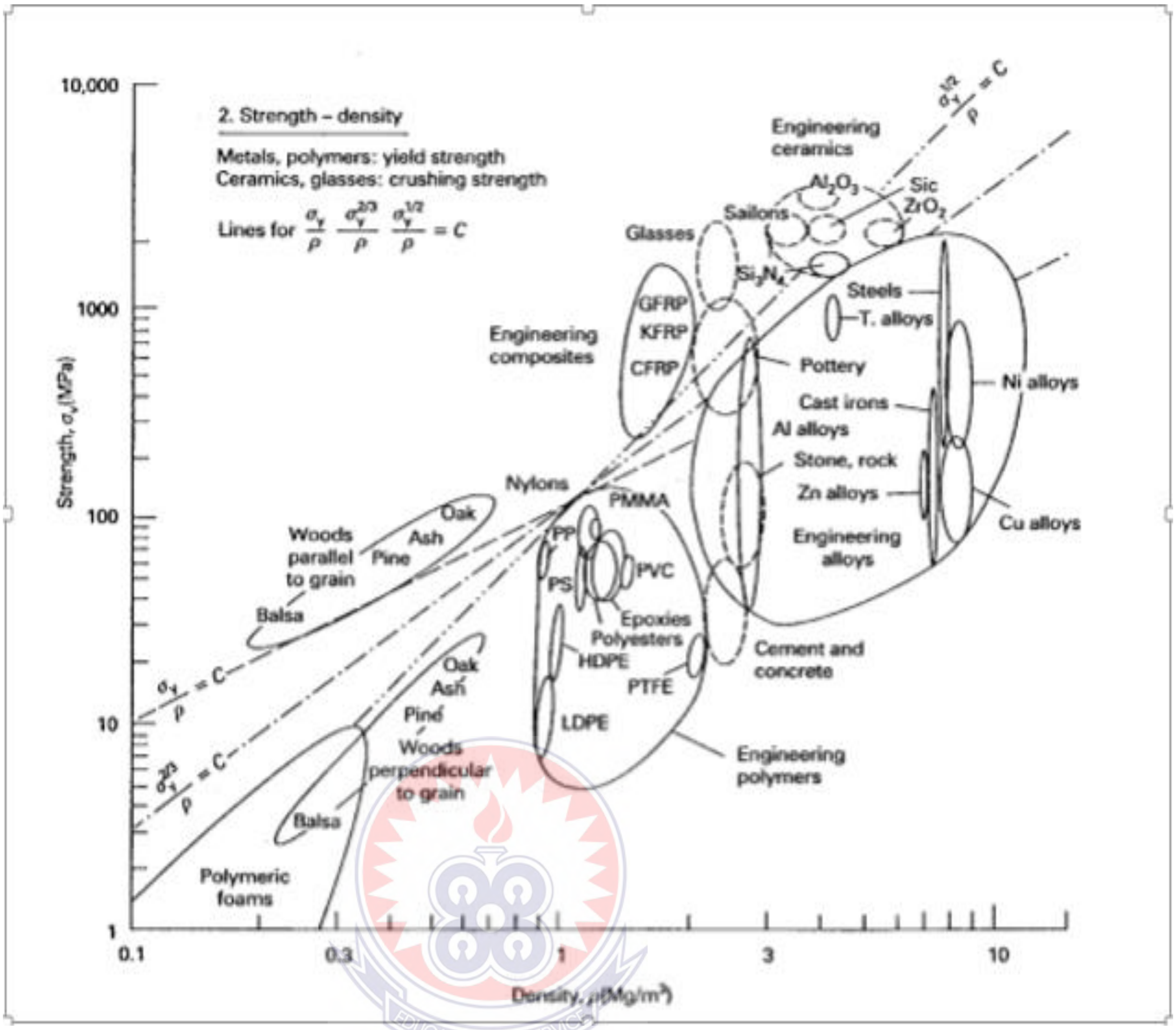


Figure 3.1 Material Selection Chart (Ashby, 2018).

In this study, A36 mild steel plate of thickness 2.5 mm was used. The numerous factors that necessitated the choice of this material were based on the fact that A36 mild steel has excellent weldability and produces a uniform and harder case and it is considered as the best steel for carburized parts. It offers a good balance of toughness, strength and ductility. Provided with higher mechanical properties, A36 mild steel also includes improved machining characteristics and Brinell hardness.

Specific manufacturing controls are used for surface preparation, chemical composition, rolling and heating processes. All these processes develop a supreme quality product that are suited to fabrication processes such as welding, forging, drilling, machining, cold drawing and heat treating.

Table 3.1 Chemical Compositions of A36 Mild Steel

Element	Content
Carbon, C	0.18-0.25%
Iron, Fe	98.0%
Silicon,	0.40%
Manganese, Mn	0.30-0.60%
Phosphors, P	< 0.03%
Sulphur, S	< 0.03%
Copper,Cu	0.20%

Table 3.2 Physical Properties of A36 Mild Steel

Physical properties	Metric
Density	7.85 g/c^3

Table 3.3 Mechanical properties of A36

Mechanical properties	Metric
Tensile strength, Ultimate	400-550 Mpa

Tensile strength, Yield	220 Mpa
Elongation at Break (in 50mm)	20.0%
Modulus of Elasticity (typical for steel)	200 GPa
Poison Ratio (typical for steel)	0.26
Shear Modulus (typical for steel)	79 GPa
Hardness, Brinell	119-162

3.2.2 Applications of A36 Mild Steel

- It is used in bending, crimping and swaging processes.
- For carburized parts that include worms, gears, pins, dowels, non-critical components of tool and die sets, tool holders, pinions, machine parts, ratchets, dowels and chain pins.
- It is widely used for fixtures, mounting plates and spacers.
- It is suitably used in applications that do not need high strength of alloy steels and high carbon.
- It provides high surface hardness and a soft core to parts that include worms, dogs, pins, liners, machinery parts, special bolts, ratchets, chain pins, oil tool slips, tie rods, anchor pins, studs etc.
- It is used to improve drilling, machining, threading and punching processes.
- It is used to prevent cracking in severe bends.

3.3 The welding electrode used

Electrodes are bare or coated rods with the same metallic elements as the parent metal to be welded. In shielded metal arc welding (SMAW), the electrode carries current from the welding cable to the tip of the electrode to generate an arc between the electrode and the parent metal, melting both the electrode and the parent metal to form a weld pool, solidifying to form a weld bead.

Selection of the right electrode is very crucial as far as the quality of the joint to be produced is concerned. Choosing the appropriate electrode is essential as good electrode enhances fast weld build-ups, excellent arc stability, minimum sparer, joint of high strength and slag which are very easy removing.

In this study, E 8018-G electrode of diameter 2.4 mm was selected for the two welding processes based on the following factors;

- All positional welding capabilities
- High welding efficiency
- Smooth appearance
- Negligible spatter loss
- Stable arc
- Contains ferrous powder in the coatings specifically formulated to resist high heat and humidity conditions
- Ideal for the vertical-down welding of thin steel ections
- Suitable for welding mild steel plate, sheet metal and galvanized iron sheet, ducting, hoppers, tanks.
- Excellent for welding joints with poor fit-up
- Gives tough weld deposit and highly crack resistant joint

Figure 3.2 Electrode E 8018-G used for the SMAW

Table 3.4 Chemical composition of E 8018-G electrode

Element	**Content**
Carbon, C	0.12%
Manganese, Mn	0.40-1.25%
Silicon, Si	0.8O%
Sulphur, S	0.03%
Phosphorus, P	0.03%
Chromium	0.15%
Molybdenum	0.35%
Vanadium	0.05%

3.4 Oxy-acetylene gas welding rod used

Gas rods are usually of three-foot lengths. The rods come in a weight of 0.454 kg per tube or 22.68 kg per box, with a minimum tensile strength of either 3102.64 KPa or 4136.85 KPa. They usually have a thin protective sheath of copper to prevent oxidation (i.e., rust) and come in six different diameters (1/16, 3/32, 1/8, 5/32, 3/16 and 1/4 inch).

Table 3.5 Welding tips and the corresponding thickness of the base metal

Metal Thickness	Tip Size
1/4 – ½	5
3/16 – ¼	4
1/8 – 3/16	3
1/16 – 1/8	2
5/64 – 3/32	1
3/64 – 5/64	0 (The zero tip is called an "ought")
1/32 – 3/64	00 ("double ought")
1/64 – 1/32	000 ("triple ought")

E 8018-G of diameter 2.4 mm which was used for the shielded metal arc welding process was selected as the filler metal for the oxyacetylene welding process. The idea was to avoid disparities in the chemical composition of the base metal used for the filler rods for the two welding processes.

Table 3.7 Chemical composition of the welding rod:

Element	content
Carbon, C	0.12%

Manganese, Mn	0.40-1.25%
Silicon, Si	0.80%
Sulphur, S	0.03%
Phosphorous, P	0.03%
Chromium	0.15%
Molybdenum	0.35%
Vanadium	0.05%

Typical Weld Deposit Properties of E 8018-G:

- Yield Strength 68-80 Kpsi
- Tensile Strength 80 Kpsi
- Elongation in 2” 24%

3.5 Methods

The A36 mild steel plate was measured and cut to a sample size of 160 mm x 100 mm x 2.5 mm using ACCURSHEAR 82506 power cutting machine. Before welding, the specimens were cleaned from dust, oil to avoid impurity in molten metal pool. The needed joint configuration was obtained by securing the plate in position using tack welding. All the necessary care was taken to avoid joint distortion. Work pieces were kept in position with respect to each other and welding was performed. The specimen were welded using oxyacetylene welding and shielded metal arc welding processes at the Welding and Fabrications Department of Kumasi Technical Institute. Different welding joint designs specifically (butt and lap) were carried out for the test specimen. Venus Eclectic Arc Welding Machine of Model Number CT 520D was used for the electric arc welding process. The following were the procedure or the steps used to weld the joints using shielded metal arc welding (SMAW) process;

- Step 1: Safety.

  The prime vital thing to regard was safety during welding. The arc welding not only needed power but also creates a dangerous spark. The splash and sparkle could cause damage to human eyes. So ideal personal protective equipment were employed, specifically welding gloves, helmet, safety glasses, welding mask, overcoat, welding boots, and other equipment.

  SMAW is well known to create many sparks that could simply burn any unguarded zones of the human body. So there was the need to cover-up. The splash could simply begin a fire. So every flammable fabric was kept at a reasonable distance from the welding zone.

- Step 2: Assembling essential tools and equipment.

All the essential tools and equipment needed for the project were garthered. The list of all the essential gears that were secured and employed for the welding project include; gloves, safety glasses, welding mask, muff, pliers, chipping hammer, wire brush, clamps, and tape measure.

- Step 3: Cleaning the metal.

It was vital to dirt free the zone where welding would be done. As a result, the metal specimen were thoroughly cleaned from dust, rust and oil using wire brush Cleaning dirt from the metal improves quality of the weld.

- Step 4: Measuring and Cutting the Metal.

After cleaning, the mild steel plate was measured and cut to the required sample size of 150 mm x 100 mm x 3 mm using ACCURSHEAR 82506 power cutting machine. Steel rule, chalk, scriber and try square were used for measuring and marking out the plate.

- Step 5: Setting up the workpiece.

  After the cleaning, measuring and cutting, the workpieces were set up. The needed joint configuration was obtained by securing the plate in position using tack welding. All the necessary care was taken to avoid joint distortion. Work pieces were kept in position with respect to each other and welding was performed initially by simply tack welding them. If the project was a high production task, some sort of jig would have been devised and used

- Step 7 Welding the Specimen

  The various joints were produced, taking all the necessary precautionary measures. Steady movement of the electrode for each joint was employed. The welding speed used was 120 mm/min. The joints were welded using one pass.

- Step 8: Cleaning up the workpiece.

  After welding of the various joints have been completed, the work was bunched of splash left over the flux. Chipping hammer was used to remove the slag formed on the weld bead.

  The following were the steps followed to weld the workpiece using oxyacetylene welding process;

  1. All the essential materials such as safety gears, welding equipment, filler rods, parent metal to be welded etc. needed for the welding project were assembled.
  2. The materials to be welded were thoroughly cleaned to remove any contaminants that could cause welding defects later.
  3. The next step was to place the materials that was to be welded at the required place using clamps or vise grips, and then the correct size nozzle for the welding was chosen.

4. The main valve located on the cylinder was opened by rotating it 90 degrees clockwise. After opening the valve of the oxygen tank and adjusting the amount of pressure, the flame was ignited.
5. The required pressures of acetylene gas and oxygen gas were set to the normal working pressures of 0.5 Psi and 5 Psi respectively to obtain correct welding flame needed for the welding process.
6. The specimen were welded moving from left to right direction to complete the joints.

After all the welding processes had been done, each sample specimen was allowed to cool down under the same atmospheric condition (still air) so as to avoid disparities that could occur to the internal properties in relation to the cooling rate after the welding processes. The welding parameters used for the shielded metal arc welding process has been detailed in table below;

Figure 3.3 Accurshear 82506 Power Cutting Machine for cutting plate

Table3.8 welding parameters

Element	Parameter
Polarity	AC-DC
Voltage	240 V/
Current	79 Amp
Welding speed	120 mm/min
Electrode type	E 8018-G

Figure 3.4 Venus Electric Welding Machine. Model CT-520D used for the arc welding process.

(a)

(b)

Figure 3.5 Specimen joined using shielded metal arc welding process (a) ---butt joint (b) ---lap joint

Figure 3.6 Oxyacetylene Welding Equipment.

(a)

(b)

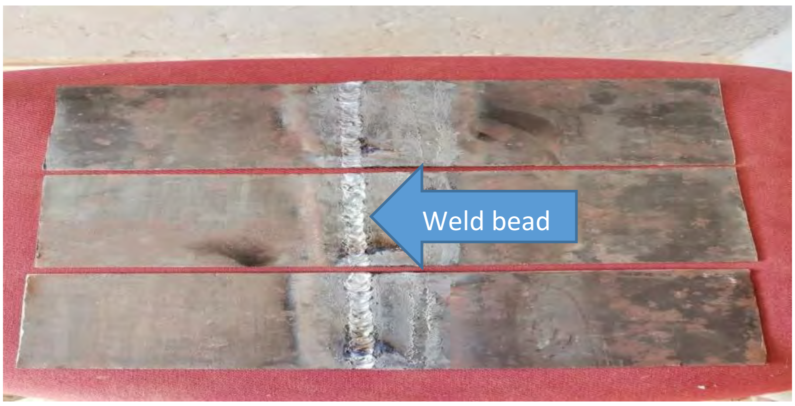


Fig 3.6 Oxyacetylene welded joints (a) ---butt joint (b) ----lap joint

3.6 Modelling of Surface Tension

Liquid surfaces are in a state of tension, as though they possessed an elastic skin, because fluid molecules at or near the surface experience uneven molecular forces of attraction. Since abrupt changes in molecular forces occur when fluid properties change discontinuously, surface tension is an inherent characteristic of material interfaces. Surface tension results in a microscopic, localized "surface force" that exerts itself on fluid elements at interfaces in both the normal and tangential directions. Fluid interfacial motion induced by surface tension plays a fundamental role in many natural and industrial phenomena.

Surface tension at a free surface was modeled with a localized volume force prescribed by the continuum surface force (CSF) model. Instead of a surface tensile force or a surface pressure boundary condition applied at a discontinuity, a volume force acts on fluid lying within finite thickness transition regions continuously. Surface tension modeled with the continuum method eliminates the need for interface reconstruction, and can be easily calculated by applying Lagragean momentum equation for inviscid fluid which is given as;

$$\rho \frac{du}{dt} = -\nabla p + f_a \tag{3.1}$$

In Equation 3.1, u is the velocity, ρ is the fluid density, p is the scalar pressure, f_a is the force per unit interfacial area.

In its standard form, the surface tension force per unit interfacial area is

$$F_{sa}(x_s) = \sigma k(x_s) n(x_s) \tag{3.2}$$

Where σ , k, and n are the surface tension coefficient, the surface curvature and the unit normal to the surface at a point of x_s on a free surface.

It can be reformulated to as a volume force by satisfying Green's Theory:

$$\lim_{h \to 0} \int_{\Delta V} F_{sv}(x)dV = \int_{\Delta S} F_{sa}(x_s)dS \quad (3.3)$$

The volume force F_{sv} is identified as:

$F_{sv}(x)dV$ is the fluid color function, which varies smoothly over a thickness h of transition regions at an interface.

3.6.1 Calculation of Electromagnetic Force

The effect of welding current on the metal transfer includes the determination of the electromagnetic force, which is part of the body force in the momentum Eq. (3.1). According to Lorentz's law, the electromagnetic force generated by the welding current and self-induced magnetic field is expressed as:

$$F_m = J \times B \quad (3.4)$$

Where J is current density, and B is the magnetic flux density. The magnetic flux density of the self-induced magnetic field B is derived from Ampere's law

$$B_\theta = \frac{\mu_0}{x} \int_0^s J_y x dx \quad (3.5)$$

and the current density J is calculated from Ohm's law

$$J_x = -\sigma \frac{\delta \phi}{\delta x} \qquad J_y = -\sigma \frac{\delta \phi}{\delta y} \quad (3.6)$$

Therefore, the electromagnetic force is written as

$$F_m = -J_y B_\theta i + J_x B_\theta j \quad (3.7)$$

3.6.2 Modeling of Metal Transfer

Metal transfer occurs in a model as an unsteady incompressible viscous flow with strong surface tension on free surface. The electromagnetic force significantly influences the metal transfer process. The electric field, which was used to solve the electromagnetic force, is assumed to be quasi-steady state. An axisymmetric geometrical shape was used to model the shape of molten metal.

In the present work, a current density distribution on the droplet surface was proposed:

$$f(i,j)=\frac{1}{\sqrt{2\pi}}\exp(-\xi_{i,j}^{2}/2)$$

$$\xi_{i,j}=\frac{X_{i,j}}{D} \qquad (3.8)$$

Where Xi,j is the arc (curve) length on the droplet surface between the lowest point on the droplet and the free surface cell (i, j), and D is diameter of the electrode when the welding current is constant. The assumption was proposed based on the current density distribution over the surface of the underlying workpiece, for which a radially symmetric distribution was detected by experiments.

3.6.3 Calculation of Stress and Strain

When a force is applied to a structural member, that member will develop both stress and strain as a result of the force. Stress is the force carried by the member per unit area, and typical units are lbf/in^2 (psi) for US Customary units and N/m^2 (Pa) for SI units:

$$\sigma=\frac{F}{A} \qquad (3.9)$$

Where F is the applied force and A is the cross-sectional area over which the force acts. The applied force will cause the structural member to deform by some length, in proportion to its stiffness. Strain is the ratio of the deformation to the original length of the part:

$$\epsilon=\frac{L-L_0}{L_0}=\frac{\delta}{L_0} \qquad (3.10)$$

where L is the deformed length, L_0 is the original undeformed length, and δ is the deformation (the difference between the two).

3.6.4 Bending Stress (3-point)

The equation for bending stress is given as

$$\sigma_b = \frac{My}{I_c} \tag{3.11}$$

In the equation for bending stress, M is the bending moment, y is the distance between the centroidal axis and the outer surface, and I_c is the centroidal moment of inertia of the cross section about the appropriate axis.

3.6.5 Stiffness

Stiffness, commonly referred to as the spring constant, is the force required to deform a structural member by a unit length. All structures can be treated as collections of springs, and the forces and deformations in the structure are related by the spring equation:

$$F = k\ \delta_{max} \tag{3.12}$$

where k is the stiffness, F is the applied force, and δ_{max} is the maximum deflection deflection in the member.

If the deflection is known, then the stiffness of the member can be found by solving k = F/δ_{max}

equivalent of the of the spring equation is:

$$T = k\ \phi \tag{3.13}$$

Normal stress: $$\sigma_{\theta=} \frac{\sigma x + \sigma y}{2} + \frac{\sigma x - \sigma y}{2} \cos 2\theta + \tau \sin 2\theta \tag{3.14}$$

Shear Stress: $$\tau_{\theta=} \frac{\sigma x - \sigma y}{2} \sin 2\theta + \tau \cos 2\theta$$

(3.15)

At any point in the material, it is possible to find the angles of the plane at which the normal stresses and the shear stresses are maximized and minimized. The maximum and minimum normal stresses are called *principal stresses*. The maximum and minimum shear stresses are called the *extreme shear stresses*. The angles of the principal stresses and the extreme shear stresses are found by taking the derivative of each transformation equation with respect to θ and finding the value of θ where the derivative is zero.

Principal Stress Angles: $$\theta_{\sigma 1}\theta_{\sigma_2} = \frac{1}{2} arc\tan\left(\frac{2\tau}{\sigma_x - \sigma_y}\right)$$

(3.16)

Extreme Shear Stress Angle: $$\theta_{\sigma 1}\theta_{\sigma_2} = \frac{1}{2} arc\tan\left(\frac{\sigma_x - \sigma_y}{-2\tau}\right) \qquad (3.17)$$

The angles above can be substituted back into the transformation equations to find the values of the principal stresses and the extreme shear stresses:

Principal Stresses: $$\sigma_1, \sigma_2 = \frac{\sigma x + \sigma y}{2} + \sqrt{\left(\frac{\sigma x - \sigma y}{2}\right)^2 + \tau^2} \qquad (3.18)$$

Extreme Shear Stresses: $$\tau_1, \tau_2 = +\sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau^2} \qquad (3.19)$$

The angles at which the principal stresses occur are 90° apart. Principal stresses are always accompanied by zero shear stress. The angles at which the extreme shear stresses occur are 45° from the angles of the principal stresses. Extreme shear stresses are accompanied by two equal normal stresses of $\dfrac{\sigma_x - \sigma_y}{2}$

A couple useful relationships are:

The sum of the normal stress is constant $\sigma_x + \sigma_y = \sigma_x + \sigma_y$ (3.20)

The maximum shear stress is half the difference of the principal $\tau_1 = \dfrac{\sigma_1 - \sigma_2}{2}$ (3.21)

3.7 Mechanical Properties of Mild Steel Welded Joint

Mechanical properties of metals are used in mechanical designs and researches. These parameters are usual obtained from standard engineering table which were analysis of experimental results performed under standard laboratory condition. This study specifically focused on testing the tensile and flexural properties of oxyacetylene and shielded metal arc mild steel welded joints mechanically.

3.7.1 Description of Experimental Setup for Tensile Test

The universal testing machine is the main set up for conducting tensile and bending tests. The device has replaceable jaws that are capable of holding cylindrical and flat shaped specimen for tensile test. The lower section of the machine has accessories for conducting bend test as well. The modernized testing machine displays the experimental values on its monitor and the result was copied from the processing unit. Figure 3.7 is a picture of the universal tensile testing machine.

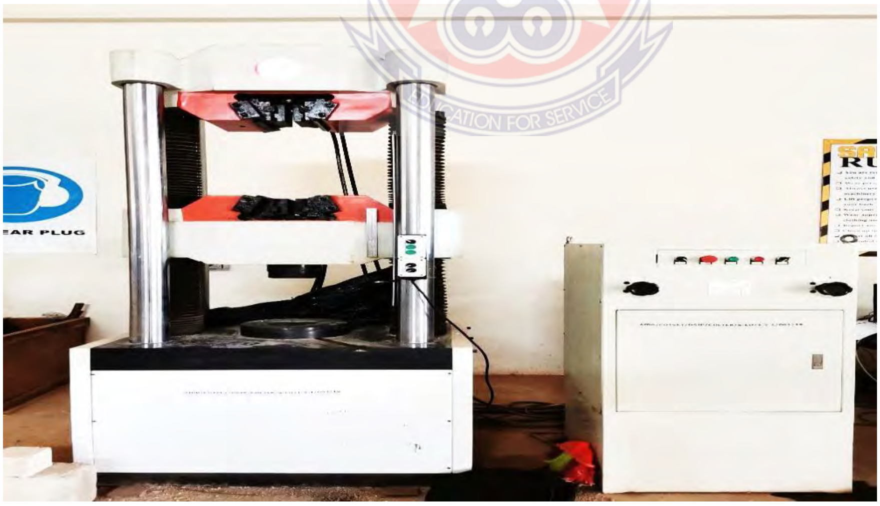


Figure 3.7 Universal testing machine – model WAW-1000H

The experiment was carried out using four samples specimen each totaling 16 pieces for each of butt and lap joints formed using oxyacetylene and shielded metal arc welding processes respectfully. In all, 32 samples specimen were tested. Before performing the tensile and bending tests on the sample specimen, each specimen was weighed on a digital balance and the weight recorded for each of the welded joints for both joints (butt and lap) so that the densities could be calculated. Figure 3.8 shows sample specimen being weighed. The tensile test was carried out using a universal tensile testing machine WAW-1000H. A sample of specimen was held in the upper and lower jaws of the tensile testing machine and pulled until failure occured. This process was repeated for all the 16 sample specimens. Figure 3.9 shows an experimental setup of a specimen in the tensile testing machine and Figure 3.10 shows how the specimens failed during the experimental process.

Fig 3.8 sample specimen being weighed

Figure 3.9 Tensile testing of specimen

Figure 3.10 Failure of specimen

Figure 3.11Sample specimens after tensile test

3.7.2 Bending Test

The test was carried out using four sample specimen each totaling sixteen pieces of butt and lap joints formed using oxyacetylene and shielded metal arc welding processes. Bend test was carried out using a universal tensile testing machine WAW-1000H. A sample of specimen was placed on the two-support stand set 200 mm apart of the tensile testing machine. The load to be applied to the sample specimen was lowered close to the sample but not touching it and then locked in position. The load was applied to the sample specimen as the machine gradually descended on it when it was powered to start operation. This process was repeated for all the 16 sample specimens. Figure 3.12 shows an experimental setup of a specimen in the tensile testing machine and Figure 3.13 shows how the specimens failed during the experimental process.

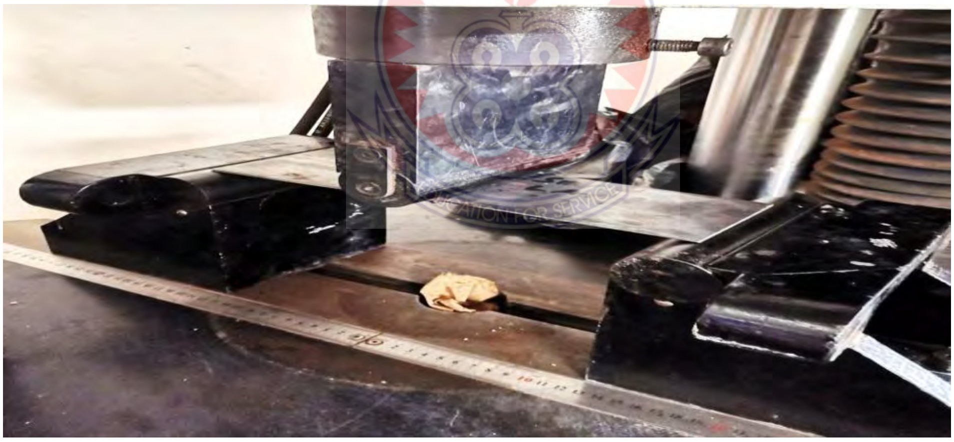


Figure 3.12 Bend testing of specimen

Figure 3.13 Bending behavior of specimen

Figure 3.14 Bent sample specimen

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter essentially presents the data collected from the experiments conducted and the detailed discussion of the results obtained from the outcome of the experiment.

4.2 Tensile Test Results for Butt Joint

Figure 4.1 shows the results of the tensile test conducted for the four-sample specimen for oxyacetylene and shielded metal arc butt joints executed. From the results, it can be seen that oxyacetylene butt joint recorded an average ultimate tensile strength of 288.75 N/mm^2 under an average force of 72.125 KN. The standard deviation and standard error of mean was 10.532 and 5.266 respectively. Shielded metal arc butt joint on the other hand, also recorded an average ultimate tensile strength of 256.75 N/mm^2 under an average force of 64.16 KN with 16.641 standard deviation and 8.320 standard error of mean. This means that in considering the two welding processes for butt joint, using A36 mild steel of 2.5 mm thickness, oxyacetylene welded joint had a higher tensile strength and could withstand much higher force than shielded metal arc.

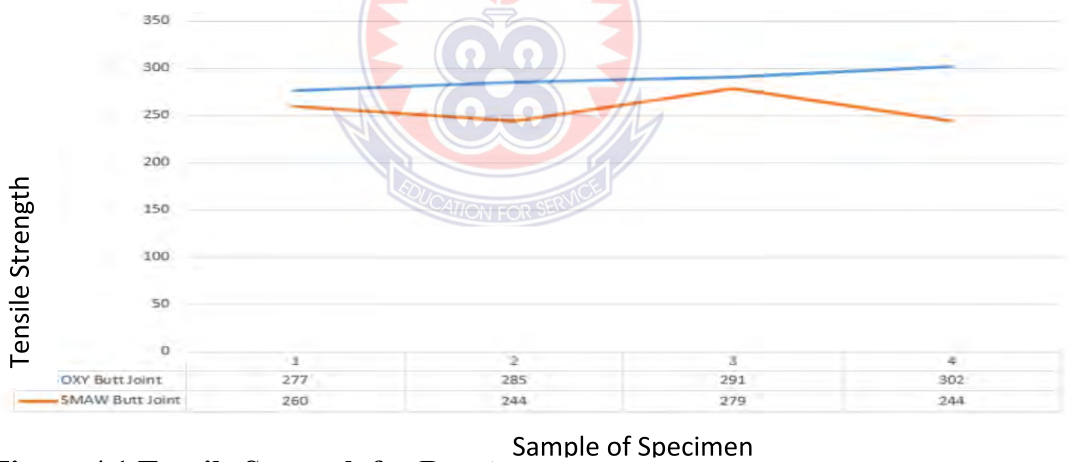
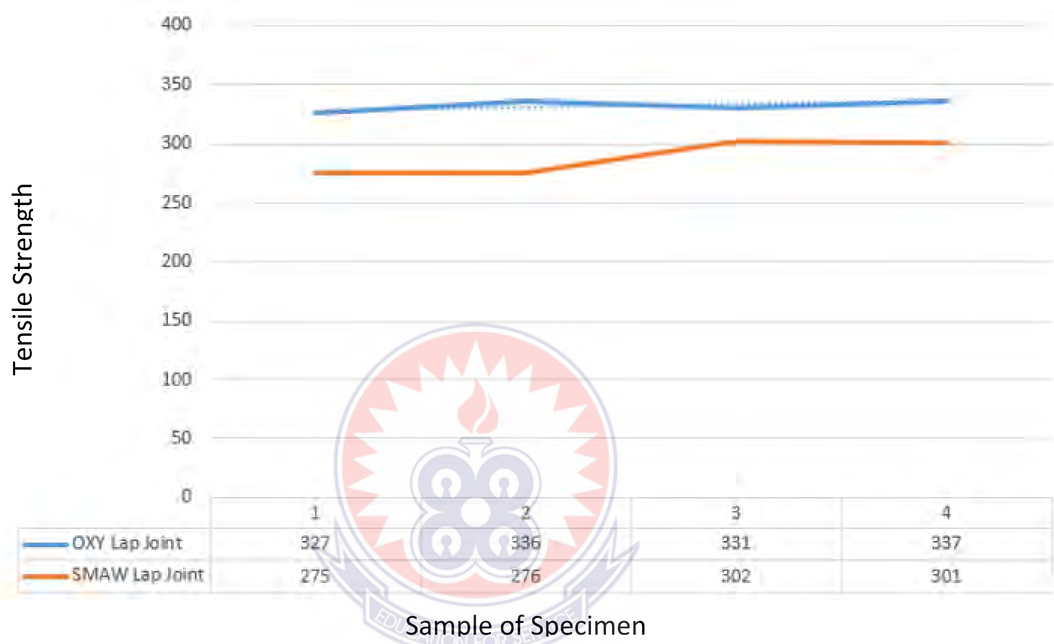


Figure 4.1 Tensile Strength for Butt Joint

4.3 Tensile Test Results for Lap Joint

Based on the results of tensile test conducted, (Figure 4.2) an average ultimate tensile strength of 332.75 N/mm^2 was obtained for the four-sample specimen under an average force of 83.19 KN for oxyacetylene welded lap joint. The standard deviation and standard error of mean was 4.646 and 2.323 respectively . In the same vein, shielded metal arc welded lap joint registered an average tensile strength of 288.50 N/mm^2 for the four-sample specimen under an average force of 72.13 KN with 15.022 standard deviation and 7.511 standard error of the mean. Here, it can be deduced and stated that in terms of lap joint, when considering the two welding processes using A36 steel of 2.5 mm thick, oxyacetylene welded joint had a higher tensile strength and could withstand much higher force than shielded metal arc welded joint.



	1	2	3	4
OXY Lap Joint	327	336	331	337
SMAW Lap Joint	275	276	302	301

Figure 4.2 Tensile Strength for Lap Joint

4.4 Density for the Tensile Test Results

Figure 4.3, shows that with oxyacetylene welded butt joint, an average density of 6334.38 kg/m^3 was obtained for the four-sample specimen of 320 mm x 100 mm x 2.5 mm each with 48.781 standard error of the mean. With the same sample size of 320 mm x 100 mm x 2.5 mm, an average density of 6325 kg/m^3 was recorded for shielded metal arc welded butt joint for the four-sample specimen with 39.857 standard error of of margin of the mean. This depicts that, in terms of density, oxyacetylene butt joint was slightly higher than shielded metal arc butt welded joint.

Again, from the data gathered, for density for the tensile test conducted, oxyacetylene welded lap joint had an average density of 7440 kg/m^3 with standard error of mean of 19.625 for the four-sample specimen each measured 300 mm x 100 mm x 2.5 mm for lap joint. An average density of 7256.67 kg/m^3 and 23.959 standard error of the mean was recorded by shielded metal arc lap welded joint for the four-sample specimen of the same size of 300 mm x100 mm x2.5 mm. The result apparently depicts that, in considering oxyacetylene lap welded joint and shielded metal arc lap welded joint, in terms of density, oxyacetylene lap welded joint was higher than shielded metal arc lap welded joint.

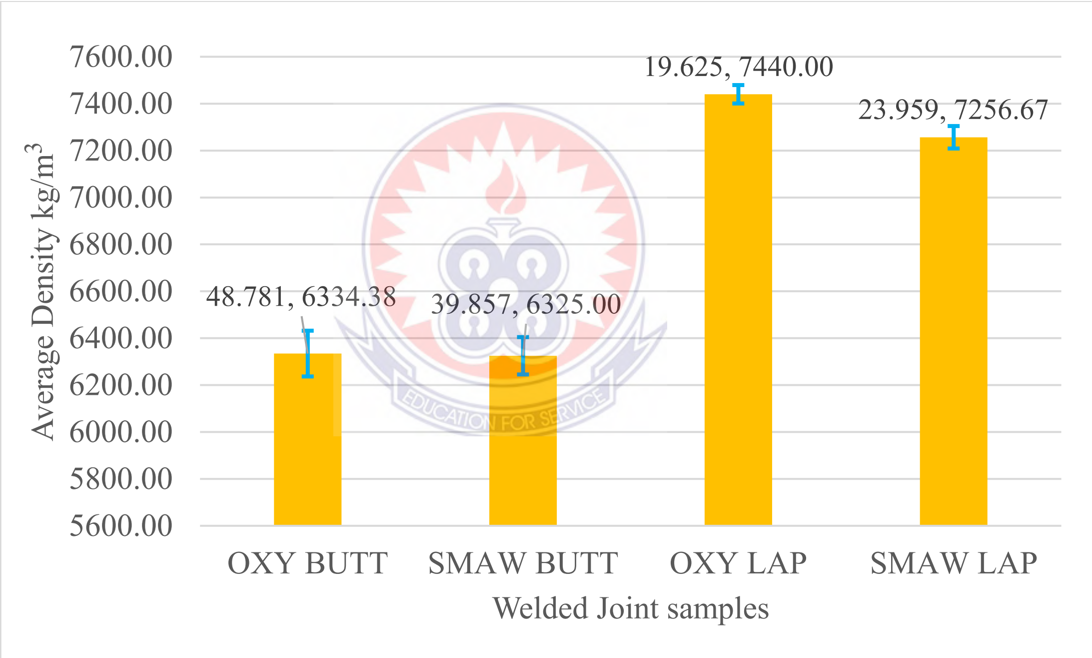


Figure 4.3 Average Density for Tensile strength

4.5 Modulus of Elasticity

Interesting revelation occurred from the modulus of elasticity data obtained in Figure 4.4. While in oxyacetylene butt welded joint, an average modulus of elasticity of 106.88 GPa and 16.006 standard error of the mean was obtained, an average of 120 GPa modulus of elasticity with 26.758 standard error of the mean was obtained for the shielded metal arc welded joint for the four-sample specimen for butt joint.

For lap joint, an average modulus of elasticity of 76.02 GPa was obtained for oxyacetylene welded joint with 18.836 standard error of the mean for the four-sample specimen while an average of 60.46 GPa with 16.901 standard error of the mean was registered by shielded metal arc lap welded joint. It can be stated here that, for modulus of elasticity, shielded metal arc butt joint was higher than oxyacetylene butt welded joint. For lap joint, oxyacetylene exhibited a higher modulus of elasticity than shielded metal arc.

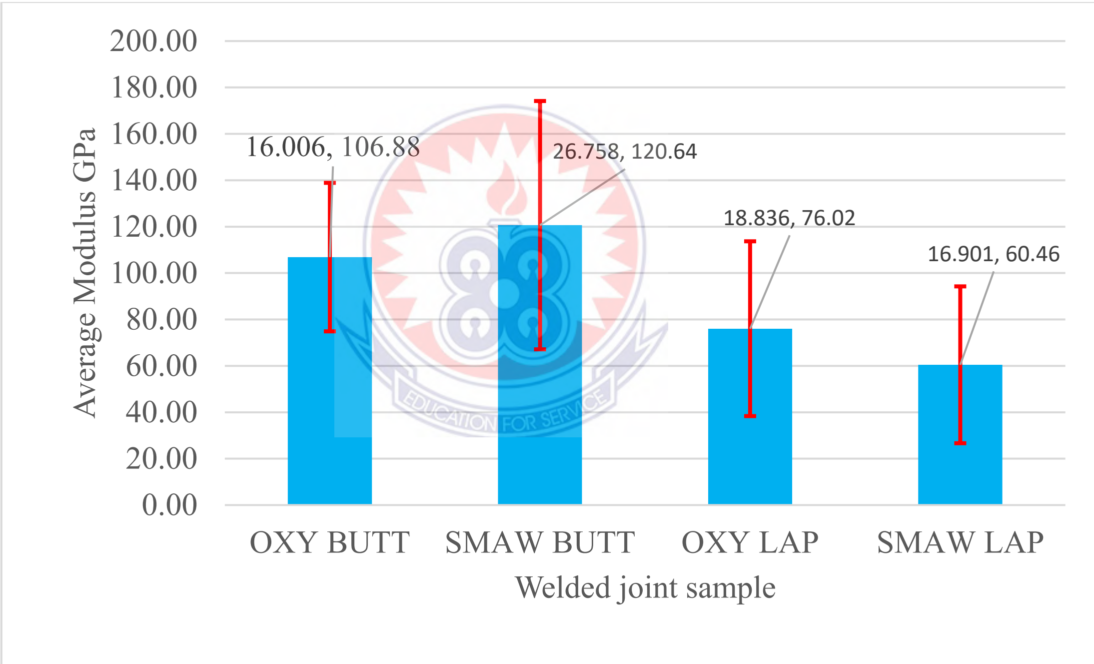


Figure 4.4 Average Modulus of Elasticity for Tensile Strength

4.6 Stress – Strain Analysis for Butt Joint

The stress-strain analysis shown in Figure 4.5 is the results which was generated from the experimental set up for tensile test. The plot was as a result as of the change in elongation of the test specimen.

A graph of stress was plotted against strain taking into account the two welded joints (butt and lap). From the graph, blue, and orange colors have been used to represent oxyacetylene welded butt joint, and shielded metal arc butt joint, respectively. It is clearly shown from the stress-strain analysis that, for butt joint, oxyacetylene recorded a maximum tensile stress of 288.75 N/mm^2 at a strain of 0.45. The material started failing when the strain had reached about 0.63. For shielded metal arc butt welded joint, the maximum stress was 256.75 N/mm^2 at a strain of 0.30. The joint failed when stain was around 0.32. Based on the figures obtained, it is evident that oxyacetylene butt welded joint sustained a higher stress and a corresponding higher strain than shielded metal arc butt welded joint which recorded a strain almost as twice as that of oxyacetylene butt welded joint when the material failed.

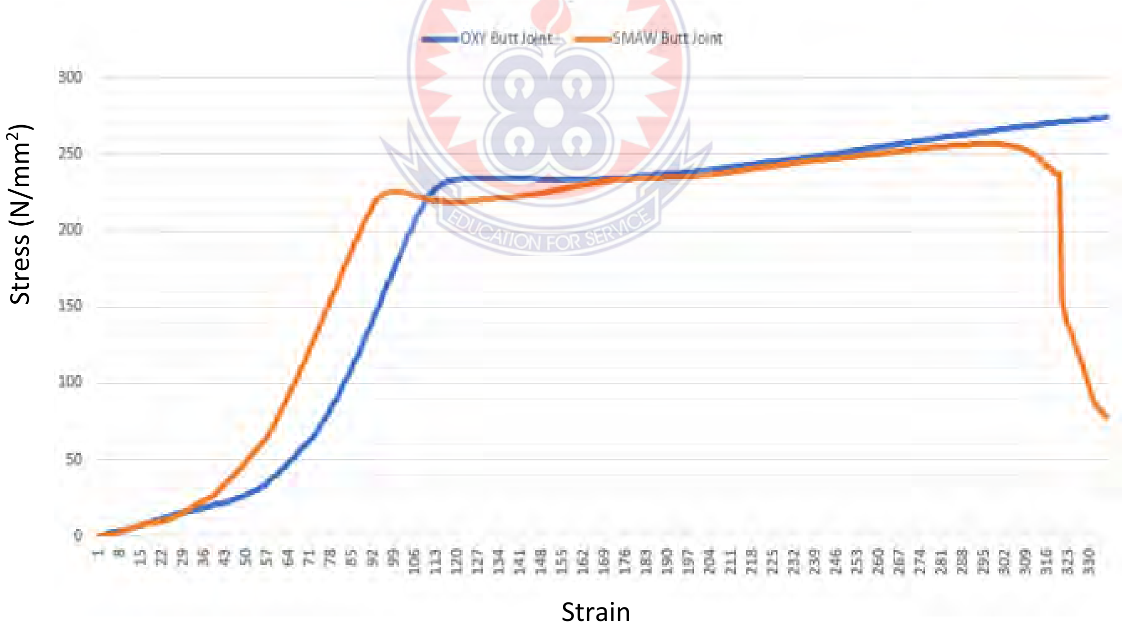


Figure 4.5 Stress-Strain for Butt Joint

4.7 Stress – Strain for Lap Joint

Based on the values obtained, in Figure 4.6, it can be seen from the stress-strain analysis that in making or establishing the relationship between oxyacetylene lap welded joint and shielded metal arc lap welded joint, oxyacetylene lap welded joint recorded the highest stress of 332.75 N/mm^2 at a strain of 0.8. Fracture occurred when the strain was 0.86. Shielded metal arc on the other hand, had a maximum stress of 288.5 N/mm^2 when the strain was about 0.5. The material failed when the strain was 0.6. It can be seen from the graph that there was a long overlap between the two welded joints with oxyacetylene lap welded joint on top and shielded matel arc welded lap joint beneath it. This confirms Hook's Law which states that , stress is directly proportional to strain. Which means that as stress increases, strain also increases accordingly. With this establishment, it is obvious that in making a comparative analysis in terms of stress-strain when oxyacetylene lap welded joint and shielded metal arc lap welded are being considered, oxyacetylene lap joint could withstand much higher stress with a higher corresponding strain than shielded metal arc lap welded joint.

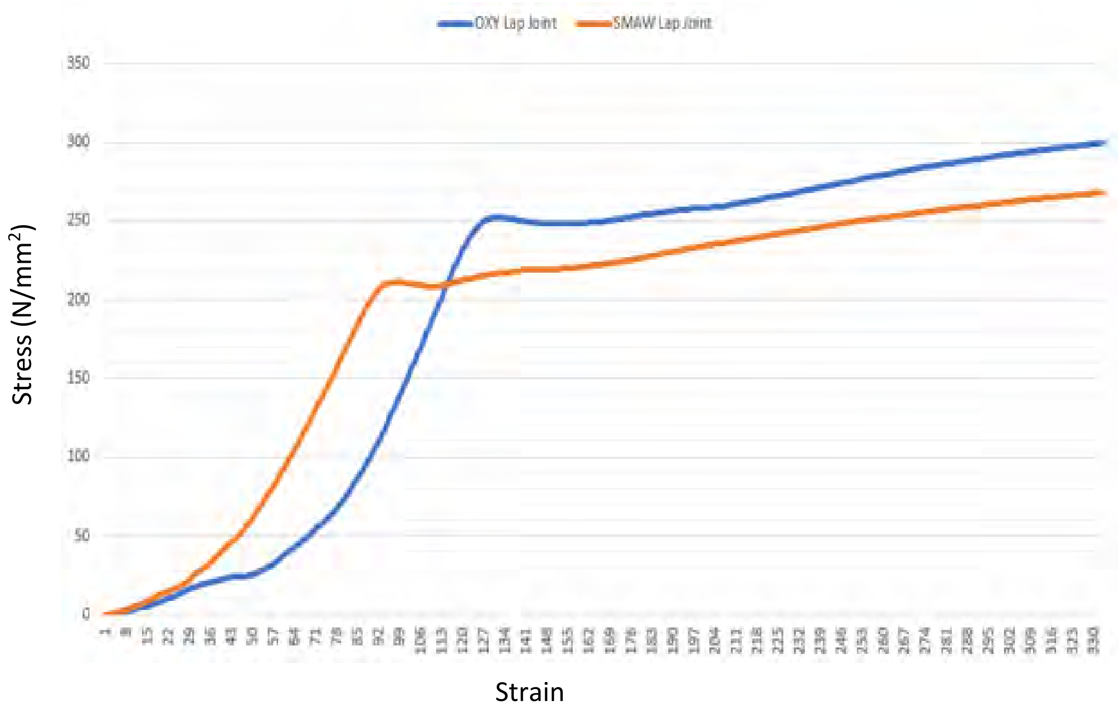


Figure 4.6 Stress-Strain for Lap Joint

4.8 Time – History Analysis for Butt Joint

The time history method used for structural systems are linearly elastic and some number of pre-defined nonlinear elements. The stress-time shown in Figure 4.7 predicts what happened during the tensile test between the oxyacetylene butt welded joint and shielded metal arc butt welded joint. Oxyacetylene welded butt joint maintaining a fair stress levels as the applied force increases gradually with shielded metal arc butt welded experiencincing a higher stress build up levels against time compared to oxyacetylene butt welded joint.

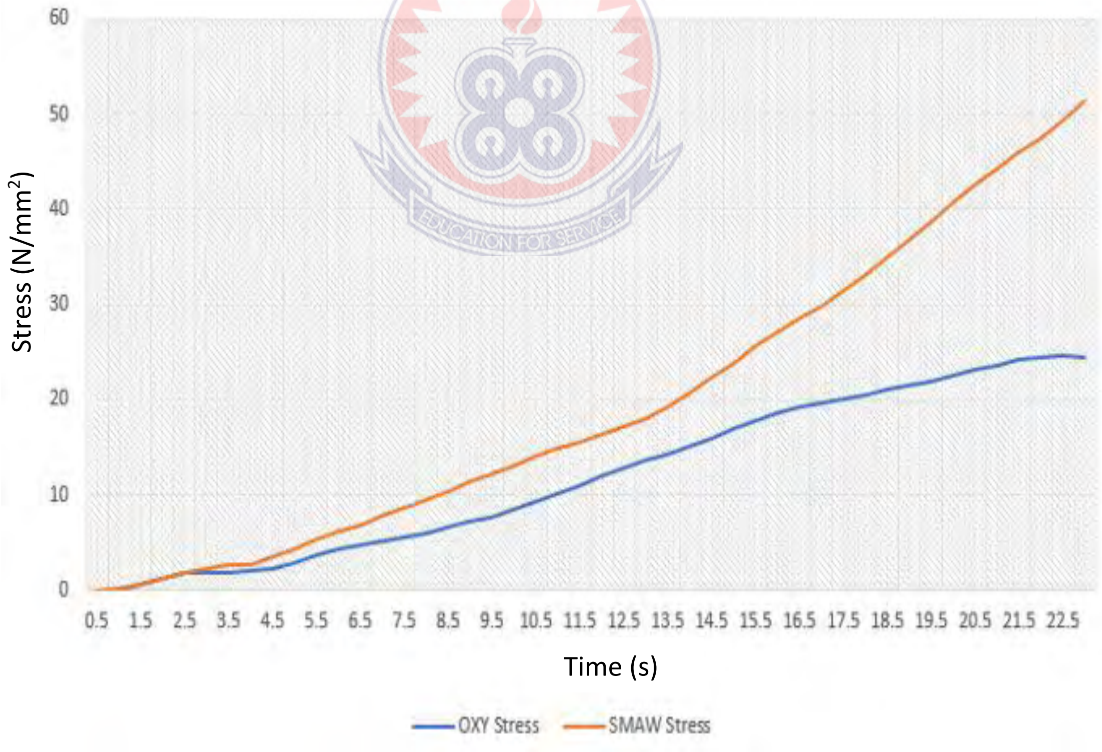


Figure 4.7 Time-History Analysis for Butt Joint

4.9 Time-History Analysis for Lap Joint

The stress-time graph shown in Figure 4.8 predicts what happened during the tensile test between the oxyacetylene lap welded joint and shielded metal arc lap welded joint at 22.5 seconds. The values of stress against time indicates a long curve for maintaining a constant rising gradient till attaining maximum stress value. The intersection of the two curves happening at the early stages and at the middle stages of the process indicate that the two welded joints exhibited similar characteristics with a high effect of force on the material, given shielded metal arc lap joint a high stress values against oxyacetylene lap welded joint keeping low stress values with increase in applied force.

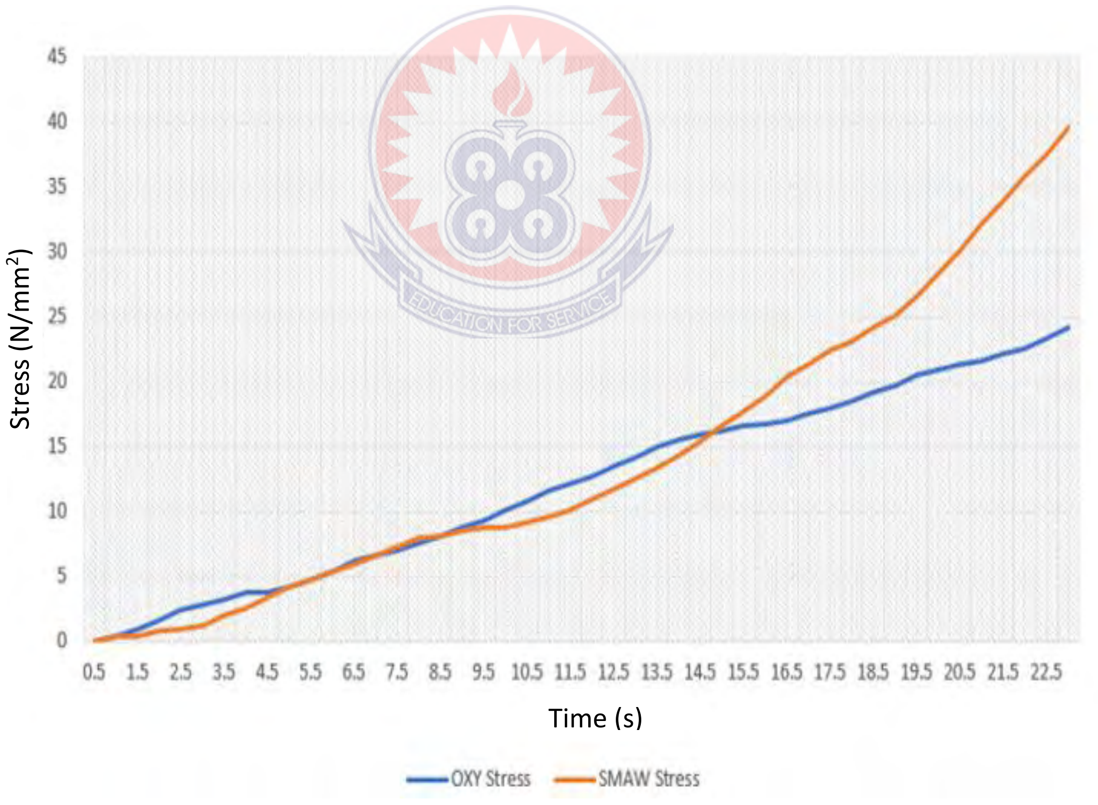


Figure 4.8 Time-History Analysis for Lap Joint

4.10 Average Bending Strength

Based on the results obtained for the bending test conducted on oxyacetylene welded butt and shielded metal arc butt welded joints of A36 mild steel plate of 2.5 mm thickness, Figure 4.9, oxyacetylene butt-welded joint recorded an average bending strength of 5.88 N/mm^2 under an average load of 0.59 KN with a standard error of mean of 0.239 for the four-sample specimen used while an average bending strength of 6.00 N/mm^2 by an average force of 0.60 KN with 0.000 standard error of mean was produced by shielded metal arc butt welded joint. With these results, it can be established here that, in considering bending strength of oxyacetylene and shielded metal arc butt welded joints, the latter appeared marginally higher than oxyacetylene butt welded joint.

Again, in considering oxyacetylene lap welded joint and shielded metal arc lap welded joint under bending strength, the results gathered from the test depict that, averagely, oxyacetylene lap welded joint recorded 6.38 N/mm^2 under an average load of 0.64 KN with 0.125 standard error of the mean for the four-sample specimen used. On the other hand, shielded metal arc lap welded joint generated an average bending strength value of 6.50 N/mm^2 under an average force of 0.65 KN with a standard error of the mean of 0.354 for the four-sample specimen employed. Based on the average bending strength values obtained, comparatively, shielded metal arc lap welded joint was slightly higher than oxyacetylene lap welded joint.

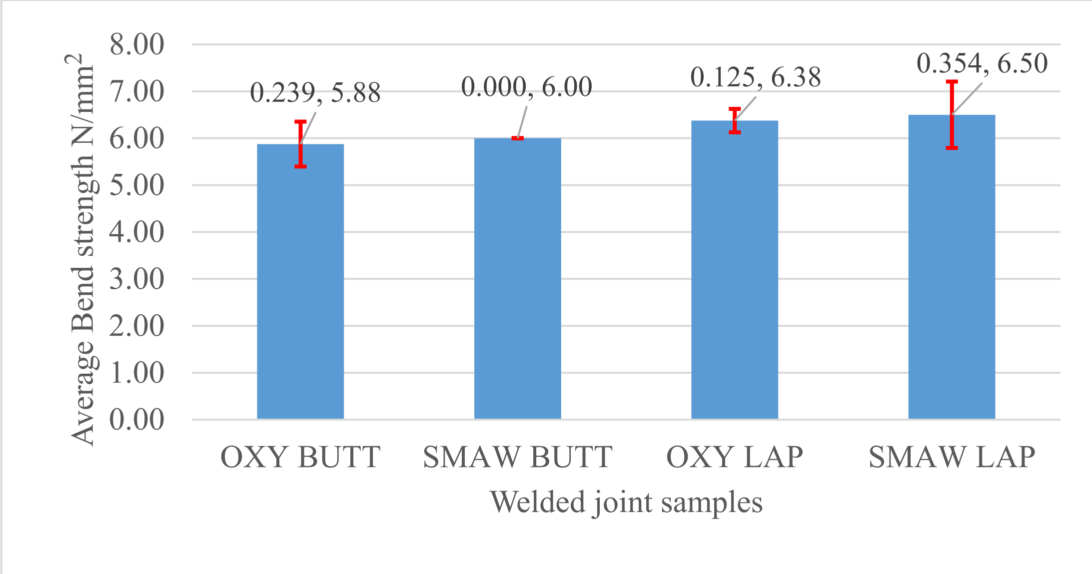


Figure 4.9 Average Bending strength

4.11 Average Density for Bending Strength

Presented results regarding densities of the bending test performed, Figure 4.10, showed that with oxyacetylene welded butt joint, an average density of 6275 kg/m^3 and 25.516 standard error of the mean was obtained for the four-sample specimen of 320 mm x 100 mm x 2.5 mm each. With the same sample size of 320 mm x 100 mm x 2.5 mm, an average density of 6325 kg/m^3 with 36.799 standard margin of error of the mean was recorded for shielded metal arc welded butt joint for the four-sample specimen. This depicts that, in terms of density, oxyacetylene butt-welded joint was slightly higher than shielded metal arc butt welded joint.

Again, from the data gathered, for density for the bending test conducted, oxyacetylene welded lap joint had an average density of 7020 kg/m^3 and 43..034 standard error of margin of the mean for the four-sample specimen each measured 300 mm x 100 mm x 2.5 mm for lap joint. An average density of 7180 kg/m^3 and 12.765 standard error of margin of the mean was recorded by shielded metal arc lap welded joint for the four-sample specimen of the same size of 300 mm x100 mm x2.5 mm. The result apparently depicts that, in considering oxyacetylene lap welded joint and shielded metal arc lap welded joint, in terms of density, oxyacetylene lap welded joint was higher than shielded metal arc lap welded joint.

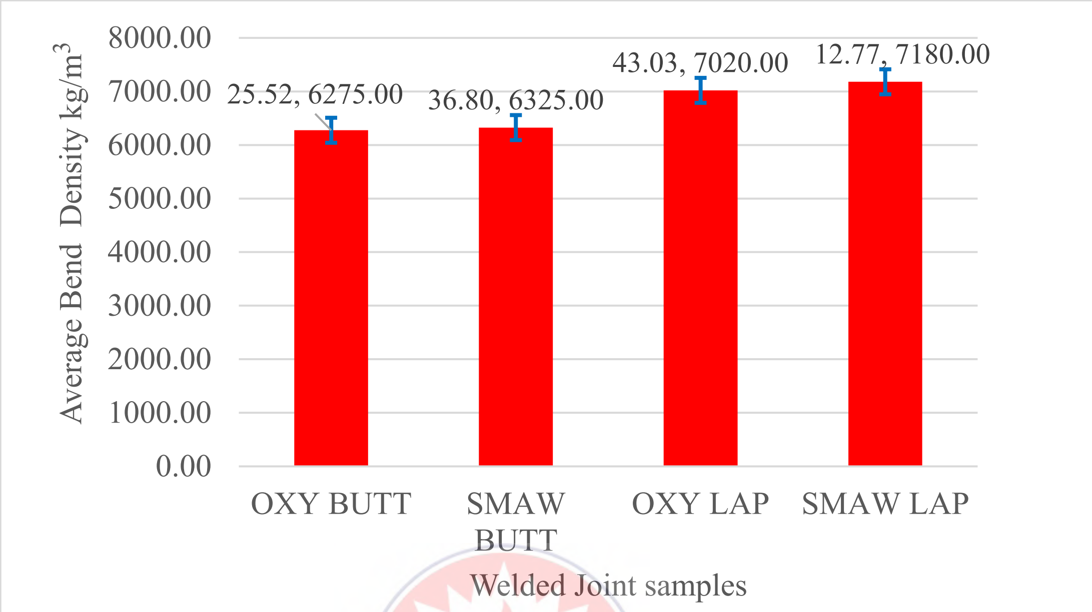


Figure 4.10 Average Density for Bending Strength

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter basically highlights on the summary of findings, conclusion, recommendations and suggestion for future study of the comparative analysis of the mechanical properties of oxyacetylene and shielded metal arc welded butt and lap joints executed using A36 mild steel plate of 2.5 mm thickness.

5.2 Summary of Findings

In this study an attempt was made to investigate or make a comparative analysis of tensile and bending strength of A36 2.5 mm thick mild steel plate welded by the processes of oxyacetylene and shielded metal arc welding (SMAW) to form butt and lap joints. The specimen, having been carefully welded were subjected to tensile and bening tests using universal testing machine WAW-1000H. Four test runs were performed for each welded joint (butt and lap). Analysis of the results obtained from the tests conducted showed that;

For tensile test conducted for the four sample specimen for oxyacetylene butt joint and shielded metal arc butt joint showed that oxyacetylene butt joint recorded an average ultimate tensile strength of 288.75 N/mm^2 under an average force of 72.125 KN. The standard deviation and standard error of the mean was 10.532 and 5.266 respectively. Shielded metal arc butt joint on the other hand, also recorded an average ultimate tensile strength of 256.75 N/mm^2 under an average force of 64.16 KN with 16.641 standard deviation and 8.320 standard error of the mean. An average ultimate tensile strength of 332.75 N/mm^2 was obtained for the four sample specimen under an average force of 83.19 KN for oxyacetylene welded lap joint. The standard deviation and standard error of the mean was 4.646 and 2.323 respectively . In the same vein, shielded metal arc welded lap joint registered an average tensile strength of 288.50 N/mm^2 with 15.022 standard deviation and 7.511 standard error of the mean for the four sample specimen under an average force of 72.13 KN.

For density, an average of 6334.38 kg/m^3 density was obtained for the four sample specimen of 320 mm x 100 mm x 2.5 mm for oxyacetylene butt welded joint with 48.781 standard error of margin of the mean. With the same sample size of 320 mm x 100 mm x 2.5 mm, an average density of 6325 kg/m^3 and a standard error of margin of the mean of 39.857. was recorded for shielded metal arc welded butt joint. Again, from the data gathered, for density for the tensile test conducted, oxyacetylene lap welded joint had an average density of 7440 kg/m^3 with 39.857 standard error of the mean for the four sample specimen each measured 300 mm x 100 mm x 2.5 mm for lap joint. An average density of 7256’67 kg/m^3 and 23.959 standard error of the mean was recorded by shielded metal arc lap welded joint for the four sample specimen.

For modulus of elasticity, interesting revelations occurred from the data obtained. While in oxyacetylene butt welded joint, an average modulus of elasticity of 106.88 GPa and 16.006 standard error of the mean was obtained, an average of 120 GPa modulus of elasticity and 16.006 standard error of the mean was obtained for the shielded metal arc welded butt joint for the four sample spcimen.

For lap joint, an average modulus of elasticity of 76.02 GPa was obtained for oxyacetylene welded joint with 18.836 standard error of the mean for the four sample specimen while an average of 60.46 GPa with 16.901 standard error of the mean was registered by shielded metal arc lap welded joint.

For stress-strain, for butt joint, oxyacetylene recorded a maximum tensile stress of 288.75 N/mm^2 at a strain of 0.45. The material started failing when the strain had reached about 0.63. For shielded metal arc butt welded joint, the maximum stress was 256.75 N/mm^2 at a strain of 0.30. The material failed when stain was around 0.32. Oxyacetylene lap welded joint recorded the highest stress of 332.75 N/mm^2 at a strain of 0.8. Fracture occurred when the strain was about 0.86. Shielded metal arc on the other hand, had a maximum stress of 288.5 N/mm^2 when the strain was about 0.5. The material failed when the strain was 0.6.

The experimentally obtained results for bending test conducted on oxyacetylene welded butt and shielded metal arc butt welded joints of A36 mild steel plate of 2.5 mm thickness, oxyacetylene butt welded joint recorded an average bending strength of 5.88 N/mm^2 under an average load of 0.59 KN with a standard error of the mean of 0.239 for the four sample specimen while an average bending strength of 6.00 N/mm^2 by an average force of 0.60 KN with a standard error of the mean of 0.000 was produced by shielded metal arc butt welded joint. On the other hand, shielded metal arc lap welded joint generated an average bending strength value of 6.50 N/mm^2 under an average force of 0.65 KN with a standard error of mean of 0.354 for the four sample specimen employed while oxyacetylene lap welded joint produced an average bending strength of 6.38 N/mm^2 under an average force of 0.64 KN with a standard error of mean of 0.125

Presented results regarding density of the bending test performed showed that with oxyacetylene welded butt joint, an average density of 6275 kg/m^3 and 25.516 standard error of mean was obtained for the four sample specimen of 320 mm x 100 mm x 2.5 mm each. With the same sample size of 320 mm x 100 mm x 2.5 mm, an average density of 6325 kg/m^3 and standard margin of erreor of mean of 36.799 was recorded for shielded metal arc welded butt joint for the four sample specimen. Oxyacetylene welded lap joint had an average density of 7020 kg/m^3 with 43.034 standard error of mean for the four sample for lap joint. An average density of 7180 kg/m^3 and 12.765 standard error of mean was recorded by shielded metal arc lap welded joint for the four sample specimen of the same size.

5.3 Conclusion

In this study, oxyacetylene and shielded metal arc welding processes were experimentally compared using the output results obtained from the mechanical tests performed on the welded joints of A36 mild steel plate of 2.5 mm thick. Tensile test data indicated that both the weldments undergo a ductile type of fracture. However, the oxyacetylene welded joint produced a higher ultimate tensile strength compared with shielded metal arc welded joint. Where in oxyacetylene lap welded joint, an average maximum ultimate tensile strength of 332.75 N/mm^2 was obtained for the four sample specimen, shielded metal arc lap welded joint, recorded an average maximum ultimate tensile strength of 288.50 N/mm^2. For butt joint, oxyacetylene recorded an average tensile strength of 288.75N/mm^2 as against 256.75 N/mm^2 for shielded metal arc welded joint. It is believed that the low tensile strength registered by the shielded metal arc welding process in the tensile test of both the lap and butt joints was as a result of the higher heat generated by the arc.

However, in considering the bending strength of oxyacetylene butt and lap welded joints and shielded metal arc butt and lap welded joints where the joined workpiece would or might be subjected to bending working conditions, shielded metal arc butt and lap joints appeared to be slightly beneficial as it recorded a higher bending strength of

6325 N/mm^2 and 7180 N/mm^2 for butt and lap joints respectively as against 6275 N/mm^2 and 7020 N/mm^2 for oxyacetylene welded butt and lap joints respectively.

The study extends knowledge by showing how a metal behaves with different joining techniques under tensile and bending situations. Gaining the knowledge and understanding of the underlying issues in welding will make the decision of selecting the appropriate method of welding easier. Practically, the outcome from the experiment, offers a nuanced view of when a particular material with a particular joint proves scientifically resilient for engineering applications.

5.4 Recommendations

Based on the results obtained experimentally in this study, it can be recommended to welding practitioners, engineers and fabricators that, for tensile strength, using 2.5 mm thick mild steel plate, oxyacetylene butt and lap welded joints should be used compared with shielded metal arc butt and lap welded joints as the former could withstand much higher tensile strength than the latter.

However, in considering bending strength and density of oxyacetylene and shielded metal arc butt and lap welded joints, shielded metal arc butt and lap welded joints appeared slightly beneficial than the other.

5.5 Suggestion for Future Study

The following suggestions outlined for future research will widen the knowledge base of a comparative analysis of mechanical properties of mild steel plate using oxyacetylene and shielded metal arc welding processes for lap and butt joints;

The research focused on the mechanical properties of two welding joints (lap and butt) using an electrode E 8018 as the filler metal. Similar study can be conducted on other types of welding joints with different welding electrode such as E 7018 or E 6013.

In this study, a comparative analysis of tensile and bending strength of 2.5 mm mild steel plate using oxyacetylene and shielded metal arc welding processes were considered. It will equally be good to conduct a similar research on the microstructure of the selected material using the same two welding processes.

Finally, similar or same research work could be carried out on a thicher plate or bar with thickness ranging between 3 mm and 6 mm using the same or different electrodes as the filler metal.

REFERENCES

Acherjee, B., Mondal, S., Tudu, B. & Misra, D. (2011). *Application of artificial neural network for predicting weld quality in laser transmission welding of thermoplastics.* Appl. Soft Comput. 11(2): 2548–2555.

Akkas, N., Karayel, D., Ozkan, S. S., Ogˇur, A., & Topal, B. (2013). *Modeling and analysis of the weld bead geometry in submerged arc welding by using adaptive neurofuzzy inference system. Math.* Problems Eng. doi: 10.1155/2013/473495.

Alipooramirabad, H., Paradowska, A., Ghomashchi, R., Reid, M. (2017). *Investigating the effects of welding process on residual stresses, microstructure and mechanical properties in HSLA steel welds. J. Manuf. Process.* 28, 70–81.

American Welding Society (AWS) (2015). *Welding Inspection Handbook,* 4e. Miami,

Ashby, M.F. (2018). *Materials Selection in Mechanical Design,* 5e. Oxford, UK: Butterworth-Heinemann/Elsevier Ltd.

Balasubrarnanian, J., Lakshrninarayanan, V. (2008). Mechanical Properties of GMAW, GTAW and FSW Joint" of RDE-40 Aluminium Alloy [J:J, *International Journal of Microstructure and Materials Properties.* 3(6): 837.

Balasuramanian, V., Shanmugam, K., Lakshminarayanan, A.K. (2009).Tensile and Impact Properties of Shielded Metal Arc Welded Ferritic Stainless Steel Joint" *International Journal of Materials Science*

Bralla, J. G. (2009). *Handbook of Product Design for Manufacturing,* Second Edition, McGraw-Hill, New York, USA.

Callister, W.D. Jr. & Rethwisch, D.G. (2013). *Materials Science and Engineering:* An Introduction, 9c. Hoboken, NJ: Wiley.

Cary, H. B. (2001). *Modern Welding Technology,* Fourth Edition, Prentice-Hall, Inc., USA.

Chen, C., Zhang, X., Zhao, M., Lee, C.-K., Fung, T.C., Chiew, S.-P. (2017). *Effects of Welding on the Tensile Performance of High Strength Steel T-stub Joints. Structures,* 9, 70–78.

Choi, J. H., Lee, J., & Yoo, C. D. (2001). *"Dynamic Force Balance Model for Metal Transfer Analysis in Arc Welding",* J. Phys. D: Appl. Phys., Vol.34, pp.2658-2664.

David, S. A., & Debroy, T. (2017), "Current Issues and Problems in Welding Science", *Journal of of Science,* Vol. 41, No. 6, pp 566-570

Davies, A. C. (2004). *Welding, Tenth Edition,* Cambridge University Press, UK.

Derek Pritchard (2001). *Soldering, Brazing and Welding;* A Manual of Techniques, Paperback Edition, The Crowood Press Ltd., UK, ISBN 1-86126-391-0.

Dhas, J. E. R. & Kumanan, S. (2010). *Neuro hybrid model to predict weld bead width in submerged arc welding process.* J. Scientific Ind. Res. 69: 350–355.

Dundjer, M., Samardžic´, I., ´Coric´, A., Salopek, G.(2018). *Effects of real welding parameters of high-strength* S1100QL steel on hardness and impact energy properties. Metallurgy, 57, 242–244.

Durmusoglu, S¸.; Türker, M.; Tosun, M. (2015). *Effect of welding parameters on the mechanical properties of GMA-welded HY-80 steels.* Mater. Test. 57, 866–871.

Farag, M. M. (2002). *Quantitative methods of materials selection*. In: Kutz M, editor. Handbook of materials selection. Wiley and Sons, Inc. New York.

Farag, M. M. (2008). *Quantitative methods of materials substitution: application to automotive components.* Mater Des; 29:374–80.

Gao X-L, Zhang L-J, Liu J, et al.(2013). *A comparative study of pulsed Nd:YAG laser welding and TIG welding of thin Ti6Al4V titanium alloy plate.* Mater Sci Eng 559: 14–21.

Ghosh, A., Mukherjee, S., Chattopadhyaya, S. & Sarkar, P. (2007). *Weld bead parametric estimation of SAW process through neural network.* Ind. Welding J. 40(4): 33.

Gourd, L. M. (2014). *Principles of Welding Technology,* Third Edition, Published by Edward Arnold, A Division of Holder Headline PLC, UK.

Groover, Mikell, P. (2002). *Fundamentals of Modern Manufacturing, Materials Processes and Systems,* Second Edition, John Wiley and Sons, Inc. USA.

Haslberger, P., Holly, S., Ernst, W., & Schnitzer, R. (2018). *Microstructure and mechanical properties of high-strength steel welding consumables with a minimum yield strength* of 1100 MPa. J. Mater. Sci. 53, 6968–6979.

Hibbeler, R.C. (2016). *Mechanics of Materials,* 10e. Upper Saddle River, NJ: Pearson Publishing.

Hosseinioun, M., Moeini, G., Konke, C., Tahaei, A. (2017). *Investigations on multi-run metal made of HSLA steel – Heterogeneous microstructure and mechanical properties.* Mater. Test. 59, 662–672.

Kiran, D., Basu, B. & De, A. (2012). *Influence of process variables on weld bead quality in two wire tandem submerged arc welding of HSLA steel.* J. Mater. Process. Technol. 212(10): 2041–2050.

Leonard, P., Connor, F. (2013). *Welding Handbook,* Eighth Edition, Volume 1, Welding Technology.

Lin, Q., Li, X., & Simpson, S. W. (2001). *"Metal Transfer Measurements in Gas Metal Arc Welding",* J. Phys. D: Appl. Phys., Vol.34, pp.347-353

Messler, R. W. Jr. (2019). *A Practical Guide to Welding Solutions: Overcoming Technical and Material-Specific Issues,* Weinheim/New York, NY: Wiley-VCH Verlag/ Wiley.

Messler, R.W. Jr. (2011). *The Essence of Materials for Engineers.* Sudbury, MA: Jones

Mikell P., Groover, (2002), *Fundamentals of Modern Manufacturing, Materials Processes and Systems,* Second Edition, John Wiley and Sons, Inc. USA. Montgomery C. Douglas, and Runger C. George, (2011). Physical Metallurgy of Steel Weldability, John Wiley and Sons, Inc.

Modenesi et al, (2000). Welding with Single- Component Fluxes. *Journal of Materials Processing Technology,* Vol. 99, Issues 1-3, pp. 260-265.

Nagesh, D. and Datta, G. (2002). *Prediction of weld bead geometry and penetration in shielded metal-arc welding using artificial neural networks*. J. Mater. Process. Technol. 123(2): 303–312.

Nagesh, D., and Datta, G. (2010). *Genetic algorithm for optimization of welding variables for height to width ratio and application of ANN for prediction of bead geometry for TIG welding process.* Appl. Soft Comput. 10(3): 897–907.

Nový, F., Boku˚vka, O., Trško, L., Jambor, M. (2019). *Safe choice of structural steels in a region of ultra-high number of load cycles.* Prod. Eng. Arch. 24, 25–28.

Otakar, B., Liptáková, T.,Palcˇek, P., Chalupová, M., Trško, L. (2013). *The Influence of Welded Joint Quality on Safety and Reliability in Operation.* Prod. Eng. Arch. 2013, 1, 6–9.

Rao, R. V. (2008). *A decision making methodology for material selection using an improved compromise ranking method.* Mater Des; 29:1949–54.

Raveendra, J., & Parmaris, R. (2000). *Mathematical models to predict weld bead geometry for flux cored arc welding.* Metal Constr. 19(1): 31.

Sathiya, P., Panneerselvam, K., & Jaleel, M. A. (2012). *Optimization of laser welding process parameters for super austenitic stainless steel using artificial neural networks and genetic algorithm.* Mater. Des. 36: 490–498.

Saxena, A., Kumaraswamy, A., Reddy, G.M., Madhu, V. (2018). *Influence of welding consumables on tensile and impact properties of multi-pass SMAW Armox 500T steel joints vis-a-vis base metal.* Def. Technol. 14, 188–195.

Sen, M., Mukherjee, M., & Pal, T. K. (2014). *Prediction of weld bead geometry for double pulse gas metal arc welding process by regression analysis.* Fifth International and 26th All India Manufacturing Technology, Design and Research Conference, 814-6, IIT Guwahati.

Sidhu, S., & Chatha, S, S. (2012). Int. J. Emerg. Technol. Adv. Eng. pp.746–750.

Wang, G., Huang, P. G., and Zhang, Y. M. (2003). *"Numerical Analysis of Metal Transfer in Gas Metal Arc Welding",* Metall. Mater. Trans. B, Vol.34B, pp.345-353

Wang, Y., & Tsai, H. L. (2001). *"Effects of Surface Active Elements on Weld Pool Fluid Flow and Weld Penetration in GMAW",* Metall. Mater. Trans. Vol.32, pp.501-515.

Wu, C. S., Wang, L, Ren, W. J. et al. (2014). *Plasma arc welding:* process, sensing, control and modeling. J Manuf Proc 16(1): 74–85.

Xiong, J., Zhang, G., Hu, J. & Wu, L. (2014). *Bead geometry prediction for robotic GMAW-based rapid manufacturing through a neural network and a second-order regression analysis.* J. Intell. Manuf. 25(1): 157–163.

Zhang, X.Z.; Zhao, M.S.; Chiew, S.P.; Lee, C.K.; Fung, T.C. (2016). *Influence of welding on the strength of high performance steels.* In Proceedings of the Australasian Structural Engineering Conference, ASEC, Barton, Australia, 23–25, November; pp. 311–320.

APPENDICES

APPENDIX A - ABREVIATIONS

AI – Artificial Intelligence

ANFIS – Artificial Neural Fuzzy Interface System

ANN – Artificial Neural Networks

AWS – American Welding Society

BPNN – Back Propagation Neural Network

CFD – Computational Fluid Dynamics

CSF – Continuum Surface Force

DFBM – Dynamic Force Balance Model

FCAW – Flux core Arc Welding

FL – Fuzzy Logic

GMAW – Gas Metal Arc Welding

GTAW – Gas Tungsten Arc Welding

HAZ – Heat Affected Zone

MIG – Metal Inert Gas

MRA – Multiple Regression Analysis

NHM – Neuro Hybrid Model

OAW – Oxyacetylene Welding

OFW – Oxy Fuel Welding

SFBT – Static Force Balance Technique

SMAW - Shielded Metal Arc Welding

So – Stick Out

TIGW – Tungsten Inert Gas Welding

Ts – Traverse Speed

VOF – Fractional Volume of Fluid

Wf – Wire Feed

APPENDIX B

KEY WORDS AND DEFINITIONS

Adhesive – A substance (such as glue or cement) that is used to make things stick together.

Arc length – It is the distance between the part that has to be welded and the electrode tip.

Bonding agent – A substance used for holding metal, plastic, ceramic, and composite materials together.

Brazing – it is a process of joining two or more metal pieces together by melting and flowing a filler metal, usually borax into the joint. The filler metal has a lower melting point than the parent metal being joined.

Carburizing flame – When the amount of acetylene exceeds the amount of oxygen, then carburizing flame is produced.

Current density – In electromagnetism, current density is the amount of charge per unit time that flows through a unit area of a chosen cross section.

Deformation – The action or process of changing in shape or distorting, especially through the application of force or pressure.

Density – It is defined as mass per unit volume of a substance

Electromagnetic force – It is a type of physical interaction that occurs between electrically charged particles. This force can be attractive or repulsive.

Filler metal – It is the metal to be added in making a welded, brazed, or soldered joint to fill and strengthen it.

Flux – Substances usually applied or used when soldering, brazing, silver soldering to clean and prevent formation of new oxides at the joint.

Forge – Shaping a metal by heating and hammering it on an anvil.

Fusion welding – Welding process in which the parent metal pieces being joined are fused together into a molten pool and allowed for solidification.

Galvanized – Coated iron or steel with a protective layer of zinc.

Heat affected zone –In welding, the heat affected zone is the area of base material either a metal or a thermoplastic, which is not melted but has had its microstructure and properties altered by welding or heat intensive cutting operations.

Magnetic flux density – This is defined as the amount of magnetic flux passing through a unit area placed perpendicular to the direction of magnetic field. It is a vector quantity, usually denoted by B. The SI unit of magnetic flux density is Tesla (T).

Mechanical fastening – It is the use of bolts and nuts, screws studs, and rivets to join metal or plastic pieces together either temporally or permanently.

Metal transfer -- Metal transfer describes the process of the molten metal movement from the electrode tip to the workpiece across the arc in gas metal arc welding

Model – A system or a thing used as an example to follow or imitate; thus the miniature form of an intended artefact, unit, or object.

Modulus of elasticity – It is a quantity that measures an object or substance's resistance to being deformed elastically when a stress is applied to it. It is the slope of stress-strain curve in the elastic deformation region.

Molten metal – Metal in a liquid form.

Neutral flame – This is the type of welding flame in which the amount of oxygen is equal to the amount of acetylene.

Oxidizing flame – This flame is generated when the amount of oxygen is more than that of acetylene.

Parent metal – The metal being welded, brazed or soldered.

Polarity – Way of connecting the ends of the electrode and the worktable to the positive and negative terminals of the welding machine.

Preheating – Prior heating of the parent metal to be cut before the use of cutting pressure using neutral oxyacetylene welding flame.

Shielded Metal Arc Welding – It is a type of arc welding in which a flux covering is used to join the two metal pieces together. It uses a consumable electrode that has a flux covering on it that gives off shielding gas to protect the weld area against atmospheric contamination.

Slag – It is elongated lines either continuous or discontinuous along the length of the weld which forms a shielding gas that cover the hot weld pool and the arc from atmospheric contamination.

Solder – It is an alloy of lead and tin.

Soldering – It is the process of joining metal pieces together permanently using solder.

Spatter –It is a splash droplets of molten metals that are generated at or near the welding arc.

Weld bead –This occurs as a result of a welding pass that deposits filler material into a joint.

Weld pool – This refers to dime-sized workable portion of a weld where the base metal has reached its melting point and is ready to be infused with filler material.

Welding – It is the process of joining two metal workpieces together to form one unit.

Welding current – It is the term used to describe the electricity that jumps across the arc gap between the end of the electrode and the metal being welded.

Welding speed – This is the speed of travel of the torch.

APPENDIX C

TABLES OF TENSILE TEST RESULTS

Tensile Strength and Modules Results

Sample name	Sample Number	Area mm^2	Force kN	Stress/strength N/mm^2	Modulus GPa
OXY Butt joint	1	250	69.15	277	151.76
	2	250	71.25	285	105.33
	3	250	72.7	291	92.94
	4	250	75.4	302	77.5
	Average	**250**	**72.125**	**288.75**	**106.88**
SMAW Butt joint	1	250	65.05	260	97.04
	2	250	60.95	244	118.1
	3	250	69.7	279	195.71
	4	250	60.95	244	71.72
	Average	**250**	**64.1625**	**256.75**	**120.64**
OXY Lap joint	1	250	81.65	327	35.92
	2	250	84.05	336	126.15
	3	250	82.7	331	64.44
	4	250	84.35	337	77.56
	Average	**250**	**83.1875**	**332.75**	**76.02**
SMAW Lap joint	1	250	68.85	275	108.57
	2	250	69	276	52.65
	3	250	75.5	302	29.36
	4	250	75.15	301	51.25
	Average	**250**	**72.125**	**288.5**	**60.46**

Density for the Tensile Results

Sample name	**Sample Number**	**Length mm**	**Width mm**	**Thickness mm**	**Volume mm3**	**Mass kg**	**Density kg/m^3**
OXY Butt joint	1	320	100	2.5	80000	0.500	6250.00
	2	320	100	2.5	80000	0.500	6250.00
	3	320	100	2.5	80000	0.514	6425.00
	4	320	100	2.5	80000	0.513	6412.50
	Average	**320**	**100**	**2.5**	**80000**	**0.507**	**6334.38**
SMAW Butt joint	1	320	100	2.5	80000	0.515	6437.50
	2	320	100	2.5	80000	0.501	6262.50
	3	320	100	2.5	80000	0.502	6275.00
	4	320	100	2.5	80000	0.506	6325.00
	Average	**320**	**100**	**2.5**	**80000**	**0.506**	**6325**
OXY Lap joint	1	300	100	2.5	75000	0.557	7426.67
	2	300	100	2.5	75000	0.558	7440.00
	3	300	100	2.5	75000	0.562	7493.33
	4	300	100	2.5	75000	0.555	7400.00
	Average	**300**	**100**	**2.5**	**75000**	**0.558**	**7440**
SMAW Lap joint	1	300	100	2.5	75000	0.545	7266.67
	2	300	100	2.5	75000	0.539	7186.67
	3	300	100	2.5	75000	0.547	7293.33
	4	300	100	2.5	75000	0.546	7280.00
	Average	**300**	**100**	**2.5**	**75000**	**0.544**	**7256.67**

Average Tensile Strength N/mm^2				
Sample Number	OXY Butt joint	SMAW Butt joint	OXY Lap joint	SMAW Lap joint
1	277	260	327	275
2	285	244	336	276
3	291	279	331	302
4	302	244	337	301
Mean (Average)	**288.75**	**256.75**	**332.75**	**288.5**
Standard Deviation	**10.532**	**16.641**	**4.646**	**15.022**
Standard Error of Mean	**5.266**	**8.320**	**2.323**	**7.511**

Tensile Strength Modulus GPa

Sample No.	OXY BUTT	SMAW BUTT	OXY LAP	SMAW LAP
1	151.76	97.04	35.92	108.57
2	105.33	118.1	126.15	52.65
3	92.94	195.71	64.44	29.36
4	77.5	71.72	77.56	51.25
Mean (Average)	**106.88**	**120.64**	**76.02**	**60.46**
Standard Deviation	**32.001**	**53.517**	**37.672**	**33.801**
Standard Error of Mean	**16.006**	**26.758**	**18.836**	**16.901**

Average Density for Tensile Strength kg/m^3				
Sample No.	OXY BUTT	SMAW BUTT	OXY LAP	SMAW LAP
1	6250.00	6437.50	7426.67	7266.67
2	6250.00	6262.50	7440.00	7186.67
3	6425.00	6275.00	7493.33	7293.33
4	6412.50	6325.00	7400.00	7280.00
Mean (Average)	**6334.38**	**6325.00**	**7440.00**	**7256.67**
Standard deviation	**97.561**	**79.713**	**39.250**	**47.917**
Standard Error of Mean	**48.781**	**39.857**	**19.625**	**23.959**

APPENDIX D

TABLES OF BEND TEST RESULTS

Bend Strength Test Results						**Density for Bend Test Results**							
Sample name	Sample Number	Area mm^2	Force kN	Stress/ strength N/mm^2	Modulus GPa	Sample name	Sample Number	Length mm	Width mm	Thickness mm	Volume mm^3	Mass kg	Density kg/m^3
OXY Butt joint	1		0.65	6.5		OXY Butt joint	1	320	100	2.5	80000	0.508	6350.00
	2		0.60	6			2	320	100	2.5	80000	0.501	6262.50
	3		0.55	5.5			3	320	100	2.5	80000	0.5	6250.00
	4		0.55	5.5			4	320	100	2.5	80000	0.499	6237.50
	Average		**0.59**	**5.88**			Average	**320.00**	**100.00**	**2.50**	**80000.00**	**0.50**	**6275.00**
SMAW Butt joint	1		0.6	6		SMAW Butt joint	1	320	100	2.5	80000	0.512	6400.00
	2		0.6	6			2	320	100	2.5	80000	0.502	6275.00
	3		0.6	6			3	320	100	2.5	80000	0.51	6375.00
	4		0.6	6			4	320	100	2.5	80000	0.5	6250.00
	Average		**0.60**	**6.00**			Average	**320.00**	**100.00**	**2.50**	**80000.00**	**0.51**	**6325.00**

	1		0.65	6.5			1	300	100	2.5	75000	0.536	7146.67
	2		0.65	6.5			2	300	100	2.5	75000	0.523	6973.33
OXY Lap joint	3		0.6	6		OXY Lap joint	3	300	100	2.5	75000	0.522	6960.00
	4		0.65	6.5			4	300	100	2.5	75000	0.525	7000.00
	Average		**0.64**	**6.38**			Average	**300.00**	**100.00**	**2.50**	**75000.00**	**0.53**	**7020.00**
	1		0.55	5.5			1	300	100	2.5	75000	0.54	7200.00
	2		0.65	6.5		SMAW Lap joint	2	300	100	2.5	75000	0.54	7200.00
SMAW Lap joint	3		0.7	7			3	300	100	2.5	75000	0.538	7173.33
	4		0.7	7			4	300	100	2.5	75000	0.536	7146.67
	Average		**0.65**	**6.50**			Average	**300.00**	**100.00**	**2.50**	**75000.00**	**0.54**	**7180.00**

Sample name	Average Bend Strength N/mm^2						Sample name	Density kg/m3	
OXY Butt joint	5.88						OXY Butt joint	6275	
SMAW Butt joint	6.00						SMAW Butt joint	6325	
OXY Lap joint	6.38						OXY Lap joint	7020	
SMAW Lap joint	6.50						SMAW Lap joint	7180	

Density for Bend Test Results				
Sample No.	OXY BUTT	SMAW BUTT	OXY LAP	SMAW LAP
1	6350	6400	7146.67	7200
2	6262.5	6275	6973.33	7200
3	6250	6375	6960	7173.33
4	6237.5	6250	7000	7146.67
Mean (Average)	6275.00	6325.00	7020.00	7180.00
Standard deviation	51.031	73.598	86.069	25.530
Standard Error of Mean	25.516	36.799	43.034	12.765

Bend Strength Test Results				
Sample No.	OXY BUTT	SMAW BUTT	OXY LAP	SMAW LAP
1	6.5	6	6.5	5.5
2	6	6	6.5	6.5
3	5.5	6	6	7
4	5.5	6	6.5	7
Mean (Average)	5.88	6.00	6.38	6.50
Standard deviation	0.479	0.000	0.250	0.707
Standard Error of Mean	0.239	0.000	0.125	0.354