OPTIMIZATION PROCESS FOR DETERMINING ACCEPTABLE WELDING PARAMETERS USING SWARA-ARAS METHOD

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CERTIFICATION

This is to certify that this project was undertaken in accordance with the regulations and requirement of the Department of Production Engineering, University of Benin, Benin City, by **JAMES GOODLUCK MADUKA,**

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DEDICATION

This project work is dedicated to God Almighty for His love, mercy and goodness in our lives and for giving me strength to carry out this work and also to my parents for their support towards my studies.

ACKNOWLEDGEMENT

I give God all the glory, the most compassionate and the most merciful for giving me the strength and opportunity to finish this project.

I like to also express gratitude towards our supervisor, Prof. J.I. Achebo for giving me the guidance, support and ideas in completing this project.

Finally, I am also using this opportunity to acknowledge and then my parent Elder and Mrs. James Okoroafor, my sibling and my friends who in one way or the other have helped in completion of my studies.

ABSTRACT

Optimization of process parameter to improve on weld joint quality has been at the centre of global research. Some optimization methods have produced welds of low strength and quality whereas , some have made remarkable improvements on the quality of welded joints. In this study, the SWARA-ARAS method was adopted to access its effect on the quality of the obtained welded joints.

Stepwise Weight Assessment Ratio Analysis (SWARA) method was used to determine the geometric mean of weights for each of the output parameters that is the mechanical test and measurement results.

Additive Ratio Assessment (ARAS) was applied to optimize these parameters by utilizing the weights generated by using SWARA. From applying the SWARA-ARAS method, weldment 8, was found to possess the best input and output parameters.

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CHAPTER ONE

1.0 Introduction

1.1 Preamble

Gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) and metal active gas (MAG) is a welding process in which an electric arc forms between a consumable MIG wire electrode and the workpiece metal(s), which heats the workpiece metal(s), causing them to fuse (melt and join). Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from atmospheric contamination.

Welding input parameters play a very significant role in determining the quality of a weld joint. The joint quality can be defined in terms of properties such as weld-bead geometry, mechanical properties, and distortion. Generally, all welding processes are used with the aim of obtaining a welded joint with the desired weld-bead parameters, excellent mechanical properties with minimum distortion. The welding parameters must also be properly controlled in order to achieve an effective and accurate welding performance. Weld mechanical properties must be assessed in order to accomplish this. Weld mechanical properties are assessed not only by experiments, but also by experts in the field. Physical examination of the weld specimen and subsequent scoring or ranking using the Likert Scale Preference Method may be required as part of the expert evaluation (LSPM).

Metal works and parts that fail when forces are applied are commonly found to be affected by the retrogressive nature of their welded joints, according to experts. This failure is linked to flaws in the application of various input process parameters including welding current, welding voltage, gas flow rate, and welding speed, among others. As a result, careful selection of the most suitable welding parameters is needed to achieve the required optimum weld joint quality. Gas Metal Arc Welding, which is widely used in construction and manufacturing, has proven to be more effective than other welding methods. Some of the characteristics that set it apart from other welding processes are High reliability, all-position capability, ease of use, low cost, High productivity, Suitable for both ferrous and non-ferrous metals, high deposition rate, flux-free, leanliness and mechanization

The weld process parameters must be configured in order to achieve the above features. Some researchers have worked in this field, such as Yam et al. (2017), who used the Fitness Sharing Genetic Algorithm to optimize multi-objective arc welding parameters (FSGA). FSGA was proposed as a way to save energy and increase thermal efficiency.

Pondi P. Achebo suggested using the Taguchi method to optimize GMAW parameters to boost weld ultimate tensile strength (UTS) and to determine the degree of contribution of each input weld parameter (voltage, current, weld time, and weld speed) on the UTS answer parameter. Via Taguchi's orthogonal experiment array design, signal-to-noise ratio, and Grey relational analysis, Sarfcar and Das optimized the weld metal toughness, bending load at a bend angle of 10°, geometry of weld bead reinforcement, and depth of penetration of GMAW on stainless steel specimens. Rizvi, Tewari, and Ali incorporated the Taguchi technique into the MIG welding process parameter on IS2062 steel. The signal-to-noise functions were responsible for the optimization, and the L16 orthogonal array was set. The degree of contribution of the input welding parameters was also determined using an ANOVA. The Taguchi method was used by Yousefieh, Shamanian, and Saatchi to optimize the pulsed current gas tungsten arc welding (PCGTAW) parameters for the corrosion resistance of super duplex stainless steel (UNS S32760) welds as a DOE technique. Yao, Zhou, Lin, Xu, and Yue used the grey relational based process to explore the weld bead forming rule and verify the weld parameter effects using the double-pulsed GMAW technique, resulting in a new method for weld bead forming. Based on the GMAW additive manufacturing process parameters, Waqas, Qin, Xiong, Wang, and Zheng optimized the effective area of deposition, and the mechanical and microstructural properties of a multi-layer weld were investigated. The weld bead and its formation mechanism were studied by Zhang and Xue. Each test used a different amount of current, and the weld profile was calculated using the gas metal arc welding process. Yao, Zhou, and Huang also used an optimization method focused on welding robot input parameters. These variables were grouped into nine three-level experiments in an orthogonal experimental framework. The mechanical properties of the weld were then assessed. Kurt, Oduncuoglu, Yilmaz, Ergul, and Asmatulu investigated the effects of weld parameters using an arc stud welding process and two approaches, one based on a Taguchi approach and the other based on an artificial neural network, before comparing the two methods based on the experimental findings. Schneider, Lisboa, Silva, and Lermen investigated weld bead geometry and optimized it using the Taguchi method of 27 experiments, but the welding process was TIG in this case.

The above study work band experiment demonstrates that welding process parameter optimization is critical for producing a perfect weldment.

Expert evaluation of mild steel weldment was used in this study to optimize the mechanical properties of the weldment using the SWARA-ARAS process.

A step-by-step approach to the SWARA-ARAS method is clearly elucidated in this analysis.

1.2 History of Welding

One of the most important phase in modern metal fabrication is welding. Is a fabrication technique for joining materials, typically metals or thermoplastics, by melting them together and allowing them to cool, resulting in fusion. Welding differs from lower-temperature metal-joining methods like brazing and soldering in that welding does not melt the base metal. Welding's invention is linked to the discovery and shaping of metals. The history of metals begins with the discovery and shaping of copper, bronze, silver, gold, and iron in ancient civilizations. After that, metalworking moved on to steel. Gold ornaments are considered to be the first welded parts.

Until the Industrial Revolution in the 1700s and 1800s, when metal modernization began, technology remained largely unchanged. Forge welding technology was used at the time. Its operation is based on the use of heated metal to tie two parts together. Furthermore, Until the late 1800s, the only welding method was forge welding, which had been used by blacksmiths for centuries to join iron and steel by heating and hammering. Late in the century, arc welding and oxy-fuel welding were among the first processes to emerge, preceded by electric resistance welding. As the market for efficient and affordable joining methods grew during the early twentieth century, welding technology advanced rapidly. Following the wars, many modern welding techniques were developed, including manual methods such as shielded metal arc welding, which is now one of the most widely used, as well as semi-automatic and automatic processes such as gas metal arc welding, submerged arc welding, flux-cored arc welding, and electro-slag welding. In the latter half of the century, developments progressed with the advent of laser beam welding, electron beam welding, magnetic pulse welding, and friction stir welding. Robot welding is now popular in industrial settings as technology advances, and researchers continue to develop new welding methods and gain a better understanding of weld efficiency.

Morehead and Wilson discovered how to produce acetylene by mistake in 1892. The hottest flame temperature was found to be 5720 degrees F when acetylene and oxygen were combined. The acetylene welding process evolved quickly since this is far above the melting point of most metals.

The carbon electrode welding method was first demonstrated in 1881 by a Russian inventor named Benardos. An arc was formed between the work and basically a moderately consumable carbon electrode. A rod was added to provide the extra metal that was needed. Oscar Kjellberg, the founder of ESAB, invented and patented the covered electrode in 1904. This electric welding process produced excellent quality, solid welds in a short amount of time.

Many new welding techniques were developed around the turn of the century. Kyle Taylor was the first to introduce stud welding in 1930, and it quickly became common in shipbuilding and construction. Submerged arc welding was developed in the same year and is still widely used today. Konstantin Khrenov, a Russian, was the first to use underwater electric arc welding in 1932. After decades of progress, gas tungsten arc welding was finally mastered in 1941, followed by gas metal arc welding in 1948, which allowed for quick welding of non-ferrous materials but required costly shielding gases. Shielded metal arc welding, which uses a flux-coated consumable electrode, was invented in the 1950s and quickly became the most common metal arc welding method. The flux-cored arc welding process, in which the self-shielded wire electrode could be used with automatic equipment, resulting in greatly improved welding speeds, was introduced in 1957, and Robert Gage invented plasma arc welding the same year. Electro-slag welding was first developed in 1958, and its cousin, electro gas welding, was introduced in 1961. The diffusion bonding method was suggested by Soviet scientist N. F. Kazakov in 1953.

Other recent welding breakthroughs include the 1958 invention of electron beam welding, which allowed deep and narrow welding using a focused heat source. Laser beam welding debuted several decades after the invention of the laser in 1960, and has proven to be particularly useful in high-speed, automated welding. Since 1967, magnetic pulse welding (MPW) has been used in industry. Wayne Thomas of The Welding Institute (TWI, UK) invented friction stir welding in 1991, and it has since found high-quality applications all over the world. Due to the high cost of the required equipment, all four of these modern processes are still very costly, which has restricted their implementations. This new method of welding reduces or even removes the risks that welding poses to humans. In the future, the welding process will only improve and become more advanced.

However, it all began with the discovery of acetylene at the turn of the nineteenth century, which allowed for the use of a controllable welding source. Modern welding, on the other hand, began to take shape in the early twentieth century, at the same time as electricity became more commonly available.

Since the military needed welding methods and technology quickly during World Wars I and II, innovation in welding methods and technology began to emerge. Welding was not used to connect metals in critical structures such as ships until after World War II.

The Co2 Welding process and its increasingly growing popularity dominated the 1950s, or the time immediately following WWII. Many of the major advancements in modern welding, on the other hand, occurred in the 1960s. Electro slag, Inner shield, and Dual shield welding are examples of these advances or advancements. Plasma arc welding was another significant breakthrough during this decade.

In the year 1970, a slew of new soldering techniques were developed, many of which were designed to aid electronic miniaturization. Infrared, hot gas, and vapour phase were among them.

TWI invented Friction Stir Welding in 1991, ushering in the most recent era of modern welding. However, it was eight years later that the critical next breakthrough in welding was made: a technique for greatly increasing flux penetration into a weld. Magnetic pulse welding was launched a year later.

With the advancement of Gas Metal Arc Welding-Brazing and the use of laser technology and a lap joint in aluminium and low-carbon steel welding in the same year, we saw metal composites being welded for the first time. This is how modern welding has progressed over time.

1.3 Basic Principles of Welding

A weld is a metal coalescence formed by heating to a suitable temperature with or without pressure and with or without the use of a filler material.

A heat source creates and maintains a molten pool of metal of the necessary size in fusion welding. Electricity or a gas flame may also be used to provide heat. Since molten metal is created during electric resistance welding, it is called fusion welding.

Without melting the base material or adding a filler metal, solid-phase processes achieve welds. Pressure is often used, and heat is usually given as well. Ultrasonic and friction joining generate frictional heat, while diffusion bonding typically uses furnace heating.

Welding uses an electric arc, which is a high-current, low-voltage discharge with a current range of 10–2,000 amperes and a voltage range of 10–50 volts. An arc column is made up of a cathode that emits electrons, a gas plasma for current conduction, and an anode area that becomes hotter than the cathode as a result of electron bombardment. Normally, a direct current (DC) arc is used, but AC arcs may also be used.

Since not all of the heat produced can be efficiently used, total energy input in all welding processes exceeds that which is needed to produce a joint. Efficiencies range from 60% to 90%, depending on the process; some unique processes deviate significantly from this figure. Heat is lost to the environment by conduction through the base metal and radiation.

When hot, most metals react with the air or other metals in the vicinity. A welded joint's properties can be severely harmed by these reactions. When molten, most metals, for instance, oxidize quickly. The proper bonding of the metal can be hampered by a coating of oxide. Oxide-coated molten metal droplets become entrapped in the weld and cause the joint to become brittle. When exposed to the air, some useful materials added for particular properties react so quickly that the metal deposited does not have the same composition as it did before. Fluxes and inert atmospheres have been used to solve these issues.

Flux plays a defensive role in fusion welding by promoting a regulated metal reaction and then preventing oxidation by forming a blanket over the molten metal. Fluxes can be active and aid the process, or they can be passive and simply protect the surfaces during the joining process. Similar to fluxes, inert atmospheres provide protection. An inert gas—usually argon flows continuously from an annulus around the torch, displacing the air from around the arc in gas-shielded metal-arc and gas-shielded tungsten-arc welding. The gas does not react chemically with the metal; instead, it protects it from oxygen in the air. Metal entering metallurgy is critical to the joint's functionality. The arc weld depicts all of a joint's essential characteristics. When a welding arc passes through, three zones emerges: The fusion region, also called the weld metal, the heat-affected zone is the second type of zone,the region that has not been impacted.

The weld metal is the molten part of the joint. The heat-affected zone is an area adjacent to the weld metal that hasn't been welded but has changed microstructure or mechanical properties as a result of the welding heat. The substance that was not heated enough to change its properties is the unaffected material.

The structure of the weld metal and the conditions under which it freezes (solidifies) have a big impact on the joint's ability to perform. The weld metal in arc welding is made up of filler metal and molten base metal. The weld metal cools quickly after the arc passes. A cast structure exists in a one-pass weld, with columnar grains extending from the molten pool's edge to the weld's core. Depending on the type of metal being welded, this cast structure can be changed in a multi-pass weld.

The heat-affected region, or base metal adjacent to the weld, is exposed to a variety of temperature cycles, and its structural change is proportional to the peak temperature at any given stage, exposure time, and cooling rates. While there are far too many different forms of base metal to cover here, they can be divided into three categories: Welding-unaffected materials, materials that have been structurally altered have become harder, precipitation processes hardened the materials.

Welding causes materials to become stressed. These forces are caused by the weld metal contracting and the heat-affected zone expanding and contracting. The unheated metal restricts the above, and as contraction takes precedence, the weld metal is unable to contract freely, causing tension to build up in the joint. This is often referred to as residual stress, and it must be eliminated in some important applications by heat treating the entire fabrication. In all welded structures, residual stress is inevitable, and if it is not managed properly, the weldment will bow or distort. Welding process, jigs and fixtures, construction techniques, and final heat treatment are all used to keep things under control.

1.4 Statement of the Problem

There have been some shortcomings found in welded metals. Bad quality welded joints were discovered to be the source of these limitations.

Any of the input process parameters, such as welding current, welding voltage, gas flow rate, welding speed, and so on, could cause this failure. To achieve the desired optimum weld join efficiency, it is necessary to select the appropriate welding parameters with care.

By selecting the required process parameters, optimal weld joint quality will hold or maintain the engineered load for an extended period of time without failure. This is only possible if the appropriate optimization model or approach is used.

1.5 Aim and Objective of the Study

The aim of this study is to use the SWARA-ARAS method to test and optimize the Mild Steel Weld process parameters.

The following are the objectives: Assess the weldments mechanical properties, to use the SWARA-ARAS method to monitor the input parameters of current, voltage, and gas flow rate in order to optimize the output parameters of bead penetration, impact energy, and ultimate tensile strength, to evaluate and discuss the optimal weldment properties' effects.

CHAPTER TWO

2.0 Literature Review

2.1 Gas Metal Arc Welding

Gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) is a welding process in which an electric arc forms between a consumable MIG wire electrode and the work-piece metal(s), which heats the work-piece metal(s), causing them to fuse (melt and join). Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from atmospheric contamination. The process can be semi-automatic or automatic. GMAW, also known as metal inert gas (MIG) welding, is a type of gas-shielded welding generally used in the manual mode but can be automated. The filler wire also is the electrode, and it is supplied in coils of solid bare wire. The coil is fed automatically into the joint, melted in the arc, and deposited in the weld groove. Alloying elements arc in the wire, and the shielding inert gas may be argon, helium, nitrogen, carbon dioxide, or a combination of these gases, depending on the application. A constant voltage, direct current power source is most commonly used with GMAW, but constant current systems, as well as alternating current, can be used. There are four primary methods of metal transfer in GMAW, called globular, short-circuiting, spray, and pulsed-spray, each of which has distinct properties and corresponding advantages and limitations. Originally developed in the 1940s for welding aluminium and other non-ferrous materials, GMAW was soon applied to steels because it provided faster welding time compared to other welding processes. The cost of inert gas limited its use in steels until several years later, when the use of semi-inert gases such as carbon dioxide became common. Further developments during the 1950s and 1960s gave the process more versatility and as a result, it became a highly used industrial process. In 1948, GMAW was developed by the Battelle Memorial Institute. It used a smaller diameter electrode and a constant voltage power source developed by H. E. Kennedy. It offered a high deposition rate, but the high cost of inert gases limited its use to non-ferrous materials and prevented cost savings. In 1953, the use of carbon dioxide as a welding atmosphere was developed, and it quickly gained popularity in GMAW, since it made welding steel more economical. In 1958 and 1959, the short-arc variation of GMAW was released, which increased welding versatility and made the welding of thin materials possible while relying on smaller electrode wires and more advanced power supplies. It quickly became the most popular GMAW variation. The spray-arc transfer variation was developed in the early 1960s, when experimenters added small amounts of oxygen to inert gases. More recently, pulsed current has been applied, giving rise to a new method called the pulsed spray-arc variation. Gas metal arc welding (GMAW) is mostly applied in chassis parts, where it is important to secure the strength and rigidity of the joint. The process also has the freedom to join parts of various shapes to structural members such as pipes and brackets. Long fatigue life of the weld joint is a prerequisite. Spatter, fit-up and gap issues need to be dealt with in parts formed during welding. Certain component designs preclude the use of resistance spot welds. Further, there are closed parts that cannot be reached with resistance spot welding guns. For such applications, the GMAW process is preferred.

The GMAW process is also known as metal inert gas or metal active gas welding. Carbon dioxide is the active shielding gas in the latter process. Consumables with matching strengths are preferred to meet the mechanical property requirements of the joint, but lower-strength wires have been used to attain mechanical properties by depositing extra material. One can refer to auto steel partnership program reports in which welding parameters and weld joint properties for various AHSS combinations have been reported (A/SP Joining Technologies, 2004). Consumable ER70S3 wires and shielding gas comprising 90 percent argon and 10 percent carbon dioxide produced acceptable welds.

Higher heat input GMAW causes the HAZ to soften in DP steels, which in turn affects the fatigue properties. Studies have been carried out to correlate the effect of weld geometry and microstructure on the fatigue properties of AHSS butt welds. Some showed that the bead geometry and microstructure could act as a notch for the initiation and propagation of cracks under fatigue conditions. The lowest hardness point is in the subcritical HAZ of DP590 steel, and most samples fail in this location during tensile testing, regardless of the bead geometry. Specimens with large beads (convex profile with higher height to width ratio) show a significantly shorter fatigue life, with fractures initiated at the toe of the weld. A shallow bead, that is, lower height/width ratio, with appropriate microstructure can improve fatigue performance in GMAW welds (Ahiale & Jun Oh, 2014).

For welding galvanize AHSS, wires with chemical composition of low silicon to manganese ratio have typically been used with a welding angle less than 30°. The weld pool flows in the direction of the arc and prevents the formation of blow holes and porosities, which is a major issue during arc welding of zinc-coated sheets. The beads are flatter with a smooth curvature at the toe region. In fact, a welding wire with low silicon content and a base metal with higher silicon content gives the best bead profile.

2.1.1 Principles of Operation

Gas metal arc welding (GMAW) is a welding process that uses an electric arc to produce heat and uses a continuous-feed consumable electrode that is protected by an externally supplied gas. Figure 2.1 illustrates the terms used in the GMAW method in a basic schematic diagram.

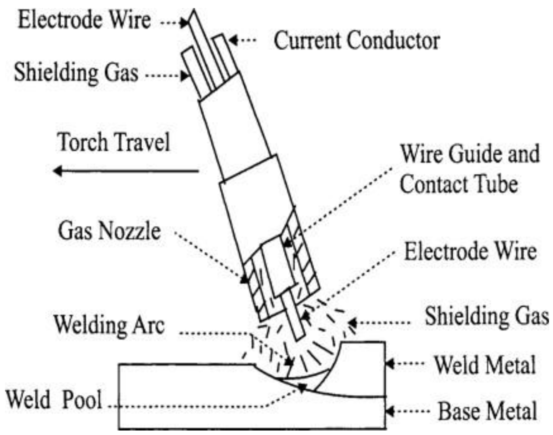


Fig.2.1 Gas metal arc welding

The GMAW process also requires an electric power supply, an electrode wire-feed unit, and a source of shielding gas, in addition to the welding gun. The electrode, current, and shielding gas tubes are all directed by the gun. A constant voltage power supply with a constant wire-feed speed unit, as defined in the next section, maintains self-regulation of the arc length. A constant-current voltage supply may also be used, with the wire-feed speed being regulated by arc voltage. There are three ways to accomplish GMAW;

Equipment only monitors the electrode wire feeding in semiautomatic welding. Hands monitor the movement of the welding gun. Hand-held welding is the term for this process.

Machine welding entails the use of a gun that is linked to some kind of manipulator (not handheld). The controls that drive the manipulator must be set and adjusted by an operator on a regular basis.

Automatic welding is when machinery welds without the need for a welder or operator to constantly change controls. Automatic sensing systems on certain equipment keep track of the proper gun alignment in a weld joint.

2.1.2 Metal Transfer Modes for GMAW

Metal transfer modes used by GMAW include the following:

Carbon dioxide is used as a shielding gas in the globular metal transfer mode, which is useful because carbon dioxide is less costly than argon, the other main shielding gas. Furthermore, the globular mode has a high deposition rate, which allows for faster welding speeds. However, as compared to other modes, globular produces a lot of heat, produces irregular or uneven welding surfaces, is susceptible to spatter, requires thicker workpieces, and must be used on flat or horizontal weld positions. Because of these disadvantages, it is one of the least common GMAW welding techniques in industry.

SCT or short-arc GMAW are two terms used to describe the short-circuiting transfer mode. The molten metal droplets bridge the gap between the electrode and the weld pool in this mode, effectively extinguishing the arc. The surface friction between the molten bead and the weld pool, on the other hand, causes the bead to be pushed away from the electrode and the arc to re-ignite almost immediately. This process occurs at a rate of about 100 times per second and is not apparent to the naked eye, so the arc appears to be continuous. The process, however, necessitates a slower wire feed rate. It also has the advantage of being able to be used on thinner work-metal parts than the globular method; however, it can only be used on ferrous metals, and when used on thicker metals, it can result in inadequate weld penetration and fusion.

Spray – Invented in the 1940s to allow for the welding of non-ferrous metals such as aluminium, the spray transfer mode is the original GMAW transfer process. The welding electrode is quickly moved through a stable electric arc to the workspace in this transfer mode, resulting in a better weld finish with minimal or no spatter. Since the molten droplets change from globules to smaller droplets and then to vaporized steam at higher currents and voltages, this is possible. This, however, necessitates more heat and a wider weld pool, implying that the workpiece must be at least a quarter inch thick. Because of the wide weld pool, the number of possible weld positions is restricted.

Pulsed-Spray is a term used to describe a form of spray that is used to deliver A variant on the spray transfer mode is the pulsed-spray transfer mode, which is also known as pulsed gas metal arc welding, pulsed MIG, or GMAW-P. It uses a pulsing current rather than a steady current. Per pulse, a single molten metal droplet will fall. Since the average current is lower, heat is reduced and the weld pool is smaller. Welding on thinner metal and in all places is possible thanks to the lower heat and smaller weld pool. As a result, GMAW-P has become one of the most widely used industrial welding methods. In a subsequent post, we'll go through it in greater depth.

2.1.3 The Advantages of GMAW

When compared to Manual Metal Arc and Gas Tungsten Arc welding processes, the GMAW process has the highest deposition rate. This is due to the high current-to-wire-diameter ratio, as well as the elimination of the need for electrode changes, chip slag, and other maintenance. The use of a continuously fed, gas-shielded electrode helps to achieve these advantages. The following are some of the advantages of this method over manual metal arc welding (MMAW):

- High deposition rates compared to manual metal arc welding
- No electrode stub wastage
- No slag removal
- Less operator skill required
- A wide range of applications
- Low hydrogen deposit

When compared to manual metal arc welding, there is less distortion on thin materials.

2.1.4 GMAW's Negative Qualities

Although GMAW is a popular and versatile welding process with the benefits listed above, it has some drawbacks:

- Cannot be used in windy conditions (AS 1554-1 prohibits the use of gas-shielded processes in wind speeds exceeding 10 km/hr).
- In some cases, the lack of fusion defects can be a major issue, making the process unsuitable for work outside the factory.
- Setting weld parameters necessitates a certain level of expertise; troubleshooting equipment necessitates a certain level of knowledge.

2.2 Safety in Gas Metal Arc Welding

2.2.1 Darker Welding Filters

The primary concern in this regard is arc intensity, which is much greater than that associated with MMAW electrodes. A darker welding filter will be required for the GMAW process when compared with MMAW. A filter one shade darker than that used for welding at the same amperage with the MMAW process will be required. For example:

- Up to 200 amps: a shade 11 is required
- 200–300 amps: a shade 12 is required

Safety glasses worn at all times are essential, as the higher emission of ultraviolet (UV) radiation may result in increased and more severe arc flashes.

2.2.2 Body Protection

This same arc intensity also requires operators to ensure their body is completely covered with protective clothing. Even extraneous light from the arc (UV radiation bouncing from a reflecting wall) can result in a rather uncomfortable ‘ray burn’.

You must wear safety boots, gloves, long sleeves, and a suitable face shield. For more intense work, wearing a leather apron and a cap are also necessary

Experience has shown that cotton materials have less resistance to ultraviolet rays than woolen materials. Cotton, and particularly synthetics, will quickly break down and eventually disintegrate. It is therefore preferable to wear leather or woolen materials.

2.2.3 Ventilation

During arc welding a toxic gas called ozone is given off from the arc, with higher current densities producing higher ozone levels. Although ozone is not dangerous under most conditions, it is advisable to use exhaust extraction when working in confined spaces where ventilation is restricted. Natural ventilation and exhaust fans can also be advantageous. Any ventilation system used must not interfere with the gas shielding of the weld zone.

2.2.4 Protecting Others

To protect other workers, you must shield your working area with suitable screens to prevent stray arc rays escaping the work area as well as any sparks from welding or grinding.

2.3 Equipment

The major equipment items which make up a GMAW plant are:

- The power source
- The wire feeder
- The welding gun cable assembly
- The gas supply system

Fig.2.2 Weld setup

A constant voltage (constant potential) power source is required for GMAW as shown in fig 2.2. This is commonly a transformer/rectifier or, increasingly, an inverter. The output requirement is for direct current. All solid wires for GMAW run on direct current electrode positive (DC+). The GMAW process is intolerant to variations in arc voltage, and the constant voltage output provided by the constant voltage (CV) power source ensures that the arc length is self-adjusting and remains constant despite uneven torch movement

2.3.1 Wire Feed Unit

The primary function of the wire feed unit is to feed wire to the arc pool. This unit houses a reel of electrode wire and a DC motor to which feed rollers are attached. Feed rollers push the electrode wire to the arc pool. The speed of the drive motor is governed by a potentiometer (the wire feed control) and is influenced by variations in arc voltage. Increasing the wire speed also increases the amperage. Incorporated into the unit are the shielding gas connections, gas solenoid and, in the case of a water cooled torch, water connections.

2.3.2 Gun Cable Assembly

- The gun cable assembly consists of a large outer cable which covers and protects several smaller conduits by which electrode wire, current and shielding gas are conveyed to the welding arc pool. It connects to the wire feeder and terminates at the ‘gun’ or ‘hand-piece’.
- The electrode wire travels through the wire conduit or ‘liner’ which runs through the Centre of the gun cable. The welding current is carried through the cable by a heavy copper lead within the cable.
- Shielding gas is also carried through the cable, and is distributed at the weld pool via the gas diffuser and gas nozzle.
- There are two trigger control wire cables, a positive and a negative, which send back a signal to the power unit when the torch trigger on the hand-piece is depressed. This starts the whole welding operation.

Welding is started by depressing the torch trigger. This initiates three separate functions:

1. The welding current contactor solenoid is ‘pulled in’ (closed) and welding current becomes available. Welding current is transferred to the wire as it passes through the contact tip.

2. The gas solenoid valve opens and allows shielding gas to flow.

3. The wire feed motor starts up and feeds wire at the preset, constant speed through the wire conduit. Because of the heat generated in the weld pool and the heat generated through electrical resistance at the contact tip, torches have to be efficiently cooled. The majority of torches are air-cooled; however, water-cooled torches may be required when high amperages are used on a continuous basis.

2.3.3 Gas Supply System

Shielding gases for gas metal arc welding (GMAW) are usually supplied from a single cylinder; however, large consumers may use manifold systems. The components of the gas supply system are:

- A cylinder of gas containing either carbon dioxide (CO2), argon (Ar) or an argon/CO2 mixture which may include oxygen (O2)
- A regulator to reduce cylinder pressure
- A flow meter to control shielding gas flow rate
- A heater – when CO2 is used as a shielding gas, a heater is fitted between the cylinder and the regulator to prevent freezing at the regulator.

2.3.4 Interconnecting Cables

These consist of:

- The work return lead
- The electrode lead – from the power source to the gun cable adaptor of the wire feeder
- The control cable from the power source to the wire feeder.

Wire Feed Systems

There are three basic types of GMAW wire feeding systems, each requiring different torches.

1. The Push System

The push system is by far the most popular wire feed system. The wire feed unit pushes the electrode wire along the wire conduit (liner), through the gun and contact tip and to the weld pool. Push systems are generally robust, lightweight and very functional, as well as being the least expensive of the three systems. The system works very well with hard wires such as steel and stainless steel up to 4.5 meters in length. Wire in spools of 15 kg or larger are usually used with this system. This keeps costs down and increases efficiency. The major disadvantage of the push system is unreliability of wire feeding caused by friction in dirty liners or kinked gun cables. This is a particular problem when feeding soft wires such as aluminium.

2. The Pull System

The pull system is ideally suited to feeding soft wires such as aluminium or where welding is to be carried out at a location remote from the power source. The drive motor and drive rollers are built into the handle of the welding torch. This offers a short, direct wire travel, with little friction through the conduit. The drawbacks of this system are the high initial cost of equipment, the cost of consumable wire on small spools and the weight of wire carried on the gun. Although this system is mainly used for aluminium work, mild steel and stainless steel wires can also be used.

3. The Push/Pull System

As the name implies, both push and pull motors are employed. One motor is in the welding torch handle and pulls the wire through the torch. The other motor is in the wire feeder and pushes the wire through the wire conduit. The motors are synchronised to feed the wire at the same speed. This enables the feeding of both hard and soft wires up to 10 metres from the welding machine and still offers the economy of 15 kg (or larger) spools of wire. The push/pull system is a versatile system; it is particularly suited to aluminium, but may also be used for hard wires as well.

2.3.5 Wire Conduit (Liner)

The liner is used to guide the wire through the gun cable to the hand-piece, and through to the contact tip. When welding with carbon and stainless steels the liner is made of spiral wound wire. Teflon® is used when feeding aluminium wire. To ensure reliable wire feeding, it is imperative that the liner is cut to the correct length and properly fitted in the gun cable. It is also important that the gun cable is kept as straight as possible when welding.

Contact Tip

The contact tip serves two functions:

- To guide the wire to the arc
- To transfer welding current to the wire.

The contact tip is a most important component of the welding torch. It is here that the filler-wire is energized or 'picks-up' the welding current. It is usually made from copper and is directly attached to the power lead via the gas diffuser and torch body. Contact tips are matched to each wire size. It is important that the contact tip is maintained in a clean condition free from spatter on the end, and with a smooth internal bore. Worn contact tips reduce the efficiency with which the welding current is transferred to the electrode wire and contribute to uneven wire feeding. They should be replaced when worn.

2.4 Metal Transfer Modes

With most of the commonly used welding processes the operator has little control over the way metal is transferred across the arc. With GMAW the operator can select and control the type of metal transfer. This is done primarily by selection of arc voltage, although wire diameter and shielding gas also influence metal transfer.

The metal transfer mode determines the characteristics of the GMAW process. The operator must select the most appropriate mode of transfer and set the machine accordingly before starting the weld.

Apart from the pulsed transfer mode, which requires sophisticated power sources, the welding operator can select from three transfer modes:

- Dip (or short arc) transfer
- Globular transfer
- Spray transfer.

Dip Transfer

Dip transfer is also known as ‘short arc’ transfer (short for ‘short circuiting arc’). In the dip transfer mode, low current and low voltage settings are used. The low voltage employed cannot maintain a continuous current flow across the gap between the electrode wire and the work piece. As the electrode nears the work piece the electrical resistance across the arc gap is overcome and an arc is established.

During welding, the tip of the electrode wire contacts the work piece and a short circuit occurs. This results in a rapid temperature rise in the wire (caused by the short circuit current flowing through to the work piece) and the end of the electrode wire is melted off. An arc is immediately formed between the tip of the wire and the weld pool. This arc maintains the electrical circuit for a short time until the electrical resistance across the increasing arc gap causes the arc to be extinguished. The electrode wire continues to feed, and the tip once again dips into the pool and the cycle is repeated. This sequence of events is repeated at a frequency of up to 200 times per second, and produces sufficient heat for fusion and to keep the weld pool fluid. This method of transfer is suitable for all positional welding due to rapid freezing of the weld pool, and has the advantage that the heat input to the work piece is kept to a minimum. This limits distortion and enables thin sheet material to be welded. However, on thicker material, the low heat input tends to give rise to lack of fusion defects if care is not taken with machine adjustment and welding technique.

Typical weld conditions:

Volts 13–23

Amps 60–200

Stickout 6 mm–15 mm

The Dip Transfer Cycle

1. Trigger is depressed – wire starts to feed.

2. Wire contacts the work piece and heats up due to electrical resistance and begins to melt.

3. Wire melts off and an arc is established.

4. Arc length increases as the end of the wire melts slightly.

5. Arcing ceases due to the low arc voltage being unable to overcome the electrical resistance across the arc gap.

6. Wire is fed into the weld pool which has been created and the cycle begins again.

Features of Dip Transfer:

- low currents are used
- Low heat input
- Low penetration
- Low deposition rate compared with other transfer modes
- Relatively cold weld pool
- Ideal for thin materials
- Can be used for out-of-position welding such as vertical ups and •lack of fusion' faults in overhead welds are an issue, particularly when plate thickness exceeds 5 mm.

Spray Transfer

Spray transfer, unlike dip transfer, uses an arc that burns continuously. When welding steel, the arc voltage must be above approximately 23 volts in order to achieve this (depending on wire size and shielding gas composition).

Furthermore, the amperage used must be greater than the 'threshold current.' The threshold current is the current that causes tiny droplets to be pinched off and projected axially through the arc gap when it exceeds a certain value. Droplet detachment occurs below the threshold current when a molten droplet of wire grows in size until it is large enough to be removed by gravitational forces.

Welding conditions that are typical:

Amps 24–40

Volts Upwards from 200

15–30 mm of protrusion

Spray transfer has much higher deposition rates than dip transfer, produces less spatter, and does not have the fusion faults that dip transfer does. Spray transfer is only appropriate for use on plates over 5 mm thick and in the down-hand (flat) position due to the hot, fluid weld pool associated with it. Spray transfer has the following characteristics:

- High currents
- High heat input
- Moderate/deep penetration
- High deposition rates
- Low spatter

- Good appearance
- Fluid weld pool
- Unsuitable for out-of-positional welding like overhead welding
- Requires a shielding gas with a high argon content

2.5 Globular Transfer

Globular transfer happens at current stages, where dip and spray transfer are used. The voltages are high enough to maintain a steady arc, but the amperage is set below the spray transfer threshold current. As a result, the wire melts in the arc, forming a molten globule at the wire's end. If the globule melts, its size increases until its own weight causes the droplet to detach due to gravitational forces. Because of the effect of arc forces repelling the droplet away from the wire, droplet detachment is erratic, resulting in high spatter levels. The size of the droplet is much greater than the wire diameter.

Volts 20–26

Amps 200–280

Volts 200–280

12–22 mm of protrusion

Globular transfer has the following characteristics:

- Moderate amperages are used
- Low to moderate penetration
- Moderate to high spatter levels
- Coarse appearance
- Metal droplets are detached by gravitational forces
- Largely unsuitable for out-of-position welding
- Occurs even at high amperages when the shielding gas contains more than 23% CO_2

GMAW is also known as ‘MIG Welding' in Australia (Metal Inert Gas). This is deceptive since it implies that all shielding gases are harmless. An active shielding gas is used in all GMAW processes for carbon and low-alloy steels. This indicates that the shielding gas reacts with the metal droplets as they move through the arc. For welding stainless steels and non-ferrous metals, inert shielding gases are used. When welding carbon and low-alloy steels, some oxidizing action in the arc is needed to achieve the desired arc stability. This can be accomplished in one of two ways:

(i) Using carbon dioxide (CO2) as a shielding gas, or

(ii) Using argon (Ar) as the foundation with CO2 and/or O2 added (oxygen).

Carbon dioxide: As carbon dioxide is used as a shielding gas, a highly reactive arc results. The welding arc benefits from CO2 because it facilitates the following characteristics:

- High heat input
- Deep penetration
- High spatter levels
- High deposition rates
- When CO2 is used as a shielding gas, real spray transfer is impossible.

Dip transfer works best with carbon dioxide. CO2 adds heat to the mix, which helps to solve the issue of "lack of fusion" and speeds up deposition. Carbon dioxide produces convex bead shapes and a lot of spatter.

Argon: Argon is a real inert gas that can't be used to weld carbon or low-alloy steels by itself. When used alone to weld non-ferrous metals, it creates an arc with the following characteristics when compared to CO2:

- Smooth arc
- Less penetration
- Less heat input
- Less spatter
- Better bead form
- Better spray transfer

Mixtures of Gases

Argon is used as the base gas in welding steel mixtures, with various amounts of CO2 and/or O2 added to achieve desired arc characteristics. The further O2 and CO2 levels are present, the more the arc characteristics resemble CO2 characteristics. The opposite is true: the lower the CO2 and O2 addition, the more the arc aligns toward argon shielding gas characteristics. The ionizing effect of the shielding gas has an impact on the form of the beads as well as the amount of penetration that can be achieved.

2.6 Welding Parameters

Wire-feed speed is directly proportional to welding current (if the wire extension beyond the guide tip is constant). The welding current will differ in the same direction as the wire-feed speed. In other terms, as the wire-feed speed increases (or decreases), the current increases (or decreases) . For different diameter wires, Figure 1 depicts the standard wire-feed speed vs. welding current relationship. The "burn-off" feature is a term used to describe this relationship. The graph also shows that the welding current increases (or decreases) as the diameter of the wire electrode is increased (or decreased) at every wire-feed speed (or lower). The burn-off characteristics of each wire type (steel, aluminum, etc.) are different. The form of each burn-off curve is an important factor to consider. The curve is nearly linear in the lower current range for each wire size. To put it another way, any increase in current causes a proportional (and constant) increase in melt off. The burn-off curve becomes non-linear at higher welding currents, particularly with small diameter wires. Higher welding currents cause greater burn-off increases in this area. Resistance heating of the wire extension outside the guidance tube causes this. PR heat is the abbreviation for resistance heating, where I = welding current and R = resistance. The PR heating is proportional to the welding current. This is illustrated in fig 2.2

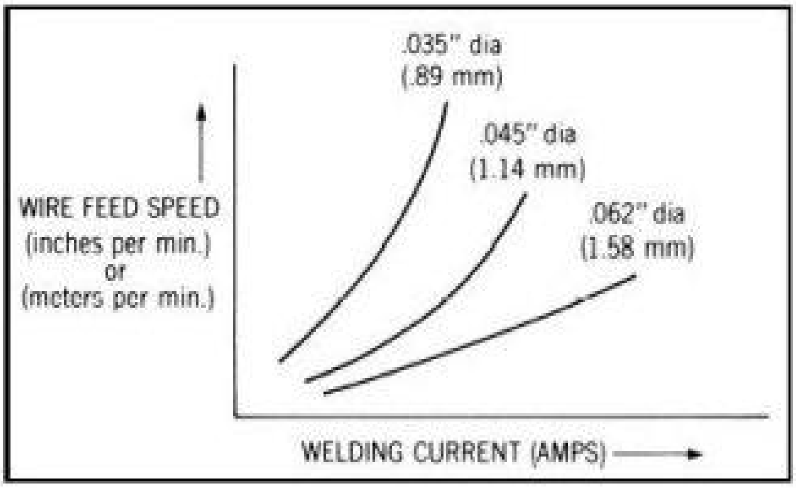


Fig.2.3 Graphical view of Wire extension

Wire Electrode Extension: The distance between the last point of electrical contact, normally the end of the contact tip, and the end of the wire electrode is known as wire extension or "stick-out." Wire extension is shown schematically in Figure 2.2. The PR preheating effect occurs in this field.

Wire Electrode Extension: The distance between the last point of electrical contact, normally the end of the contact tip, and the end of the wire electrode is known as wire extension or "stick-out." Wire extension is shown schematically in Figure 2.3. The PR preheating effect occurs in this field.

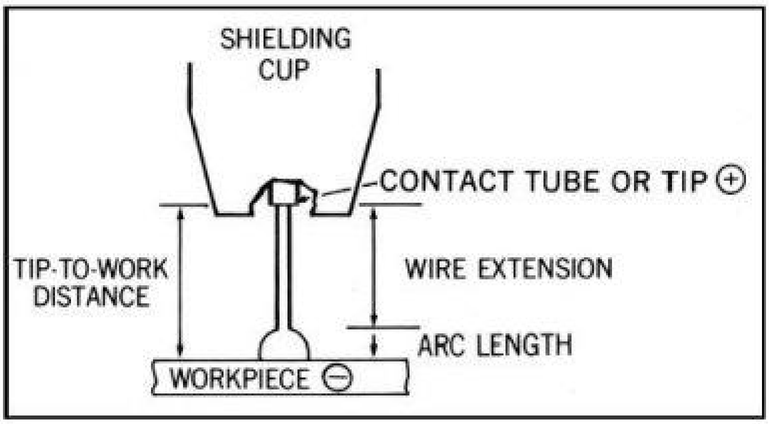


Fig.2.4 Weld contact diagram

The welding current needed to melt the wire at a given feed speed is influenced by the contact tip-to-work distance, which has an effect on wire extension. Graph The welding current requirement can vary depending on tip-to-work distance, as shown in Figure 2.3. The amount of I2R heating increases as the tip-to-work distance increases, while the welding current needed to melt the wire decreases. It's also true in the opposite direction.

Arc Travel Speed: The arc travel speed is the rate at which the arc travels along the workpiece in a linear direction. Inches or meters per minute are the most common units of measurement. Regarding the arc travel speed, three general statements can be made:

1) The travel speed must be slowed as the material thickness increases.

2) As the welding current is increased, the arc travel speed increases for a given material thickness and joint design. It's also true in the opposite direction.

3) By using the forehand welding method, higher welding speeds are possible.

2.7 Welding Techniques

The first general welding technique that affects weld characteristics is torch position. This refers to the manner in which the torch is held with respect to the weld joint. The position is usually described from two directions – the angle relative to the length of the weld and the angle relative to the plates as illustrated in fig. 2.4 respectively. Both backhand and forehand welding techniques are shown in fig 2.4. The backhand method means the torch is positioned so that the wire is feeding opposite to the direction of arc travel. Filler metal is being fed into the weld metal previously deposited. For the forehand method, the torch is angled so that the electrode wire is fed in the same direction as arc travel. Now the filler metal is being deposited, for the most part, directly on the workpiece. It should be noted that a change in welding direction is not required to facilitate forehand or backhand welding, only a reversal in the longitudinal torch positioning. Generally, operators find that the backhand technique

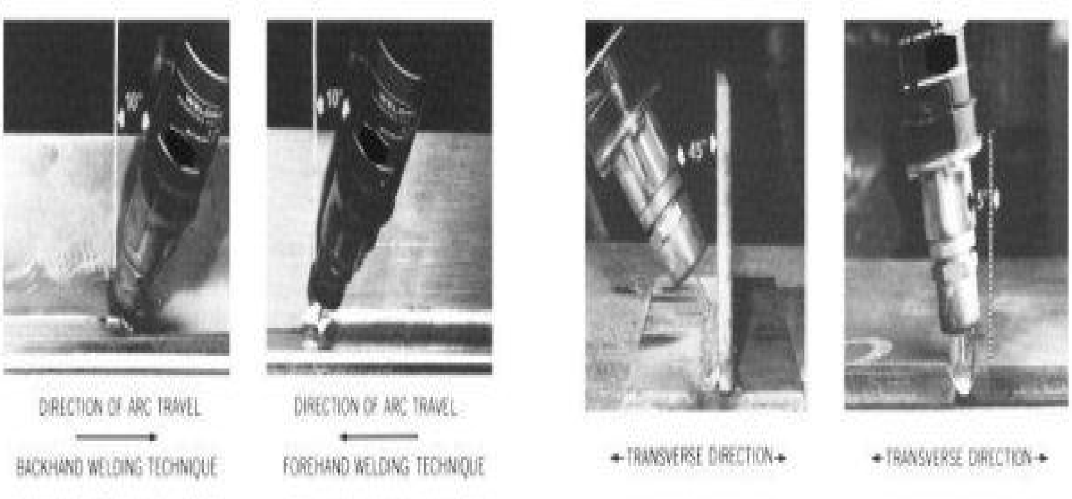


Fig. 2.5

The angle relative to the plate for the fillet weld shown in Figure 2.5 is usually 45 deg. However, for a bevelled butt joint, this angle may only be a few degrees from the vertical to allow for proper wetting of the weld metal to the side wall. The second general welding technique that should be considered is that of arc travel direction when the welding must be performed in the vertical position. As Figure 2.5 illustrates, there are two methods with which this welding can be done – vertical up and vertical down.

Here the torch positioning is extremely important and welding should be performed only as shown. In either case, the arc must be kept on the puddle's leading edge so as to insure complete weld penetration.

This completes a definition of the factors which make up the controllable welding parameters and techniques. We shall now turn our attention to the manner in which each of these affect certain weld characteristics.

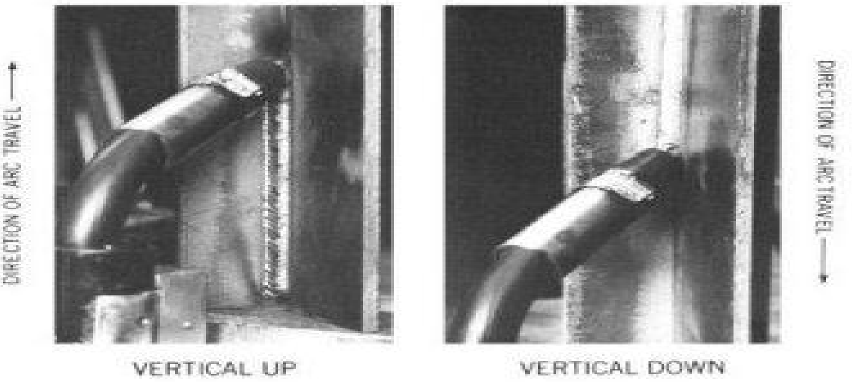


Fig 2.6 welding in vertical position

2.8 Weld Bead Characteristics

2.8.1 Penetration

Weld penetration is the distance that the fusion line extends below the surface of the material being welded. Welding current is of primary importance to penetration. As Figure 2.3 illustrates, weld penetration is directly related to welding current. An increase or decrease in the current will increase or decrease the weld penetration respectively.

However, we have seen that welding current can be varied without changing the wire feed speed; namely, through the variation of the tip-to-work distance. The effect of tip-to-work distance on weld penetration is opposite in nature to that of welding current. An increase in the tip-to-work distance will decrease welding current and penetration. Of course, the converse is also true. In some applications, many operators have found it helpful to use this property to control penetration. Changing the tip-to-work distance while welding prevents burn through when there are discontinuities in material thicknesses or joint gap.

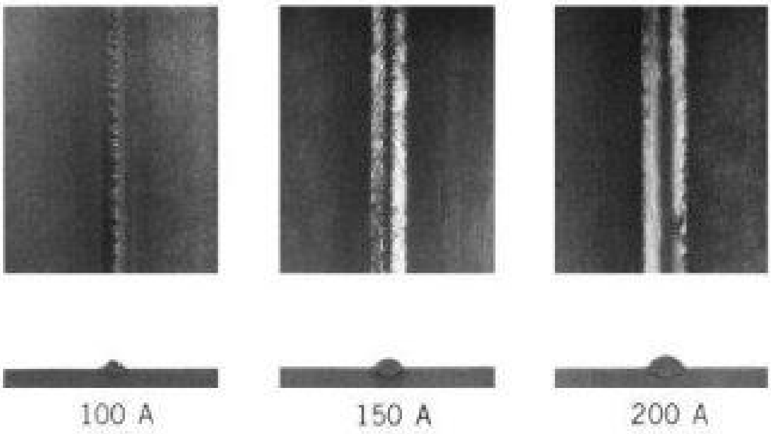


Fig 2.7 Effect of current on bead

The remaining factors have comparatively little effect on penetration and do not provide a good means of control. Figure 2.7 illustrates the effect of welding voltage. In this example, penetration is greatest at 24 volts and decreases as the voltage is either increased or decreased. Twenty-four volts is the optimum voltage for the amperage used and yields the most stable arc. Arc instability decreases penetration.

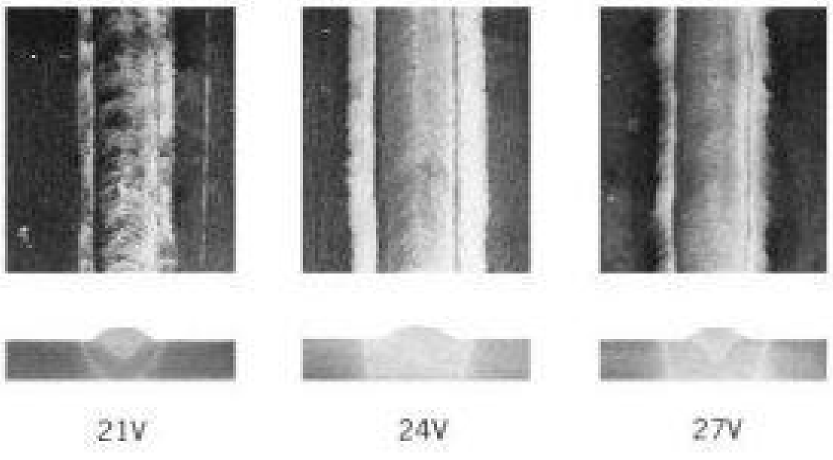


Fig.2.8 Effect of voltage on weld

Effect of Welding Voltage on Weld Penetration Aluminium-Spray Arc-Argon Shielding

Effects of arc travel speed are similar to that of welding voltage – penetration is a maximum at a certain value and decreases as the arc travel speed is varied. Figure 2.8 shows that at 12 inches per minute (30.5 cm/min)travel speed, penetration is at a maximum. At either 7 ipm (17.8 cm/min) or 17 ipm (43.2 cm/min) it is decreased. With the lower speeds, too much metal is deposited in an area and the molten weld tends to roll in front of the arc and “cushions” the base plate. This prevents further penetration. At high speeds, the heat generated by the arc hasn’t sufficient time to substantially melt the area of base material.

Torch position has a slightly greater effect than does welding voltage or arc travel speed. The effect of changing the longitudinal torch angle, or switching from a forehand to backhand welding technique is shown in Figure 2.7. It can be seen that generally the forehand welding technique yields shallower penetration than does the backhand technique. Maximum weld penetration is achieved with a torch angle of 25 deg. and the backhand welding technique. However, beyond this degree of torch angle, arc instability and spatter will increase. For very thin materials or where low penetration is required, a forehand technique is generally used.

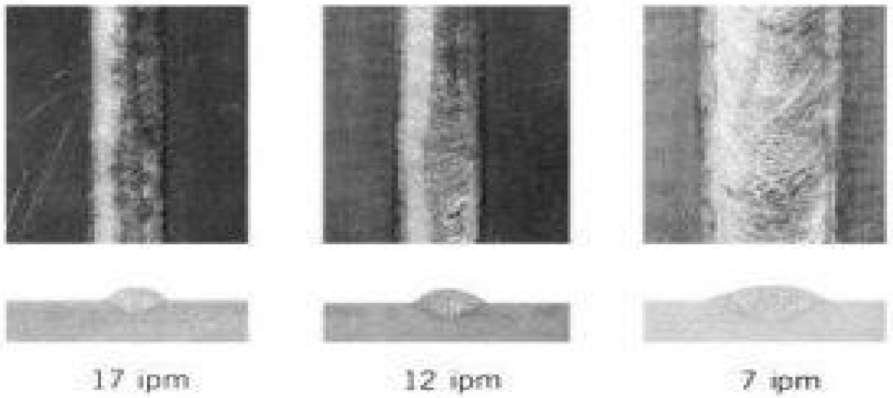


Fig 2.9: Effect of Welding Travel Speed on Weld Penetration Aluminium-Spray Arc-Argon Shielding

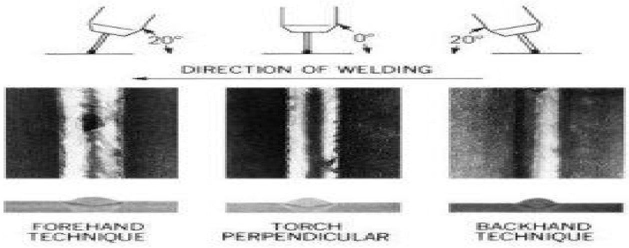


Fig.2.10 Effect of weld penetration

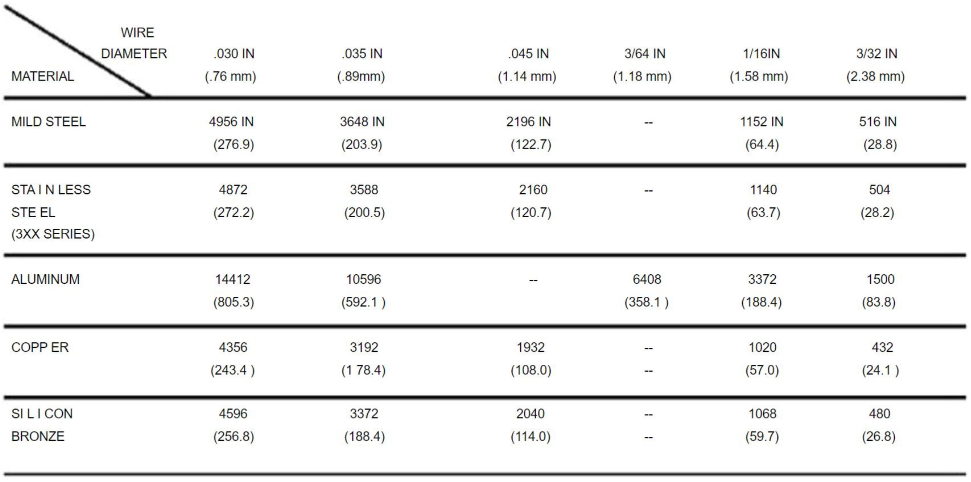
Effect of Longitudinal Torch Position on Weld Penetration

2.9 Deposition Rate

The deposition rate describes how much usable weld metal will be deposited in one hour of actual arc-on time. Because the mig process is very efficient, only a very small amount of weld metal is lost as spatter.

The deposition rate for any wire is calculated by the equation:

$$\text{Deposition rate(lbs./hr.)} = \frac{\text{wire feed speed (m./min.) x 60 min/hr}}{\text{inches of wire per lb.(m/kg)}}$$



MATERIAL \ WIRE DIAMETER	.030 IN (.76 mm)	.035 IN (.89mm)	.045 IN (1.14 mm)	3/64 IN (1.18 mm)	1/16IN (1.58 mm)	3/32 IN (2.38 mm)
MILD STEEL	4956 IN (276.9)	3648 IN (203.9)	2196 IN (122.7)	--	1152 IN (64.4)	516 IN (28.8)
STAINLESS STEEL (3XX SERIES)	4872 (272.2)	3588 (200.5)	2160 (120.7)	--	1140 (63.7)	504 (28.2)
ALUMINUM	14412 (805.3)	10596 (592.1)	--	6408 (358.1)	3372 (188.4)	1500 (83.8)
COPPER	4356 (243.4)	3192 (178.4)	1932 (108.0)	-- --	1020 (57.0)	432 (24.1)
SILICON BRONZE	4596 (256.8)	3372 (188.4)	2040 (114.0)	-- --	1068 (59.7)	480 (26.8)

Table 2.1 Illustration of the inches of wire per pound (m/kg) for various wire electrodes in a variety of sizes.

Deposition rate is synonymous with wire feed speed. Figure 2.7 gives deposition rate versus wire feed speed. The current to achieve a given deposition rate can also be varied by changing the tip-to-work distance. As Figure 2.8 shows, the wire feed speed can be increased with increasing tip-to-work distance to maintain a constant welding current. This results in a higher deposition rate than usually associated with a given current level.

Long tip-to-work distances and high wire-feed speeds are used for high speed welding of thin materials, as the welding current can be kept low. Usually the forehand welding technique is employed. Increasing the deposition rate in this manner will also have an effect on weld penetration. Because more metal is being deposited at a given welding current, the penetration will be reduced. This results from a ”cushioning” of the arc force by the extra weld metal deposited

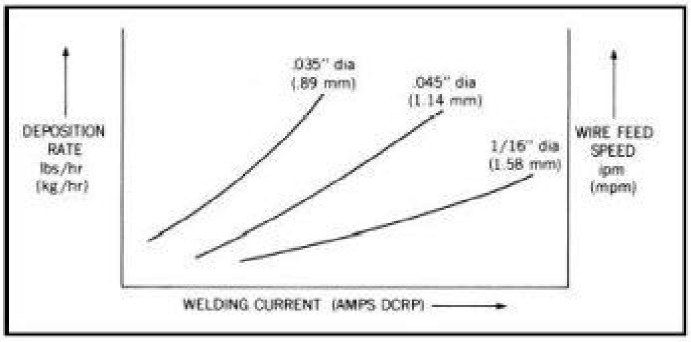


Fig 2.11: Deposition Rate vs. Welding Current

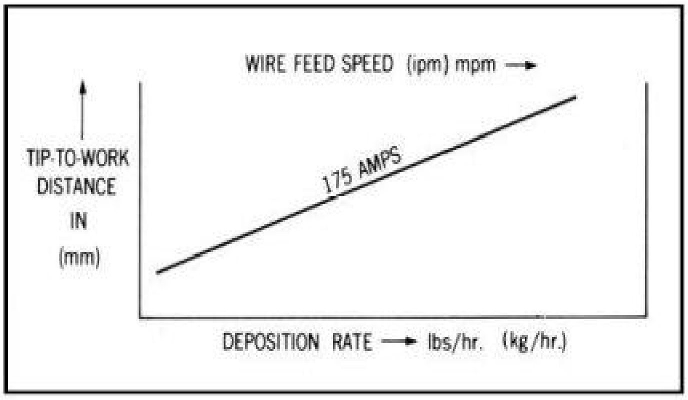


Fig 2.12: Effect of Tip-To-Work Distance on Deposition Rate

2.9.1 Weld Bead Appearance

Two characteristics of the weld bead are the bead height and width, as shown in Figure 2.10. These characteristics are important to assure that the weld joint is properly filled, with a minimum of defects, particularly in multi-pass weldments. In this case, if the bead height is too great, it becomes very difficult to make subsequent weld passes that will have good fusion. The more peaked and narrow the weld bead, the greater the chance that poor fusion may occur. The weld bead characteristics may be altered via both size and shape.

In order to change weld bead size, the lbs. (kg) of weld metal deposited per linear foot (m) of the weldment must be changed. Welding current and travel speed are the welding parameters primarily used to control weld bead size. For instance, when the current is decreased, the weld bead will become smaller. The converse is also true. This relationship can be seen by referring to Figure 2.7

Weld bead size can also be changed by varying the arc travel speed. As seen in Figure 2.9 bead size and travel speed are inversely related. A decrease in travel speed will result in an increase in the weld bead height and width. An increase in travel speed will result in a decrease in the weld bead height and width Again, the pounds (kgs) of filler metal deposited in a linear foot (m) of weld are increased (or decreased).

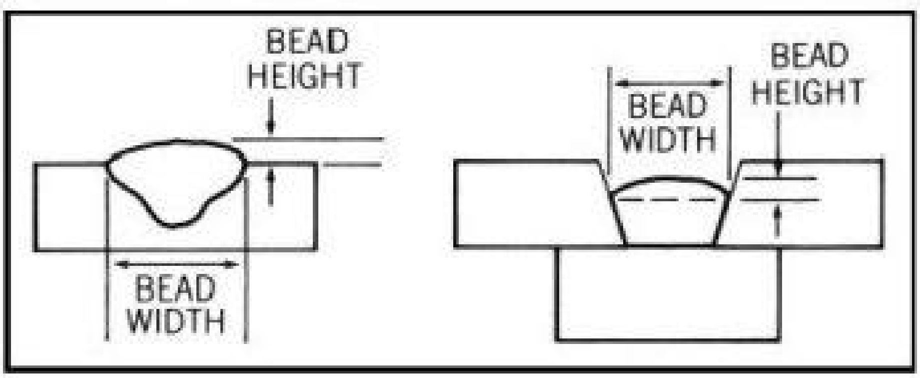


Fig.2.13

Weld Bead Characteristics

Both welding current and travel speed have little effect on weld bead shape. The bead width and height increase or decrease together.

Arc voltage is used to control the shape of the weld bead. As can be seen in Figure 2.10, as the arc voltage (arc length) increases, the bead height decreases and bead width increases. Here the overall size of the weld bead remains constant. Only the shape or contour of the bead is changed. By increasing the bead width, the bead height becomes flatter and the weld metal is said to ”wet” the base materials more efficiently. Fusion to the base plate is improved.

Wire extension and the welding technique employed (backhand or forehand welding) also affects these characteristics, but only to a limited extent. When long extensions are used to increase deposition rates, bead height will increase to a greater extent than bead width. Although larger, the weld bead becomes more peaked as shown in Figure2.11. A backhand welding technique will also produce a high, narrow weld bead.

Decreasing the lagging torch angle will decrease the bead height and increase the width. The forehand technique yields the flattest, widest weld bead. This section has discussed the various effects of several welding parameters and techniques. As a summary, Table 2.8 outlines these parameters and the changes necessary to alter a variety of weld characteristics.

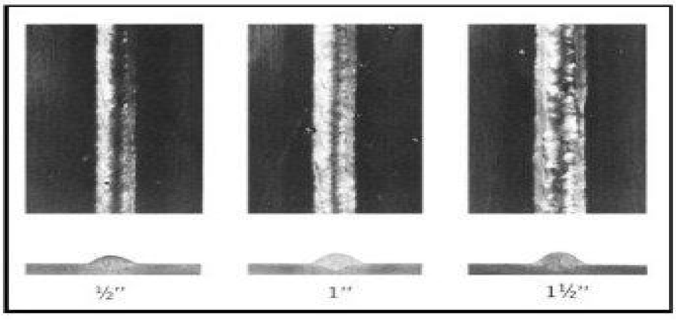
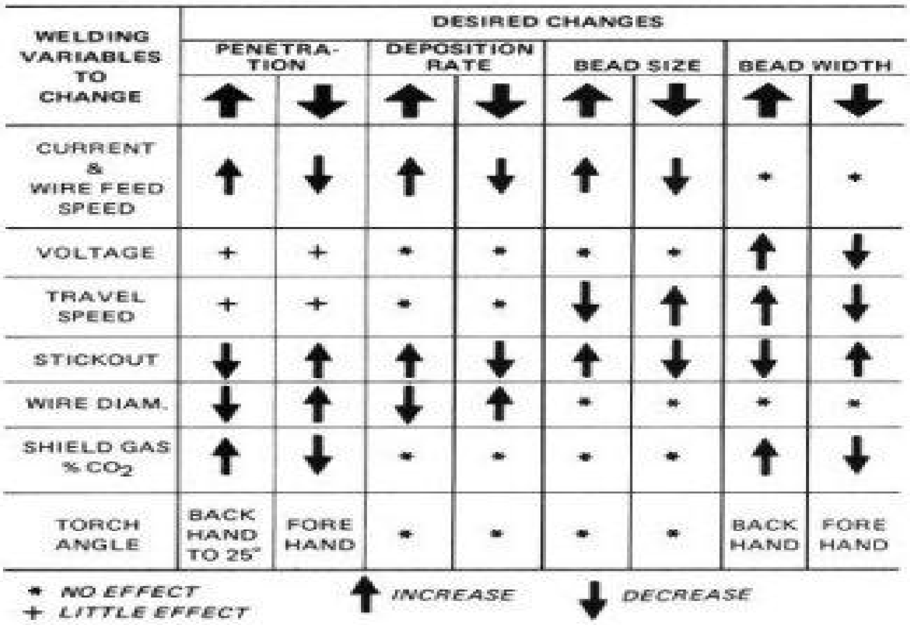


Fig 2.13: Effect of Electrode Extensions on Weld Bead Characteristics

Table 2.2 Adjustments in Welding Parameters & Techniques



WELDING VARIABLES TO CHANGE	DESIRED CHANGES							
	PENETRATION		DEPOSITION RATE		BEAD SIZE		BEAD WIDTH	
	↑	↓	↑	↓	↑	↓	↑	↓
CURRENT & WIRE FEED SPEED	↑	↓	↑	↓	↑	↓	*	*
VOLTAGE	+	+	*	*	*	*	↑	↓
TRAVEL SPEED	+	+	*	*	↓	↑	↑	↓
STICKOUT	↓	↑	↑	↓	↑	↓	↓	↑
WIRE DIAM.	↓	↑	↓	↑	*	*	*	*
SHIELD GAS % CO_2	↑	↓	*	*	*	*	↑	↓
TORCH ANGLE	BACK HAND TO 25°	FORE HAND	*	*	*	*	BACK HAND	FORE HAND

* *NO EFFECT*
+ *LITTLE EFFECT*
↑ *INCREASE*
↓ *DECREASE*

2.10 Torch Manipulations

No discussion of welding techniques would be complete without some reference to the methods of torch manipulation. The recommendations which follow are only to serve as a guide to be used during welder training. As the individual welders become more proficient with the Mig process, they will adapt their torch manipulations to best suit the job at hand.

Flat Position

Recommended weaving patterns, torch positions and bead sequence are shown in Figure 2.14. For the single-pass, butted joint, a slight back-stepping motion is used. Gapped root passes are made with a small, back-and-forth weave pattern. For fill and cover passes, the same weave, with an adjustment for the desired width, is used, with care taken to pause at the sidewalls to obtain adequate fill in these areas.

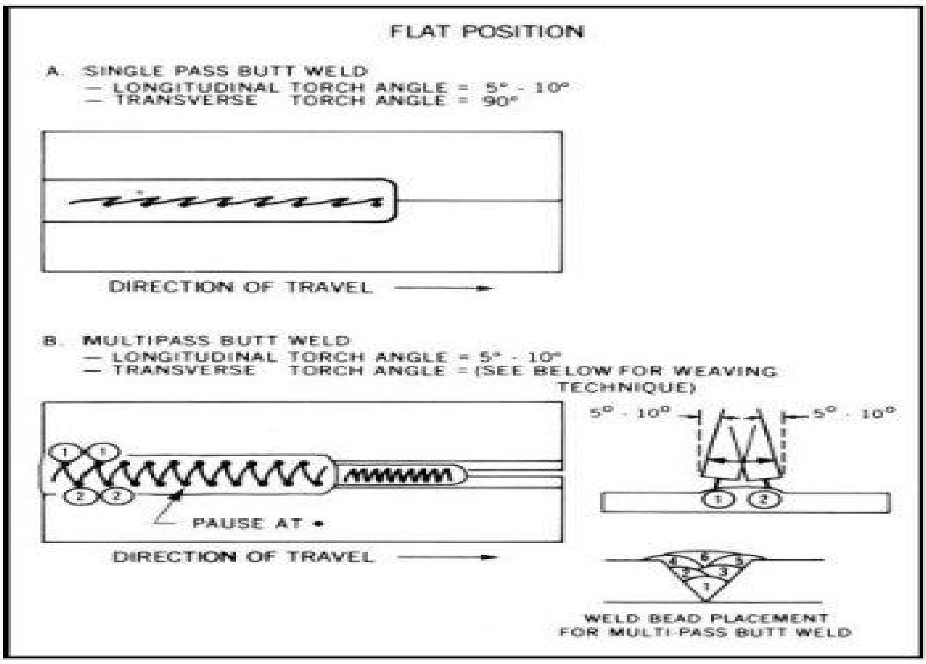


Fig 2.15: Torch Manipulation

HORIZONTAL POSITION

Recommended weaving patterns, torch positions and bead sequences are shown in Figure 2.15. For fillet welds, a circular motion is recommended. For butt weld root passes and fill passes, an in-line, back-and-forth motion is used with width adjustments as required. A slight pause is used at the tie-in to the previous bead.

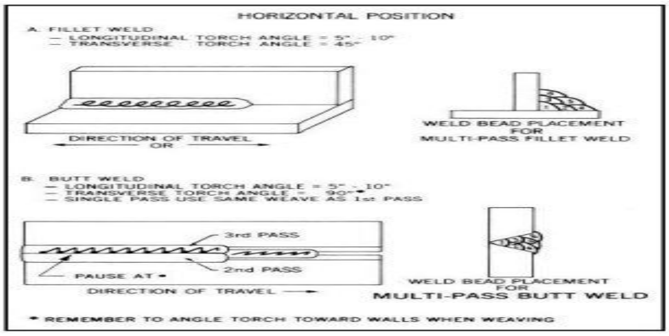


Fig 2.16: Torch Manipulations

VERTICAL POSITION

Recommended weaving patterns and torch positions for vertical up and vertical down are shown in Figure 2.16. With vertical up, for a square edge preparation an in-line, back-and-forth weave is used. For a bevelled , multi pass joint a ”U” pattern is used for the root. The fill and cover passes are made using a side-to-side weave with a back step at the walls. The length of the back step is on the order of a wire diameter. For a vertical up fillet a ”Christmas Tree” pattern is used with pauses at the side walls. For vertical down an inverted ”U” pattern is used, pausing at the side walls for the root, fill, and cover passes. Always take care in vertical down welding to keep the arc on the leading edge of the puddle. Preventing the molten metal from running ahead of the arc will improve weld soundness.

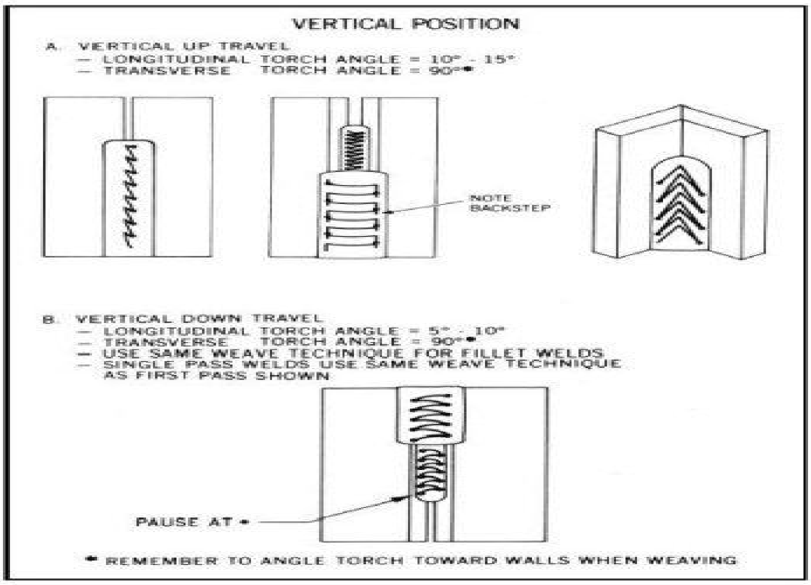


Fig 2.17: Torch Manipulations

OVERHEAD POSITION

Recommended weaving patterns and torch positions for the overhead position are shown in Figure 2.17. Again, a back-and- forth weave is used with pauses at the plate sidewalls. This applies to root, fill, and cover passes.

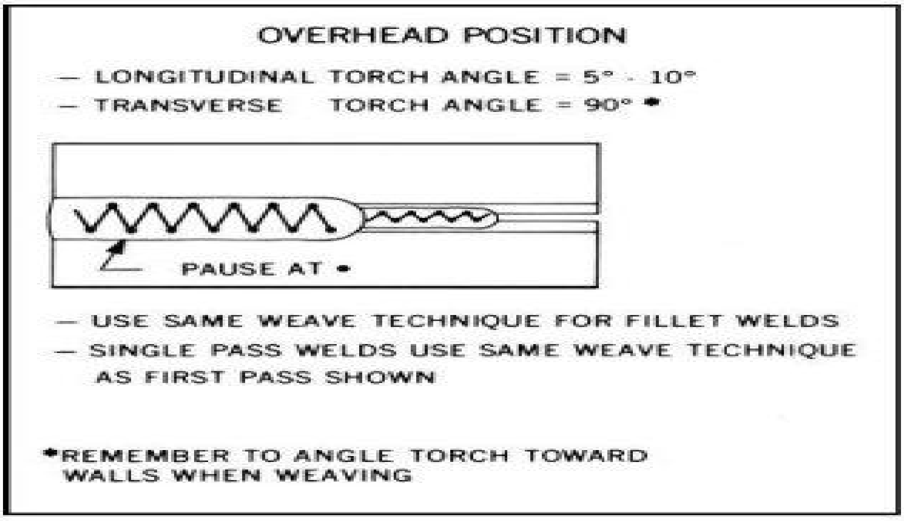


Fig 2.18

2.11 Welding Current

When a weld is produced, the welding current is the electrical amperage in the power system. It's normally read from the power source meter, but it's also common to use a separate ammeter. In other words, as the wire-feed speed increases (or decreases), the current increases (or decreases). Operators find that the backhand technique produces a more stable arc and less spatter on the work piece.

Heat input rate or arc energy was an important parameter in welding that could be determined using the formula: Heat input rate=V x I x 60/ v J/mm, where V= Arc voltage in volts, I= Welding current in ampere, and v= welding speed or arc travel speed (mm/min).

2.11.1 Size and Type of Electrode

The materials used and the current selected decide the form and size of electrode for any fabrication work to a large extent. To melt the parent material, the electrode size must be greater than the thickness of the material. To stop burn through, the electrode gauges must be smaller than the substrate thickness. The electrode to be used is often determined by the form of work being performed. A mild steel electrode can be used to patch an amid steel plate. It's also worth noting the electrode composition. The majority of electrodes are composed of cellulose, iron powder, titanium dioxide, calcium fluoride, metal carbonate, and rutile potassium, which are all chemically mixed to form a solid coating.

Voltage in an Arc

The voltage around the welding arc is referred to as arc voltage. It has an effect on the form and bead width of a weld and, unlike welding current, should be varied within a narrower range. Overly high voltages result in wider, flatter beads. Excessively high voltage should be avoided at all costs, as it can lead to cracking. If the voltage is too low, a narrow bead may develop (Richard 1964)

Dimensions of An Arc

The distance between the electrode tip and the adjacent weld pool surface is measured in arc length. At all times, the shortest possible electrode to work distance must be kept, allowing for easy rod feeding into the weld pool. When welding near butt and v-butt, an arc length of less than 3mm is recommended for the best results. Where there are root holes, it's normally best to lengthen the arc and play it on the filler rod top. This will help you avoid a burnout. The electrode must be lowered continuously in order to maintain a steady arc length. It's crucial to keep the arc stable because a significant change in the arc length would impact the weld.

2.11.2 Amperage Wire Pace

A GMAW plant uses a single potentiometer to monitor wire speed and amperage. As a result, these variables are incompatible with one another. The current density in the wire increases as the amperage is increased, and the wire melts off at a faster rate. When determining heat input into the metal to be welded, amperage is the most significant element. By increasing the wire speed/amperage power, you'll be able to accomplish the following:

- Speed up the wire feed
- Improve the current flow
- Boost the rate of deposition
- widen the audience
- Add more heat
- Increase the size of the weld bead for a given travel speed

2.12 Weld Analysis

The element that has melted and are solidified as a result of the welding process is referred to as weld metal. The weld metal has the same composition as the parent material in situations where no filler material is used (resistance, electron beam, laser, and some autogenous arc welding).

It's critical to know that a weld can follow a desired or code of standard, but it's also critical to consider the weldment's consistency, reliability, and strength.

Welding is used in a variety of applications, including pressure vessels, pipework, bridges, and more. The technique described here can also be used in machine frames and other mechanical applications.

The consistency of the welds must be assessed by appropriate testing procedures to ensure that a welded structure performs satisfactorily. As a result, they're put to the test in conditions that are similar to or worse than those that welded structures face in the field.

These tests show any weak or faulty parts of the material that can be repaired before it is released for use in the field. The tests also assess the correct welding configuration for ordnance equipment, which helps to avoid staff injury and inconvenience.

The consistency of most welds is determined by their intended purpose. If you're welding a component to a machine, the weld is usually considered right if the machine works properly. There are several methods for determining whether or not a weld is correct:

- Weld material is evenly distributed between the two materials being joined.
- Slag and other waste materials are not present in the weld.

The slag should peel away from the project once it has been allowed to cool. It ought to be easy to get rid of it. Any shielding gas residue can be easily removed during MIG (Metal Inert Gas) welding. TIG (Tungsten Inert Gas) can produce no waste because it is the cleanest process. When you see waste in TIG welding, it normally means the material being welded hasn't been properly washed.

- Strength: The majority of welds must show that they are strong enough. Starting with a filler metal and electrode rating that exceeds the strength criteria is one way to ensure proper strength.
- Leak-Proof: If you're working on a liquid-containing component, a leak is an easy (and obvious) way to spot a problem. The same goes with everything containing a gas. Soap bubbles (which can be quickly added with a squirt bottle) are one technique for checking for problems.
- Tightness: A loose joint implies a weld problem. In oxyacetylene welding, where there is no filler material, the weld must be tight. The same is true for TIG autogenous welding. The difference is less important in other forms of welds because the filler material fills in any gaps.

2.12.1 Welding Test Classification

Weld Testing's Importance

Welding mistakes can cause serious damage to weld metals, resulting in a loss of strength and toughness, as well as costly structural failures.

A variety of welding inspection techniques, such as visual inspection and other testing services that measure weld quality, are used by testing facilities to ensure that items are fit for purpose.

Ensure that strict requirements are followed to ensure the smooth operation of assets and the prevention of mistakes and additional costs.

Visual Inspection (VT)

This is the most popular method of non-destructive research. Only visual inspection will be performed on the majority of welds. This is a straightforward approach in which the weld is approved if it appears to be in good condition and refused if it appears to be in poor condition. When more advanced non-destructive research equipment is available, this technique is often ignored. It must not be ignored, however (Howard 1998).

Over 75% of finished weld rejection can be avoided with an active inspection schedule. Visual inspection will easily check for fit-up, welder technique, interpose acceptance, and other variables that can affect weld efficiency. Until a weld is finished, minor issues may be detected and fixed. This reduces the need for expensive repairs and rejection to a bare minimum. Before performing any kind of mechanical non-destructive testing (NDT), a visual inspection should be completed first.

Non-destructive weld consistency testing offers the following advantages:

- Low-cost options (usually only labour expense)
- Machinery that is affordable
- There is no need for electricity
- Early detection of faults and subsequent repair costs as a result of not catching problems early

Disadvantages

Inspector education is required.

- Clear vision or 20/40 corrected vision is needed.
- Internal flaws can be overlooked.
- Inspector's report must be kept on file.
- Human errors are possible.

Until the material is released for use in the field, tests are used to identify the location and size of defects that can be fixed. In addition, the tests assess the correct welding configuration for ordinance equipment, preventing injury and inconvenience to staff.

Destructive and non-destructive welding tests are the two types of welding tests.

Testing without causing damage

Destructive testing is used to determine the physical properties of base metals and components in order to better understand how they work under various conditions. Destructive testing methods are usually simpler to perform than non-destructive testing methods, and they also provide more detail and make results analysis easier.

Mechanical testing, such as tensile stress, bend tests, and impact tests, are examples of destructive testing. Hardness testing and material analysis are also examples of destructive testing. Since it is against economic interests to kill a large number of specimens, these research techniques are most effective when testing goods that are not going to be mass-produced. The following are some of the most frequently used destructive tests:

- Tensile test
- Bend test
- Impact test
- Fillet test
- Pressure test
- Peel test (for spot weld)

Non-Destructive Testing (NDT)

Non-destructive weld testing evaluates the structural quality of components without causing them harm. This method of testing saves time and money when evaluating and researching products. NDT approaches are used in forensic engineering, mechanical engineering, petroleum engineering, and electrical engineering, among other fields of engineering.

Magnetic particle inspection, also called magnetic particle testing, is an example of a non-destructive testing technique. This technique is used to detect possible defects on the surfaces of ferromagnetic materials like iron, nickel, cobalt, and a few of their alloys. Magnetic particle inspection has a number of advantages over other non-destructive testing methods, including cost, portability, and the lack of a thorough cleaning procedure prior to use. However, there are some limitations to this approach, such as the requirement that the material used be ferromagnetic, and that the magnetic field's direction and intensity be considered.

2.13 Tensile Test

A destructive test, the tensile test is used to determine how strong a material is. A prepared sample is subjected to a tensile (pulling or stretching) load until it snaps. Tensile checks are normally conducted on flat strips or round bars as specimens. Easy rounds are often used to measure only the weld material, which is referred to as weld metal testing. The round specimens are carved out of the weld metal's base. Flat bars (used in test analysis) are often used to test the weld as well as the surrounding metal. Flat bars are cut at a 90-degree angle to the weld in most cases (Davies,1996). A typical specimen for a tensile test with units in inches is depicted in fig. 2.16

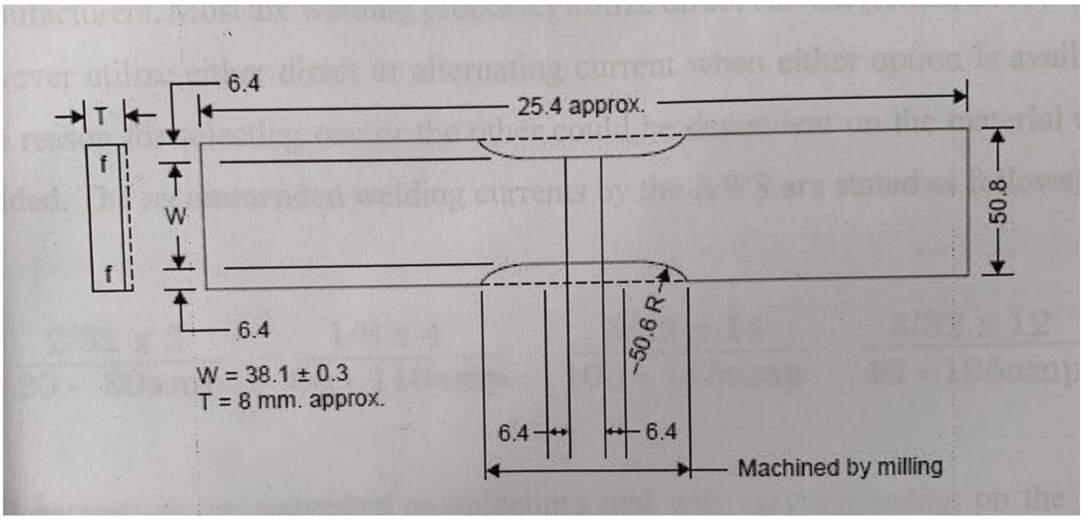


Fig 2.19 Tensile specimen of a flat weld

Weld Defects

Welding Defects can be described as the irregularities created in the given weld metal due to wrong welding process or incorrect welding patterns, etc. The defect can vary from the desired weld bead form, scale, and intended quality. Welding defects can occur either outside or within the weld metal. Some of the defects may be permitted if the defects are under allowable limits but other defects such as cracks are never recognized. See fig 2.17

Types

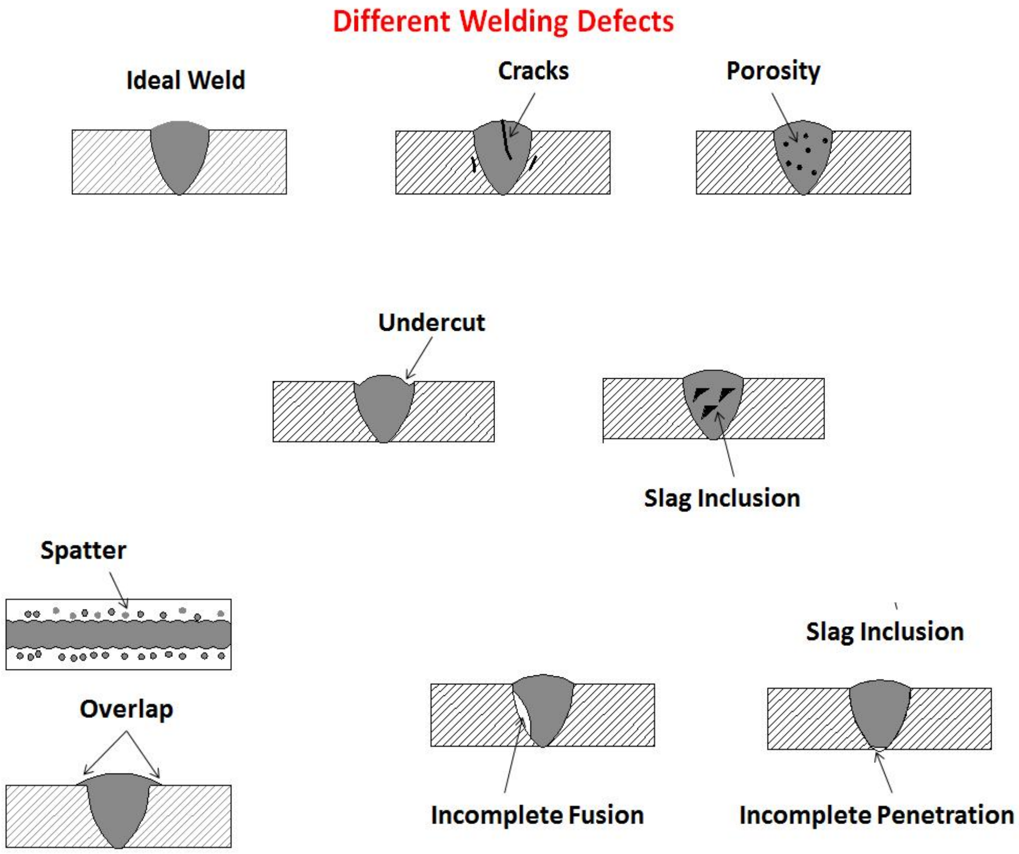


Fig2.20 Welding defects can be classified into two types as external and internal defects

External Welding Defects:

1. Weld Crack

2. Undercut

3. Spatter

4. Porosity

5. Overlap

6. Crater

Internal Welding Defects:

1. Slag Inclusion

2. Incomplete Fusion

3. Necklace cracking

4. Incompletely filled groove or Incomplete penetration

External Welding Defects

The various types of external defects with their causes and remedies are listed below:

1. Weld Crack

Among all the other welding flaws, this is the most despised. Welding cracks may occur on the surface, inside the weld material, or in heat-affected areas as shown in fig. 2.21.

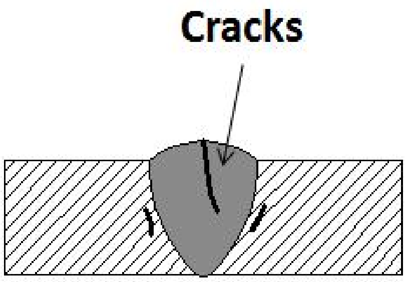


Fig 2.21

At different temperatures, cracks can appear:

Hot Crack – This occurs more frequently during the crystallization of weld joints, where temperatures can reach over 10,000°C.

Cold Crack – This type of crack develops near the end of the welding process, when the temperature is very low. Several hours after welding, or even a few days later, a cold crack may be visible.

Weld Crack Causes:

- i. The base metal is not ductile enough.
- ii. Residual stress in the weld metal can result in a crack.
- iii. The rigidity of the joint, which makes metal expansion and contraction difficult.
- iv. Cracks may appear if there is a high sulpur and carbon content.
- v. 5. When welding ferrous materials, using hydrogen as a shielding gas.

Remedies for Weld crack

- i. Using the right materials will help to reduce the chances of a crack.
- ii. Cracks may be reduced by preheating the weld and slowing down the cooling speed of the joint.
- iii. Use fair weld joints to reduce the distance between the weld joints.
- iv. When welding, the clamping force is gradually released, increasing the fill-to-capacity of the welding material.

2. **Undercut**

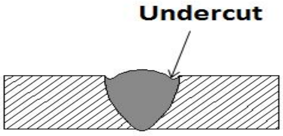


Fig 2.22

Undercut is a type of defect that occurs when the base of metal melts away from the weld region, forming a groove in the shape of a notch. It lowers the joint's fatigue power. See fig 2.22

i. This defect will occur if the arc voltage is extremely high.
ii. If we use the incorrect electrode or the electrode is angled incorrectly, a defect can develop.
iii. It's also not a good idea to use a big electrode.
iv. One of the reasons for this defect is a high electrode speed.

Undercut Remedies include the following:

i. Shorten the arc or reduce the voltage of the arc.
ii. For the standing leg, maintain an electrode angle of 30 to 45 degrees.
iii. The electrode must have a small diameter.
iv. Slow down the electrode's movement.

3. Spatter

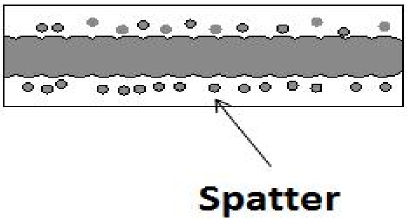


Fig 2.23

Spatter is a defect that occurs when certain metal drops are ejected from a weld and stay attached to the surface as shown in figure 2.23

Causes of Spatter:

- i. This defect can be caused by a high welding current.
- ii. The longer the arc, the more likely it is to develop this flaw.
- iii. The polarity is incorrect.
- iv. This defect may also be caused by a lack of adequate gas shielding.

Remedies for Spatter:

- i. Shortening the welding arc and lowering the welding current
- ii. Welding with the correct polarity and in accordance with the welding conditions.
- iii. Using adequate gas shielding and increasing the plate angle.

4. Porosity

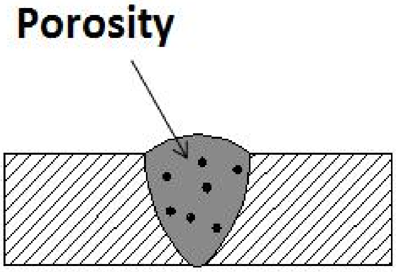


Fig 2.24

Porosity in the condition in which the gas or small bubbles gets trapped in the welded zone. See figure 2.24.

Causes of Porosity

- i. It occurs when the electrode is not coated properly.
- ii. Using a longer arc may also increase its chances.

iii. Increased welding currents.
iv. Rust or oil on the welding surface.

Remedies for Porosity:

i. Proper selection of the electrode.
ii. Decreasing the welding current.
iii. Using smaller arc and slowing the process to allow the gases to escape.
iv. Remove rust or oil from the surface and use a proper technique.

5. Overlap

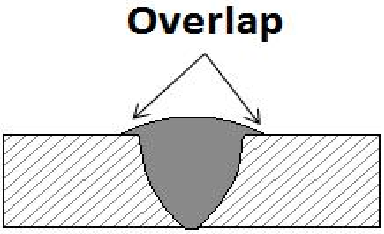


Fig.2.25

When the weld face extends beyond the weld toe, then this defect occurs(see figure 2.25). In this condition the weld metal rolls and forms an angle less than 90 degrees.

Causes of Overlap:

i. Improper welding technique.
ii. By using large electrodes this defect may occur.
iii. High welding current

Remedies for Overlap:

i. Using a proper technique for welding.
ii. Use small electrode.
iii. Less welding current.

6. Crater

It occurs when the crater is not filled before the arc is broken, which causes the outer edges to cool faster than the crater. This causes a stress and then crack is formed.

Causes of the Crater:

- i. Incorrect torch angle.
- ii. Use of large electrode:
- iii. Improper welding technique

Remedies for Crater:

- i. Using a proper torch angle may reduce the stress on the metal
- ii. Using a small electrode may also decrease the crater.
- iii. Use a proper technique.

Internal Welding Defects

The various types of internal welding defects with their causes and remedies are listed below:

1. Slag Inclusion

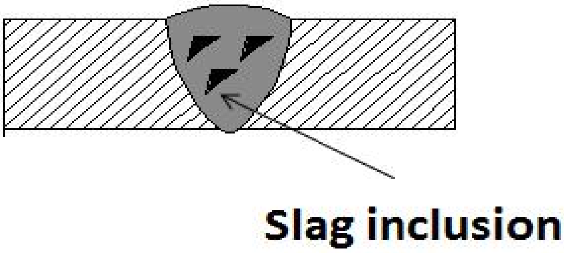


Fig 2.26

If there is any slag in the weld, then it affects the toughness and metal weldability of the given material. This decreases the structural performance of the weld material (see figure 2.26). Slag is formed on the surface of the weld or between the welding turns.

Causes of Slag:

1. Slag is formed if the welding current density is very small, as it does not provide the required amount of heat for melting the metal surface.
2. If the welding speed is too fast then also slag may occur.
3. If the edge of the weld surface is not cleaned properly then also slag may form.
4. Improper welding angle and travel rate of welding rod.

Remedies for Slag Inclusion

1. Increase the current density
2. Adjust the welding speed so that the slag and weld pool do not mix with each other.
3. Clean the weld edges and remove the slags of previous weld layers
4. Have a proper electrode angle and travel rate.

2. Incomplete Fusion

Incomplete fusion occurs when the welder does not accurately weld the material and the metal pre solidifies which leads to a gap which is not filled with the molten metal.

Causes of Incomplete Fusion:

1. It occurs because of the low heat input.
2. When the weld pool is very large and runs ahead of the arc.
3. When the angle of the joint is too low.

iv. Incorrect electrode and torch angle may also lead to incomplete fusion.
v. Unproper bead position.

Remedies for Incomplete Fusion

i. Increasing the welding current and decreasing the travel speed helps in removing the chances of incomplete fusion.
ii. Reducing the deposition rate.
iii. Increasing the joint angle.
iv. Try to position the electrode and torch angle properly so that the edges of the plate melt away.
v. Positioning the bead properly so that the sharp edges with other beads can be avoided.

3. Necklace Cracking

It occurs in the use of electron beam welding where the weld does not penetrate properly. Therefore, the molten metal does not flow into the cavity and results in a cracking known as "Necklace Cracking".

Causes of Necklace Cracking:

i. Improper welding technique.
ii. It occurs in materials such as nickel base alloys, stainless steel, carbon steels and Tin alloys.
iii. Using high speed of electron beam welding

Remedies for Necklace Cracking:

i. Using a proper welding technique reduce the chances of necklace cracking.
ii. Using proper materials for welding.
iii. Using a constant speed during the welding process.
iv. Improper welding technique
v. Incomplete Penetration

These defects occur only in the butt welds where the groove of the metal is not filled completely. It is also called as incomplete penetration defect.

Causes of an Incomplete Filled Groove Are

i. Less deposition of the weld metal
ii. Use of improper size of the electrode
iii. Improper welding technique

Remedies for Incomplete Filled Groove Are

i. More deposition of the weld metal.
ii. Use a proper size of the electrode.
iii. By using a proper welding technique.

Therefore, we have listed all types of welding defects present during any manufacturing process. While welding, it is very important to remove all the defects of welding present in the workpiece.

If there would be defects in the welding material, then in severe conditions the components of the material would fail which may lead to loss of property and sometimes also life.

2.14 Steel

Steel is an iron-carbon alloy that is commonly used in building and other applications due to its high tensile strength and low cost. Carbon, other elements, and inclusions in iron serve as hardening agents, preventing dislocations from moving around in the crystal lattices of iron atoms (Howard, 1998)

Carbon can make up to 2.1 percent of the weight of a standard steel alloy. By varying the amount of alloying elements in the steel, either as solute elements or as precipitated phases, the movement of the dislocations that make iron so ductile and weak is slowed, and the hardness, ductility, and tensile strength of the resulting steel can be regulated. Steel's superior strength to pure iron can only be achieved at the cost of ductility, which iron has in abundance.

2.14.1 Stainless Steel Classification

The three most common steel classifications are:

- Stainless steel (carbon)
- Aluminum alloy
- Stainless steel is used.

Carbon Steel - Carbon steel is divided into three groups based on its carbon content: low-carbon steel (or mild-carbon steel), medium-carbon steel (or medium-carbon steel), and high-carbon steel (or high-carbon steel). Steel is considered carbon steel when no minimum content of chromium, cobalt, columbium [niobium], molybdenum, nickel, titanium, tungsten, vanadium, or zirconium, or any other element to be added to obtain a desired alloying effect, is specified or required; when the specified minimum for copper does not exceed 0.40 per cen; and when the specified minimum for nickel does not exceed 0.40 per cen.

Carbon steel can be graded as rimmed, capped, semi-killed, or killed, depending on how it is deoxidized. The properties of steel can be affected by deoxidation practices and the steelmaking process. Carbon content, on the other hand, has the greatest impact on mechanical properties, with higher carbon content resulting in improved hardness and strength. As a result, carbon steels are classified based on their carbon content. Carbon steels are classified as low-carbon steels, medium-carbon steels, and high-carbon steels, and can contain up to 2% total alloying elements. Each of these designations is listed below.

Steels containing up to 0.30 percent carbon are known as low-carbon steels. Flat-rolled goods (sheet or strip) are the most common type of steel in this group, and they are typically cold-rolled and annealed. These high-formability steels have a very low carbon content, less than 0.10 per cent C, and up to 0.4 per cent Mn. Automobile body panels, tin plate, and wire products are all popular applications. Carbon content in rolled steel structural plates and parts can be increased to about 0.30 per cent, with manganese content up to 1.5 per cent. Stampings, forgings, seamless tubes, and boiler plate can all be made from these materials.

Steels with a carbon content ranging from 0.30 to 0.60 per cent and manganese content ranging from 0.60 to 1.65 per cent are known as medium-carbon steels. Medium carbon steels can be quenched and tempered by raising the carbon content to about 0.5 per cent and increasing the manganese content at the same time. Shafts, axles, gears, crankshafts, couplings, and forgings are among the applications for medium carbon-manganese steels. Rails, railway wheels, and train axles are made of steels with a C content of 0.40 to 0.60 percent.

Steels with a carbon content of 0.60 to 1.00 percent and manganese contents of 0.30 to 0.90 percent are referred to as high-carbon steels. For springs and high-strength cables, high-carbon steels are used.

Carbon is the most common steel alloy used in industry. Hardness, strength, and hardenability all improve as carbon content is increased. However, because of its propensity to form martensite, carbon increases brittleness and reduces weld efficiency. As a result, when it comes to industrial steel, carbon content can be a blessing and a curse.

A heat-quench-temper cycle can now be used to harden any steel with a carbon content of 0.35 to 1.86 percent. The vast majority of commercial steels are divided into three categories:

1. Carbon steels that are plain in appearance
2. Low-alloy steels are a type of steel that does not contain any alloying elements
3. Steels with a high degree of alloying

Low-alloy steels have a carbon content of less than 0.25 percent, and sometimes less than 0.15 percent, when built for welded applications. Nickel, chromium, molybdenum, manganese, and silicon are common alloying elements that improve notch durability at low temperatures and add strength at room temperatures. The tensile and yield strengths of low alloy structural steel are higher than those of mild steel or carbon structural steel. They minimize dead weight in freight cars, truck frames, and heavy machinery by virtue of their high strength-to-weight ratios. In critical applications, ordinary carbon steels that brittle at low temperatures are unreliable. As a result, for low-temperature applications, low-alloy steels with nickel additions are often used. High temperatures cause steel to lose a lot of its power. Tiny quantities of chromium or molybdenum are applied to compensate for the strength loss at elevated temperatures. These alloys can increase corrosion resistance and influence the steel's heat treatment response when used together in the right proportions. However, since the alloys added will affect crack susceptibility, low-hydrogen welding processes should be used for them. It's possible that preheating is needed. The carbon equivalent formula, which we'll discuss in more detail in a later topic, can be used to calculate this.

High Alloy Steel - This pricey and advanced steel has an alloy content of more than 10%, making it exceptional properties. Austenitic manganese steel has a high carbon and manganese content, giving it two unique properties: the ability to harden when cold working and a high degree of durability. The crystalline structure of these steels is known as austenitic. Stainless steels are corrosion-resistant high-alloy steels. The high chromium content, which is at least 10%, is responsible for these characteristics. Some stainless steels often contain a significant amount of nickel. Cutting and shaping operations are done with tool steel. They are high-quality steels that are used to make tools, punches, shaping dies, extruding dies, and forgings, among other things. Water hardening, shock resistant, oil hardening, air hardening, and hot work tool steel are some of the terms used to describe their properties and applications. Welding high alloy steel necessitates extra caution and practice due to the high levels of alloying elements present.

By adding such alloys including chromium, nickel, molybdenum, nitrogen, titanium, and columbium to austenitic stainless steels, special properties such as corrosion resistance, oxidation resistance, and strength at high temperatures can be added. Although carbon can increase strength at high temperatures, it can also minimize corrosion resistance by combining with chromium. Heat treatment cannot be used to harden austenitic alloys. They do not harden in the welding HAZ, so this is a good thing.

2.14.2 Steel Specifications and Applications

Steel structures may be the most visible contributions to the Earth's landscape by humanity. Steel would be found in the most study and formidable structures that had evidently not evolved from natural geological processes if all life on Earth was teleported elsewhere and a party of aliens happened to investigate: skyscrapers, bridges, heavy equipment, and basically everything that had to endure strong forces over time. You may have an understanding of where steel "comes from" and what it "is," if nothing else. Steel is known as an alloy or a combination of various metals, which is natural if you consider it a metal. Regardless of the precise formula, almost all of the primary metal is iron, but as you'll see, even small quantities of carbon will greatly alter steel's properties. Prepare to learn a lot about what is perhaps the most important content in the history of architecture and engineering.

Steel Properties (Physical and Chemical)

Steel is known for its resilience, hardness, and toughness, as you probably know from having seen, read, and come into contact with your fair share of it. It's also known for its lustrous appearance in some instances. In physical terms, these properties lead to a very high melting point (about 1,510 °C, higher than most metals; copper, for example, has a melting point nearly 500 degrees lower) and a very high density (7.9 g/cm3, nearly eight times that of water). Steel is generally harder and stronger than iron, which it is said to be derived from. Despite this, it has a high tensile strength and is highly flexible (i.e., its ability to withstand applied loads, or forces, without losing its shape).

Steel has a high tensile strength as compared to other materials, but it varies greatly between steel types. Tensile intensity ranges from 290 N/mm2 to 870 N/mm2 at the extremes. One millionth of a square meter is one square millimetre (mm2). Steel can have a tensile strength of 870 million newton per square meter, which is equivalent to a mass of 88.8 million kilograms (97,831 tons) on Earth! If you've ever used a cast-iron skillet, you've probably noticed how solid (or at the very least heavy) it is. Iron is more brittle than steel when it is the sole or nearly sole component of an item such as a pan.

However, the functional difference between iron and steel may be negligible for most everyday cooking temperatures (which appear "hot," but are far from smelting-furnace-like). Even though they typically look different, the practical distinction between iron and steel cannot be readily apparent.

2.14.3. Types of Steel

Even though it can contain metals other than iron and carbon, such as silicon and manganese, most steel manufactured today is simply referred to as carbon steel, or plain carbon steel. On the surface, the amount of steel difference does not appear to be important because carbon seldom makes up more than 1.5 percent of steel. When you know that this tiny fraction can vary by a factor of ten (0.15 percent to 1.5 percent), you can see how significant the physical effect can be.

Steel can be classified into many groups based on a variety of factors. Those used by scientists (who are often more interested in the properties of objects than in actually using them) are often different from those whose primary concern is the types of steel end products.

Mechanical aspects: Steel's tensile strength can range from 290 N/m2 to 870 N/m2, as previously stated. Adding carbon to steel makes it harder because the carbon atoms effectively scatter among the iron atoms, making material dislocations extremely difficult, resulting in "grains" of Fe3C. This also makes steel more brittle than iron, so despite the obvious advantages of the latter, converting iron to steel is not without cost. Steel that is graded primarily on the basis of its mechanical properties begins with "Fe," followed by 1) E and the minimum yield stress value if the steel is classified primarily on this basis, or 2) only the tensile strength value if tensile strength is the primary classification trait. (_Yield stress is a measure of mechanical deformation resistance.) Steel with a tensile strength of 290 N/mm2 is known as "Fe 290," whereas steel with a yield stress of 220 N/mm2 is known as "Fe E 220."

Compound: Plain carbon steels with carbon content ranging from 0.06 percent to 1.5 percent are classified into the following categories based on their carbon content.

i. Up to 0.15 percent carbon in dead mild steel
ii. Low carbon or mild steel — carbon content ranges from 0.1 to 0.45 percent.
iii. Steel with a carbon content of 0.45 to 0.8 percent.
iv. High carbon steel, with a carbon content ranging from 0.8 to 1.5 percent

Stainless steel is a type of steel that is known for its resistance to oxidation (rusting) and corrosion, such as that which may occur when a strong acid is applied. It was invented in 1913 by British metallurgist Harry Brearley, who discovered that adding large concentrations of the metal chromium to steel (13 percent) caused the chromium to react with oxygen in the air, forming a self-renewing protective film around the object.

Today, stainless steel comes in a variety of forms:

Martensitic stainless steels, which contain 12 to 1 percent carbon and 0.12 to 0.35 percent, were the first to be produced. These steels are magnetic and can be heat treated to harden them. Hydraulic motors, steam pumps, oil pumps, and valves are among the engineering devices that use these.

Ferritic stainless steels have higher chromium content (16 to 18%) and around 0.12% carbon. These steels are more corrosion resistant than martensitic stainless steels, but they have limited heat hardening capability. Because of their high corrosion resistance, these stainless steels are mainly used in shaping and pressing operations. Austenitic stainless steels are high in chromium and nickel, with low carbon content. There are several different chemical compositions, but the most common is 1% chromium and 8% nickel, with low carbon content. They have excellent corrosion resistance but are not heat treatable to any significant degree. Pump shafts, supports, sheathing, and everyday parts like screws, nuts, and bolts are all made of these steels.

Advantages of Steel

Steel has a number of attractive qualities, one of which is that it is environmentally friendly. Huge steel structures dotting the sky cape in sometimes unappealing places do not always appear to be that way, but their great longevity ensures that they will not degrade into anything harmful and leach undetected into groundwater and other areas. Stainless steel is widely used in renewable energy sources such as solar, wind, and hydropower. Steel is now the most recycled material on the planet; despite its weight, its magnetic properties make it easier to extract from streams and other environments than other waste. It has the potential to minimize CO2 emissions.

Steel uses less energy than other materials to build comparatively steel elements, and it can be formed into a variety of shapes. It has a better shape and edge than iron, which is commonly used in arms manufacture.

2.14.4 Steel's Uses and Functions

Steel is used in the automotive industry, as previously mentioned. Consider the number of vehicles on the roads of your own city during rush hour, all of which have steel frames, doors, engines, suspensions, and interiors.

Steel accounts for around half of a car's weight. Steel is used in the construction of farm vehicles and machinery, in addition to passenger vehicles. Refrigerators, televisions, toilets, ovens, and other appliances in modern homes are often made of "plain" steel. Many who enjoy spending time in the kitchen are also conscious of the importance of stainless steel in fine cutlery. Stainless steels are particularly well-suited to maintaining a sterile setting, which is one of the characteristics that makes them a good option for surgical instruments and implants. Iron, rather than just making up the invisible foundation of modern structures, has been featured in its own right in examples of contemporary architecture because it lends itself to the simple formation of welds. In areas where high winds are a part of the local climate, so-called "mild" steel is used for daily building construction.

CHAPTER THREE

3.0 Materials and Methods

3.1 Material

A 10mm mild steel was subjected to gas metal arc welding (GMAW) operation. The semi-automatic has input parameters such as voltage, current, and gas flow rate.

The welding machines contain the welding gun, shielding gas consisting of 80% argon and 20% carbon dioxide. A 1.6mm consumable wire electrode of AWS classification ER70S-3

Other equipment used was Charpy impact energy tester. The impact test is attest for determining the energy absorbed in fracturing a test piece of weldment at high velocity. The absorbed energy is a measure tester consists of a swinging pendulum or hammer with an energy of 0-300 J and a swinging speed of 5-7m/s.

The hammer has thickness of 18mm and about 18mm long. A pivotal view of the impact tester used in this study is shown in the fig 3.1

Fig 3.1 Impact Tester

Five welded deposits were made using each input process parameter. These weldments were bisected and the world bead penetration measured. The average of the bead penetration values was recorded. This was done for each welding operation.

Power saw was to cut the weld bead so that the bead width and height can be measured. The sawing machine is a machine tool designed to cut material to a designed length or contour. It functions by drawing a blade containing teeth through the work piece. The sawing machine is preferred to the hand saw since it is faster and easier and principally produces an accurate square or metered cut on the work-peice.

The power saw is used for squared or angle cutting of metal. It uses a reciprocating (back and forth) cutting action (see fig 3.2).

Fig 3.2 Power Saw

3.2 METHODS

3.2.1Application of SWARA

The SWARA process, which was used in this analysis, can approximate experts' opinions on how to weigh each performance parameter. Expert investigations necessitate a physical and technical inspection of the welded specimens, followed by ranking or rating them using the Likert Scale Preference Method.

The following is a step-by-step procedure for using the SWARA method:

Determine the relative significance of the average value ;

1. Comparative importance of average value , S_j

2. Coefficient, $K_j = \begin{bmatrix} 1; j = 1 \\ S_j + 1; j > 1 \end{bmatrix}$ (1)

3. Recalculated weight, q_j

$$K_j = \begin{Bmatrix} 1; j = 1 \\ \frac{K_j - 1}{K_j}; j > 1 \end{Bmatrix} \tag{2}$$

4. Relative weight, W_j for each criteria

Application of ARAS

1. Optimal performance ratings, X_{oj} are calculated as $X_{oj} = Max\,X_{ij}$ (3) 2. Normalized performance ratings. r_{ij}

$$r_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \tag{4}$$

3. Weighted normalized performance ratings V_{ij}

$$V_{ij} = w_j . r_{ij} \tag{5}$$

4. Overall performance, index, S_i for each alternative

$$S_i = \sum_{j=1}^{m} V_{ij} \tag{6}$$

5. Degree of utility for each alternative $Q_i = \frac{S_i}{S_o}$ (7)

S_0 is the overall performance index of optimal alternative, and it is usually 1

6. Rank alternatives and or select the most efficient one. That is the alternative with the greater value of Q_i is expected to have a higher priority, that is best placed (rank).

CHAPTER FOUR

4.0 Presentation and Discussion of Results

4.1 Presentation of Solids

Table 4.1 Shows the Measured Mechanical Properties

Input Parameters			**Output Parameters**		
Weldment Number	Current I	Gas flow rate L/min	Bead Penetration (mm)	Impact Energy (J)	Ultimate Tensile Strain (MPA)
1	160	12	7.68	80	280
2	160	15	10.15	120	320
3	190	12	6.92	75	265
4	190	15	9.25	100	300
5	160	12	8.10	86	295
6	160	15	9.05	98	310
7	190	12	8.78	80	278
8	190	15	10.20	109	315

Table 4.2 shows the assessment of First Expert evaluation process

Table 4.2: Expert evaluation

Weldment	**Weld mechanical properties**		
	Maximum		**Minimum**
	UTS	**CVN**	**BH**
1	4	4	3
2	3	3	5
3	5	4	3
4	3	4	4
5	4	3	3
6	3	3	4
7	4	5	3
8	4	3	2

Table 4.3 shows the assessment of second Expert evaluation process

Table 4.3: Second Expert Evaluation

Weldment	**Mechanical Properties**		
	Maximum		**Minimum**
	UTS	**CVN**	**BH**
1	5	4	3
2	2	3	3
3	3	3	2
4	5	3	4
5	4	3	3
6	3	4	4
7	3	5	3
8	5	3	3

Table 4.4 shows the assessment of third Expert evaluation process

Table 4.4: Third Expert Evaluation

Weldments	**Weld Mechanical Properties**		
	Maximum		**Minimum**
	UTS	**CVN**	**BH**
1	4	2	5
2	4	3	4
3	2	4	2
4	4	2	3
5	3	4	2
6	2	5	4
7	4	4	5
8	3	3	3

Table 4.5 shows the assessment of the fourth Expert evaluation process

Table 4.5: Fourth Expert Evaluation

Weldment	**Weld Mechanical Properties**		
	Maximum		**Minimum**
	UTS	**CVN**	**BH**
1	3	4	5
2	4	3	2
3	4	3	4
4	4	3	2
5	4	4	3
6	5	5	4
7	5	4	3
8	4	4	3

Table 4.6 shows the assessment of the fifth Expert evaluation process

Table 4.6: Fifth Expert Evaluation

Weldment	Weld Mechanical Properties		
	Maximum		Minimum
	UTS	CVN	BH
1	3	3	3
2	3	4	3
3	3	4	2
4	3	2	4
5	4	2	4
6	4	3	2
7	3	3	2
8	3	3	4

After the different evaluation of the weldments by the Experts, the next step here is to determine the corporative importance of average value S_j for each of the evaluation criteria using the method adopted by stanujkic *et al* (2015). In determining S_j, the first step is to determine the relative weights of responses (see Table 6) obtained from the first Expert as contained in Table 4.7.

Table 4.7 Determining of Relative Weights from the First Expert Evaluation

	Weld Mechanical Properties			
	UTS	**CVN**	**BH**	**Overall score**
Total	30	29	27	86
Relative weight	30/86	29/86	27/86	
W_j	=0.35	0.34	0.31	

The relative weights as contained in table 7 are rearranged in the descending order of arrangement as shown in Table 8

Table 4.8: Determination of Comparative Importance of Average Value S_j from the Reponses of the First Expert.

Relative Weight W_j	W_{j-1}	W_{j-1}	$\frac{W_j - W_{J-1}}{W_j} = S_j$
0.31	0.31	0.31	0
0.34	i) 0.34 – 0.31 =0.03 ii) 0.31 – 0.03 =0.28	0.28	0.2
0.35	i) 0.35 – 0.34 = 0.01 ii) 0.28 -0.01 = 0.27	0.27	0.23

Table 4.9 shows the final results of SWARA method in weighing assessment indicator from the First Expert evaluation.

Table 4.9: Final results of SWARA method in weighing of First Expert Response.

Mechanical Properties	Comparative importance of average value S_j	Coefficient $K_j = S_j + 1$	Recalculated weight $W_j = \frac{W_j + 1}{K_j}$	Weight $q = \frac{w_j}{\sum w_j}$
BH	0	(0 + 1) = 1	1	1/2.505 = 0.400
CVN	0.2	(0.2 +1) = 1.2	1/1.2 = 0.83	0.83/2.505=0.331
UTS	0.23	(0.23 + 1) = 1.23	0.83/1.23=0.675	0.847/2.505= 0.269
		Total	2.505	1

Table 10 shows the relative weight determination of the responses obtained from the second Expert evaluation.

Table 4.10: Determination of Relative Weight from the Second Expert Evaluation

	WELD MECHANICAL PROPERTIES			
	UTS	**CVN**	**BH**	**Overall score**
Total Score	30	28	25	83
Relative Weight W_j	0.36	0.34	0.30	

Table 4.11 shows the determination of the relative weights from comparative importance of average value, Sj obtained from the responses of the second expert.

Table 4.11: Determination of Comparative Importance of Average Value (s) from the Responses of the Second Expert.

Relative weight W_j	W_{j-1}	$S_j = \frac{W_j - W_j - 1}{W_j}$
0.30	0.30	0
0.34	(i) 0.34 – 0.30 = 0.04 (ii) 0.30 – 0.04 = 0.26	0.24
0.36	(i) 0.36 – 0.34 = 0.02 (ii) 0.26 – 0.02 = 0.24	0.33

Table 4.12 shows the final results of SWARA method in weighting assessment indicator from the second Expert Evaluation.

Table 4.12: Final Results of SWARA-ARAS Method in Weighting of Second Expert Reponses.

Criterion mechanical properties	Comparative importance of average value S_j	Coefficient $K_j = S_j + 1$	Recalculated weight $W_j = \frac{W_j + 1}{K_j}$	Weight $q = \frac{W_j}{\sum W_j}$
BH	0	(0+1) = 1	1	0.41
CVN	0.24	(0.24+1) = 1.24	(1/1.24) = 0.81	(0.81/2.42) = 0.33
UTS	0.33	(0.33+1) = 1.33	(0.81/1.33) = 0.61	(0.61/2.42) = 0.25
		Total	2.42	1.00

Table 4.13 shows the relative weight determination of the responses obtained from the third Expert evaluation.

Table 4.13: Determination of Relative Weight from the Third Expert Evaluation.

Criterion	**Weld Mechanical Properties**			
	UTS	**CVN**	**BH**	**Overall Score**
Total score	26	27	28	26+27+28=81
Relative weight W_j	26/81 = 0.32	27/81 =0.33	28/81 =0.34	

The relative weights as contained in Table 4.13 are rearranged in the descending order of arrangement as shown in Table 4.14. These weights are also use for the computation of comparative importance of average value.

Table 2.14 shows the determination of comparative importance of average value, **S_j** from the responses of the third expert.

Table 4.14: Determination of Comparative Importance of Average Value S_j from the Responses of the Third Expert

Relative weight W_j	$W_j - 1$	$S_j = \frac{W_j - W_j - 1}{W_j}$
0.32	0.32	0
0.33	(i) 0.33 – 0.32 = 0.01 (ii) 0.32 – 0.01 = 0.31	0.06
0.34	(i) 0.34 – 0.33 = 0.01 (ii) 0.31 – 0.01 = 0.30	0.12

Table 4.15 shows the final results of SWARA method in weighting assessment indicator from the Third Expert Evaluation.

Table 4.15: Final Results of SWARA method in Weighting of Third Expert

Criterion or Mechanical Properties	Comparative Importance or Average Value S_j	Co-efficient $K_j = S_j + 1$	Recalculated weight $W_j = \frac{W_j + 1}{K_j}$	Weight $q = \frac{W_j}{\sum W_j}$
UTS	0	0+1 = 1	1	1/ 2.78 = 0.36
CVN	0.06	0.06 + 1 = 1.06	1/1.06= 0.94	0.94/2.78 = 0.34
BH	0.12	0.12 + 1 = 1.12	0.94/1.12 = 0.84	0.84/2.78 = 0.30
Total			2.78	1.00

Table 4.16 shows the relative weight determination of the responses obtained from the fourth Expert evaluation.

Table 4.16: Determination of Relative Weight from the Fourth Expert

Criterion	Weld Mechanical Properties			Overall Score
	UTS	CVN	BH	
Total Score	33	31	26	90
Relative Weight W_j	33/90 = 0.37	31/90 = 0.34	26/90 = 0.28	1.00

The relative weights as contained in Table 4.16 are rearranged in the descending order of arrangement as shown in Table 4.17. These weights are also used for the computation of comparative importance of average value for the fourth expert responses.

Table 4.17: Determination of Comparative Importance of Average Value S_j from the Response of the Fourth Expert.

Relative Weight W_j	W_{j-1}	$S_j = \frac{W_j - W_j - 1}{W_j}$
0.28	0.28	0
0.34	(i) 0.34-0.28 = 0.06 (ii) 0.28-0.06 = 0.22	0.35
0.37	(i) 0.37-0.34 = 0.03 (ii) 0.22-0.03 = 0.19	0.49

Table 4.18 shows the final results of SWARA method in weighting assessment indicator from the Fourth Expert Evaluation.

Table 4.18: Final Results of SWARA Method in Weighting Assessment of Fourth Expert

Criterion or Mechanical Properties	**Comparative Importance of Average Value S_j**	**Coefficient** $K_j = S_j + 1$	**Recalculated weight** $W_j = \frac{W_j + 1}{K_j}$	**Weight** $q = \frac{W_J}{\sum W_j}$
BH	0	(0+1)=1	1	1/2.24=0.45
CVN	0.35	(0.35+1)=1.35	1/1.35 =0.74.	0.74/2.24=0.33
UTS	0.49	(0.49+1)=1.49	0.74/1.49=0.50	0.50/2.24=0.22
TOTAL			=2.24	1.00

Table 4.19 shows the relative weight determination of the responses obtained from the fifth Expert evaluation.

Table 4.19: Determination of Relative Weight from the Fourth Expert.

Criterion	**Weld Mechanical Properties**			**Overall Score**
	UTS	**CVN**	**BH**	
Total score	26	24	34	84
Relative weight W_j	26/34 =0.31	24/84 =0.29	34/84 =0.40	1.00

Table 4.20 shows the determination of the comparative importance of average value S_j obtained from the responses of the fifth Expert the relative weights are rearranged in a descending order.

Table 4.20: Determination of Comparative Importance of Average Value S_j from the responses of the Fifth Expert.

Relative weight W_j	**W_{j-1}**	$S_j = \frac{W_j - W_j - 1}{W_j}$
0.29	0.29	0
0.31	(i) 0.31 -0.29 =0.02 (ii) 0.29 – 0.02 = 0.27	0.13
0.40	0.40 – 0.31 = 0.09 0.27 – 0.09 = 0.18	0.55

Table 4.21 shows the results of SWARA method in weighing assessment indicator from the fifth expert evaluation.

Table 4.21: Final Results of SWARA Method in Weighing of Fifth Expert.

Criterion Mechanical Properties	Comparative importance average value S_j	Coefficient $K_j = S_j + 1$	Recalculated weight $w_J = \frac{w_J + 1}{k_J}$	Weight $Q = \frac{w_J}{\sum w_J}$
CVN	0	(0 + 1) = 1	1	1/ 2.45 = 0.41
UTS	0.13	(0.13+1)=1.13	11/13 = 0.88	0.88/2.45 =0.36
BH	0.55	(0.55+1)=1.55	0.88/1.55=0.57	0.57/2.45 =0.23
Total			2.45	1.00

Table 4.22 shows the geometric mean of weight obtained from the experts. The weight obtained from table 9, 12, 15, 18 and 21

Table 4.22: The Geometric Mean of Weight

Criterion	**Geometric mean of weights**
UTS	$\frac{0.27 + 0.25 + 0.22 + 0.36 + 0.36}{5} = 0.3$
CVN	$\frac{0.34 + 0.33 + 0.33 + 0.33 + 0.41}{5} = 0.35$
BH	$\frac{0.40+0.41+0.30+0.45+0.23}{5} = 0.36$

4.2 Application of Additive Ratio Assessment (ARAS) Method

Table 4.23 shows the average ratings of experts’ responses considering Tables 2, 3, 4, 5 and 6

Table 4.23: Average rating experts Responses

	Weld Mechanical Property		
Weldment W	UTS	CVN	BH
W_1	$\frac{4+5+4+3+3}{5} = 3.8$	$\frac{4+4+2+4+3}{5} = 3.4$	$\frac{3+3+5+5+3}{5} = 3.8$
W_2	$\frac{3+2+4+4+3}{5} = 3.2$	$\frac{3+3+3+3+4}{5} = 3.2$	$\frac{5+3+4+2+3}{5} = 3.4$
W_3	$\frac{5+3+2+4+3}{5} = 3.4$	$\frac{4+3+4+3+4}{5} = 3.6$	$\frac{3+2+2+4+2}{5} = 2.6$
W_4	$\frac{4+5+4+3+3}{5} = 3.8$	$\frac{4+3+2+3+2}{5} = 2.8$	$\frac{4+4+3+2+4}{5} = 3.4$
W_5	$\frac{4+4+3+4+4}{5} = 3.8$	$\frac{3+3+4+4+2}{5} = 3.2$	$\frac{3+3+2+3+2}{5} = 2.6$
W_6	$\frac{3+3+2+5+4}{5} = 3.4$	$\frac{3+4+5+5+3}{5} = 4.0$	$\frac{4+4+2+4+2}{5} = 3.6$
W_7	$\frac{4+3+4+5+3}{5} = 3.8$	$\frac{5+5+4+4+3}{5} = 4.2$	$\frac{3+3+5+3+2}{5} = 3.2$
W_8	$\frac{4+5+3+4+3}{5} = 3.8$	$\frac{3+3+3+3+4}{5} = 3.8$	$\frac{3+4+4+5+5}{5} = 4.2$
MAXIMUM Value $=W_0$ of W	3.8	4.2	4.2
Total, $W_T = W_0 + W_1 + W_2 + W_3 + W_4 + W_5 + W_6 + W_7 + W_8$	32.8	32.4	31

Table 4.24 shows the normalized decision making matrix of table 22

Table 4.24: Normalized Decision Making Matrix

Weldment W	**Weld Mechanical Properties**		
	UTS	**CVN**	**BH**
0	3.8/32.8 = 0.116	4.2/32.4 = 0.130	4.2/31 = 0.135
1	3.8/32.8 = 0.116	3.4/32.4 = 0.105	3.8/31= 0.123
2	3.2/32.8 = 0.098	3.2/32.4 = 0.099	3.6/31= 0.116
3	3.4/32.8 = 0.104	3.6/32.4 = 0.111	3.8/31= 0.123
4	3.8/32.8 = 0.116	2.8/32.4 = 0.086	3.4/31= 0.109
5	3.8/32.8 = 0.116	3.2/32.4 = 0.099	3.4/31= 0.109
6	3.4/32.8 = 0.104	4.0/32.4 = 0.123	3.8/31= 0.123
7	3.8/32.8 = 0.116	4.2/32.4 = 0.130	3.6/31= 0.116
8	3.8/32.8 = 0.116	3.8/32.4 = 0.117	4.2/31= 0.135

Table 4.25 shows the normalized decision making matrix and weights. The weights were imported from table 22

Table 4.25: Normalized Decision Making Matrix and Weights

Weldment W	**Weld Mechanical Property**		
	UTS	**CVN**	**BH**
Weight W_i from table 22	0.30	0.35	0.36
0	0.116	0.130	0.135
1	0.116	0.105	0.123
2	0.098	0.099	0.116
3	0.104	0.111	0.123
4	0.116	0.186	0.109
5	0.116	0.099	0.109
6	0.104	0.123	0.123
7	0.116	0.113	0.116
8	0.116	0.117	0.135

Table 4.26 shows the weighted normalized performance rating

Table 4.26: Weighted Normalized Performance

Weldment W	**Mechanical Property**		
	Maximum		**Minimum**
	UTS (MPa)	**CVN (J)**	**BH (mm)**
1	0.116x0.30 = 0.0348	0.105x0.35 =0.0368	0.123x0.36 =0.0443
2	0.098x0.30 = 0.0294	0.099x0.35 =0.0347	0.116x0.36 = 0.0418
3	0.104x0.30 = 0.0312	0.111x0.35 =0.0389	0.123x0.36 =0.0443
4	0.116x0.30 = 0.0348	0.086x0.35 =0.0301	0.109x0.36 =0.0392
5	0.116x0.30= 0.0348	0.099x0.35 =0.0347	0.109x0.36 =0.0392
6	0.104x0.30 = 0.0312	0.123x0.35 =0.0431	0.123x0.36 =0.0442
7	0.116x0.30 = 0.0348	0.130x0.35 =0.0455	0.116x0.36 =0.0418
8	0.116x0.30 = 0.0348	0.117x0.35 =0.0410	0.135x0.36 =0.0486
0	0.116 × 0.30 = 0.0348	0.130×0.35 = 0.0455	0.135 ×0.36 = 0.0486

Table 4.27 shows the overall performance index of the Experts' responses.

Table 4.27: Overall Performance Index

Weldment (W)	Insert equation	$\boldsymbol{Q_i = \frac{S_i}{S_o}}$ Where $\boldsymbol{S_o = W_o}$	Rank
0	0.0348+0.0455+0.0486 = 0.1289		
1	0.0348+0.0368+0.0443 = 0.1151	Q_1 = 0.1151/0.1289 = 0.8991	4
2	0.0294+0.0347+0.0418 = 0.1059	Q_2 = 0.1059/0.1289 = 0.8216	7
3	0.0312+0.0389+0.04428 = 0.1144	Q_3 = 0.1144/0.1289 = 0.8875	5
4	0.0348+0.0301+0.03924 = 0.1041	Q_4 = 0.1041/0.1289 =0.8076	8
5	0.0348+0.0347+0.03924 = 0.1087	Q_5 = 0.1087/0.1289 = 0.8433	6
6	0.0312+0.0431+0.04428 = 0.1186	Q_6 = 0.1186/0.1289 = 0.9201	3
7	0.0348+0.0455+0.04176 = 0.1221	Q_7 = 0.1221/0.1289 = 0.9472	2
8	0.0348+0.0410+0.04860 = 0.1244	Q_8= 0.1244/0.1289 = 0.9650	1

4.2 Discussion of Result

Table 1 shows the eight experimental welding runs made with the corresponding input parameters and output parameters respectively. The output parameters comprises of Ultimate tensile strength (UTS), absorbed impact strength (CVN), Bead height (BH).

The properties obtained from table 4.1 was given to 5 experts in welding technology to rate, the average of each of the rates of the experts was recorded.

The recorded rating are shown n table 4.2-4.6. Table 4.7, 4.10, 4.13, 4.16 and 19 shows the determination of relative weights obtained from the first , second, third, fourth and fifth experts evaluation. These relative weights were used to obtain the comparative importance of the average value from the response of the first, second, third, fourth and fifth expert as shown in table 4.8, 4.11, 4.14, 4.17 and 4.20. These values of the comparative importance of the average value from the evaluation made by these experts were used to obtain the final results of the weighing assessment indicator by the application of SWARA to the experts, evaluations. The weighing indicators obtained are shown in table 4.9, 4.12, 4.15, 4.18, and 4.21. The table 4.22 shows the average of each of the weights obtained for each of the weld properties. This average weight which is also known as the geometric mean of weight. These weights were the actual weights obtained and used for the optimum selection process.

The optimum selection process was carried out by applying the additive ratio assessment (ARAS) method. By applying the ARAS method, it require that the average ratings of the experts responses be obtained and this is shown in table 4.23. Table 4.24 and 4.25 shows the normalized values of the average ratings in table 4.22. Table 4.26 contains the product of the normalized values of each of the weld [parameters and their corresponding weights as obtained initially from table 4.22. Table 4.27 shows the overall performance index of the experts responses. This performance index indicates that weldment 8 possesses the best weld properties, having UTS of 315Mpa, Impact Strength of 109J, bead penetration of 10.8mm.

CHAPTER FIVE

5.0 Conclusion and Recommendations

5.1 Conclusion

In this study, the SWARA-ARAS method was used to select appropriate and optimized process parameters that showed some promise in improving the quality of the welded joint. The SWARA-ARAS method appears to be novel in its application to the optimization of welding process parameters. This method has proven its potency by successfully optimizing the welding process parameters.

Considering the analysis done on this study, weldment 8 has been proven to have the best welding parameters. This weldment status confirms with the criteria that weldment with larger Ultimate tensile Strength and Impart strength ensures better weldment result with a function of its corresponding bead height and width.

5.2 Recommendations

From the findings, it Is hereby recommended that

(i) Other optimization tools be applied to this study and the result obtained, compared with the one obtained in this research study.

(ii) The effect of the input process parameters be investigated.

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