COMPARATIVE STUDY OF MECHANICAL PROPERTIES OF PLATES OF DIFFERENT SIZES OF WELDED ALUMINUM ALLOYS BY TIG AND MIG TECHNIQUES

2017
M. Sc. Thesis
Mechanical Engineering

Hashem M. Mohamed ABDALY

COMPARATIVE STUDY OF MECHANICAL PROPERTIES OF PLATES OF DIFFERENT SIZES OF WELDED ALUMINUM ALLOYS BY TIG AND MIG TECHNIQUES

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES OF
KARABUK UNIVERSITY

BY

Hashem M. Mohamed ABDALY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE IN
MECHANICAL ENGINEERING

June 2017

I certify that in my opinion the thesis submitted by Adnan Ali Jaber SWESI Titled "DETERMINING OF THE OPTIMAL TURNING PARAMETERS USING THE TAGUCHI METHOD" is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

Assist. Prof. Dr. Ibrahim ÇAYIROĞLU ....
Thesis Advisor, Department of Mechatronic Engineering

This thesis is accepted by the examining committee with a unanimous vote in the Department of Mechanical Engineering as a master thesis. June 07, 2017

Examining Committee Members (Institutions)	Signature
Chairman : Yrd.Doç.Dr. Ibrahim MAHARIQ (THK)	....
Member : Assist. Prof. Dr. Gökhan SUR (KBU)	....
Member : Assist. Prof. Dr. İbrahim ÇAYIROĞLU (KBU)	....

...../...../ 2017

The degree of Master of Science by the thesis submitted is approved by the Administrative Board of the Graduate School of Natural and Applied Sciences, Karabuk University.

Prof. Dr. Nevin AYTEMİZ ....
Head of Graduate School of Natural and Applied Sciences

“I declare that all the information within this thesis has been gathered and presented in accordance with academic regulations and ethical principles and I have written and submitted this thesis according to the requirements of these regulations and principles and cited all those, which did not originate in this work.”

Hashem M. Mohamed ABDALY

ABSTRACT

M. Sc. Thesis

COMPARATIVE STUDY OF MECHANICAL PROPERTIES OF PLATES OF DIFFERENT SIZES OF WELDED ALUMINUM ALLOYS BY TIG AND MIG TECHNIQUES

Hashem M. Mohamed ABDALY

Karabük University
Graduate School of Natural and Applied Sciences
Department of Mechanical Engineering

Thesis Advisor:
Assist. Prof. Dr. İbrahim ÇAYIROĞLU
May 2017, 77 pages

This thesis was carried out with the aims of measuring effects of samples' thickness on weld joints as well as the mechanical properties of the welding through TIG and MIG welding. Aluminum alloy 1050 plates were welded under different thicknesses (2, 4, 6, and 8mm). All welding parameters including welding speed, electric current and voltage on weld joints were monitored during all the experiments. The mechanical properties were investigated for all samples to know the optimum mechanical properties (Tensile stress, hardness, and ductility) of different thicknesses of plates.

Key Words : TIG-MIG welding, aluminum alloys, thickness, hardness, strength.
Science Code : 902.2.042

ÖZET

Yüksek Lisans Tezi

TIG VE MIG TEKNİĞİ İLE KAYNATILMIŞ FARKLI BOYUTLARDAKİ ALÜMİNYUM ALAŞIMLARIN MEKANİK ÖZELLİKLERİNİN KARŞILAŞTIRMALI İNCELENMESİ

Hashem M. Mohamed ABDALY

Karabük Üniversitesi
Fen Bilimleri Enstitüsü
Makine Mühendisliği Anabilim Dalı

Tez Danışmanı:
Yrd. Doç. Dr. İbrahim ÇAYIROĞLU
Haziran 2017, 79 sayfa

Bu tez çalışmasında, TIG ve MIG kaynaklarının için numune kalınlığının kaynak bağlantısı üzerindeki etkileri ve kaynak bölgesinin mekanik özelliklerin araştırılmıştır. Kaynaklar alüminyum alaşım 1050 plakalarının farklı kalınlıklarında (2, 4, 6 ve 8mm) yapılmıştır. Tüm deneylerdeki kaynak bağlantılarında kaynak hızı, akım ve gerilme parametreleri sabit tutulmuştur. Her bir numunenin farklı kalınlıklarına göre optimum mekanik özelliklerini (çekme gerilmesi, sertlik ve süneklik) bulmak ve optimal özelliklere ulaşmak için araştırma yapılmıştır.

Anahtar Kelimeler : TIG-MIG kaynağı, alüminyum alaşımları, kalınlık, sertlik, mukavemet.

Bilim Kodu : 902.2.042

ACKNOWLEDGMENT

First, I would like to thank my advisor for his kind help and Assist. Prof. Dr. İbrahim ÇAYIROĞLU for a great deal of interest and assistance in the preparation of this thesis as well as guidance during the course.
Hashem.

CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

INDEX OF SYMBOLS AND ABBREVITIONS

ABBREVITIONS

GMAW : Gas Metal Arc Welding
TIG : Tungsten Inert Gas
MIG : Metal Inert Gas

CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

1.1.1. Welding History

Welding is a metal joining process through heat or pressure, or both, sometimes by using added minerals and sometimes without using them. Types of welding include metal arc, submerged arc spot, atomic hydrogen, and nails. Welding process in recent times is usually the best way to use for joining metals and alloys.

Welding began more than 3,000 years ago. Humans melted iron, bronze, and other metals according to the old method [1] during the Bronze and Iron Age and welding had a decisive impact on people's lives. Egyptians began to make iron tools and weapons during the period 850-900 BC. After 800 BC, bronze and iron were used in various applications such as pots and shields [2] for years.

In 1800, Humphrey Davy discovered a tiny pulse of electric arc and displayed the outcomes of his discovery in 1801 [3]. It has been used as soldering iron column in the Indian city of Delhi, which was built in the fourth century with a weight of 5.4 tons and height of about 7 meters. The evidence of welding is also present in the Middle Ages because welding projects including manufacturing metal goods, roads and steel welding was done in those times. Moreover, all of these were primitive welding operations.

With the advent of the industrial revolution, the need to develop techniques for welding increased. There was a major development in the methods and techniques of welding in the late nineteenth century and in the beginning twentieth century.

There have been many developments in the welding industry in 1960s. Double [3] shield and dual shield welding were introduced. Inner shield and electric welding are some important welding developments. Plasma arc welding Gage was also invented during this period. It has been used for spraying metals. The French developed electron beam welding and it is still used in the aircrafts in the US aviation industry.

Some recent developments in the friction welding process took place in Russia including laser welding. This is because of inherent ability of laser to perform all types of welding jobs [4].

The welding devices were upgraded to make them compatible with industrial demands, which led to improved quality. It gave rise to the concept of gas arc welding (GMAW) for the first time in the early 1900s, but later, it was used as a reliable technology in 1948. It was believed to have high current density, compact diameter, process dependence on bare metal electrodes and inert gas. So, MAG has been utilized for the efficient use of gas to weld a metal.

Previous developments included integrated process using pulse current/low direct current, and applied on large number of substances using any reactive gases (especially CO2) and other mixed inert gases. Other expansion processes resulted in formal recognition of the welding arc, for which, expression gases (GMAW), the metal inert gases (MIGs) and metal active gases (MAGs) were used.

The set of basic metals GMAW uses a pole that need gas screen to save molten weld from atmospheric impurities. This process can operate with a semi commercial metal either automatically, using carbon steel, strong steel alloys including stainless variety or using shielding gas to weld aluminum, which changes current parameters like voltage and others [5].

C.J. Holler invented AC in 1919 but it remained unpopular until 1930s when it was manufactured using heavy coated electrode. In 1920, automatic welding was initiated. They used bare electric wire on the current, which uses direct arc voltage for regulating the feed rate.

P.O. Nobel, invented automatic welding [6] for making worn motor shafts/worn crane wheels for General Electric Company. The automobile industry also used it for manufacturing rear axle housings.

In 1920s, various types of electric welding wire were developed. It was debated during the 1920s because it had a significant advantage as compared to previous technologies. It has developed for heavy-coated poles, and tossed out by Lang troth and financiers A.O. Smith Inc., which used it in 1927. Lincoln made an electricity pole extruded rods company, which was sold out in the stock exchange. The poles were used in the year 1930 on a large scale. Welding codes that require higher quality welding led to increased utilization of covered electrodes. In 1920s, researches used arc protection and externally applied gas welding [6]. In this process, oxygen and nitrogen interact with molten weld metal, which resulted in fragile and porous welds.

Alexander Langmuir did not operate circuits with hydrogen to create atmosphere-feasible situation for welding but instead he used two poles having carbon electrodes, and later changed to tungsten electrodes. Hydrogen has been changed to the hydrogen atoms in the arc, then hot flame was used for arc formation on a wide range of atomic hydrogen through a molecular model and heat release, which led to making of a half bow using lots of heat and flame of oxygen and acetylene [6].

In 1940 the tungsten gas welding (GTAW arc) was popular, which gave rise to the idea of CL coffin welding without oxidizing gas, which was registered in 1890 but the concept was again researched in 20s by HM Hobart, who tried helium gas to protect the divers PK. It was best for welding magnesium, aluminum, and stainless steel. Meredith claimed its patents in 1941 and called it Halyard welding. Gas tungsten arc welding became a highly significant method.

Welding process has developed through a gas-shielded metallic arc in the Battelle Memorial Institute in 1948. It looks like a bracket of tungsten arc. Tungsten electrode replaced electric wire's continuous feed. This was one of the fundamental changes, which enabled the electrical wiring easier to use with small diameter and constant power source.

In 1960, inert gas was used with very less quantities of oxygen, which made the difference and it was commercially used in 1960s. In recent times, pulsed current has been widely used. The electric current switches from high to low voltage one or two times. The welding work has developed a variation by taking advantage of a special electric wire. This is called as corps, described as electric phenomenon from inside and outside, tubular along with cross section containing melted agents. This method has been named as Dual shield method, which uses external shielding gas by used gas flow produced in the wire. Bernard claimed to have invented it in 1954, but it was patented in 1957.

The friction welding uses rotation speed and pressure, which provides heat and friction, and this method was discovered in the former USSR. It is a highly specialized method, which is important for a cut that needs welding. This method is known as inertia welding.

Laser welding is a latest type of welding and it was developed in Bell Labs. It was only due to its enormous power concentration, it became a strong heat source. It is utilized for cutting metals and non-metals. Laser welding has applications in car manufacturing [6].

1.1.2. Aluminum Gas Metal Arc Welding (GMAW)

With increasing use of Al alloy because of their applications in buildings, cars and other industries, this type of welding is suitable for fabricating and multiple other ways [7]. By understanding the properties of the appropriate procedures, aluminum and its alloys can be welded with ease. A welder hits MIG welding arc between the electrode and sheet metal for welding. Pole used in the machine is actually a copper wire shaped like a filler metal [7]. Welding is protected by CO2 to prevent oxidation.

With increasing use of Al alloys because of its wide applications in buildings and vehicles and the application of space, solder joint is suitable for fabricating them into different shapes [7]. By understanding the properties, aluminum and its alloys can be easily welded. For that, we must hit the MIG welding arc in the middle of electrode and sheet metal [7].

TIG welding is a process that uses Tungsten electrode for welding. Welding areas are protected from pollution by an inert shielding gas (either helium or argon) [5].

1.1.3. Problem Statements

Mechanical properties of alloy Al, welded or joined, depends on several criteria such as thickness of the sheet or pipes, solder, size of the model, and residual stress etc. Parameter and mechanical properties are important for welding. Tensile strength or connections between two power-welded parts is also important, so, the term "effect thickness" is used widely in the literature to explain the mechanical properties. This leads to better understanding the effect of plate thickness on the mechanical properties of welded materials and to decide the best size for the welding process.

This will work on several samples of each alloy with 2.4, 6 and 8mm thicknesses. These samples can be weld using both processes MIG and TIG. We will investigate the mechanical properties of all the samples to find the optimum one. The mechanical properties (tensile stress, hardness, and elasticity) are different for different plate sizes.

1.1.4. Objectives of the Project

The objectives of this project are:

1. Making experimental comparison between MIG and TIG of Al alloy in terms of mechanical properties of different sizes and thicknesses
2. Creating better understanding on the influence of plate thickness on mechanical properties of welded Al alloy

CHAPTER 2

LITERATURE REVIEW

This paper investigates the microscopic and the mechanical properties of the joints containing 1420 aluminum lithium alloys before and after the heat treatment by CO2 and MIG welding [1].

This study deals with the investigation of microstructures and/or mechanical properties of weld joint of AA5052-H32 & AA6061-T6 aluminum alloys weld by using MIG. This research thesis investigated the effect of parameters on the mechanical properties and microstructure of both AA5052-H32 and AA6061-T6. The thesis describes the proper MIG welding process using automatic table to calculate the effect on microstructure and mechanical properties on weld joint of AA5052-H32 and AA6061-T6 [2].

This research analyzed the outcomes of arc voltages, weld current and audio signals, which affect the quality of the welding process. The statistics tools are used for detecting variations in the voltage and finding current data, which is linked with the welding procedure [3].

This thesis studies the design/fabrication of MIG welding. This research aims to develop welding-jigs to clamp work-piece and decrease deflection, which takes place because of thermal stress. Moreover, welding-jigs can clamp work pieces with thicknesses up to 8mm and widths up to 80mm. Therefore, the effect of thickness of the work piece was analyzed [4].

This research study presents the comparison between the MIG and TIG welding processes keeping in view their mechanical properties and metallographic aspects [5].

This research studies the quality-linked aspects, productive possibilities and the economic feasibility in the industrial welding in countries of West Africa including Ghana, Cameroon, and Nigeria. It has two parts: The theoretical background, and a review of the relevant literature on metals, welding, soldering, quality-analysis, productivity-analysis and the economic feasibility. Later experimental part determines mineral manufacturing activities, which are widely used for welding and represent quality, productivity and economy in metal processing companies [6].

This study has investigated the impact of the current speed welding and welding on the tensile strength keeping in view each type of weld [7].

This study is focused on getting information about the different parameters of welding including current, voltages, and rate of gas flow on the welding strength of aluminum alloy 6351[8].

Raveendra and others conducted a similar experiment. Each experiment has been conducted to determine the effect of pulsed current on element properties by GTAW. Welding 3mm 304 stainless steel welding current arc 80-83000 moved on a speed of 700-1230mm/min. It may be in the HAZ region because of the refinement of grain for rigidity. Pulsed higher tensile strength exists in the current elements. We noted during the experiment that the value of UTS/YS of non-current pulsed was higher as compared to its parent metal [9].

Microscopic study made up of TIG welded Al gaseous magnesium, and manganese alloy show multiple ranging conditions. It is welded with the current 100-190000 and welding speed 420-1500mm/min. Minute microstructures were found during welding, which happened because of the high cool-down speed in the middle of welding. We understood that increased welding rate increases the cooling rate at the center, and the output is smaller than the size of the dendrite structure [10].

The TIG welding of Al alloy of 4mm was conducted at welding current 40-90 A and welding speed 210-230mm/min. Effort was made to improve the way pulsed welding process parameters TIG enhances the mechanical properties, for which, regression models have been developed. Microscopic study was conducted to observe the mechanical properties. It was observed that 10-15% improvement in mechanical properties actually took place after the internal pressure redistribution [11].

The investigation of the hydrogen effect on argon also protects the TIG process conducted on 316L austenitic stainless steel. The researchers applied 115 A current at 100mm/min welding speed and 10 l/min gas flow rate on a 4mm plate. The hardness of welded metal was less as compared to HAZ and other base metals. Depth of penetration, grain welding and average grain size increases with rising hydrogen percentage [12].

TIG welding operation proposed to double the welding of protected Cr13Ni5Mo 9mm stainless steel thick using pure internal shielding layer is a mixture of gas and CO2, which is shielding the outer layer. Welding speed and welding current is within the scope of experimentation were 120 to 140000 and 90 to 300mm/min,. 2-4 times efficiency of TIG welding dual display provides greater protection than the conventional TIG [13].

There are many types of welding to weld different metals. Aluminum is second in terms of annual consumption; however, steel has the highest. In this study, the mechanical properties and microstructure of welds work pieces were analyzed. Comparison between MIG and TIG processes was also done [14].

In this study, distributional rigidity and structural characteristics of the small joints in relation to conventional MIG welding process are discussed [15].

This paper makes a comparison between the mechanical behavior and the microstructure of welded 7075 aluminum alloy through three different techniques for welding: MIG, TIG and FSW. Results were compared in terms of microscopic examination of tensile properties and hardness [16].

CHAPTER 3

WELDING TECHNIQUES

3.1. WELDING

Welding joins at least two or more than two metal strips/pieces through thermal energy applications or pressure. It is an accurate and reliable way to join with affordable material cost. Thus welding is necessary for the production of most of the usual things from large structures such as bridges, ships, vehicles, electronic components etc. [2,8]. Various techniques of welding, such as welding with electrodes coated (especially basic poles and retile), shielded welding MIG/MAG process brackets (wire and gas protected), submerged arc welding (various wires and flows) have been tested[9]. As compared to other methods, welded structures tend to be lighter, stronger and cheaper to produce. Welding is critical in the manufacturing process; the last step in the assembly plays an important role in the structural performance. Moreover, it is usually used to repair structures that were not originally welded, and in this way, it increases the life of metal parts [2,9]. There are many processes in the field of welding technology. These techniques allow great flexibility in the design.

3.1.1. Types of Welding Processes

Different welding methods such as TIG, MIG, spot-welding, flow metal arc welding (FAKAU), electric welding slag (ESO), and submerged arc (r) have been discovered so far. The two most popular types of metals and processes of gas arc welding are tungsten (GMAO) inert gas (TEG) and MEG [10].

Welding procedures are categorized based on heat sources, which each method uses. They are as follows:

3.1.1.1. Arc Welding

It is used for power supply to create an arc between the work piece and the electrode, which makes the work-piece metal melt and then, welding becomes possible. Arc welding power supply can possibly be AC/DC. Welding pole is non-expendable, so, it can be used as filler material [11].

- Gas Welding: It uses high temperature focused gas flame that melts a metal piece to weld metals. Proper use of external welding filler material is necessary. Welding process commonly uses oxygen gas and acetylene by reacting both oxygen and acetylene to produce heat [4,12].

- Resistance Welding: This process generates heat because of a major electric passage (1000-100000a) by creating resistance through contact between the two metal surfaces. Spot welding is the most common. Continuous-type resistance spot welding is done wherever the pole is used in the form of wheel [4,12,13].

- High Energy Beam Welding: It uses high intensity focused energy beam, which seems like laser or electron beam, for melting work pieces to put them together. It is mainly used for precision welding, joining advanced materials, or joining different materials [4,12,13].

3.1.1.2. Solid-State Welding

It does not involve melting materials for joining work piece. Common welding sub-forms of this type of welding include ultrasonic, explosion, electromagnetic pulse, friction, and friction-stir welding etc [4]. In this work, we will focus on MIG and TIG welding applications on alloys and the impact of these operations on the mechanical properties of different thicknesses of alloys.

3.2. MIG WELDING

The welding of MIG aircraft was first done in 1940 and 60 years after, the general principle is the same. Arc welding uses electricity to create a short circuit between the anode continuous feed (+acres wire welding torch) and negative (the metal being welded) see Fig. 3.1

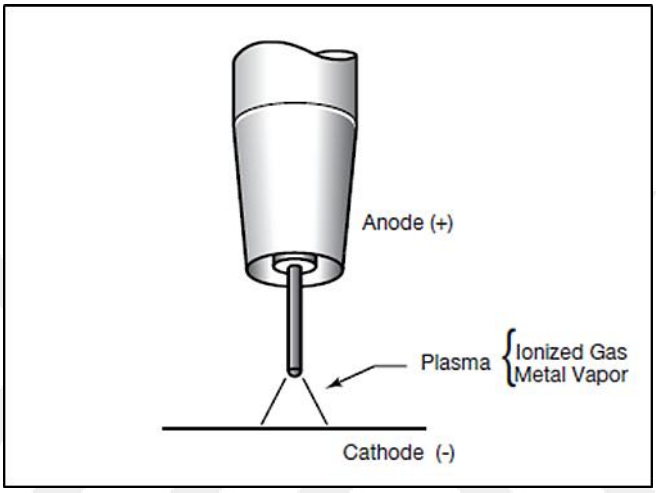


Figure 3.1. Cross section of a GMAW arc.

MIG is also called GMAW or metal-active gas welding (MAGW). MIG is utilized for electrical wiring and shielding gas [14]. It feeds on the wire automatically and continuously by welding gun. Electrical wiring diameter should be approximately 0.8-6.5mm depending on the part's thickness, which needs welding. Shielding gases, inert gases including helium/argon/active gases including CO2 are usually used for welding [14]. The choice of gas depends on the kind of minerals, for examples inert gases are used to weld aluminum alloys and stainless steel, but the carbon dioxide is used for low/medium carbon steel. These gases eliminate the cover slag. MIG process provides excessive time as compared with shielded metal-arc welding (SMAW) in different industries. MIG creates short-circuit between the electric line (anode) and welding of metals (cathode). It produces substantial thermal energy for metal melting for joining them together. This process is shown with the help of a graph and the image of the traditional MIG welding in fig1. The development of welding for MIG aircraft in 1940 was a major development. Arc welding uses large quantities of electricity to create a short circuit between the anode continuous feed (+acres wire welding torch) and negative (metals being welded). Welding process of MIG works in the capital (DC) that normally interacts with anode and the process is commonly called "reverse polarity." Welding currents range from 50 amps up to more than 600 amps typically with voltages from 15V to 32V.

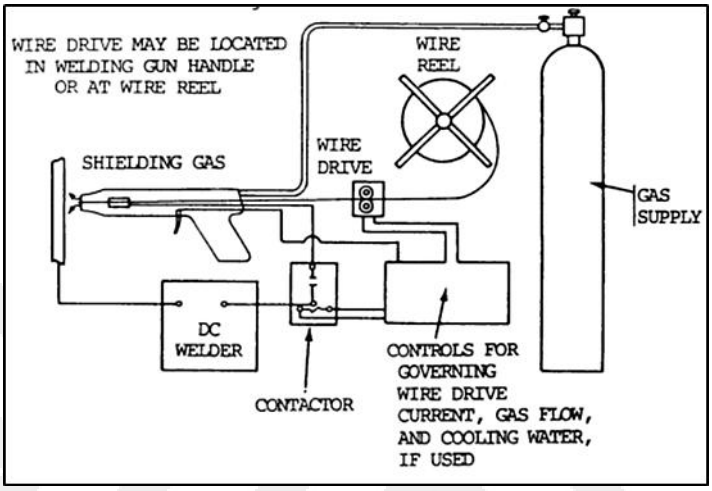


Figure 3.2. MIG welding machine schematic diagram.

A stable, self-correction utilizing the arc voltage by continuous electric feeding has been obtained. Progress has been made to continue the MIG welding, which applies to most of the commercially significant metals and alloys including aluminum, copper, steel including stainless variety etc. 0.03inches or 0.76mm thick material is possible to be welded in all ways such as flat, vertically and overhead. Choosing equipment, wiring, shielding gas, and welding conditions is simple and they are able to produce high quality layers at low cost [15]. Figure 3.3 displays machine for MIG welding in the laboratory, which are used for the analysis of the results and some experiments.

Figure 3.3. MIG welding machine in the welding laboratory.

3.2.1. Advantages of MIG Welding

MIG process can be used on large scale due to its possibility to weld large number of ferrous and non-ferrous alloys for low cost. The following are the advantages of MIG [15-17]:

- Possibility to weld multiple material types and thickness
- Easily affordable spare parts are available.
- High efficiency welding operations as compared to other options
- MIG welding can be adapted easily for speedy robotics, automation and semi-welding operations.
- Allows welding in all positions
- Remarkable weld-bead outlook
- Low hydrogen-weld deposits, normally lower than 5 ml/100g

- Low heating input needs in comparison with other options
- Minimum spatter-welding slag, which is quick and easy to clean
- Welding fumes are less as compared to SMAW and FCAW protected operations
- Generally lower cost of weld metal in comparison with open arc welding
- Low-cost pole
- Lower distortion in pulsed spray transfer mode
- Ability to deal with poor fit-up with GMAW-S & STT.
- Generates less smoke
- Minimum after-welding cleaning needs

3.2.2. Limitations of MIG Welding

- The lesser heat-input restricts its operational utility for thin metallic substances.
- Higher heat-input spray transfer normally limits its utilization for welding thick base materials.
- Its larger heat input mode is just limited to flatter/horizontal positions.
- Argon-based shield gas and pulsed spray are 100% more expensive than CO2.

3.2.3. Components of MIG Welding

The field of arc welding is very complex, which consists of forces and chemical reactions. The parts of arc-interaction affect mineral transfer and quality of the final weld. It influences the behavior of the arc of the filler metal type, and the circumstances of base metals based on preventive and clean parameters for welding such as voltages & current, and the interaction of gravity and forces, surface tension, and electromagnetism [18]. It consists of an energy source, electric welding gun, reel, rod feed, and some extra equipment.

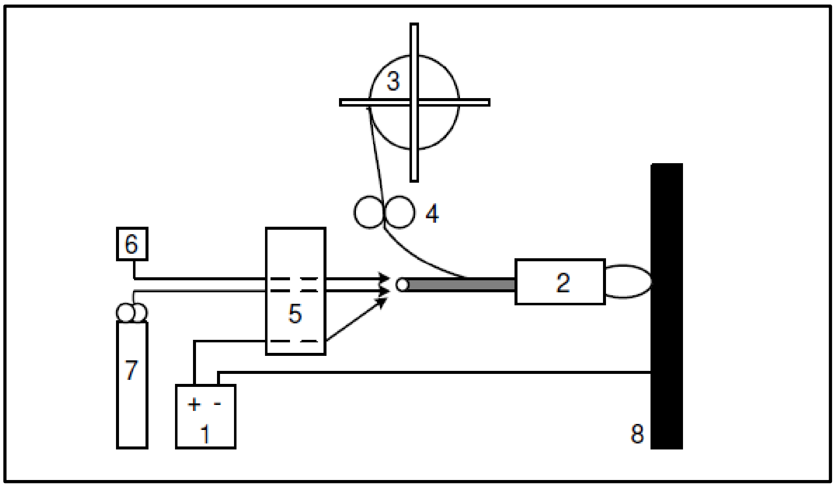


Figure 3.4. Sketch of MIG welding equipment. 1) Source of power, 2) Gun, 3) electrodes 4) wire feeding equipment, 5) controller, 6) water, 7) gas, and 8) work piece.

The wire feeder is fed through the electrode wire at a consistent speed. In fact, it feeds between 2-20m/min. And it is fed on the power supply, water and gas, which are joined in a hose that is linked to welding gun [19]. Fig. 3.4 shows sketch of the welding equipment [19].

3.2.3.1. Power Source

MIG source power is often direct current (DC) that connects the anode rod-mail, while the negative pole is linked to the work piece. Strength properties are very critical for the stability of the ignition arc welding and the transfer of electrical wiring melted on the work piece. The aim is to design rectifier transformers with consistent power source. See Fig3.5. The commonly used energy resource is transformation of the average main transformer with constant voltage for all 415V O1 properties 3-phase 240V. For details, see entries [20]. Current debug output immediately after the full wave of 3-phase machine is very smooth.

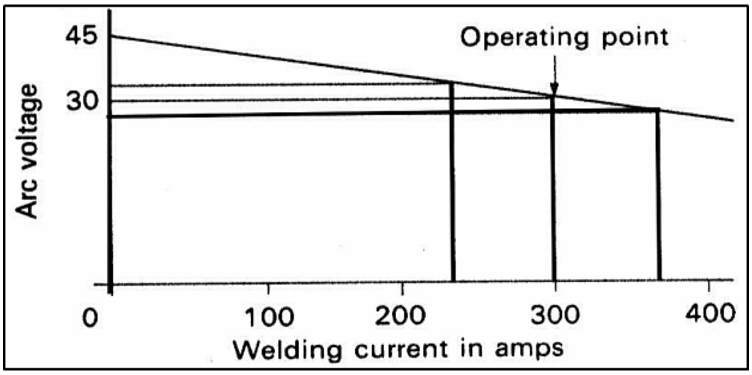


Figure 3.5. Volt–ampere curve of typical constant voltage of a power source.

To smooth DC, a wave came for correction with the full Phase 1 Machine. Because of this account, many of the single-phase low-cost machines neglect this element and thus provide property-poor welding. Main transformer provides output voltage for production of plants as an energy source. Another method for the production of various efforts in the production of energy sources is the use of plants.

Transistor rate provides a consistently variable voltage, which is useful for Android systems and its cost is partially compensated without having to switch the primary effort or one basic major key-tapped transformer.

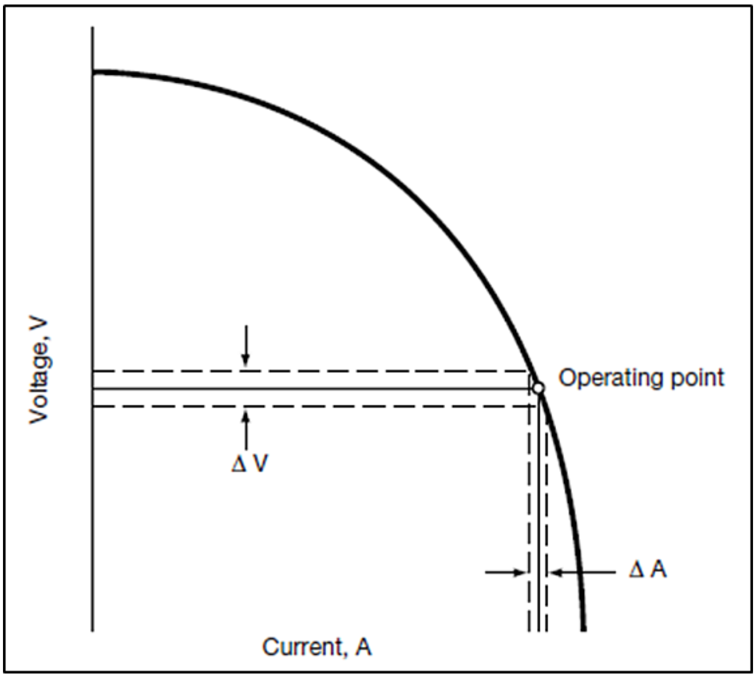


Figure 3.6. (Constant Current) Power source Volt-Amp characteristics.

MIG power sources use a turn ON/OFF trigger with MIG torch system. Delay switches off range and this usually acts as a breaker to let burning of the welding wire. Heat remains in the most important energy source point with contactor coil for providing thermal protection for this device. Performance of the source of energy can be assessed by its capability to generate stream for 10 minutes. This is the "business cycle." Straight and dropped energy source properties help maintaining control over the arc. It finds out arc length voltage while the current (amps) organizes itself during welding. For melting the electrical wiring level, we depend on welding wire feeder speed and the wire content. There is a very wide range of available MIG ingredients. Each system design provides the perfect arc to perform specific transport minerals. It includes the following check for constant power inputs, wire drives and three-phase input power accessories [18]. See figure 3.7.

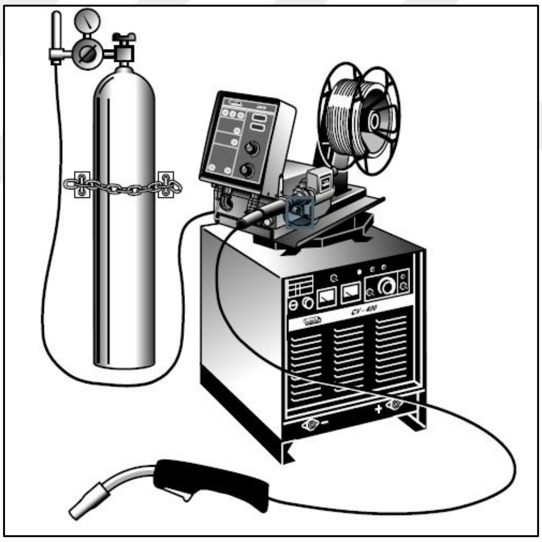


Figure 3.7. Constant voltage-400 MIG System.

Another example is given in Figure 3.7, in which, combined power systems and drives, with capacity range 135 to 350amp are shown. Lower power source/wire feeder combinations offer few sheet metal applications.

Figure 3.8. Power MIG 350MP System.

3.2.3.2. The Wire Drive System

GMAW uses a wide range of solid electrodes or extracted minerals, 0.025 "- 1/16" (0.6 to 1.6mm). It may be pre-wired feed speed and it can be set by digital readout or tags calibrated to control the speed of the wire feed system. It is the ability to provide accurate job of wire speed and good control of welding procedures. Standard GMAW engine wires have a magnetic motor to start and stop feeding. Wire feed speed range is a significant factor and they provide 70 to 800 IPM to engines (inches/min from the wire's feeding speed). Highest engines for applications require wire feed speed up to 1,200 at speed 30m/min. Considerations include optional elements, engine timing and wiring for blocking the gas flow before and after the flow. Optional purge protects gas controls and assures the flow of gas in the bow early, and the displacement of air in the system. Pay gas connects from the solenoid, which activates when the depression of the trigger system provides GMAW torch. Controls prevent the flow of gas before and after the flow of the solenoid circuit conditions and provide gas before/after the arc establishment. Optional water connections should be provided with guns and water-cooling of GMAW [18] See Figure 3.9.

Figure 3.9. GMAW wire drives.

3.2.3.3. Shielding Gas Regulation

It is delivered to arc and it plays a significant role for the final weld quality. GMAW needs regulating devices to measure gas flow from each multilateral system, which includes many of the compressed gas cylinders. Overall inert gas distribution is used to perform with welding cells/gas out of a cylinder. It provides opportunity for monitoring welding readings: Initially we read the internal pressure of the disc, and it allows the solder to identify the amount of gas, which is left in the cylinder. Later, we measure the shielding gas flow in CFH (cubic feet/hour) or L/min (liters per minute). Connecting hose regulates the gas solenoid in the wire, which extends from engine front towards the nipple copper wire in GMAW torch. Multiple systems linked with the pipe blend shielding gas and they typically have pressure that operates as the line-pressure regulator.

3.2.3.4. Bulk Electrode Packaging

For minimizing electrode package changing process, GMAW equipment can use bulk electrode dispensing system/s. Four kinds of packages are available:

- Vertical Reels

- Horizontal Reels (fixed/moving)
- Drums
- Boxes

Every one of them needs electrode conduit, orbital arms or some other mechanical dispensing device/s.

3.2.4. Shielding Gases for MIG Welding

MIG operates with nitrogen to some extent and oxygen reacts with carbon for making CO. The shortcomings of welding appear in the form of fusion defects because of oxides. Strength is lost because majority of metals exhibit strong tendency to react with oxygen to make oxides, which results in porosity, oxide-formation and nitride-formation. Metal welding gets brittle because of dissolving oxides and nitrides, which easily form and react because the air has almost 80% nitrogen and 20% oxygen [21].

Shielding gas creates significant effect on welding and consequent weld:

- Properties of arc
- Metal transfer mode
- Weld bead and penetration
- Welding speed
- Tendency to undercut
- Actions for cleaning

In welding and other important processes, shielding gas protects weld pool from air pollution, which can cause porosity and defects in the weld. The shielding gas helps arc welding, and its start and run functions. It is used worldwide and with argon gas for TIG welding. It is also used abroad with helium in some countries, and it was called Halyard welding. Each of these two gases has its advantages. Because of the high cost of helium, a mixture of argon and helium is used, which is the best of all gases [2].

Argon

- Better arc starting
- Good cleaning action
- Lower arc voltage
- Low gas flows needed

Helium

- Faster travel
- Better penetration
- Higher arc voltages

3.2.5. Safety

The main risks in the GMAW are vapors and gases, which can be harmful to health. Electricity with High-voltage can injure and kill, so it is another major risk. Arc rays can damage the eyes and burn the skin. Presence of Aldaudhaoual can damage hearing. The type and amount of smoke and gas present during welding depends on the electrode used, the type of welded alloy, and paint on the metal base. For the prevention of potential hazards, we must keep on top of welding plume of smoke and avoid inhalation of vapors and gases coming from the arc. It requires ventilation. Pole shock can result in exposure to the high open circuit voltages coming from welding power supply. All the electrical equipments and the work pieces must be connected to an electrical ground. Cables must have sufficient size to withstand the maximum required current. It must be isolated from cuts and corrosion, and the cable must not come in contact with oil, paint or other liquids that may cause degradation [22]. When the noise becomes excessive in the work area, ear protection should be used. This can prevent spatter from entering the ear. Conventional fire prevention requirements such as removing combustible materials from the work area should be fulfilled. Sparks can make spatter travel long distances, so workers must be careful to limit the fire. For more information, please refer to the guidelines drafted by the National Association of Fire Protection NFPA ISPM No. 51B: "Fire protection during cutting/welding processes." Precautions must be applied while handling, storage and using cylinders of liquefied gases. It must be used as approved by regulators to reduce the pressure to provide pressure, which can be done through continuous monitoring of the equipment.

Grease or tubes containing oxygen can come in contact with the air and they can contribute to a catastrophic fire [22].

3.3. TIG WELDING

It began as simple arc welding during the initial part of 19th Century but tHumphrey Davy did the groundwork when he found out short pendants of electric pulse in 1800. Vastly Petro electric arc was produced in 1802 (followed by Devy) but it was not even recognized as a technology until 1880s. In order to make use of this technology for growing industrial use, carbon electrodes were used in the carbon arc welding. By 1890, metal electrodes were introduced by Nikolai Slavyanov and Jim L. coffin; however, in 1920s, his successor invented the early GMAW. They use a bare electric wire and DC current in the arc voltage to regulate the feed rate. No protective gas was used for weld protection. In 1926, GMAW was discovered and documented but it was not suitable for practical use. Battelle Memorial Institute finally developed GMAW as a feasible welding method for practical use. HE Kennedy used a pole with small diameter to use as a source of energy. It also provided higher deposition but pricy inert gases were exclusively utilized for non-ferric substances. The industrial production of CO2 in 1953 created feasible situation for its use in welding, and it suddenly became popular in GMAW, which made steel welding highly affordable. A short arc GMAW was released, which led to increased diversity and made welding of thin substances practical while depending on more advanced thin electrode-wires and power supply. GMAW made a difference, so it became very popular within short time. The arc spraying in the early 1960s provided scientists a chance to spray small quantities of oxygen as well as inert gases. Later, the application of pulsed current resulted in a new method called pulsed spray arc GMAW, which is perhaps the most popular industrial welding method in the entire history of welding research. It is widely utilized in metal-sheet industries and the automotive industries as well. In many cases, it is used as a means of spot welding arc, which replaced the installation/resistance-spot welding. It is also used in automatic welding with robots/robotic devices to accelerate the production speed. It is difficult-to-perform in the outdoor atmosphere because it may dispel shielding gas, which allows pollutants in the arc welding to escape. Similarly, the use of gas shield GMAW is not suitable for welding under water. Welding, Welding gas flow or tungsten-arc welding [23].

Gas Tungsten Arc Welding (GTAW) or Halyard process uses tungsten inert gas (TIG), and tungsten-arc welding, which were discovered and operationalized back in 1930s because they were needed for welding magnesium. Russell Meredith [22] improved it using helium and tungsten electrode. It was used to build aircraft with aluminum and magnesium components. It is even used for welding them even now with many improvements and changes in the name, but with no change in fundamentals, which is obvious from Meredith melting temperature that is required for welding in the GTAW process and obtained by maintaining an arc between alloy, tungsten electrode and the work piece [22].

3.3.1. Advantages of GTAW (TIG)

Since welding needs a heat source and control of minerals, it also requires different temperatures on different points, which is possible without burning or penetration while repairing complex mechanical devices. GTAW provides high quality welding, which is spatter-free, and without impurities/flaws. It can weld large number of metals and alloys and is particularly useful for welding refractive substances including titanium, aluminum, and magnesium. All-position welding is quite possible through this technique. GTAW provides precision of welding variables. It combines quality arc welding because there is no smoke. Thinner work piece can be weld through this method autogenously without additional filler. It provides excellent control of GTAW pass root penetration welding especially for structural welds. TIG welds act on the steel body of the automobile industry in a softer and a more supple way than GMAW welds, which makes it more appropriate for the formation without cracking [23].

More skill-hand-dexterity/coordination is needed for other methods of welding. The welder has to hold torch and filler in those processes. For work needing more precision, the welder has to control arc current with a foot a fingertip when the welding process continues.

- GTAW offers lesser deposition and output in comparison with other methods.

- Equipment has higher complexity and price than other methods.
- Work piece metal has to be clean for GTAW's lower contaminant tolerance.
- Unlike SMAW & FCAW, GTAW does not burn paint, dirt & rust, and leaves defect with minimum surface contamination.
- Shielding gas may blow away in drafty situations.
- Pricier than consumable electrode arc method for pieces thicker than 3/8"
- Tungsten-inclusion is possible, which happens when inexperienced/less experienced welders perform it.
- Torches, which are cooled with the help of water, may leak/contaminate welds or tragic shock hazards.

3.3.2. Equipment

It is necessary for the operation of the tungsten-arc-welding equipment, including the torch, power supply constant-current welding, and the source of shielding gas. See Figure 3.10.

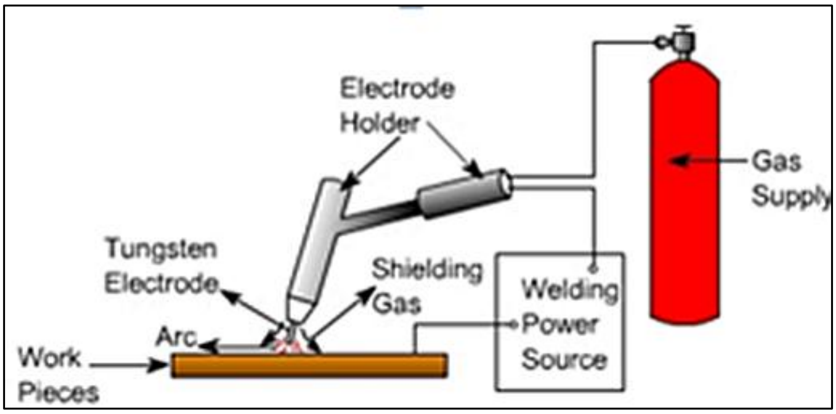


Figure 3.10. Schematic diagram of TIG welding system.

3.3.2.1. Welding Torch

Welding torches of any design require automated cooling process or they are equipped with air/water-cooling mechanisms. Automated/manual torches are similar, but manual ones have handles while automatic torches have mounted brackets. The angle between the handle-axis and tungsten electrode-axis is called as the head angle, which varies in different torches and depends on operators' choices. Often it is utilized for less for air-cooling systems. The cooling water requires higher current (up to 600,000). Cable-tied torches contain power supplies and water-hoses along with a shielding gas. The manufacturing of metal parts of the interior of the torch is done using the steel alloy or copper to help the transfer of energy and heat. See Figure 3.11.

Figure 3.11. Some torches used in GTAW welding.

3.3.2.2. Power Supply

Tungsten arc welding works with DC power, which remains consistent even in case of changes in the arc distance. It is significant as majority GTAW applications are either manual/semi automatic, which require the operator to carry the torch. Often it uses DC current with DCEN electrode while welding titanium, steel, and nickel etc. Helium can act as shielding gas during GTAW welding of aluminum or magnesium. Negative electric charging creates heat through electrons that travels through the bow, causing ionization of shielding gas and ionization of core material increases temperature. Ionized gas flows towards pole, which allows oxides on the surface of the weld. DC current and +ve charged DCEP electrode are not common but they have been used for shallow welds because of less heat generation. In DCEN, electrons move towards other direction/s resulting in very high temperatures on the pole. For maintaining shape or avoid softening, biggest pole is used because electrons flow towards the pole, and the ionization of the gas moves to basic material, which cleans weld, removes oxides and other unwanted materials for improving quality/appearance. AC current is typically used while welding manually or semi-automatically on aluminum and magnesium surfaces, it mixes two currents directly for alternating among positive & negative charges. It makes electron-flow to change direction, which does not let tungsten electrode to get overheated and maintain the core temperature. Surface oxides should be removed in positive part. Some companies' power supply systems allow adjustment of time spent by the current in the electrodes, allowing better heat control and cleaning action. Practically, it must be operators' fear of correction, which failed to ignite the bow when they can perform reverse polarity (positive electrode).

Figure 3.12. Shows a power supply used in GTAW welding.

3.3.2.3. Tungsten Electrode

It is used in GTAW welding of tungsten/tungsten alloys, as tungsten possesses highest pure metal smelting temperature, which is 3422 degrees Celsius (6192 degrees Fahrenheit). The electrode remains intact during welding but erosion/burn might take place. They can be cleaned after the welding process or they can be chemically cleaned whenever required but the earth should end in uniform size and polished surface, which makes them useful heat conductors. The electrode diameter may be 0.5-6.4mm (0.02-0.25in), with length 75-610mm (3.0-24.0in). International Organization for Standardization has standardized tungsten alloys the US Welding Society (ISO 6848) & AWS A5.12 did so for use as GTAW electrodes. Tungsten electrodes (WP/EWP) are common purpose and economical as they show lower temperature resistance and emission of electrons; therefore, their use is limited predominantly in AC welding i.e. magnesium and aluminum welding. Consider the following facts:

- Cerium oxide (or ceria) is an alloy that improves arc stability, starting ease and low burn-off.
- The Lanthanum oxide (or lantana) alloy behaves like cerium and like cerium. It is not radioactive.
- The thorium oxide (or thorium) alloy offers very good arc performance and that makes it a reliable electrode; however, its radioactivity can be hazardous because inhaling thorium vapors or its dust creates environmental risk.
- Zirconium oxide (or zirconia) electrodes improve current handling capacity, arc stability and electrode life.
- Filler metals can be used with GTAW, but thin material welding is an exception. These metals are easily available in multiple diameters and material types. The filler metal shaped like a rod is manually put in a weld pool while some applications require automatic feeding of the filler metal.

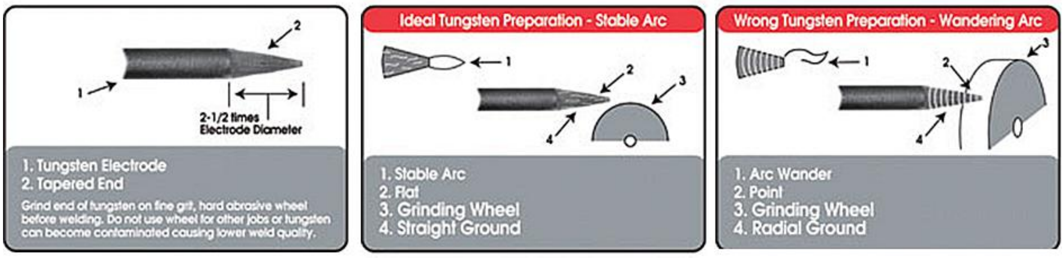


Figure 3.13. Tungsten preparation for negative electrode welding, DC and AC power sources and the formation of a wave.

3.3.2.4. Shielding Gas

GTAW protects welding place clear of atmospheric gases including nitrogen and oxygen, which may deform fusion, create pores, cause brittleness due to mistaken shielding gas contact, or arc welding. It transmits heat through tungsten electrode towards metal, which supports the entire process by starting/maintaining stable arc. Choosing shielding gas relies on some facts such as type of material, and expected look of the weld. Argon gas masks are commonly used for GTAW because they prevent flaws of differing arc length. When utilized with a rotator, argon blocks the current and creates high quality welding. Often used shielding gas helium increases the welding penetration and also increases the welding speed for highly conductive metals including copper and aluminum. The big drawback is striking arc with helium, which results in low quality welding as a consequence of variable arc length. Argon-helium mixture is used in GTAW because it increases heat input control and still maintains advantages of argon. The mixtures are generally made using helium (75% or more) and argon. They improve quality and speed of AC's aluminum welding and strike an arc. A second mixture of argon-hydrogen is also utilized for mechanical steel welding of light gauge but since hydrogen causes porosity, its usage is quite limited. Moreover, nitrogen is also added help stabilize stainless steel welds and for increasing copper welding penetration [23]. Porosity problems arise in ferrite alloys with few advantages, so, it is not so popular.

3.3.3. Method of Welding

Gas tungsten arc welding/manual welding is relatively hard way because of the needed welding coordination. Welding torch used in GTAW needs hands, as many applications need manual feeding with one hand and controlling welding torch in the other. To maintain short arc length, and to prevent link between electrode and work piece, it is essential to strike the arc welding. It gives the electric spark, which leads to current from the shielding gas and lets arc start while the electrodes separate and the work piece is normally 1.5-3mm (0.06 to 0.12in) apart. Once arc-welding torch moves in circular way to make the weld pool, it depends on pole and the current. While maintaining separation among electrode and work piece, the welder moves back the torch and leans backwards 10 to 15 degrees. He adds filler metals manually in front as much as needed. Welding often uses rapid rotation of the torch and adds filler metal. Then the filler rod is pulled every time but it is always kept inside the gas shield for preventing oxidation and contamination. It consists of metal rods having low temperature melting filler like aluminum, which requires the welder to keep distance from the arc. If anybody holds it very close to the arc, the rod melts before making contact with welding filler. When the welding is completed, often a gradual reduction in the current arc allows making a welding hole and prevents cracks in welding end of the hole.

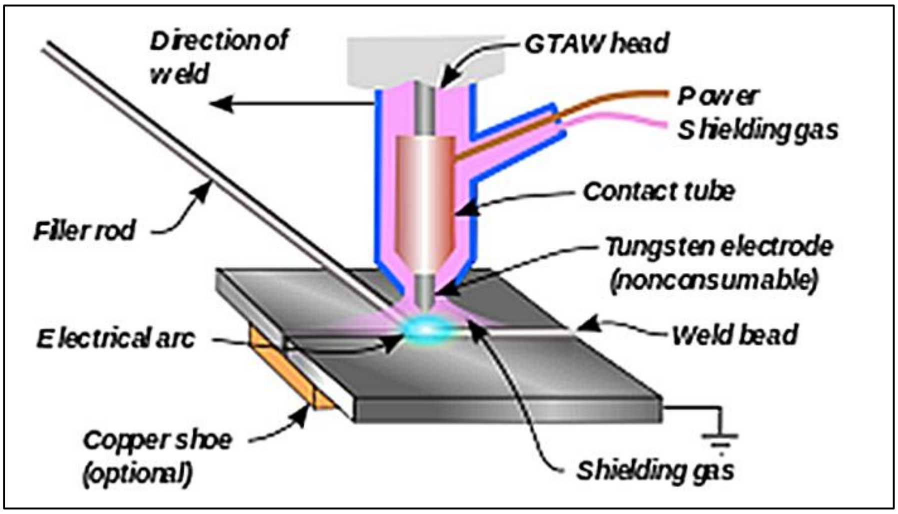


Figure 3.14. Apertures of gas tungsten arc welding.

3.3.3.1. Metals Used in Tungsten Arc Welding

It uses welding gas tungsten that is utilized for welding stainless steel or non-ferrous materials but it is applicable to almost all the metals except for zinc alloys. Its usage for welding carbon steels is limited for practical constraints including availability of better and affordable steel welding techniques including welding arc and gas shielded welding. Moreover, GTAW has several functions but it largely depends on the welder's skills and materials undergone welding

3.3.4. Applications

The aviation industry is the main beneficiary of the tungsten arc welding; however, this method has been successfully utilized in some other areas as well. GTAW welding is used for welding thinner work pieces, and non-ferrous metals. It is widely used in the spacecraft industry, as well as for small welding diameters, thinner walls exactly as the ones used in bicycle pipes. Moreover, GTAW is also utilized to perform first pass welds on pipes with different sizes. For maintenance/repair work, it is usually utilized for repair tools and dyes specifically those made up of aluminum and magnesium [18]. A wide variety of filler metal is available to engineers. Many welding processes allow a lot of gold bullion for product configurations. Filler alloys including aluminum/chromium, might be wasted through volatilization. It does not happen in GTAW because welds possess chemical integrity or closely match base metals. GTAW welds are corrosion-resistant and do not crack for long that makes GTAW critical for welding operation procedures like sealing fissile fuel before waste.

3.3.4.1. Filler Rods

Filler rods are specific for TIG welding and normally, they are available in 1m length with following diameters:

- 1.6mm
- 2.4mm
- 3.2mm
- 4.8mm

The filler rods must be selected according to the metals, which need welding.
They should be placed in clean and dry situations for preventing corrosion. They should be rust-free, oil-free, and moisture-free, which contaminates welds, so they must be cleaned with steel wool or aluminum oxide before use. After cleanup, they should not be touched with bare hands. A welder must wear clean and soft leather/ fire-proof gloves.

3.3.5. Process Parameters of TIG Welding

The affecting parameters of the TIG welding are as follows:

3.3.5.1. Welding Current

Higher TIG welding current leads to splatter and damage the work piece. Lower current settings result in sticky filler wire. Greater heat affects areas found for lower current because higher temperatures should be maintained for long time for depositing same quantity of filling metals. The fixed current changes the voltage for maintaining constant arc current.

3.3.5.2. Welding Voltage

Welding volts are either fixed or adjustable according to the use of TIG equipment. Higher voltage allows easy arc beginning and greater working tip distance. Higher volts can affect the welding quality.

3.3.5.3. Inert Gases

The selection of shielding gas relies on working metals and their properties, cost, temperature, arc stability, welding speed, splatter, and electrode lifetime etc. It affects finishing of final weld, its penetration/depth, surface profile, porosity, corrosion-resistance, stiffness/fragility of the weld. Argon/helium is used for TIG welding. Pure argons materials are extremely thin. Argon provides a general arc, which runs more smoothly and less quietly. Penetration, when using argon arc, is gained through using helium. Thus, argon is suitable in most of the functions unless a welder wants to raise temperatures and spread solder for high thermal conductivity with thick work piece. Aluminum and copper possess higher thermal conductivity as compared to other metals, so, this type of material need helium because it helps welding thick work pieces for example doors. Pure argon is utilized to weld steel, low-alloy steel, stainless steel, aluminum, titanium, magnesium and copper. Argon is used for hydrogenated welding mixture of some grades of alloys including stainless steel and nickel. It is used for pure aluminum and copper. You can use a mixture of helium and argon for low alloy steel, aluminum and copper.

3.3.5.4. Welding Speed

Welding speed is significant factor in the TIG process. When the speed limit of welding is increased through electricity or heat, it consolidates the results, and thus reduces less welding and penetration. Welding speed and the speed of movement and control affects the size of a grain of penetration welding. Excessively higher welding speed reduces quality of work, and increases the porous grains while slower welding reduces porosity.

CHAPTER 4

ALUMINIUM ALLOYS AND PROPERTIES

4.1. INTRODUCTION

The presence of aluminum has been assumed (Al) by Sir Humphrey Davy in early 19th Century and minerals were isolated in 1825 by Hans Christian Ousted. Out of his curiosity, he began some commercial production after the next 30 years but in 1886, aluminum ore was extracted, which made welding an industrial process. He invented a method, which is still used today, and Paul Herald and Charles M. Hall contributed to it. Since interactivity did not exist in the nature of aluminum, it exists in the earth's crust in several hundred compounds, and Bauxite is the best of them. By the end of 20th Century, the percentage of aluminum scrap recovered a million tons of REMELTED aluminum through this supply source alone per year in Europe alone. For increasing the strength, aluminum alloy generally has pure metals including copper (Cu), manganese (Mn), magnesium, silicon (Si) and zinc (Zn). It was one of the initial alloys of aluminum and copper. In 1910, the age precipitation hardening of alloys was found out.

4.2. PROPERTIES OF ALUMINUM

The use of wrought/cast aluminum is increasing because of its properties. The features of aluminum/its alloys include lightweight –about 1/3 of steel. Cubic inch aluminum weighs 0.098 pounds/cubic inch while steel weighs 0.283 pounds/cubic inch.

- Aluminum provides better strength properties varying from 13,000 tensile up to 90,000 tensile.
- Aluminum has remarkable corrosion-resistance. The refractory oxide on the surface provides a protective layer.

- It is a good heat conductor and about five times more conductive than steel.
- Aluminum reflects heat, and its finish is used for this feature.
- It is easily available in extruded shapes/wrought sheet in a wide range of alloys.
- It is available as a die cast base material [18] for welding, which is important for welding aluminum .

4.2.1. Types of Wrought Alloys

International system set alloy is the most widely accepted label on a wide range of wrought alloy system. Each alloy has a 4-digit number and the first number indicates the elements.

- 1000 series means pure aluminum with at least 99% aluminum content and it can be hardened.
- 2000 series are copper alloyed, precipitation hardened, with strengths comparable to steel. It was called as duralumin, once the most common aerospace alloys, but affected by stress, corrosion, cracking and were replaced by 7000 series.
- 3000 series are alloyed with manganese, and can be hardened.
- 4000 series are alloyed with silicon also called as silumin.
- 5000 series are magnesium alloyed
- 6000 series are alloyed with magnesium and silicon. They are easily welded; they are precipitation hardened but just from 2000 to 7000. 6061 alloy is the commonly used aluminum alloy.
- 7000 series are alloyed with zinc, and are able to be precipitation hardened to the highest strengths more than any other aluminum alloy (up to 700 MPa for the 7068 alloy).
- 8000 series are alloyed with other elements. Aluminum-lithium alloys are an example.

4.2.2. Cast Alloys

The Aluminum Association (AA) defined nomenclature like wrought alloys. According to AA system, the second two digits give information of minimum aluminum percentage, e.g. 150.x corresponds to 99.50% aluminum. The digit after the decimal point takes a value of 0 or 1, denoting casting and ingot. The alloying elements in the AA system are as follows: [citation needed]

- 1xx.x series are at least 99% aluminum
- 2xx.x series copper
- 3xx.x series silicon, copper and/or magnesium
- 4xx.x series silicon
- 5xx.x series magnesium
- 7xx.x series zinc
- 8xx.x series tin
- 9xx.x other elements

4.2.3. Quick Reference Chart-Choosing an Aluminum Grade

Table 4.1. Aluminum grades.

Alloy	Formability or Workability	Weldability	Machining	Corrosion Resistance	Heat Treating	Strength	Typical Applications
1100	Excellent	Excellent	Good	Excellent	No	Low	Metal Spinning
2011	Good	Poor	Excellent	Poor	Yes	High	General Machining
2024	Good	Poor	Fair	Poor	Yes	High	Aerospace Application
3003	Excellent	Excellent	Good	Good	No	Medium	Chemical Equipments
5052	Good	Good	Fair	Excellent	No	Medium	Marine Applications
6061	Good	Good	Good	Excellent	Yes	Medium	Structural Applications
6063	Good	Good	Fair	Good	Yes	Medium	Architectural

							Applications
7075	Poor	Poor	Fair	Average	Yes	High	Aerospace Application

4.2.4. Heating and Thermal Processor

Heating grade is used to analyze the thermal effects of partition while welding of base metals with varying thicknesses is in process. It can heat the base metals and base metals 5xxx containment should not be subject to more than 3% magnesium to heating and Anterooms temperature should be higher than 250 degrees Fahrenheit (121 degrees Celsius) for 15 minutes or more for OSO D1.2. After heating, welded aluminum alloy becomes heat treatable, that is great of mechanical aspects of heat-affected alloys. When a base metal is welded in T4 temper, the energy is\ recovered after welding. Aging after welding: When a base metal is weld in mood-T6 aged heat-treated solution, which will calm -T6 after welding. Based on the materials used for the treatment of filler metal and heat aging after welding, there can be some issues. When the treatment filler metal is not responded to, the heat aging in the basic metals and welding may get lower than the base metal's mechanical properties. The concentration of stress is on the same welding, which is not a desirable situation; therefore, if a welder wants to perform welding with heat treatment and aging, the choice of filler metals will be critical. Judgment and mechanical properties (UTS & YS values) of non-current pulse was greater than the parent metal [24].

4.2.5. Aluminum Weld Ability Problems

4.2.5.1. Porosity

Porosity naturally exists in aluminum and its alloys but this issue is limited to the welded metal only. It consists of a gas, which is dissolved in the molten metal, and it traps and solidifies; therefore, it produces bubbles in the welding, which can range from small and very precise pores to bigger ones of 3 or 4mm diameter. Hydrogen has a high capacity to dissolve in heated aluminum, but with less soluble solids, as shown in Fig.3.1. This shows that it would be very difficult to have pore-free welding of aluminum. Pores tend to maintain the porosity levels at the lowest levels in the gas welds. The filler metal may increase because of pollution on wire. Of traditional fusion welding, TIG process has less than the porosity of the MIG levels because of possible hydrogen-contamination that the wire might have [25].

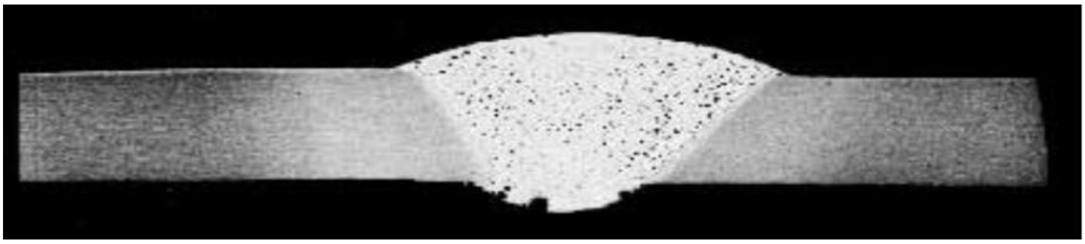


Figure 4.1. Shows porosity distributed over the welded area.

4.2.5.2. Oxide Film Removal during Welding

There is a need to eliminate the oxide film before welding for reducing the porosity risk. It is significant to disperse the film during the welding if issues including lack of fusion/oxide film entrapment have to be avoided. Figure 4.2 illustrates oxide-filming in weld that has effect on joint strength [26]. Aluminum oxide (Al2O3) is a tenacious and rapidly forming oxide, which provides aluminum valuable corrosion-resistance. This oxide has extreme melting point, which is 2060°C in comparison with pure metal that melts at 660°C. Many other metallic oxides melt on temperatures equal to or less than their metals and so, they float on top of the weld pool as molten slag.

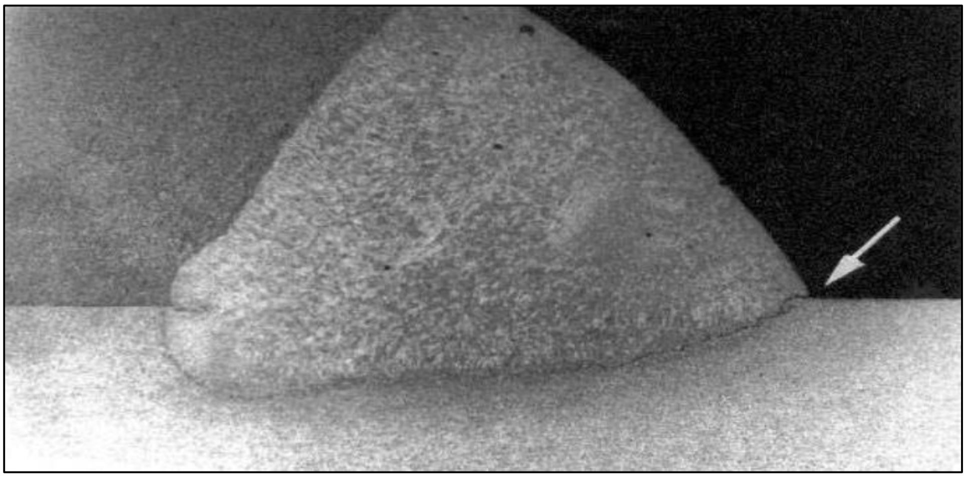


Figure 4.2. Oxide entrapment on the wild area.

4.2.5.3. Hot Cracking

Hot cracking is one of the major welding issues, which does not happen in pure metals but just in some alloys. This phenomenon is not limited to aluminum alloys but it has been observed in steels, nickel & copper alloys [27].

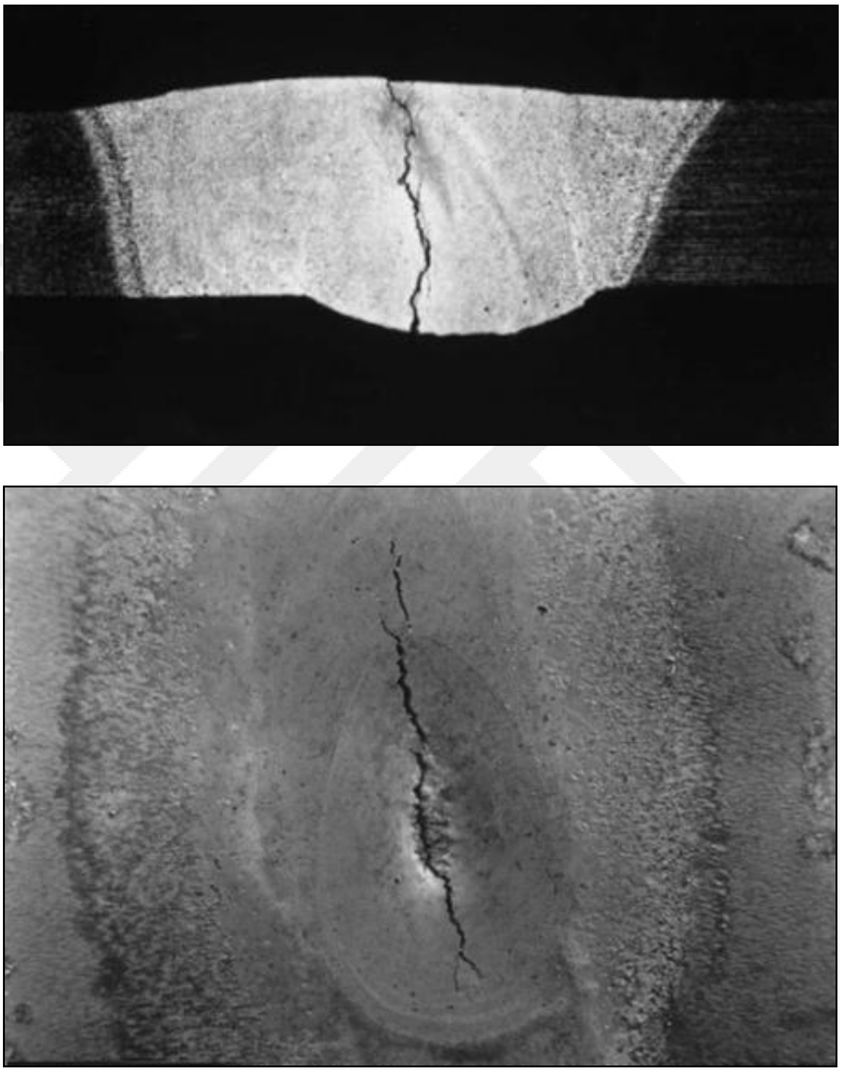


Figure 4.3. Crack appears on the welding surface.

4.2.6. The Choice of Alloy and Temper

Before selecting appropriate welding products, alloys and technologies, one must also take into account some other factors before making a final selection of the alloy such as [28].

- What is the range of products available.
- On-time delivery of the shares/plant.
- Price, etc.

Technically, users find themselves in a "give and take," for example; a good alloy with helpful properties can be very sensitive to some types of corrosion/difficult-to-weld. The availability and dimensions may vary from one alloy to another, which also reflects in price. Alloy information is provided through standards, brochures and publications, which provide information about choosing the most suitable alloy [29]. Referring to ALUSELECT alloy that has database and recommendations; however, individual alloys might show very different/changed performance under working conditions, and it would be useful to check if there is any doubt about its function/behavior/properties. Kina shows that the current speed of welding and weld joints are affected by welding tensile strength [30].

CHAPTER 5

DESTRUCTIVE TESTS OF WELDED JOINTS

5.1. INTRODUCTION

Welds play an important role in the quality, reliability, strength and durability of products in many industries. Cars, airplanes, ships, and construction of roads, bridges, buildings and pipelines with effective application of the welds is the main component of a successful final product/s [1]. Testing helps assessing the appropriateness of welding for a particular application, and taking decision whether to go ahead with further processing or acceptance/rejection. Classified test of weld joint is destructive test and there are methods of non-destructive testing as well. Destructive testing methods damage the test piece [2] to some extent - more or less. Exposed solder joints generally survive in the destructive tests such as hardness, toughness, bending and tensile testing, which helps understanding their specifications, suitable welding procedure, appropriateness of contact with other substances and welding for a particular application [3].

5.2. TENSILE TEST

Tensile strength of solder joints get the ultimate strength or softness in room temperature or a private environment, or other characteristics (low temperature, high temperature, corrosion, etc.) depending on the application requirements, which are assessed by using the tensile test, usually carried out in fixed compression rate (ranging from 0.0001 to 10.000mm/min) [31]. It is obtained from the tensile properties of contact welding in two ways: Take a sample of the transverse direction of the welding heat-affected joint of base metal, which consists of welding of heat-affected zone as shown in the Figure 5.1.

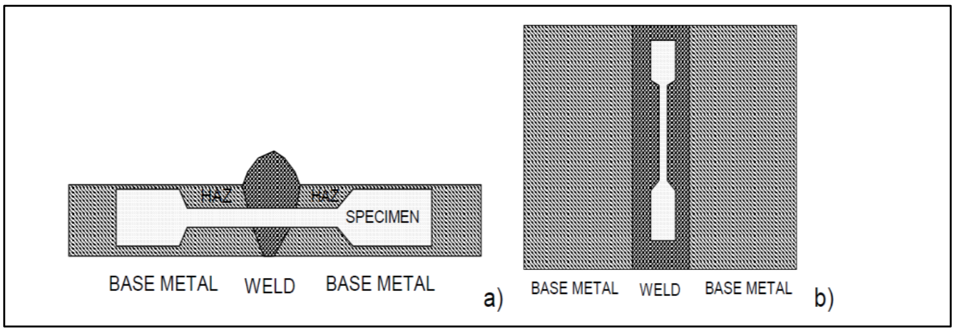


Figure 5.1. Schematic diagram of tensile specimens from 1) transverse section of weld joints and 2) all weld specimen.

It is a recommended tensile test for stress, including engineering and drawing strain, which results in pointing to the elastic modulus, elongation at the break, yield and ultimate strength (Figure 31.2). The results of tests information should be provided according to the following points:

- Type of sample (transverse weld, all weld specimen)
- Strain rate (mm/min)
- Temperature or any other environment, in which, the test was conducted
- Topography, morphology, texture of the fracture, surface indicating the mode of fracture and respective stress state should be mentioned Figure 5.2.

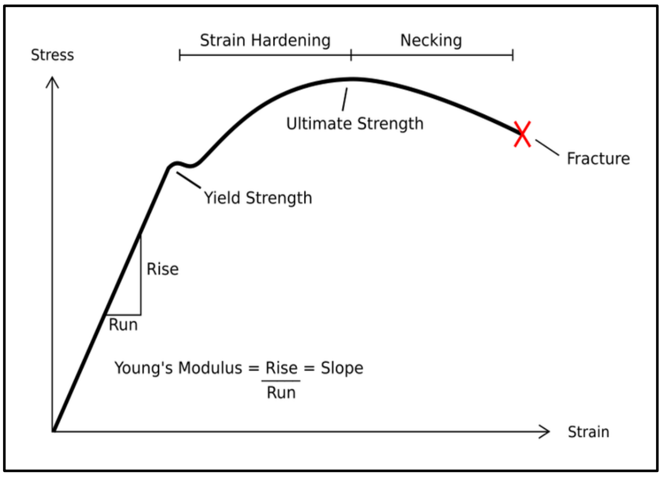
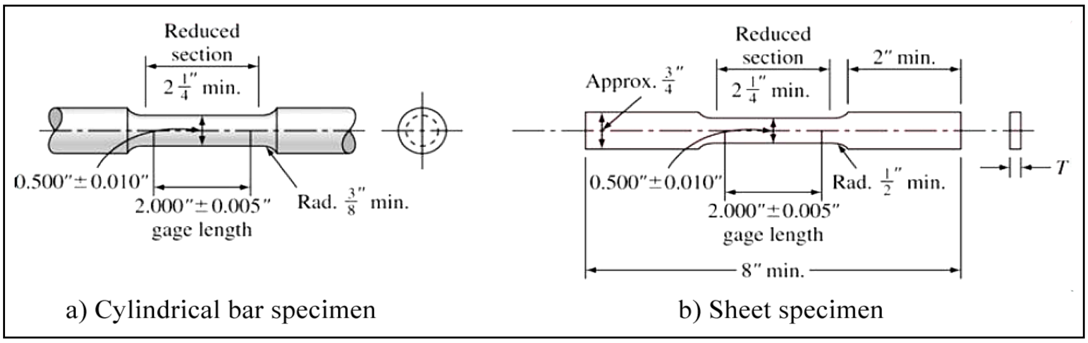


Figure 5.2. Typical stress strain diagram.

Generally, the test is implemented by using a round specimen. When you select a welded joint force, it also uses uniform flat samples. See Figure 5.3. Each of the standard samples for this test shows formats [32].



a) Cylindrical bar specimen b) Sheet specimen

Figure 5.3. Flat and round tensile test specimen.

5.2.1. Equipment Used to Test the Tensile Properties

It consists of series of simple to complex devices for control systems. The tests are conducted using mechanical systems or hydraulic machinery. Figure 4A shows relatively simple screw-driven testing. This device uses two large screws for the application of pregnancy, while the shape 4 (b) shows the hydraulic test. This device uses oil pressure in the piston for the supply of pregnancy. These types of devices can be used for not only analyzing tension, but also to assess pressure, bending and other tests.

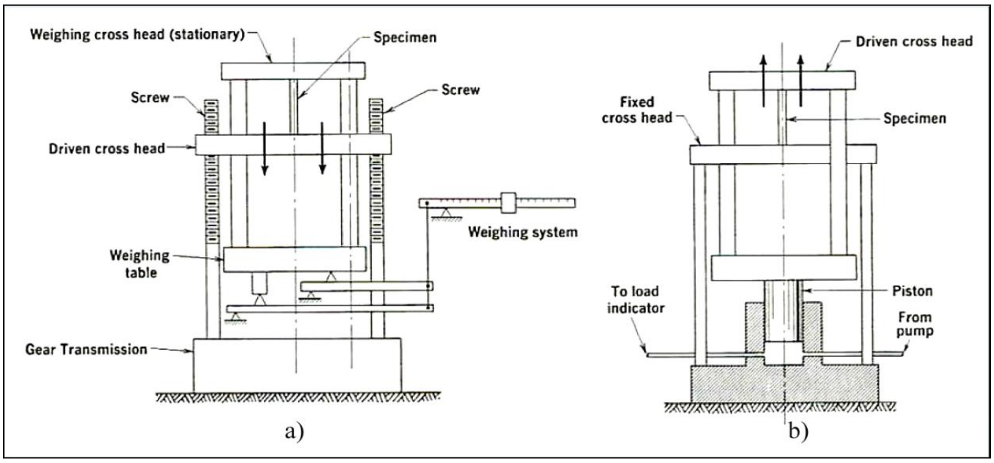


Figure 5.4. Schematics showing a) a screw driven machine and b) a hydraulic testing machine.

5.2.2. Stress and Strain Relationship

The tension and the F/A, which is the vertical force on the region, also known as the change in the length, or a change in the size. When a sample is exposed to the external tensile load, the minerals are subject to elastic deformation and plastic. At first, the metal will deform elastically, which gives a linear relationship of pregnancy and advice. Then these two parameters are used to calculate the stress and strain to give the relationship as shown in Figure 3 using equations 1 and 2 as follows:

$$\sigma = \frac{P}{Ao} \tag{5.1}$$

$$\varepsilon = \frac{L_f - L_o}{L_o} \tag{5.2}$$

Where: E is strain, P is the external axial load tensile, non-native to the cross-sectional of the sample area, and if this is the original sample length, LF is the final sample length, and engineering unit stress Pascal (Pa) or N / M2 according to units measurement SI, while the unit of psi (pounds per square inch) can also be used.

5.3. BENDING TEST

Test curve is one of the devastating experiences but the most important and commonly used to determine the softness and safety (for porosity and presence of containment penetration and other interruption of the total volume of internal welding). Welding-related products use a set of conditions for welding [4]. This can be done by using solder joint bending of the side of the face or root depending on the purpose or it may be used to analyze the root of the weld side. Moreover, bending can be performed using a simple/compressive bending die (Fig5.5)[5].

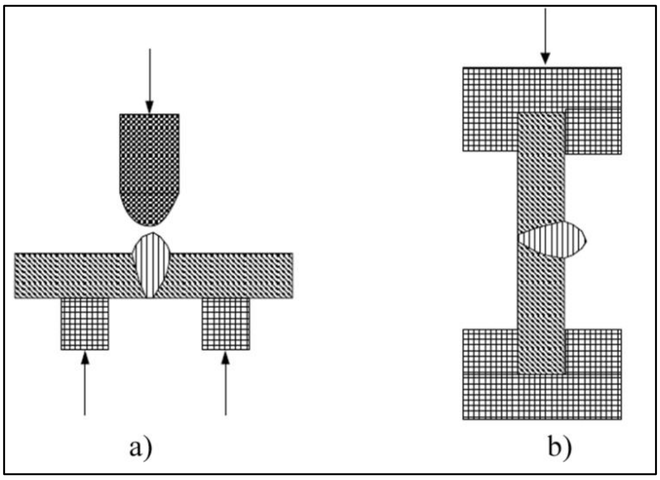


Figure 5.5. Schematics of free-bend tests.

5.4. HARDNESS TEST

Stiffness, resistance, and indentation are commonly used as measures of resistance to corrosion or scratching. To form scratch or cause erosion, relative movement should exist between the two bodies, and with all of the one body, which must penetrate/indent in the other body. Indent is the body's precise mutation (the most difficult) to another (softer) object under the external load. Resistance to penetrate depends on the hardness of the sample [5].

CHAPTER 6

FACTORS AFFECTING WELDED JOINTS

6.1. INTRODUCTION

It is useful to get access to the modern technologies and new manufacturing processes for effective studies on the structures of welded aluminum. The high demands of these structures need processes, which fully utilize the capabilities of the structural designs. Higher thermal conductivity, thermal expansion and contraction of metal are studied along with the oxidation rate. There is inadequate information in the literature about the effects of thickness of alloy on welding. Because of these characteristics of aluminum, it is much harder to understand aluminum welding and experiencing lack of strength, deformations, and stresses are more likely as compared to stainless steel [1]. Thus, the mechanical properties of the weld sharply differ from welding the mid-line of the basic materials. To understand the reasons for response and action of mechanical properties of materials (alloys), welding requires knowledge of the difference in mechanical properties in and around the weld [33].

6.2. WEAKENING OF ALUMINUM ALLOYS BECAUSE OF WELDING

The response to a solder heat is more complex than the heat treatable alloys because the heat effect depends on the degree of the peak temperature and time, when the metal is exposed to heat. Welding heat causes hardening of the small components in the HAZ followed by precipitation of small components uncontrolled in the HAZ on cooling. The degree of microscopic changes depends on the welding technology, preheat, and cooling rate.

In welding area, the temperature is above the melting point; therefore, differences in the mineral structure vary with the distance from the fusion line. It will be discussed in more detail during the analysis of the outcomes.

To study the welding effects on mechanical properties, the first point of focus is heterogeneous constitutive parameters - HAZ characterization. Substantial research has been conducted in this area. Wood and others (2002) examined global and local responses to mechanical friction of stir welded 2024 aluminum alloy both practically and numerically [34].

6.3. THICKNESS EFFECT IN WELDED JOINTS

The effect of the thickness is a phenomenon in the mechanical properties of welded connections is studied in the light of properties such as tensile strength, fatigue or other properties decrease as the thickness of the wall cracks. Gurney (1989) said that the effect of the thickness could be demonstrated using both mechanics theory of collapse and the experimental work [3].

TIG welding process best suits the metal plate, which has thickness 5-6mm. It is also used to weld thicker plate materials using multiple paths leading to the contribution of high temperature distortion or reduction of the metal's mechanical properties. Santee Kumar et al [4 tried to examine the welding of thick plates with thickness more than the TIG samples. Welded aluminum plates (about 3-5mm), and tungsten pulsed were weld with inert gas stream within 48-112000 and the rate of gas flow of 7-15 L/min. (Nearing and others.) [35] To assess the performance of TIG on steel plates with different thicknesses, they were weld with current 55-95A with welding speed 15-45mm/sec. Prediction of areas having macrostructure elements, weld-bead penetration and enhanced characteristics of the shape HAZ, and fuzzy simulation of TIG welding process have been done and studied.

Heat affected zone (HAZ) is a core area, which has microstructure and altered properties because of intensive heating, welding or cutting. Kuok et al showed in 2003 (Figure 6.1) the hardness of various door thicknesses of aluminum alloy 6061-T6 [6].

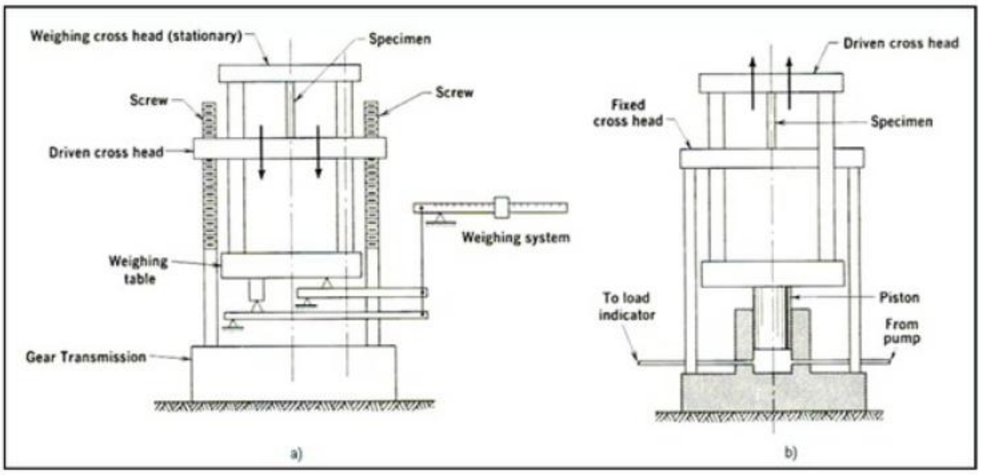


Figure 6.1. Hardness profiles for different section thicknesses & alloy 6061-T6.

6.4. WEAKENING OF ALUMINUM ALLOYS BECAUSE OF WELDING

The response to a solder heat is more complex than those, which were observed in the alloy because the heat effect depends on the degree of the peak temperature and the time of the metal exposed to heat. Welding heat causes hardening of small components in the HAZ, followed by precipitation of uncontrolled small components in the HAZ on cooling. The degree of microscopic changes depends on the welding process, technology, heating, and the cooling rate. For welding, temperatures above melting point lower away from the welding area, and therefore, the differences in the mineral structure vary according to the distance from the fusion line. It will be discussed in more detail during the analysis of the outcomes. For studying the welding effects on the properties of the alloys, the first point of focus is heterogeneous constitutive parameters of HAZ characterization. Substantial research has been conducted in this area. Wood and others (2002) examined global and local response to mechanical friction stir-welded 2024 aluminum alloy both practically and numerically [36].

CHAPTER 7

EXPEREMINTAL WORK AND METHODOLOGY

7.1. MATERIAL USE

In this research, Al alloy 1050 was used as a base material for both TIG and MIG welding methods. The composition of the Al alloy, filler metals and the gas shielding used in the experiments are given below. To measure the properties including yield stress, tensile strength, and maximum stress, a tensile test machine was used. For the hardness and the microstructure, Brinell hardness method and optical 1000x microscope were respectively used. The parameters used to weld the specimens were optimized to weld the samples with same set-up, only the difference was in thickness of the samples. The samples used in this thesis were different in thickness. The samples had rectangular shapes with dimensions (2, 15, 150mm), (4, 15, 150mm), (6, 15, 150mm), and (8, 15, 150mm), so, the obvious difference was only in the thickness of the samples.

7.2. BASE METAL (SPECIMENS)

The chemical composition of used samples is shown in table 1. Major component is Al, while the other components are traces, which have some helpful properties.

Table 7.1. The chemical composition of the specimens.

AVE	AI 99.3	Si .0744	Fe .292	Cu .0002	Mn .0032	Mg .0051	Zn .0810	Cr .0016
AVE	Ni .0003	Ti .0263	Be .0001	Ca .0027	Li .0001	Pb .0005	Sn .0050	Sr .0001
AVE	V .0075	Na .0046	Bi .0005	Zr .0023	B .0015	Ga .0133	Cd .0129	Co .0010
AVE	Ag .0009	Hg .0046	In .0041	Sb .0656	P .0030	Ce .0022	La .0019	

7.3. SHIELDING GAS

Shielding gas is used to transfer air in the weld-zone to stop contamination of the weld metal by nitrogen, oxygen and water vapors. The choice of the shielding gas depends on the material that needs welding and metal transfer type. The shielding gas mixture selected for the experiment contains 25% oxygen and 75% nitrogen.

7.4. EXPERIMENTAL SET-UP (TIG AND MIG) WELDING

The set-up used during the experiments for both techniques contains shielding gas controller, welding machine and motor, which conveys and guides the welding gun and moves with the desired constant speeds towards the samples to be welded. Figure 7.1 shows the welding instrument used for our experiment.

Figure 7.1. TIG and MIG welding machines used.

7.5. MECHANICAL PROPERTIES

The maximum tensile strength, yield point and fracture stress of the samples were measured in a calibrated ZWICE PS/1000 testing machine, which has a moderate capacity in tons. Transverse tensile test was carried out for standardization, which is a destructive test on metallic material welds. Figure 7.2 shows the test specimen. Table 3.4 shows the denominations and symbols of the test specimen.

Figure 7.2. Tensile test machine used.

The hardness was measured by Brinell hardness test, which produces relatively small indentations on the surface of the specimens. Fig7.3 shows the Brinell machine.

Figure 7.3. Brinell testing machine.

Hardness test was carried out according to standardization called as the “Hardness test on arc welded joints”. A calibrated machine, forced an indenter of quadrangle geometry under a specific load onto the surface of the test samples for the test duration. The resultant impression has been expressed as a specific measure of hardness.

7.6. METALLOGRAPHIC SPECIMEN

Metallographic specimen preparation was started with the sectioning operation. In order to get a clear view for the sections of welding and heat-affected zone from the bulk-welded specimens, optical microscopic examinations were carried out. The edges/corners were removed to improve the visibility and to avoid any misunderstanding before observing the surface of the samples. Figure 7.4 shows the optical microscope used for taking a closer look.

Figure 7.4. Optical microscopic examination.

CHAPTER 8

RESULTS AND DISCUSSION

8.1. TIG WELDING OF AL ALLOY WITH DIFFERENT THICKNESS

The work in this thesis relies on the measurements of the mechanical properties of aluminum alloy 1050 including hardness and tensile strength etc. The composition of Al alloy has been shown in Table 8.1.

Table 8.1. The chemical composition of Al alloy.

AVE	AI 99.3	Si .0744	Fe .292	Cu .0002	Mn .0032	Mg .0051	Zn .0810	Cr .0016
AVE	Ni .0003	Ti .0263	Be .0001	Ca .0027	Li .0001	Pb .0005	Sn .0050	Sr .0001
AVE	V .0075	Na .0046	Bi .0005	Zr .0023	B .0015	Ga .0133	Cd .0129	Co .0010
AVE	Ag .0009	Hg .0046	In .0041	Sb .0656	P .0030	Ce .0022	La .0019	

Moreover, the thesis presented the microstructure of the area near the weld joints (heat-affected zone) by using TIG welding. Welding parameters were used and the weld samples' dimensions in this thesis are given in Table 8.1. Temperature used in the analysis was room temperature. For reliability and clarity of the thesis, the dimensions of the V-groove, work piece, and experimental setup were kept constant. Only the thicknesses of the samples are different (2, 4, 6 and 8mm).

Table 8.2. Welding and work piece parameters.

Sample Material	Aluminum Alloy
Shape of Sample	rectangular
Sample Thickness	2, 4, 6, and 8mm
Filler Wire Material	Tungsten
Groove Angle	45 deg
Use aluminum electrode	4043
Shield Gas	Argon
Type of current	AC

The visual appearances with normal photograph of the welded specimen processed using TIG welding technique are shown in Figure 8.1.

Figure 8.1. Welded samples processed using TIG welding technique.

As shown in Fig. (8.1) in the visual examination, sample with 8 mm thickness is the best sample in terms of the shape of the semi-circular weld tape as well as the complete fusion of the edges and the absence of defects such as porosity and impurities on the welding tape on the other hand The sample with 4mm thickness is clearly shows irregular part of the welding tape , weakness in the fusion of the edges and the presence of some impurities and pores on the weld tape. But for the sample with 6 mm thickness it is clear from the visual examination that it is better than the sample with 4 mm thickness and less than the sample with 8 mm thickness. And this show that the higher the thickness o, the better the visual properties , such as the regulation of the welding tape and the lack of defects in the sample.

8.2. TENSILE TEST

Four specimens were prepared from the same Al alloy. All samples' length was the same and only thickness was different, in order to assure that the samples are welded under the same parameter, the tensile test of the joint was accomplished using universal tensile testing machine (Wicks) with maximum capacity 1000 KN as mentioned in the chapter four. Load was exerted with a speed of 1mm/min. Fig. 8.2. (a, b, c, and d) and (4, 6, and 8mm) respectively exhibit relationships between engineering stress and the engineering strain in case of welded specimens of aluminum alloy, as obtained from the tensile tests.

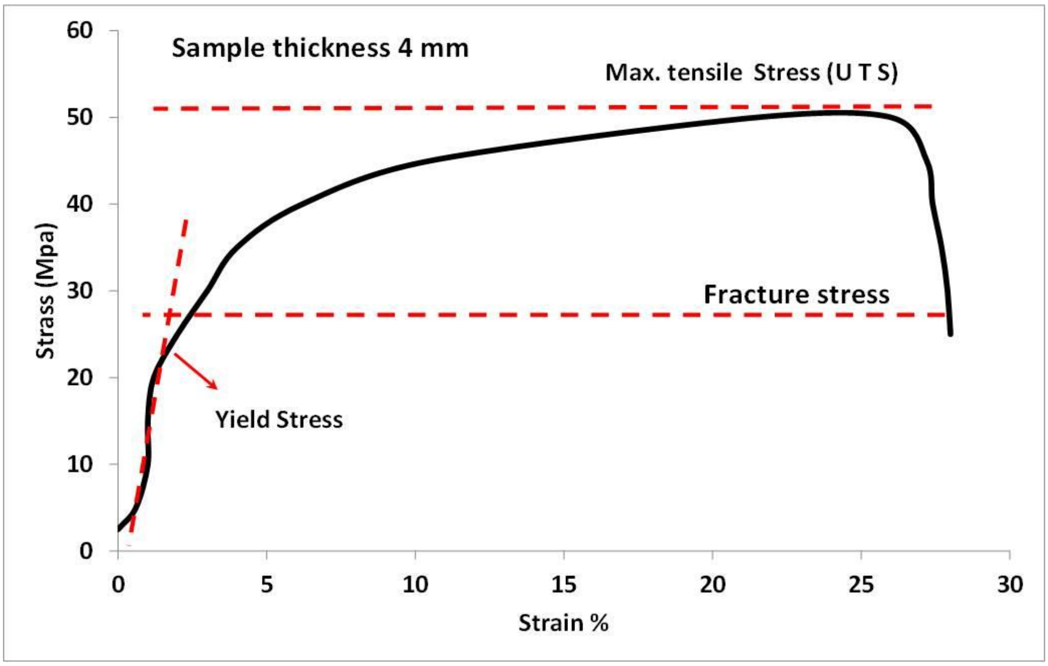


Figure 8.2. Stress versus strain curves for aluminum alloys (welded from TEG) obtained from the tensile test for 4mm thickness.

The sample, which has thickness 2mm, could not be welded and broke during the welding process. The reason for this may be less thickness that did not allow the sample to resist the temperature so it fractured. The stress-strain relationship was obtained from tensile tests, which gave us information about different mechanical properties such as maximum tensile stress (Ultimate tensile stress), yield point stress and fracture stress. All these results are recorded in table 8.3

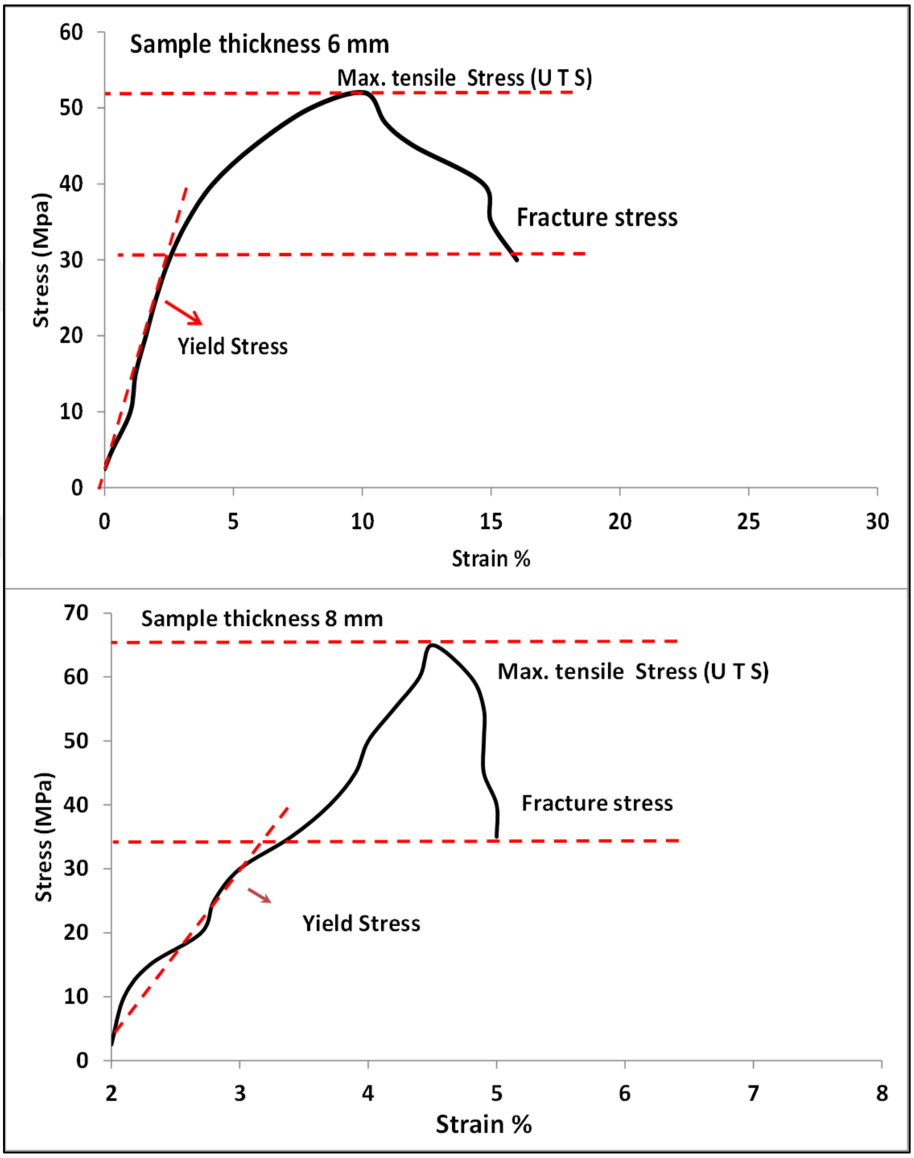


Figure 8.3. The stress versus strain curves for the aluminum alloy (welded by TIG) obtained from the tensile test for samples having 6 and 8mm thickness.

.

Table 8.3. Summary of the mechanical properties of the aluminum alloy 1050 obtained from the tensile tests.

Specimen Thickness	**Yield Stress σ_Y (MPa)**	**Max. Tensile Stress (MPa)**	**Fracture stress (MPa)**
4mm	26	51	24
6mm	30	53	28
8mm	32	65	34

It has been observed that the higher ultimate tensile strength and yield stress values were obtained in samples of 6 and 8mm thicknesses; however, the lowest was observed in samples, which have 4mm thickness. From the figures of the stress-strain curves, we can also conclude that the strain hardening of the sample, which has 4mm thickness, was higher than the 6 and 8mm thick samples. The total elongation of the samples of thickness 4mm was more than 6 and 8mm but the maximum tensile stress of the 8mm samples was the highest. All these outcomes explain that the welding of the aluminum alloy depends on the thickness of the sample. This effect will be clear in the different results obtained in table 8.3. The same effect is also true for the specimens of 6 and 8mm, which have the maximum fracture stress values. Further discussion will be done on the shape of the curves. It is obvious that the curve of 4mm thick sample is smooth and we can say that this represents the typical movement of stress and strain values while in the other curves, narrow area of elongation exists. In general, the values of the mechanical properties are affected by the thickness of samples. At the same time, it compromises other factors, which affect the welding processes. In addition, it seems as if there is no big difference between the samples, which have thicknesses 6 and 8mm as shown in results in table 8.3. This means that the joining process of these two different thicknesses can be successful, when the same yield stress will be applied and their yield stress values are likely to be similar. The results of the mechanical properties obtained from the tensile tests are likely to be a little bit low as compared to reference review presented by Dr. MacDiarmid (2012), R.R Ambry and V. Maya goatee (2011). They used Al alloy series 6000, which has better mechanical properties than pure Al. The results we got gave us good hints and explanation about the thickness effect of specimens on the mechanical properties of welded joints. According to the results, the additives have strong effect on the mechanical properties, which is clear from the reference: [23].

8.3. HARDNESS TEST

Hardness characterizes materials, and it depends on many features such as strain, plasticity, ductility, elastic stiffness, strength, toughness, and viscosity. Indentation-hardness can be easily calculated, it is a well-defined characteristic, and it can give the designer useful information about the strength of the metal. The test includes applying pressure to a diamond or a steel ball and pressing it in the material surface for examining. Fig 8.4 shows the Brinell hardness testing principle.

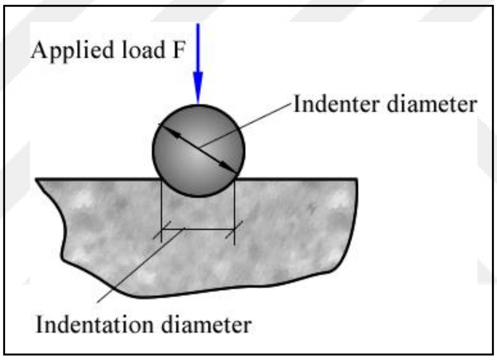


Figure 8.4. Brinell hardness test principle.

Hardness values of area closer to the welded area were found for all specimens to get better understanding of the mechanical changes the near-welded zone. We select that zone because we found some difficulties when we tried to measure the zone, and besides, we could not perform this test on the heat-affected zone. The Brinell micro hardness test was used and the outcomes are exhibited in Table 8.4.

Table 8.4. Shows the outcomes of Brinell Hardness Test.

Sample Thickness (mm)	Before Welding	After Welding
2	4.4 HB	Not welded
4	10.1 HB	9.0 HB
6	23 HB	21 HB
8	54.7 HB	59.4 HB

From the results above, we can see that the sample thickness 8mm showed the maximum hardness. The hardness in 4, 6 and 8mm samples have almost the same values before and after welding. The sample, which has 2mm thickness, could not be welded because of less thickness. There are many reasons for the same value, which we obtained and the main reason is that we used the same filler material. In addition, the thickness increase has also affected the mechanical properties of aluminum welding joints.

8.4. OPTICAL METALLOGRAPHIC ANALYSIS NEAR WELD JOINTS

Metallographic analysis of the welded material is crucial in different means. Especially for understanding about solidification, cracking behavior, porosity in the weld zone and HAZ (heat-affected zone). Optical image near the heat affected zone of the weld specimens were taken by using an optical microscope. Figure 8 (5, 6, and 7) show the microscopic images were taken with optical microscope from the face section bested welding line for samples which have 4, 6 and 8 mm). Porosity which evolved for trapping oxygen during the welding and solidification caused some vacancies area like pores. This may weakness the mechanical properties. However may be due to the optical microscope the images not appear clear. It is recommended for future work by prepare cross-section for the weld part and then the porosity will be clear if it is exist.

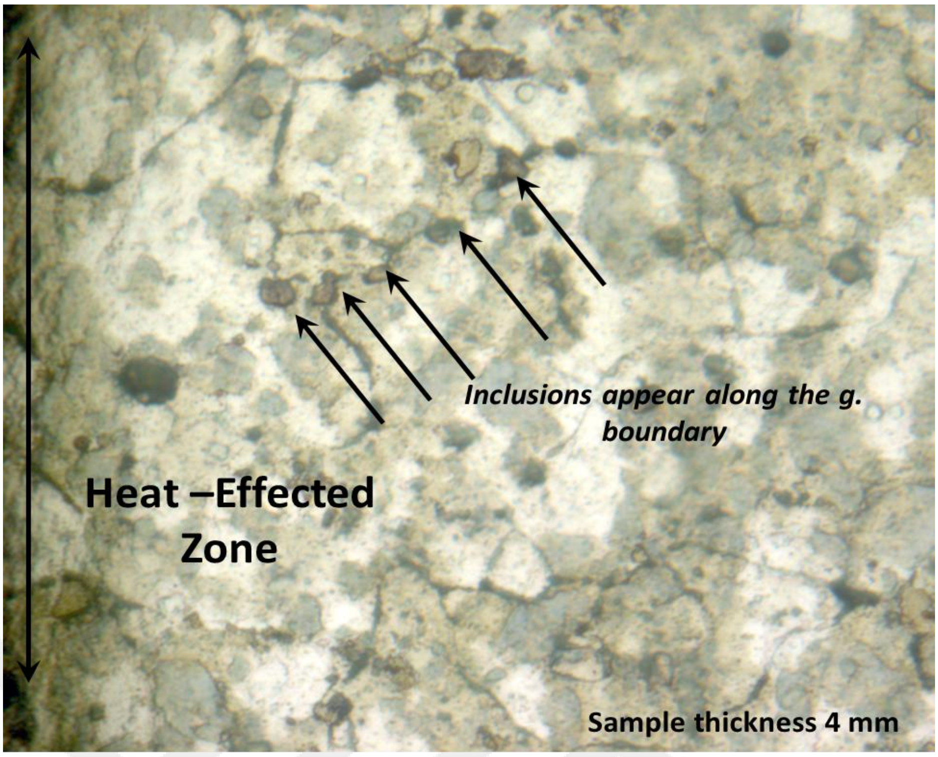


Figure 8.5. Optical microscopic image of the weld sample having thickness 4mm. The arrows show the inclusion on the boundary.

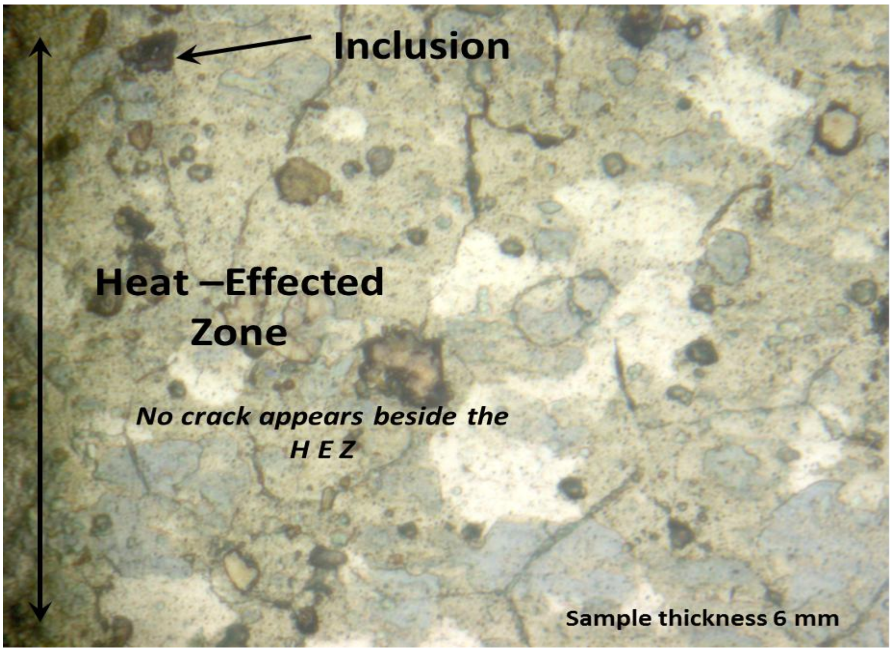


Figure 8.6. Optical microscopy image of the weld sample have thickness 6mm. The arrow show the inclusion besides HAZ.

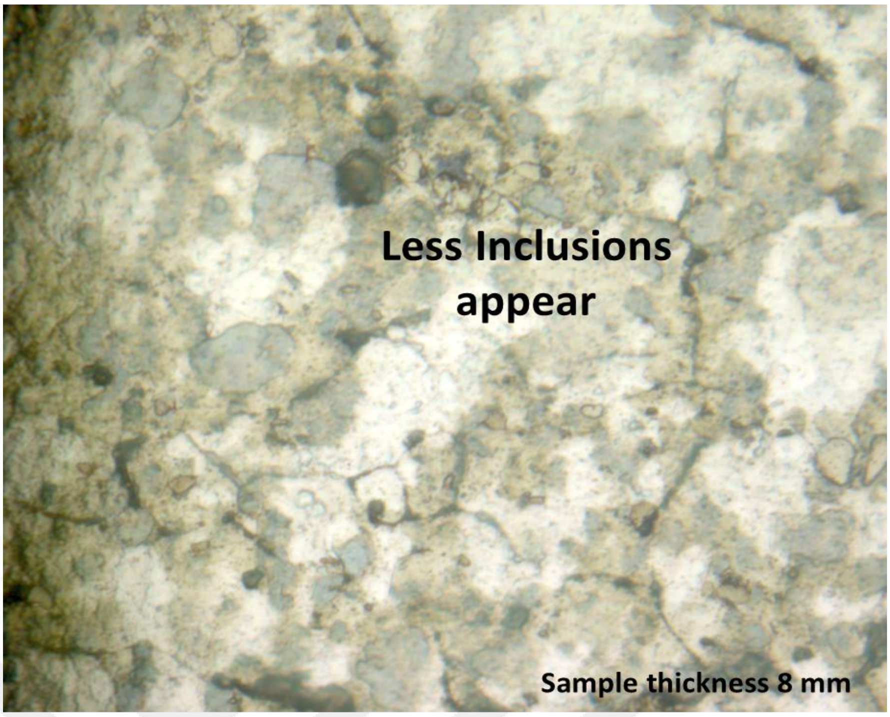


Figure 8.7. Microscopic image of the weld sample having thickness 8mm. The arrows show the inclusion on the boundary.

The heat-affected zone (HAZ) is the area of base material, either a metal or a thermoplastic, which is not melted and has had its microstructure and properties affected by welding or heat intensive cutting operations. The heat from the welding process and what following re-cooling leads this change from the weld interface to the termination of the sensitizing temperature in the base metal. The extent and magnitude of property change depends primarily on the base material, the weld filler metal, and the amount and concentration of heat input by the welding process.

A metallographic analysis of the aluminum alloy structure has shown that the base metal weld interface is not unclear, and the structure of the base metal and the weld is strongly different as seen in Figure 8 (5, 6 and 7). Before we go to explain what appears regarding to surface defects it is better to give some titles about inclusions. There are two types of inclusions: linear inclusions and rounded inclusions. Inclusions can be either isolated or cumulative. Linear inclusions occur when there is slag or flux in the weld. Slag forms from the use of a flux, which is why this type of defect usually occurs in welding processes that use flux, such as shielded metal arc welding, flux-cored arc welding, and submerged arc welding, but it can also occur in gas metal arc welding.

This defect usually occurs in welds that require multiple passes and there is poor overlap between the welds. The poor overlap does not allow the slag from the previous weld to melt out and rise to the top of the new weld bead. It can also occur if the previous weld left an undercut or an uneven surface profile. To prevent slag inclusions the slag should be cleaned from the weld bead between passes via grinding, wire brushing, or chipping. Isolated inclusions occur when rust or mill scale is present on the base metal. In our work the inclusions appear was around inclusion not linear.

There were some inclusions exist along the samples which have thicknesses 4 and 6 mm while in sample which have 8 mm is mostly no inclusion appear. This may be due to the heat fusion during the welding, since the low thickness may affect the heating more than the higher one. The precipitation of particles along grain boundaries is undesirable as it reduces the metal strength, which, in our case, was a probable cause of specimen fracture in the weld zone. This is very clear when we estimate the tensile stress and the maximum stress in sample which have 4 mm thickness. The figure 8.5 also showed the base metal near the weld has different color which means that affected with the temperature during the welding. R. R Ambrose explains the effect of heating of fusion on the metal grain structure at the mid plane.

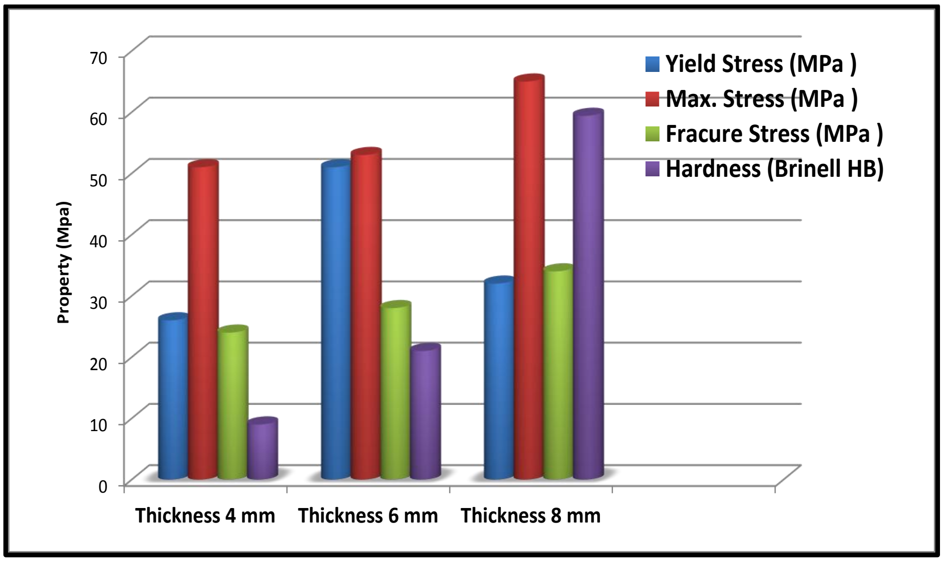


Figure 8.8. Values of tensile strength, yield strength, fracture stress and hardness with thickness of samples.

In general, welding is employed as a joining technique for aluminum in industries and that is affected by many parameters such as temperature type of welding thickness and so on. To reach the optimum, it should be discussed with all the parameters to understand and compare those parameters and comparing with other applications. Figure 7 shows the mechanical properties tested for the welded aluminum alloy. All results are shown in Figure 8.8, which explains that the thickness has effect on the mechanical properties. As the thickness increases, the mechanical behavior also increases. This is mainly logical and we found it in many literatures. The important factor, which may affect the process of welding of aluminum alloy, is the type of technique. For example, as we worked on the experiment, on which, this thesis is based and we found that the results, which we got in TIG welding, differ if we use MIG process. That means even if we have some similar properties, the other parameters may affect the results of mechanical properties. In this thesis, we performed the experiment by doing the same process of welding on the same alloy with same parameters to make a clear comparison between the two methods or techniques.

8.4.1. MIG Welding of Al Alloy with Different Thickness

As shown in Fig. (8.9) in the visual examination, sample with 8 mm thickness is the best sample in terms of the shape of the semi-circular weld tape as well as the complete fusion of the edges and the absence of defects such as porosity and impurities on the welding tape on the other hand The sample with 4mm thickness is clearly shows irregular part of the welding tape , weakness in the fusion of the edges and the presence of some impurities and pores on the weld tape. But for the sample with 6 mm thickness it is clear from the visual examination that it is better than the sample with 4 mm thickness and less than the sample with 8 mm thickness. And this show that the higher the thickness o, the better the visual properties , such as the regulation of the welding tape and the lack of defects in the sample. Following the results of the experimental analysis, we presented the results of the same procedure in MIG welding of the Al alloy 1050 with different thicknesses to see what are the differences between the two methods and what is the main factor affecting them. As seen in previous section, we will analyze the mechanical properties in terms of tensile test, hardness test and metallographic examination. Displacement data using mechanical correlations was obtained to get ultimate strength, yield stress, and other properties of the weld stress-strain curves. Moreover, HAZ structures were observed by microscopic test. The Al alloy samples with 2, 4, 6 and 8mm thicknesses were used like the previous experiment. The gas pressure used in this technique was 12 Psi, current 150 amperes, and the voltage was 15 volts. The experiment was conducted in room temperature. Before starting any test, visual examination showed that the specimens having thickness 8mm look better during the welding process. As expected because of lack of technical facilities or proper method specific for less thickness, we were unable to weld the 2mm sample. All other samples were welded but only the sample, which has thickness 2mm, could not be welded. This sample was difficult-to-weld because of the less thickness.

Figure 8.9. Welded samples with MIG welding technique.

8.4.2. Tensile Test

The stress-strain plot is shown in Figure 8.10, which displays the stress value on sample thickness 4mm for aluminium alloy-1050. The graph shows that the average tensile strength increases as strain increases, which is logical and the maximum tensile stress was around 70 Map and the curve decreased until it fractured at 40Mpa. After this point, the sample started to deform. This value was approximately 38Mpa. It is also obvious that the deformation is not as high as compared to the sample tested using MIG welding.

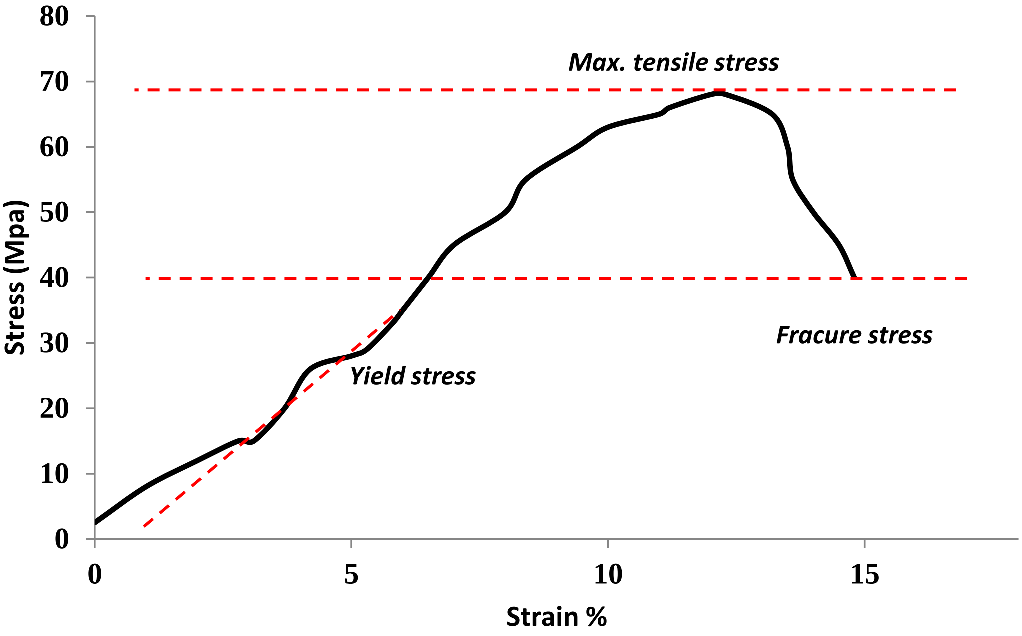


Figure 8.10. The stress versus strain curve for the aluminum alloy (welded by MIG) obtained from the tensile test for 4mm thick samples.

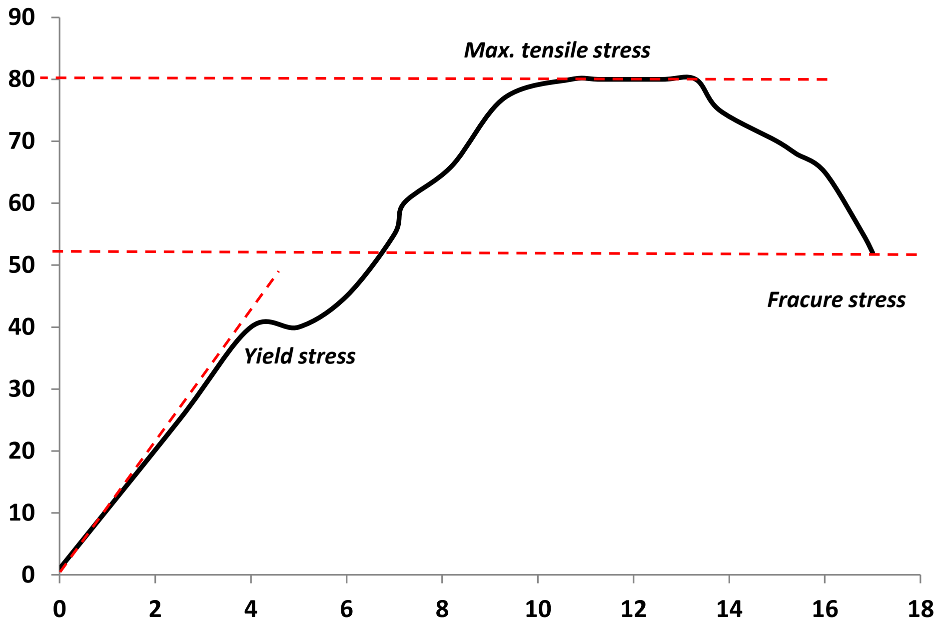


Figure 8.11. The stress versus strain curve for the aluminum alloy (welded by MIG) obtained from the tensile test for 6mm thick samples.

The stress vs strain curve for the sample, which has 6mm thickness (Figure 8.10), has different values of the yield stress, maximum strength and breaking point. The yield stress was around 42Mpa, which was higher for the thickness of 4mm. This means that the deformation started earlier, which could be given some flexibility for the application selection, and it is an advantage for 6mm rather than 4mm thick samples. The figure shows more homogeneity in loading deformation, i.e. no lactation occurred during the tension of the sample. After the yield-point, it is clear that the loader band region, which has some relaxation before the deformation started. After the ultimate tensile stress point (80Mpa), the sample started decreasing in value until it reached the breaking point (around 52Mpa). The last sample, which had 8mm thickness, has been shown in the Figure 8.12, its yield stress was around 56Mpa, the maximum stress was 100Mpa, and the fracture stress was 58Mpa. The sample, which has 8mm thickness, showed the best mechanical properties and other performance values.

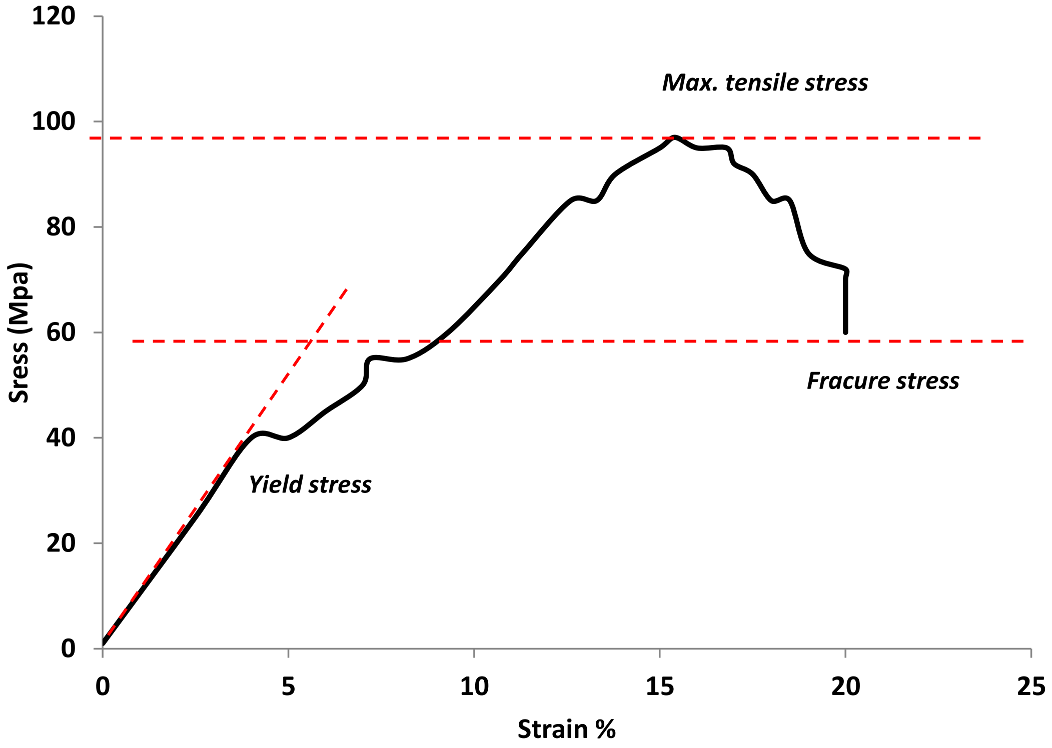


Figure 8.12. The stress versus strain curve for the aluminum alloy (welded by MIG) obtained from the tensile test for samples having 8mm thickness.

Table 8.5. Shows the summary of the mechanical properties resulting from the tensile test for the samples, which have 4, 6 and 8mm thicknesses.

Specimen Thickness (mm)	Yield Stress σ_Y (MPa)	Max. Tensile Stress (MPa)	Fracture stress (MPa)
4mm	38	70	40
6mm	42	80	52
8mm	56	100	58

8.4.3. Hardness Test

Table 8.6 shows the results of the hardness test of the MIG welding samples conducted during the previous MIG welding procedure. The results showed that the highest rigidity found in the sample was 8mm thick while the lowest was observed in a 4mm thick sample. The sample, which had a thickness of 2mm, could not be welded like the way it happened in TIG welding. This may have been due to a technical problem. The temperature during the MIG welding process was higher compared to the MIG solder and this reflects the rigidity test, which was better than the MIG welding. This also applies to tensile testing. In this test, the salad was taken in three areas and the medium was taken and the salad was raised at the welding area 60 mm from the welding area

Table 8.6. Summary of the mechanical properties of the aluminum alloys 1050 obtained from the tensile tests.

Sample Thickness (mm)	Before Welding	After Welding
2mm	4.4 HB	Not welded
4mm	10.1 HB	15 HB
6mm	23 HB	32 HB
8mm	54.7 HB	60 HB

8.4.4. Optical Metallographic Analysis near Weld Joints

Figure 8 (13,14,15) shows typical grain structures of different regions (HAZ and base metal). The figure did not show any formula for fine grain. Yet there was dynamism Re-crystallization. The area affected by the heat was very clear not only in color change but also the grains are not like the base metal. Although the grains not serene may be due to the small magnification or other factor during scanning. However it is not appear high inclusion or impurities beside the HAZ region.

To reduce the risk, rigorous cleaning of material surface and filler wire should be carried out. Three cleaning techniques are suitable; mechanical cleaning, solvent degreasing and chemical etch cleaning. In gas shielded welding, air entrainment should be avoided by making sure there is an efficient gas shield and the arc is protected from draughts. Precautions should also be taken to avoid water vapor pickup from gas lines and welding equipment; it is recommended that the welding system is purged for about an hour before use.

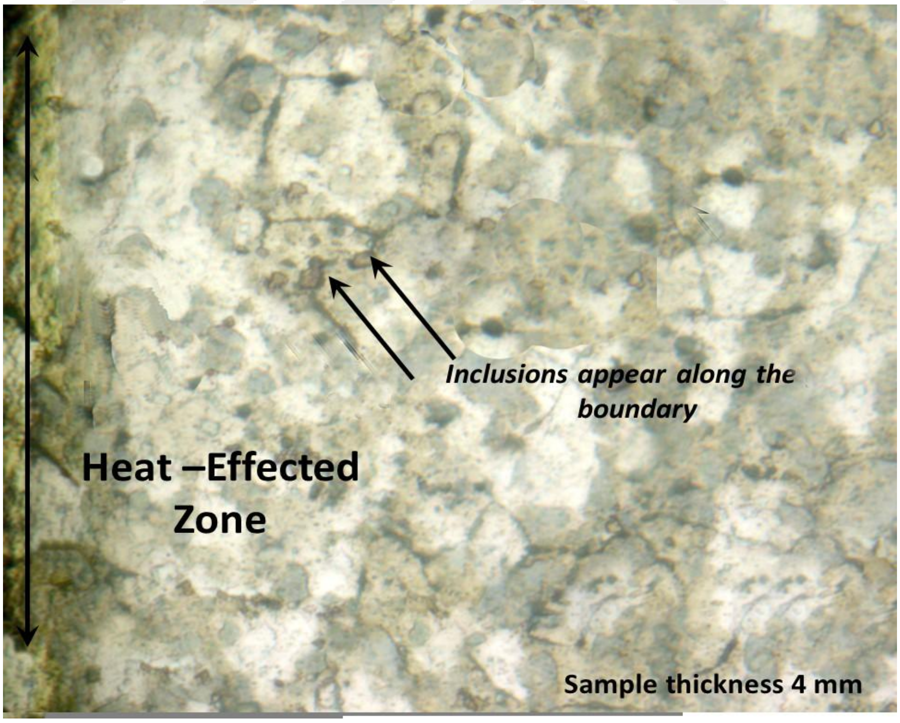


Figure 8.13. Typical microstructures near HAZ and the base metal for 4mm sample.

Figure 8.14. Typical microstructures near HAZ and the base metal for 6mm sample.

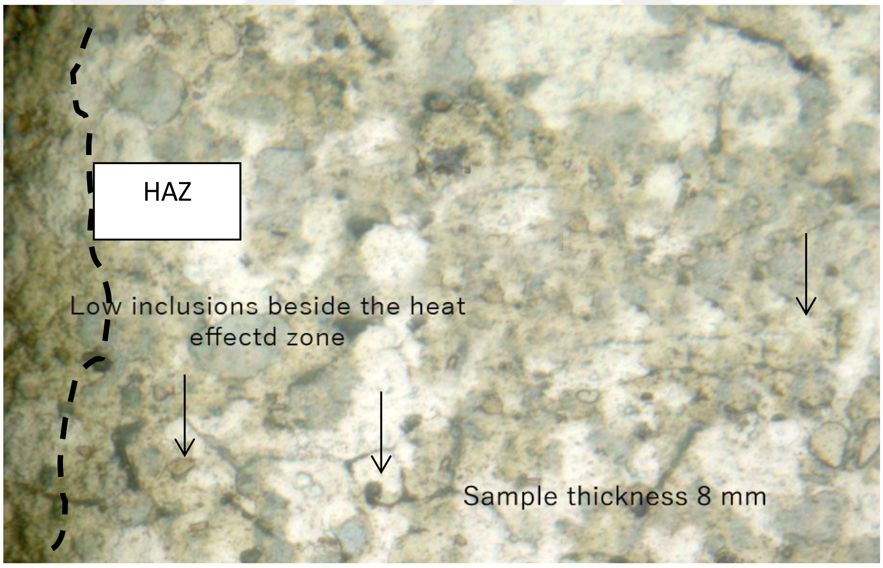


Figure 8.15. Typical microstructures near HAZ and the base metal for 8mm sample.

Moreover in Figure 81-15 the microstructure of the weld metal (HAZ) region looks like that of the base metal but with larger grain size. Compared with the others particles of HAZ region the influence of welding heat, as shown in fig. 8 (13 and 14, while 15) may due to the scanning fuzzy was not clear enough. The disadvantage is that the resulting weld metal may have a lower strength than the parent metal and not respond to a subsequent heat treatment. The weld bead must be thick enough to withstand contraction stresses.

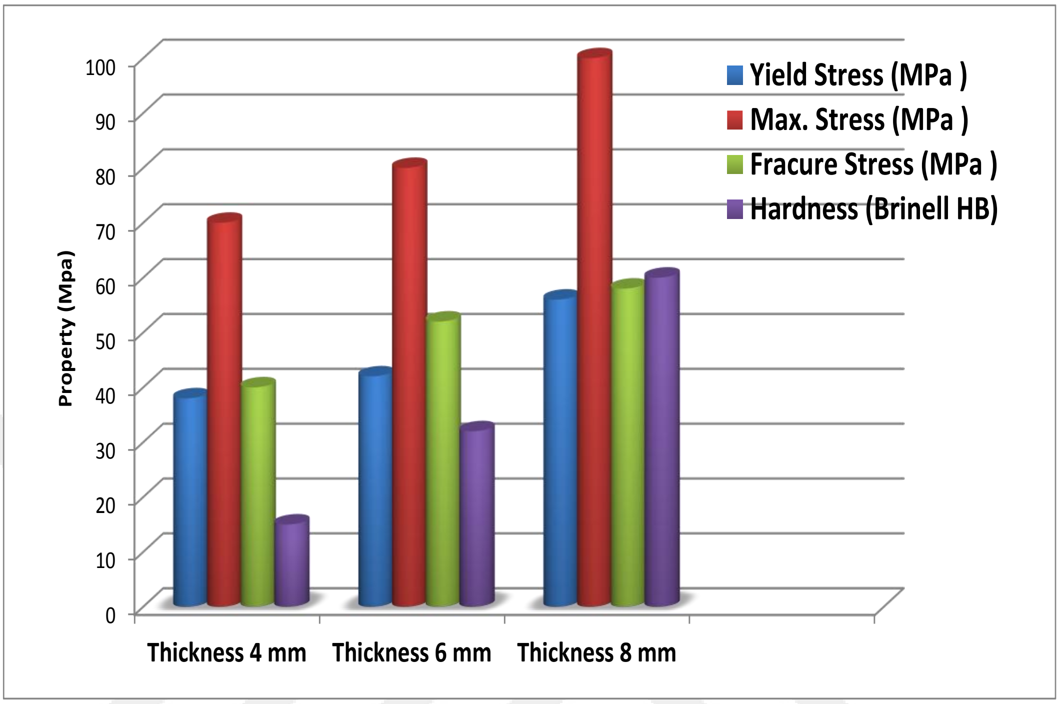
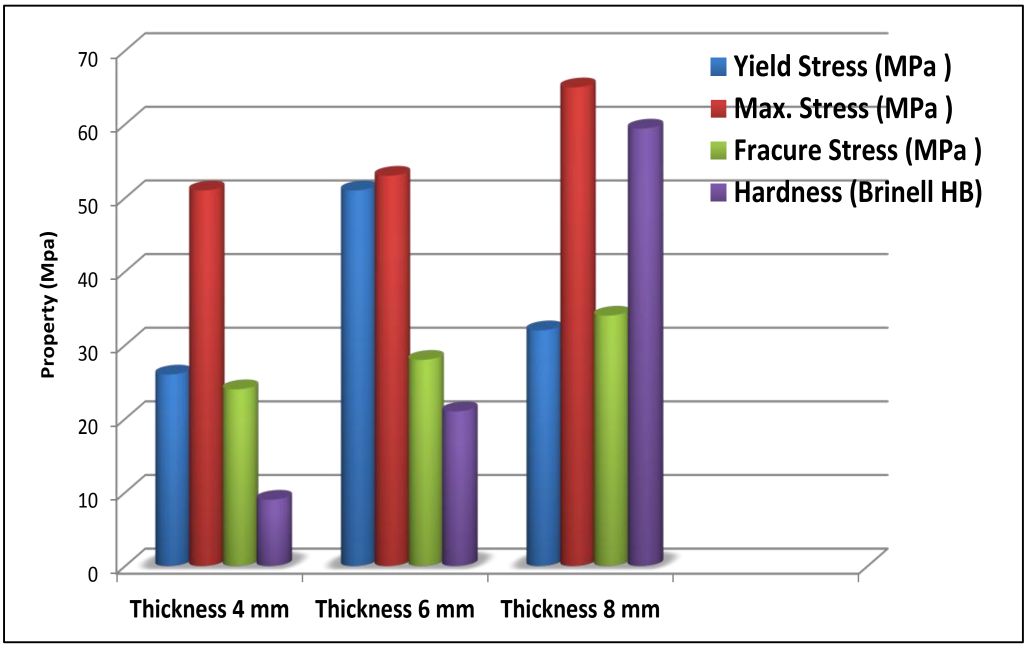
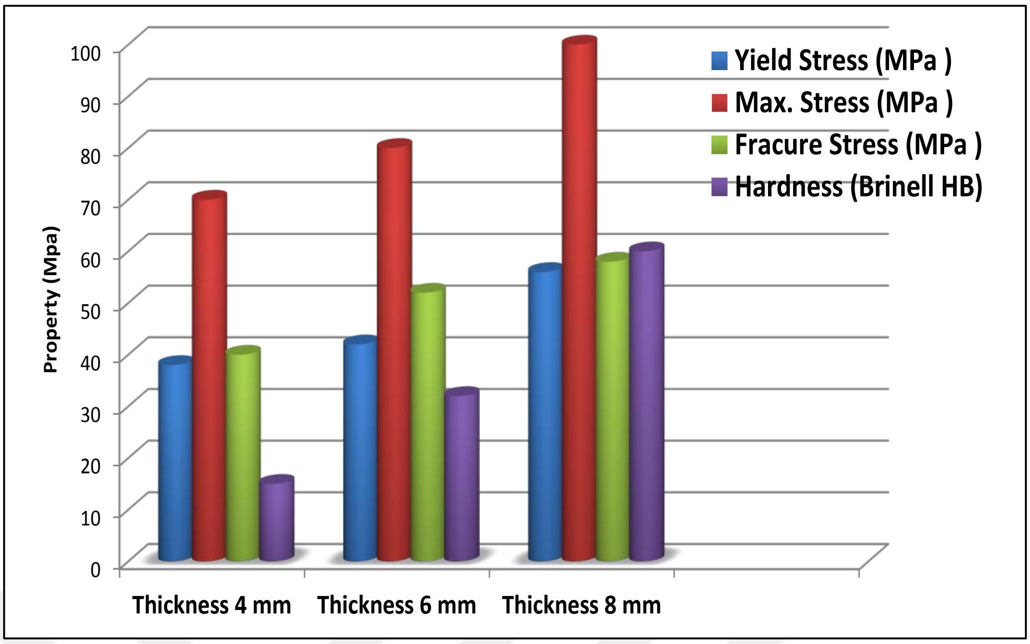


Figure 8.16. Values of tensile strength, yield strength, fracture stress and hardness with thickness of samples of MIG welding.



(a)

Figure 8.17. Comparison between (a) TIG and (b) MIG.



(b)

Figure 8.17. (continuing).

Tungsten inert gas (TIG) and metal inert gas (MIG) are the safest arc welding procedures used in joining aluminum and its alloys because of their preferred flexibility and economy. TIG welding has higher quality, stable operations, less splatter, and better bead appearance. Certainly, it has some issues including low welding speed, incomplete penetration and lack of deposit metal. On the contrary, MIG welding provides advantages in terms of highly efficient welding method and high deposition rate because of higher heat input. Excessive heat input can also cause quality issues such as deeper penetration and distortion, which are serious issues. This study has proven that the meek welding gives the mechanical properties better than the solder TIG [38].

8.5. CONCLUSIONS

In this work, scientifically valid methodology was presented to estimate the mechanical response of welded aluminum structures of different thicknesses in order to understand the effects of plate thicknesses on the mechanical properties of welded 1050 Al. The main conclusions are as follows:

1. Thickness is a crucial factor in the TIG welding. As we increase thickness, mechanical properties such as yield point and maximum stress increase.
2. Samples, which have thicknesses 4 & 6mm, show around 47% reduction in strength value as compared to the samples, which were un-welded. The sample having 8mm thickness had approximately 15% reduction.
3. Some defects appear in the structure of the 4 & 6mm thick samples and we call them inclusions.
4. The heat-affected part is cleared and not fuzzy. Moreover, no cracks appeared in any specimen.
5. The sample of thickness 2mm could not be welded because of less thickness; however, some facilities with higher structures can help welding this sample with its current thickness.
6. From the study and results, we understood that MIG welding is better than TIG welding in samples more than 4mm, while for samples with less than 3mm thickness, TIG welding is better.

The thickness of the samples has a very important effect on the mechanical properties of the alloy/s whereas the thickness improves the mechanical properties.

REFERENCES

1. Kumari, P., Archna, K., and Parmar, S., “Effect of welding parameters on weld bead geometry in mig welding of low carbon steel”, **In*ternational Journal of Applied Engineering Research,*** 6: 249-258 (2011).

2. Mashin, V., Poklyatsky, S. A. G. and Fedorchuk, V. E., “Mechanical properties of aluminuim alloys in consumable and nonconsumable electrode arc welding”, ***Paton Welding Journal C/C Of Avtomaticheskaia Svarka***, 2005: 39-45 (2005).

3. Internet: Lancaster, J. F., “Metallurgy of Welding”, **http:// books.google.com** (1999).

4. Kumar, S. and Nath, S. K., “Effect of heat input on impact toughness in transition temperature region of weld CGHAZ of a HY 85 steel”, ***Protec Journal of Materials Processing Tech.,*** 236: 216-224, (2016).

5. Narang, H. K., "Prediction of the weld pool geometry of TIG arc welding by using fuzzy logic controller", ***International Journal of Engineering, Science and Technology***, 3 (9): 77-85 (2012).

6. Kou, S., “Solidification and liquation cracking issues in welding”, JOM JOM : ***The Journal of The Minerals, Metals & Materials Society (TMS)***, 55: 37-42, (2003).

7. Aerospace, M. Aerospace, E. Hoxha, D. Rivera, F. E. and McAndrew, I., “Mechanical and aerospace engineering V ”, ***5th International Conference on Mechanical and Aerospace Engineering,*** Madrid, Spain, Pfaffikon, Switzerland (ICMAE 2014), July 18-19 (2014)

8. Welding , I. and British Institute of Non-destructive, T., “Non-destructive testing in the fitness-for-purpose assessment of welded construction”, ***An international conference,*** London**,** 20-22 November (1984)

9. Gyasi, E. A., “Quality, Productivity and Economy in Welding Manufacturing - Case Study”, ***West Africa,*** (2013).

10. Oates, W. R. and American Welding, S., “Welding Handbook", Miami, Fla. ***American Welding Society***, (1996).

11. McNatt, J. D. Superfesky, M. J. and Forest Products, L., “ How some test variables affect bending, tension, and compression values for particle panel products. Madison”, ***WI: U.S. Dept. of Agriculture, Forest Service***, Forest Products Laboratory, (1984).

12. Newby, J. R. and Committee, A. S. M. H., “Mechanical testing. Metals Park”, ***Ohio: American Society for Metals,*** (1985).

13. Films for the, Sciences, H. Films Media, G. and Meridian Education, C. “Introduction to Oxyfuel Welding”, ***School of the Art Institute of Chicago*** (2005).

14. Cary, H. B. and Helzer, S. C., “Modern welding technology", Upper Saddle River”, ***N.J. Pearson/Prentice Hall***, (2005).

15. Anders, A., “Tracking down the origin of arc plasma science-II. early continuous discharges”, ***IEEE Trans. Plasma Sci. IEEE Transactions on Plasma Science***, 31: 1060-1069 (2003).

16. Internet: Gowelding, “The History of Welding”, **http://www.gowelding.org/articles/history-of-welding/** (2011).

17. Oates, W. R. and American Welding, S., “Welding handbook", Miami, Fla ***American Welding Society***, (1996).

18. Internet: Rodoven, “Rod.oven”, **http://www.rodovens.com/welding_aearticles/history** (2015).

19. Internet: Lincoln Electric, "SuperGlaze", **http://www.lincolnelectric.com/en-us/consumables/aluminum-mig-tig/Pages/superglaze.aspx** (2014).

20. Unitor., “Handbook on welding and related thermal processes for repair and maintenance onboard", ***Kolbotn*** (2017).

21. Wegrzyn, T., “Proposal of welding methods in terms of the amount of oxygen”, ***Arch. Mater. Sci. Eng. Archives of Materials Science and Engineering***, 47: 57-61 (2011).

22. Kumari, P. Archna, K. and Parmar, R. S., “Effect of welding parameters on weld bead geometry in mig welding of low carbon steel”, **I*nternational Journal of Applied Engineering Research***, 6: 249-258 (2011).

23. Internet: Hijazi, A., "Introduction to Welding Technology", **http://www.eis.hu.edu.jo/ACUploads/10526/Intro%20to%20Welding%20Technology.pdf** (2003).

24. Davies, A. C., “The science and practice of welding”, ***Cambridge Univ. Press,*** UK (1993).

25. Skills Education, A., “Mig welding”, ed. Melbourne, ***Skills Education Australia*** (1989).

26. Weman, K. and Lindén, G. M. “MIG welding guide”, ***Institute of Materials, and Mining*** (2006).

27. Day, M. and Safetycare, A., “MIG welding”, ***Safetycare,*** Australia (1992).

28. Griffin, I. H., Roden, E. M. and Briggs, C. W., “Basic TIG & MIG welding (GTAW & GMAW) ”, ***Delmar Publishers***, NY (1984).

29. Company, T. L. E., “Gas Metal Arc Welding Product and Procedure Selection”, ***Lincoln Electronic*** (2014).

30. Svanberg, N. and Gertsovich, I., “Analysis of MIG Welding with Aim on Quality”, M. Sc. Thesis, ***Blekinge Institute of Technology*** (2008).

31. Weldability Sif Peters House., “An Introduction To Mig Welding”, ***Weldability Sif Peters House*** (2015).

32. Lincoln Electric Co, “MIG/MAG welding guide for gas metal arc welding”, (GMAW), ***Lincoln Electric Co*** (1995).

33. International, A. S. M. and Handbook, C. “ASM handbook", ***ASM*** (1993).

34. Miller Welds, “Guidelines For Gas Tungsten Arc Welding (GTAW)”, ***Miller Welds,*** 05 (2016).

35. Raveendra, A. and Kumar, B.V.R., “Effect of pulsed current on welding characteristics of En19 alloy steel using gas tungsten arc welding”, ***International Journal of Innovative Research in Science, Engineering and Technology,*** 2 (5): 1359-1367 (2013).

36. Cheng, N. P. Li, C. M. Hui, Q. and Chen, Z. Q. “Effect of particle surface treatment on the microstructure and property of SiCp/AA6066 composite produced by powder metallurgy”, ***Materials Science and Engineering: A,*** 517: 249-256 (2009).

37. Zhang, Y. Huang, J. Cheng, Z. Ye, Z. Chi, H. Peng, L., “Study on MIG-TIG double-sided arc welding-brazing of aluminum and stainless steel”, ***Materials Letters,*** 172: 146-148 (2016).

38. Kannan, S., Senthil Kumaran, S. and Kumaraswamidhas, L. A. “An investigation on compression strength analysis of commercial aluminium tube to aluminium 2025 tube plate by using TIG welding process”, ***Journal of Alloys and Compounds,*** 666: 131-143 (2016).

RESUME

Abdul Hashim Mohamed M. was born in Benghazi (Libya) in 1974 and graduated first and primary education in this city. He completed his high school education in Benghazi, High School, then began his bachelor's programs; Mechanical Engineering Department of Mechanical Welding Department 1996. From 2014 until 2017 he graduated as a Master of Science in Carabook Management of the University of Mechanical Engineering

CONTACT INFORMATION

Address: Karabük University
Graduate School of Natural & Applied Science
Demir-Çelik Campus/KARABUK

E-mail: hhhabdaly74@yahoo.com