



**OPTIMIZING AND INVESTIGATION IN TIG
WELDING PARAMETRIC INFLUENCE ON
TENSILE STRENGTH OF DISSIMILAR METALS
SS-304 AND LOW CARBON STEEL**

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M. Sc. Thesis
Mechanical Engineering**

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AND LOW CARBON STEEL**

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M. Sc. Thesis

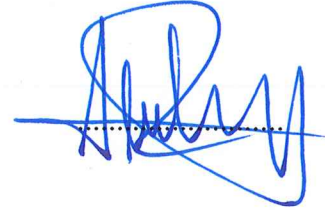
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June 2020

I certify that in my opinion the thesis submitted by ABDULADIM ABDULMAGID BOGHDADI titled “OPTIMIZING AND INVESTIGATION IN TIG WELDING PARAMETRIC INFLUENCE ON TENSILE STRENGTH OF DISSIMILAR METALS SS-304 AND LOW CARBON STEEL” is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

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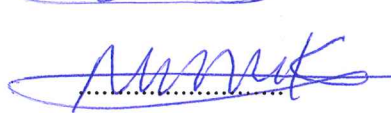
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Abduladim Abdulmagid BOGHDADI

ABSTRACT

M. Sc. Thesis

OPTIMIZING AND INVESTIGATION IN TIG WELDING PARAMETRIC INFLUENCE ON TENSILE STRENGTH OF DISSIMILAR METALS SS-314 AND LOW CARBON STEEL

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This study aims to optimizing and investigation in TIG welding parametric influence on tensile strength of dissimilar metals SS-304 and low carbon steel. The literature survey and experimental work has been done. The welding process has been designed using Minitab software. The best tensile test results recorded by sample No. 3, which welded by (8 lt/min gas flow rate and 120 A current). The best hardness results recorded by sample No. 9 by 116 in weld metal and HAZ with (12 Gas flow rate and 120 welding current ampere).

The mean, Signal to Noise Ratios (S/N), and ANOVA Test have been utilizing to find out the highly effective welding parameter (current and gas flow rate).

Key Word : Tungsten Inert Gas Welding (TIG), S/N, ANOVA, Gas flow rate, welding current, Dissimilar Metals.

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ÖZET

Yüksek Lisans Tezi

DÜŞÜK KARBONLU ÇELİK VE SS-314 BENZEMEZ METALLERİN TİG KAYNAĞI PARAMETRELERİNİN ÇEKME DAYANIMINA ETKİSİNİN ARAŞTIRILMASI VE OPTİMİZASYONU

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Bu çalışma, düşük karbonlu çelik ve SS-314 benzemez metallerin TİG kaynağı parametrelerinin çekme dayanımına etkisinin araştırılması ve optimizasyonunu amaçlamaktadır. Çalışmada literatür taramasının ardından deneysel çalışmalar gerçekleştirilmiştir. Deneysel çalışmalarda kullanılacak kaynak işlem parametreleri Minitab yazılımı kullanılarak tasarlanmıştır. En iyi çekme test sonucu 8 lt/dk. gaz akış oranı ve 120 A akım ile elde edilmiştir. En iyi sertlik sonucu ise kaynak metalinde ve İTAB'da 12 lt/dk. gaz akış oranı ve 120 A akımı kullanılarak 9. deneyde 116 A sertlik değeri elde edilmiştir.

Etkili TİG kaynağı parametrelerinin tespiti için (akım ve gaz akış oranı) Sinyal Gürültü Oranları ve ANOVA testi kullanılmıştır.

Anahtar Sözcükler : Tungsten İnerit Gaz Kaynak (TİG Kaynağı), S/N, ANOVA,
Gaz Akış Oranı, Kaynak Akımı, Benzemez Metaller.

Bilim Kodu : 91428

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SYMBOLS AND ABBREVIATIONS INDEX

- HAZ : Heat Affected Zone
TIG : Tungsten Inert Gas
S/N : Signal to Noise Ratios

PART 1

INTRODUCTION

1.1 BACKGROUND

Nowadays, welding, casting, forming, machining are the most common methods that used in industry, which most of the materials are fabricated into the desired shape. Where, the shape and size of the component, cost, material, precision required and its availability are the most important factors affecting selection of a particular techniques. In some cases, it can be used one specific process to achieve the desired object. For making the end product, It is often possible to choose between the available operations. In making the final choice, different available options economy plays the decisive role [1, 2].

welding is primarily utilized for joining metal parts in manufacturing processes. Specially, when there are needs to joined pieces together or when larger lengths of standard sections are required in fabricate a desired structure. Generally, the welding is the technique of joining metals and plastics without uses adhesives or fasteners. In fact, welding is Applying the heat and pressure on the surface of join different materials like plastics, metals, and its alloys with control the permanent joining process. The joint can be achieved using welding, the working parts that are joined during welding are incorporated into the interface and then the hardening is performed. During welding, the filling material can be used to form a welding group of magma. After solidification, a strong bond between the substances., the metallurgical changes that occur are highly affected the weldability of a material. As well as, its affected on the hardness in weld zone by rapid solidification, that may happen by oxidation, it is during the interaction of substances with oxygen in the atmosphere and the tendency to form cracks in a common position [3-6].

Quality is of most importance factor in manufacturing World today. Some references define quality as the degree of customer satisfaction when providing a purchased

product. In different application areas, product quality depends on the requirements obtained in the product that meet your functional requirements. The mechanical properties of welded metals and the heat affected region (HAZ) are highly influenced by the welding quality, in the welding field. In addition to welding chemical compositions and mineral properties. On the other hand, the quality of the weld depends on the parameters of the welding process, as these mechanical properties of the weld also depend on the welding bead's geometry [7, 8].

In today's world, inert tungsten gas welding (TIG) is a very important welding process, as is TIG welding, a metal fabrication technology that has multiple goals and multiple factors in the industrial sector. The mechanical properties, weld bead geometry, the weld chemistry, and metallurgical features of produced weld can be controlled by interact by many process parameters in a complex manner, which may lead to direct or indirect effects [9]. The quality of inert tungsten gas is strong in engineering the welding bead. Figure 1.1 shows the basic geometry of the welding bead.

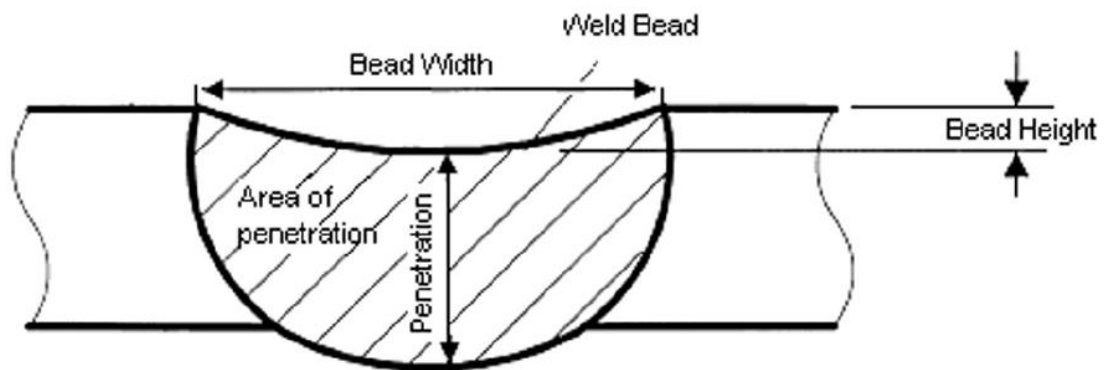


Figure 1.1. The weld bead metal of TIG welding process [9].

To weld the thin metals and its alloys, the Tungsten Inert Gas (TIG) welding classifying as a high quality welding process [10, 11]. Tungsten Inert Gas (TIG) welding is a such welding process that utilizing an electric arc to generated the heat between a non-consumable tungsten electrode and the metal, which needs to producing a high quality welding of a variety of materials [12]. In TIG welding process the argon and helium are used as shielding gases, because they does not chemically react, where to form a weld results in the formation of fumes and gases during the process of melting the work piece and filler rod [13].

In general, the bead geometry variables are greatly influenced by welding process parameters, it also plays an important role in determining the mechanical properties of a welder, such as a tensile load. The bead geometry variables can be list as following [9]:

- Bead width
- Heat affected zone,
- Bead height,
- Area of penetration
- Penetration

While the welding process parameters are following:

- Welding current,
- Welding speed
- Gap distance
- Shielding gas flow rate

In fact, to producing desired weld quality, It is needed to finding out the optimum practical condition. Such an optimize process should fulfill simultaneously all objectives that needs. This an optimization process ntechnique is called multi-response optimization.

This research aims to optimizing and investigation in TIG welding parametric influence on tensile strength of dissimilar metals SS-304 and low carbon steel. Through theoritical and exprimental research. This research includes the litrature review and survey about Tungsten inert gas (TIG) and its parametrizes to find out the best welding parameterizes. All welding operations are mainly used in order to obtain the welding bead and weld with required parameter, and it has excellent mechanical properties with quality surface. In order to find the parameters, leading to the required mechanical properties, the application of design techniques to experiment.

1.2 OBJECTIVES:

The research aims to study dissimilar metal joint using a filler metal process. In general, dissimilar welding is utilized to fabricate the thermal power plants, pressure vessels and piping in nuclear reactors, and heat exchangers, therefore the failures occurs frequently due to low tensile strength. During the welding process, the welding parameters are the most affected of tensile strength of weld specimen. This research has some sub-objectives such as:

- Find out and evaluate the TIG Welding Process Parameters for Dissimilar metals weld of SS-304 and low carbon steel.
- Spotting light on the impact of Process Parameter such as Gas flow rate and Welding Current.
- Spotting light of the important of Tensile strength and Hardness of weld.
- Trying to find out Optimum Gas flow rate parameters
- Trying to find out Optimum Welding Current parameters.

1.3 RESEARCH IMPORTANCE

In fact, the research taken its importance from title itself, which focusing on the optimizing and investigation TIG welding parametric influence on tensile strength of dissimilar metals ss-304 and low carbon steel. In addition, there are some sub-importance for this study, which can be listed as following:

- This study adding a new reference for the researchers those study welding process.
- This study classifying as experimental work in field of welding.
- This work can be applying on other metals.
- This work can be used for other welding processes.
- This work can be extended to study the effect of parameter on other responses such as heat affected zone (HAZ) and mechanical properties.

1.4 EXPECTED CONTRIBUTION

Generally, the optimization process to TIG welding parameters to get best welding joint is the main contribution. While, study the effect of TIG welding parameters on

tensile strength, in additional contribution is using dissimilar metals in this study, which are ss-304 and low carbon steel, where in most of previous studies they work with one metal or alloy. Moreover, this study has some sub-contributions such as following:

- This study could be applied on other metals.
- This study could be applied on other welding processes.
- This study could be used as references on study the effect of welding parameters on the heat affected zone, hardness and distortion.

1.5 METHODOLOGY

This study aims to optimizing and investigation in TIG welding parametric influence on tensile strength of dissimilar metals SS-304 and low carbon steel. This process will be done utilizing theoretical and experimental work. The theoretical study focuses on the Tungsten Inert Gas (TIG) welding process with dissimilar metals that done includes a literature review and survey. Which study the effect of the tungsten inert gas (TIG) welding parameters. Where, this research focuses on current and welding speed parameters. In addition, study the effect of this parameters on the tensile strength property. The experimental work divided to welding process with different welding parameters, then study the effect of this change in the produced welded. Figure 1.2 shows the research methodology with details.

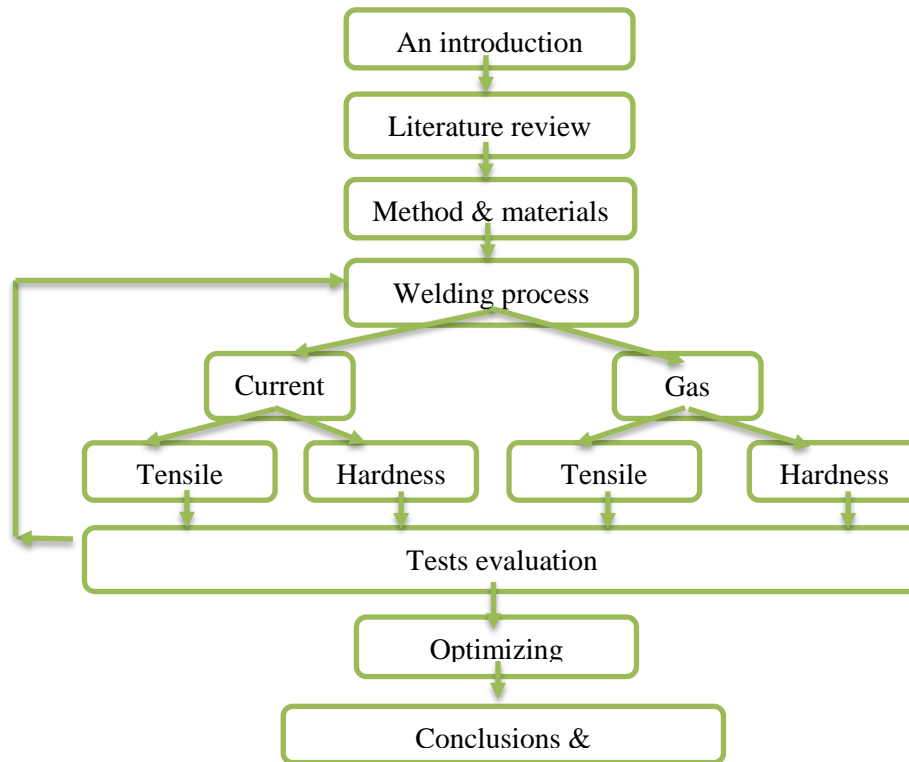


Figure 1.2. The research methodology.

1.6 SCOPE OF WORK

This study is an experimental study aims to optimizing and investigation in TIG welding parametric influence on tensile strength of dissimilar metals SS-304 and low carbon steel. The study divided to two parts, which are theoretical part represented by first and second chapters. In addition, the experimental part, which represented by third and fourth chapters, and finally fifth chapters which includes the study conclusions and recommendations. The details of all parts are following:

Part One is an introduction, which includes the research overview, research aims, importance, expected contributions, research methodology, and research scope.

Part Two is literature review, which includes welding classification, methods. TIG welding process discretion, and equipment.

Part Three is research methodology, which includes experimental started with material selection as SS 304 chemicals composition and mechanical properties. then

low carbon steel chemical composition and mechanical properties. followed by equipment and tools of welding and testing equipment.

Part Four is results and discussions, which includes overview, then welding process and testing.

Part Five is conclusions and recommendations, which includes the research finding and future recommendations.

Finally, the research references and Appendices.

PART 2

LITERATURE REVIEW

2.1 WELDING

The welding is a technical process that aims to connect two pieces in an unbreakable manner by creating a link between the two surface to be connected. This is done either with or without fusion of the edges of the two pieces, by causing spastic reactions without heating, or with heating of the two pieces and by causing spastic reactions in the two adjacent surfaces to be combined [14].

2.1.1 Classification of Welding Types

There are different characteristics of the classification of welding types, but the most common are: the type of power used in welding, and the condition of the metal in its area during the course of the work. Welding types are classified according to the type of energy used in the following groups [15, 16]:

1. Mechanical welding methods:

It uses mechanical energy that causes spastic reactions in the welding zone, which are sufficient to obtain the welded link. The mechanical welding methods are:

- Cold welding
- Explosion welding
- Frictional welding

2. Chemical Welding Methods

In which the chemical energy is converted to heat in which the metal reaches fusion without any external pressure. One of these methods are:

- Fusion welding

3. Electrical Welding methods

In which the electrical energy turns to heat to melt the edges of the pieces to be soldered. The electrical welding methods include the following [17, 18]:

- Manual or semiautomatic welding
- Electrostatic welding by spreading high heat when passing Electric current [19].
- Electronic welding
- Welding with high frequency electric current
- Laser welding

4. Electromechanical welding methods

In which the electric energy is converted to heat that using to heat the metal below the fusion state, followed by the shedding of external pressure forces to cause sparks in the surfaces of the two pieces to connect them, the electromechanical welding methods including the following:

- The method of electrically soldering (resistance welding)

5. Chemical-mechanical welding methods

In which the chemical energy is converted to heat that utilizing to heat the edges of the two pieces to be reached to the desired degree of welding without melting point also followed by the effect of spandex in the heated metal by putting external pressure forces on the two pieces to be connected, the chemical-mechanical welding methods includes [20]:

- Gas welding and compression

On other hand, if the classification is according to the condition of the metal in the weld area during the welding process, all welding types are classified into two large groups:

1. The pressure welding group
2. The fusion welding group.

Figure 2.1 shows the most common classification of welding according to (Welding processes handbook) [14].

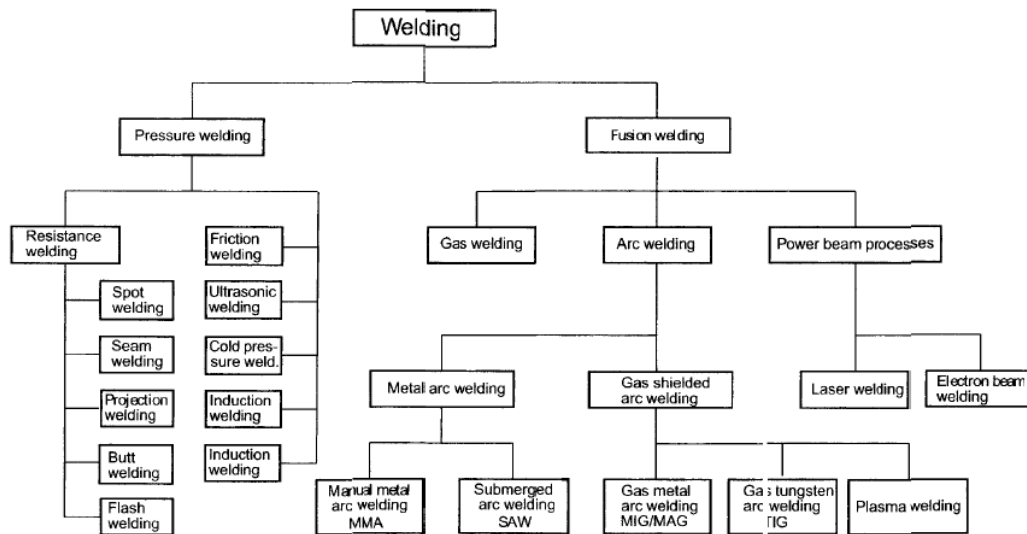


Figure 2.1. The most common welding methods [14].

1. Pressure Welding Methods

The welding process takes place at a temperature below the melting point of the metal to be welded. By external pressure, the two pieces can be welded in solid state, provided that these pressures are sufficient to cause spindle reactions in the surfaces of the two parts to be connected [21, 22].

- Friction welding
- Cold Welding,
- Gas welding and pressing,
- Welding electrodes,
- Welding spread,
- Explosion welding,
- Ultrasonic welding

2. Fusion welding method

Welding is applied by smelting the edges of the pieces to be soldered, and the welding is done without external pressure. This group includes [23-25]:

- Gas smelting welding,
- Thermite welding,
- Welding in the middle of protective gases,
- ARC welding,
- Plasma welding,
- Electron beam welding,
- Laser welding,
- Atomic hydrogen welding,
- Underwater welding.

2.1.2. Some Welding Methods

2.1.2.2 Frictional Welding

Friction welding is a method of pressure welding, the edges of the two pieces to be connected to the heat that heated by the surface friction of these two pieces, when one rotates in contact with the other, which is fixed with an increased axial pressure force, as well as a certain speed of rotation and pressure is reached, the welding process is done. Friction welding is widely used in welding pre-combustion chambers in diesel engines, rotary assemblies, coupling rods, cylinders, axial couplings, motor vehicle front axles, injection shafts, etc.

In general, friction welding is limited to circular or close sections such as hexagonal and hexagonal shapes. This cannot be sold with circular sections with more than one central axis. The pieces to be welded by the welder must withstand the wicking of the wicks and the high axial forces and resist shocks. Generally, pressing both parts together drives the part of the workpiece at a controlled speed. If the required amount of heat is generated after a preset time, the drive is disengaged and the rotation stops, which the main mechanism of friction welding as shown in Figure 2.2.

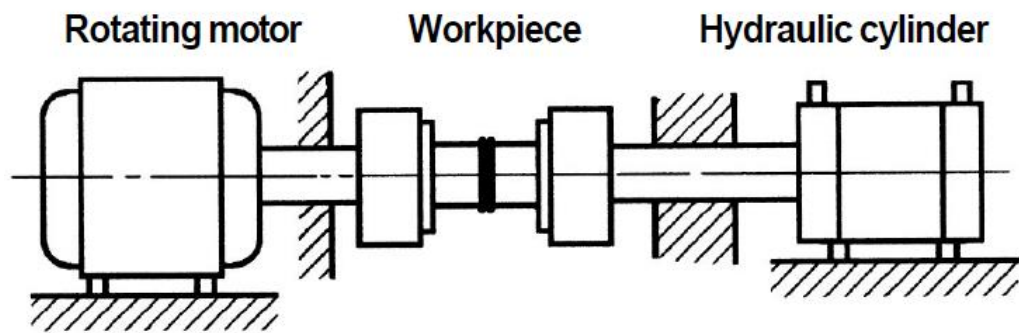


Figure 2.2. The motor driving of friction welding [14].

2.1.2.3 Cold Welding

This method is one of the methods of pressure welding, and in this way to obtain welding links by causing a large spastic reaction in the surfaces of the two pieces to be connected without any external heating of these pieces. The two plates are to be welded together and held with two handles to prevent swelling when the plates are pressed to squeeze. They are compressed by a hardened metal capsule from the metal for meat is placed.

The metal is exposed to high pressure. The metal flows in the pressure zone between the surfaces of the two plates and cracks under the influence of the metal flow. Between the points of the two surfaces, the solid bonding. The amount of elastic reactions to be generated at the two interface surfaces is related to the properties of the welded metal, the nature of the oxide crusts and the manner in which these reactions occur.

2.1.2.4 Gas and Pressing Welding

The welding principle is similar to the pressing welding, but the heating of the parts to be sold in this way is done by the flame resulting from gas combustion, the flame can be controlled and focused precisely on the points to be heated before pressing it. The heating is either done gradually by pressing the hot spot, or heating the section to be fully welded with pressure at the same time. In the second case, the section is heated only sideways or heated edges; if the heating from the side can apply pressure on the pieces during the heating of flame, but if the edges are heated only, the flame must be removed before putting pressure on the pieces. Since the flame is removed at

a short interval until the moment of pressure, the surface of the edges is oxidized by the oxygen in air. The heating of these edges must be carried out until the melting state, in order to oxidize the surface oxidized outside the welding area when the pressure is applied, the surface is completely free of oxides.

2.1.2.5 Resistance Welding

Resistance butt welding can be done with applying a pressure, as shown in Figure 2.3. The welding process is heated by the soldering material in an electrical resistance method. Very high temperature is generated when an electrical current passes through the contact surfaces between the two pieces. In the first stage, the mechanical pressure of the two pieces is raised to achieve contact between the two surfaces. In the second stage, the current is connected while the pressure remains constant. In the third phase, the current is cut off and the pressure is increased, gradually reduced and the connection is cooled. There are many methods of resistance soldering such as spot welding and others, where each of which has its own technique, features and multiple use areas [26, 27].

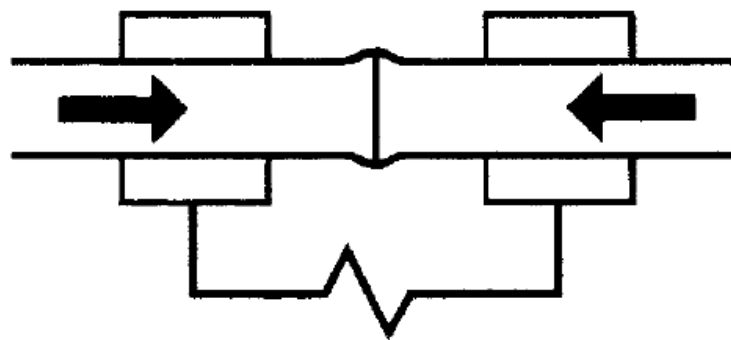


Figure 2.3. Resistance butt welding [14].

2.1.2.6 Explosion Welding

It is modern methods of special pressure welding. It is usually attributed to the group of mechanical methods of metal welding. The chemical energy produced by the transformation of the energy of the explosive material is converted into mechanical energy that drives one of the two parts to be sold at very high speed to the other, as seen in Figure 2.4. This kinetic energy, which causes the collision of the moving object with the surface of the fixed piece, results in joint splicing reactions of the

tiling metal layers, leading to the formation of the welding link, and the elasticity of the effect changes to the heat of the heating of the metal to high temperatures. This causes the fluid to flow into the metal under pressure and the appearance of a speeding vehicle. The metal of the surface layers of both parts collides to distort the specified direction at high speed. The two surfaces are bounded to one another to the maximum extent [20, 28].

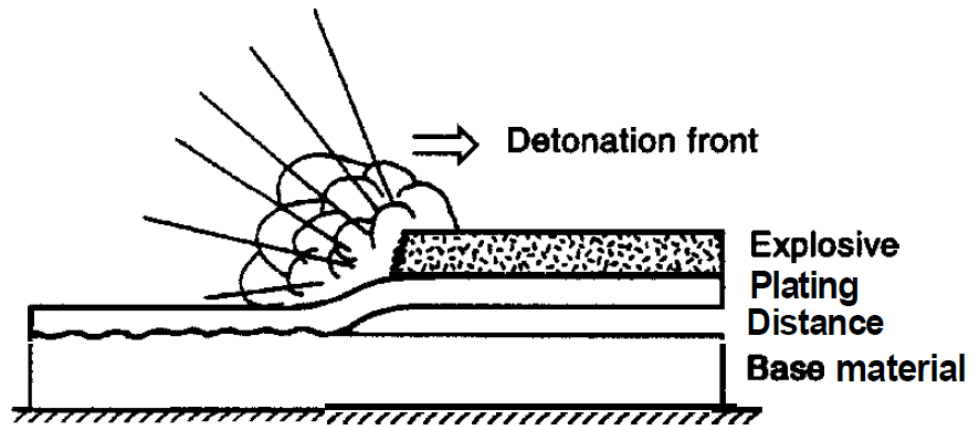


Figure 2.4. Applying plating to a billet by explosion welding [14].

The other surface oxides and dirt are crushed and collected in a certain area of the two surfaces. The future prospects and areas of the use of explosion welding can be used to form solid bonding links in their solid state, as well as the speed of the welding process and on very large surfaces. For example, weld joints with a surface area of 1-20 square meters can be made.

2.1.2.7 Ultrasonic Welding

Ultrasonic waves are used in welding for different purposes. The effect of these waves in the molten weld basin during crystallization can improve the mechanical properties of the weld link by reducing the size of the metal beads and releasing the gases better. Ultrasound can be a source of energy, with the aim of making point or point welding connections. These waves can break down natural and artificial crusts, allowing them to be used in welding metals whose surfaces are coated with oxides, paint layers or others. This method is widely used in the electronic industry, and it has developed rapidly in the plastic industry. High-quality plastic connections can be obtained. The welding of plastic materials with other welding methods is difficult or sometimes impossible. The connection resulting from ultrasonic welding is the result

of a combined effect of mechanical vibrations with high frequencies and relatively small pressure forces. The process of welding ultrasonic usually under the influence of three factors: high frequency vibrations, pressure, thermal effect that accompanies the welding process [20, 23, 29].

2.1.2.8 Thermite Welding

This method is used mainly to weld some parts of machines or installations directly at the work site. The heat diffusing reaction, the result of the reaction of iron oxide with aluminum (aluminum thermite), is the source of welding heat, because the iron oxide mixture is a highly combustible mixture. It has been observed that this reaction occurs at a very rapid rate; large amounts of up to one or more tons of magma can be obtained in one reaction in as little as 30 seconds. Figure 2.5 shows the mold set for thermite welding. The thermite welding process is widely used in railways industry [30, 31].

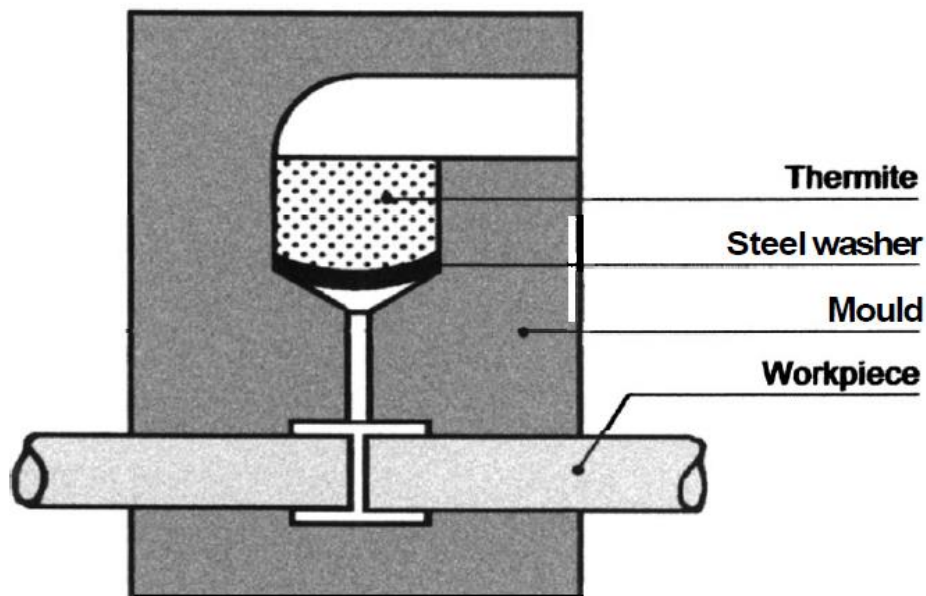


Figure 2.5. Mold set for thermite welding [14].

2.1.2.9 Gas-Smelting Welding (Gas Welding)

In this method, heat is generated by burning suitable gas with air or pure oxygen, and the flame temperature resulting from this combustion reaches several thousand. Gas is usually mixed with air or oxygen in a special torch, and the mixing ratios of these

gases are regulated to produce flame. Various gases, including acetylene, domestic gas, methane, propane, hydrogen and gasoline vapor, are used.

Gas welding is especially suitable for connecting metal sheets with thicknesses between 2 and 50 mm. Its uses today are limited to welding panels with thicknesses ranging from 1 to 10 mm, and may be used in cases where the locations of the joints to be welded are not easily accessible.

2.1.2.10 ARC Welding

The electric arc welding method is superior to all other methods, up to 90% of the total use of different smelting methods. In this way, the electric energy is converted into thermal energy used in the local fusion of the two ends of the joint. Figure 2.6 shows the schematic diagram of manual ARC welding process.

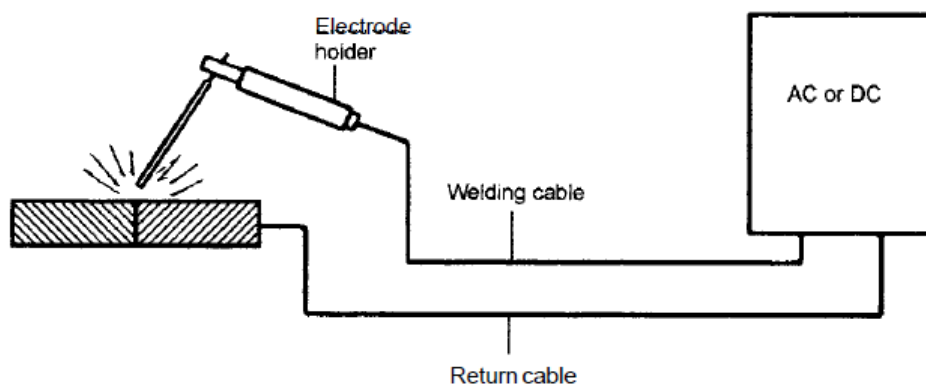


Figure 2.6. Manual metal arc welding [14].

2.1.2.11 Electron Beam Welding

The main advantage of the process of electronic radiography is the use of the energy of electrons that move very fast in the middle of the vacuum, as shown in Figure 2.7. When these electrons hit the metal surface, most of their kinetic energy is converted to heat used to melt the metal. If electronic radiation is used as a heat source for welding, it is essential to obtain free electrons, then assemble them in a pack and give very high speeds to increase their kinetic energy. This energy is then transformed into heat when the electron enters the metal to be sold.

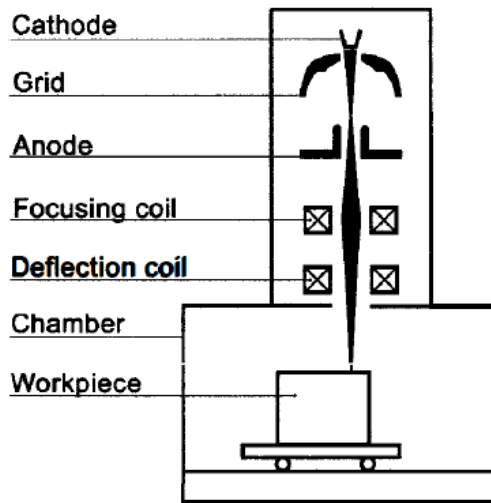


Figure 2.7. The electron gun [14].

2.1.2.12 Laser Welding

Quantum generators appeared in the second half of the 20th century. It can obtain high-intensity photovoltaic beams and focus their energies on areas no more than a thousandth of a millimeter. On this basis, in the present era, laser irradiation devices are used for welding, cutting and various heat treatments, as shown in Figure 2.8. Quantum generators convert electrical, chemical, photovoltaic, and thermal energy into ordinary photovoltaic radiation waves [31].

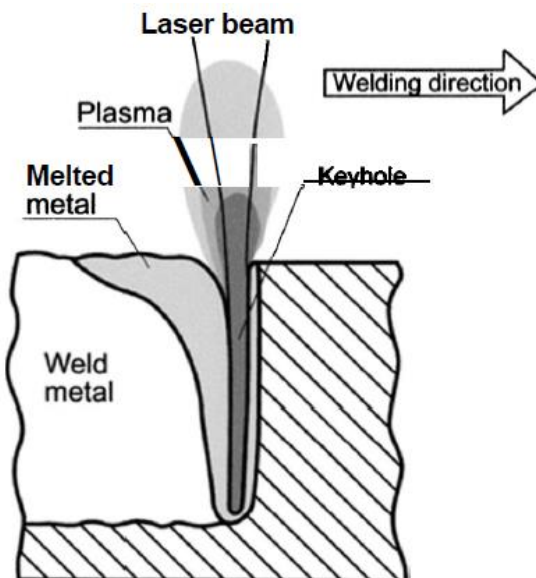


Figure 2.8. Penetration of a laser beam welding [14].

2.1.2.13 Atomic Hydrogen Welding

The metal is smelted in this way by the heat released as a result of the transformation of the atomic hydrogen into a molecular, and the burning heat of the arc between the two electrodes of tungsten. The amount of heat generated by arc radiation and the combustion of hydrogen particles in the outside area of the torch is very small when compared to the amount of heat released by hydrogen atoms hitting the metal and turning it into molecular hydrogen.

2.1.2.14 Underwater Welding

This method of modern and special welding methods, designed from the ability of the electric arc to ignite balanced in the bubble gas and because of the intensive cooling of the water surrounding this arch. The gas bubble is formed by evaporation of the water and dissolved into hydrogen and oxygen, as well as the gases formed by the fusion of the electrode metal and the coating layer [20, 32].

2.2 TIG WELDING

2.2.1 Process Discretion

Gas tungsten arc welding (GTAW) is another name for TIG welding, which means ARC collisions between the non-consumable tungsten electrode and the workpiece. The inert gas is protected from the welding electrode and electrodes. Usually, argon is provided by a gas cup at the end of the welding gun where the central electrodes are located. Figure 2.9 shows the schematic diagram of Gas tungsten ARC welding equipment.

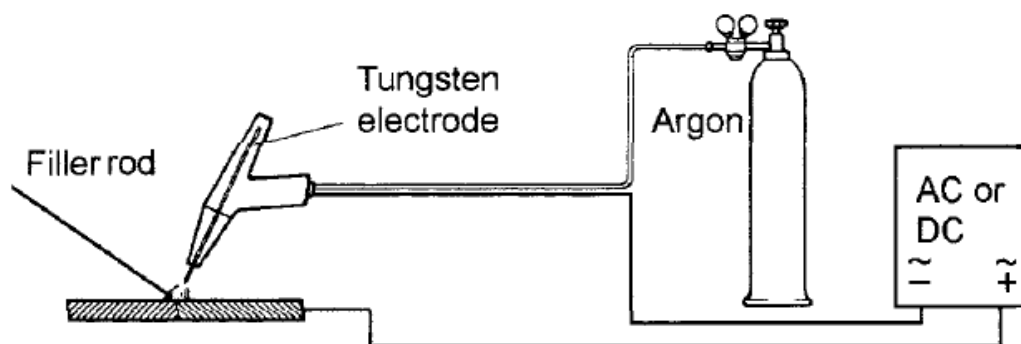


Figure 2.9. Gas tungsten ARC welding equipment [14].

In general, TIG welding can also be used for welding with manually applied fillers, similar to gas welding. TIG welding mechanical tools are used in applications such as connecting tubes and welding tubes to final plates of heat exchangers, and these automatic welding tools can incorporate many advanced features, including the mechanical supply of filler wires. This method has the following characteristics:

- Stable ARC
- Excellent control of weld results.

The main uses of TIG welding are light metal welding such as aluminum and magnesium alloy, copper welding and stainless steel welding. It is also suitable for welding all kinds of connections and all welding positions, except for lead and zinc. Additionally, TIG welding is more suitable for thin materials from about 0.5 mm to about 3 mm. Whereas, TIG welding cannot compete with methods such as short arc welding, in terms of productivity [14, 33].

2.2.2 Equipment

The main required equipment for TIG welding are as following:

- Power
- High frequency, which a generator for ARC ignition
- Welding gun
- Control equipment
- Shielding gas

2.2.2.1 Power

usually, the TIG welding is done utilizing DC, and the cathode is connected to the electrode, so most of the heat is generated in the work piece. In aluminum welding, the oxide layer breaks only when the electrode is connected to the anode, which eventually results in an excessive temperature of the electrode. The aluminum and magnesium are typically welded to AC as a compromise.

Generally, the TIG power supply is electronically controlled system, which inverter or thyristor-controlled rectifier. For constant current characteristics, the open-circuit

voltage should be around 80V. The HF generator is always engaged. Otherwise, when welding with AC (sinusoidal), and at the zero crossing the arc is turned off.

Square wave AC

Based on new technologies related to square waveforms, several new power source designs emerged in the 1970s. This means that zero crossing is very fast and has the following effects:

- Generally, continuous HF ignition voltage is not required for AC TIG welding.
- By allowing the ratio of anode and cathode currents to be variable, it is possible to control penetration and oxide breakdown just as when aluminum is welded.

Figure 2.10 shows the current waveform for a square wave supply. The equilibrium curve (left) has very fast zero crossing as opposed to the existing sine wave. The ability to switch the balance between the two polarities means that the welding speed can increase by 50-75%. General setting for a balanced waveform has a 50% cathode on the electrode. The two curves on the right are 130% positive polarity, which are faster penetration rate or speed, of 70% sound and 155% positive, which are negative oxide breakdown, of 45% positive sound. Figure 2.11 shows the pulse TIG requires principle that the weld pool be solidify in between pulses [14].

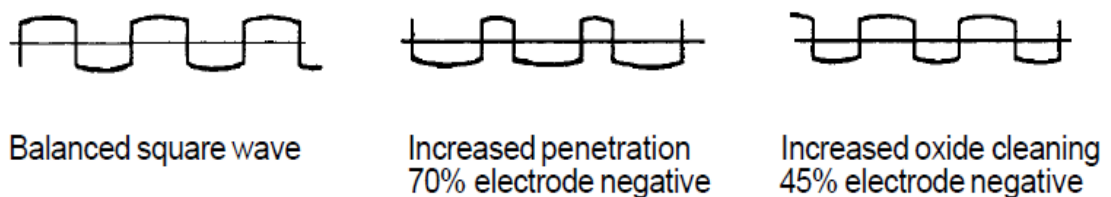


Figure 2.10. The TIG welding balance control and square wave [14].

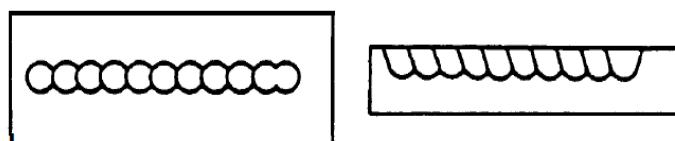


Figure 2.11. The pulse TIG requires principle that the weld pool be solidify in between pulses [14].

2.2.2.2 Welding Gun

The welding guns is the basic requirement for TIG welding, which must be easy to handle and well insulated through welding process. Requirements apply to manual welding, but for machine welding, its less important. There are two main types of welding guns:

1. Water cooling and
2. Air coolers.

Figure 2.12 shows the TIG welding gun example. In fact, the current welding guns of these two types can deliver the following welding currents:

- Water cooling: Up to approx. 400 A
- Air cooling: Up to approx. 200A.



Figure 2.12. TIG welding gun example [14].

2.2.2.3 Control Equipment

The required control equipment depends on the degree to which the welding process is mechanized. It is common that the pre-flow and post-flow of the shielding gas and the HF generator are controlled automatically. The ability to change craters and pulsate currents with the current slope is also often used. The protect electrode and weld pool from oxidation done by gas-free pre-flow and post-flow [14].

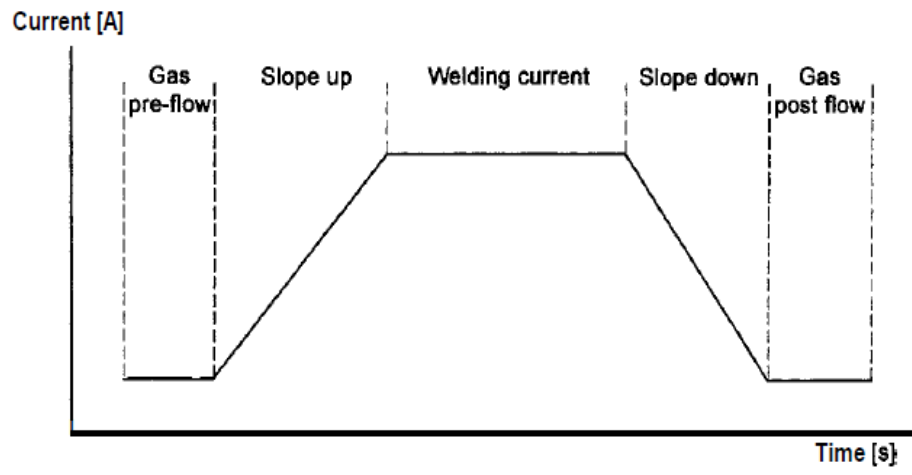


Figure 2.13. The Welding sequence example [14].

PART 3

EXPERIMENTAL

3.1 MATERIAL SELECTION

3.1.1 Stainless Steel

The house or kitchen is not without stainless steel utensils that are strong and resistant to rust and chemicals in foods and beverages, the high resistance of stainless steel made it an ideal material suitable for industrial, scientific and military uses. Stainless steel is called "stainless steel" and is a combination of several metals (metal alloy) consisting of: iron, chromium, nickel, molybdenum and carbon. The proportions of these metals vary to give several types of stainless steel, sometimes may be added metals or other materials such as magnesium, copper or nitrogen in order to give it special characteristics.

- Types of stainless steel

Stainless steel is divided by composition into four main groups that differ from each other in their corrosion resistance and mechanical properties as well as their cost and in industrial use.

1. Duplex stainless steel
2. Martensitic stainless steel
3. Austenitic stainless steel
4. Ferritic stainless steel

3.1.1.1 SS 304

Stainless steel is an ideal corrosion-resistant material. You can't distinguish between them just by looking at them, but they have different chemical properties that help us differentiate them. The chemical difference between 304L stainless steel and 316L

stainless steel. From a chemical point of view, 304 stainless steel containing 8% nickel

and 18% chrome. In addition, 316 stainless steel containing 2% molybdenum, 10% nickel and, 16% chrome. In fact, adding molybdenum is to arising resist corrosion and rust.

3.1.1.2 Chemicals Composition of SS 304

Table 3.1. The chemical composition of SS-304.

Element	Weight (%)
Carbon	0.072
Sulfur	0.011
Silicon	0.395
Molybdenum	0.276
Phosphorus	0.041
Manganese	1.421
Chromium	17.820
Copper	0.425
Nickel	7.946

3.1.1.3 Application of SS 304

Common uses for 304L stainless steel:

- 304 stainless steel is the most common form of stainless steel, and the strength of 304 stainless steel makes it easy to sterilize, thus it is ideal for use with food packaging machines.
- It is also used in forming and cutting cars, wheel covers, hose clips and any equipment that needs to be made of stainless material such as storage tanks, pressure vessels and pipes.
- One of the drawbacks of using stainless steel 304 is that it is prone to corrosion when exposed to chloride solution, so it is best to use stainless steel 316 in the packaging machinery if the product can cause a chemical reaction with the metal.

3.1.1.4 Mechanical Properties of SS 304

Table 3.2. The mechanical properties of SS-304.

Property	Value
Density	8.21 kg/m
Yield strength	293 MPa
Tensile strength	500-750 MPa
Elastic modulus	195-210 MPa
Hardness	84 max
Elongation	50%

3.1.2 Carbon Steel

Carbon steel is a metallic alloy consisting of two elements, iron and carbon, as well as other elements in very small quantities such as sulfur, phosphorous, manganese, nitrogen, silicon, and copper to influence mechanical properties. Carbon is a vacuum defect of iron which forms a solid solution with all forms of single-phase iron. All of these changes are visible along the left vertical axis of the diagram phase.

3.1.2.1 Low Carbon Steel

All steel is carbon steel. Carbon steel is used to denote carbon steel as the main alloy. The properties in carbon steel are determined primarily by the amount of carbon percentages. For these alloys, no other quantities of alloy elements such as chromium, manganese, cobalt and tungsten have been identified. Based on the carbon content =, there are four types of carbon steel.

- Low carbon Steel (0.05–0.29% carbon)
- Medium carbon Steel (0.30–0.59% carbon)
- High Carbon Steel (0.6-0.99% Carbon)
- Very High Carbon Steel (1.0 2.0% Carbon)

It increases hardness and increases carbon content. They can undergo successful thermal treatment. Therefore, this is usually a very strong and difficult, but the ductility can be low.

Mild steel with small amounts of carbon between 0.16 and 0.3%. It is therefore a low carbon steel that contains very little carbon. It is difficult to distinguish between mild steel or not with the naked eye, since it belongs to the errors of fine geometry. Mild steel is "soft and formable", cheap material with good weldability, portability, low temperature elongates crisp shift. They are used in cars, trucks, hull, bridges and other structures that are designed to handle large amounts of stress or anything that requires a huge amount of steel. It is usually used as rails or for beams, also called "structural steel" at times.

3.1.2.2 Chemical Composition of Low Carbon Steel

Table 3.3. The chemical composition of low carbon steel.

Element	Weight %
Nickel	0.021
Manganese	1.342
Carbon	0.297
Aluminum	0.031
Sulfur	0.007
Silicon	0.241
Phosphorus	0.023
Copper	0.019
Chromium	0.022
Molybdenum	0.010

3.1.2.4 Mechanical Properties of Low Carbon Steel

Table 3.4. The mechanical properties of Low Carbon Steel.

Property	Value
Density	3.24 kg/m
Yield strength	260 MPa
Tensile strength	410-540 MPa
Elastic modulus	145-205 MPa
Hardness	55 max
Elongation	24%

3.2 EQUIPMENT AND TOOLS

3.2.1 TIG Welding Machine

This welding machine adopts rectifiers designed with advanced inverter technology. Introduction of TIG inverter welding is derived from theory and inverter power devices. The TGB welding power of the high-power IGBT inverter is used to convert the working frequency from 50 / 60Hz to high frequency (20kHz or more). Then the current is regulated while voltage is reduced. A strong DC power source can be produced using PWM technology. The size and weight of the inverter welders are greatly reduced, while the efficiency increases by 30% compared to the old transformer-based welders.



Figure 3.1. Alpha-TIG200X TIG welding machine.

Table 3.5. Alpha-TIG200X specifications

Specification	Value
Power voltage	1phase AC220V±15%
Frequency	50/60 Hz
Rated Input Current (A)	TIG:28
	MMA:42.2
Output Current Regulation (A)	TIG:10-200
	MMA:30-195
No-load Voltage	50-80 V
Rated Working Voltage (V)	TIG:18
	MMA:27.8
AC BALANCE	(-5+5) 20-80%
Pulse Time On	10-90%
POST FLOW	1-10 S
Pulse Frequency	0.5-5 Hz
Base Value Current	10-200 A
Arc Starting Current	10-200 A
Arc End Amps	10-200
Remote Control	Yes
Arc Ignition Mode	high-frequency arc ignition
Efficiency	80%
Load Duration Factor	60%
Power Factor	0.73
Class of Insulation	F
IP code	IP21
Weight	67 lbs
Overall Dimension	30 x12 x24.5 inches
Max welding thickness	.5 (1/2") inches
Pulse AMPS	10%-80% PEAK

3.2.3 Testing Equipment

3.2.3.1 Hardness Test Machine



Figure 3.3. ZONHOW LHRS-150 Rockwell Hardness.

3.2.3.2 Tensile Test Machine

Servo-hydraulic load frames – HB series, 2-column

In a closed force flow, Two-column load holders are designed to test materials and components under dynamic load. During normal operation, the frame is supported by vibration isolation leveling units so that no noticeable forces are sent to the ground. When environmental conditions or tests are critical in nature, it is advisable to use the available air chambers optionally; these have a normal frequency of about 3-6 Hz. Table 3.5 shows the specifications of the tensile testing machine.



Figure 3.4. Servo-hydraulic load frames - HB series, 2-column tensile test machine

Table 3.5. Tensile test machine Specification.

Dynamic nominal force	50	100	250	500	kN
Crosshead clamping	electrohydraulic	electrohydraulic	electrohydraulic	electrohydraulic	
Crosshead adjustment	electrohydraulic	electrohydraulic	electrohydraulic	electrohydraulic	
AG100 – max. test-frame height with 100mm-stroke actuator	3175 (3675) ¹⁾	3259 (3759) ¹⁾	3523 (4023) ¹⁾	4045 (4545) ¹⁾	mm
AG250 – max. test-frame height with 250mm-stroke actuator	3475 (3975) ¹⁾	3559 (4059) ¹⁾	3823 (4323) ¹⁾	4345 (4845) ¹⁾	mm
AG400 – max. test-frame height with 400mm-stroke actuator	-	3859 (4359) ¹⁾	4123 (4623) ¹⁾	4635 (5135) ¹⁾	

A – max. column height	2690 (3190) ¹⁾	2690 (3190) ¹⁾	2900 (3400) ¹⁾	3250 (3750) ¹⁾	mm
AK – tilted dimension for installation	2820 (3320) ¹⁾	2820 (3320) ¹⁾	3060 (3560) ¹⁾	3500 (3980) ¹⁾	mm
B – max. width of test frame	1079	1079	1197	1525	mm
C – max. depth of test frame	780 (1020) ²⁾	780 (1020) ²⁾	1130 (1130) ²⁾	1130 (1370) ²⁾	mm
D1 – column spacing	565	565	670	800	mm
E – column diameter	80	80	100	120	mm
F – height of top edge of lower crosshead ³⁾	950	950	890	900	Mm
G – max. test area height ⁴⁾	1510 (2010) ¹⁾	1510 (2010) ¹⁾	1705 (2205) ¹⁾	2120 (2620) ¹⁾	mm
H – max. working test area height ⁵⁾	1434 (1934) ¹⁾	1434 (1934) ¹⁾	1614 (2114) ¹⁾	2020 (2520) ¹⁾	mm
J – crosshead displacement range	1000 (1250) ¹⁾	1000 (1250) ¹⁾	1150 (1400) ¹⁾	1250 (1400) ¹⁾	mm
Weight without T-slotted platform ⁶⁾	899 (945) ¹⁾	895 (941) ¹⁾	1361 (1430) ¹⁾	3660 (3780) ¹⁾	Kg
Weight with T-slotted platform ⁶⁾	1137 (1182) ¹⁾	1133 (1178) ¹⁾	2082 (2232) ¹⁾	4860 (4980) ¹⁾	kg
Frame stiffness with crosshead separation 1000 mm ⁷⁾	730	730	988	1529	kN/mm
Frame stiffness with crosshead separation 1000 mm ²⁾	870	870	1332	1848	kN/mm
Item No.					
Standard height	077533	924779	040159	079720	
Standard height with T-slotted platform	077370	079752	040158	079728	
Extra-high + 500 mm	750972	077534	079755	079721	
Extra-high + 500 mm with T-slotted platform	077535	079753	079756	079733	

PART 4

RESULTS AND DISCUSSION

4.1 OVERVIEW

This chapter showing the welding process of dissimilar metals with mechanical testing and evaluations.

4.2 WELDING PROCESS

The welding process has been done utilizing Alpha-TIG200X TIG welding machine, before that the welding process has been designed using Minitab software.

4.2.1 The Preparation of Samples

low carbon steel and SS-304 plates has been prepared with the dimensions of 100×25×6 mm, as well as with the bevel heights of 6 mm, and bevel angle of 45°. For welding, specimens are welded with a root gap distance 2 millimeter as shown in Figure 4.1.

4.2.1.1 Samples Geometry

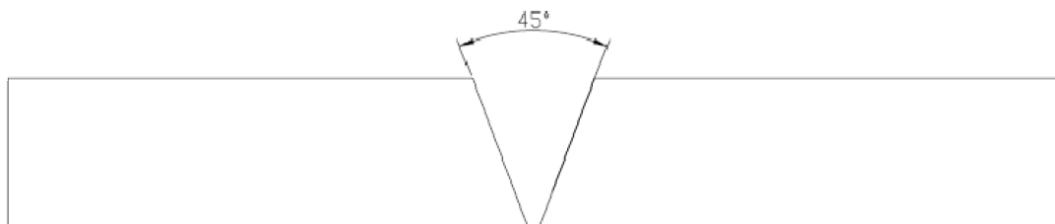


Figure 4.1. Welding specimen's geometry.

4.2.2 Welding

4.2.2.1 Welding Process Design

The Minitab program is one of the most powerful statistical programs with wide applications in the analysis of scientific research data in various fields. It was originally designed by Pennsylvania State University researchers in 1972. (Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner). This program is characterized by ease of use, accuracy of calculations, and comprehensive statistical tools provided by the basic statistics, regression and variance analysis, quality tools, experimental design, control schemes and others.

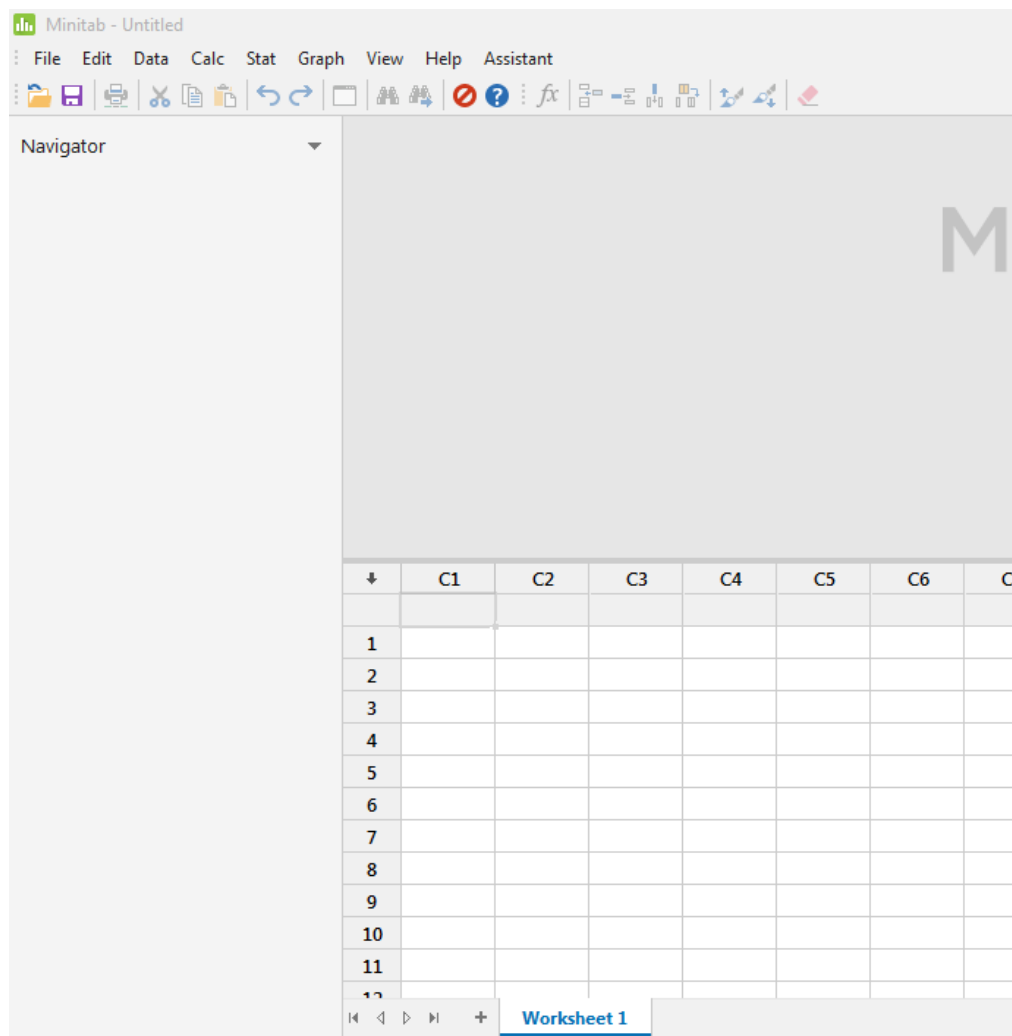


Figure 4.2. First step opening Minitab.

Second step choosing taguchi design method, then selecting type of design, which is 3-level design. In addition, number of factors. the welding factors are welding current and Gas flow rate. Figure 4.3 shows the select Stat/DOE/Factorial/Create Factorial Design.

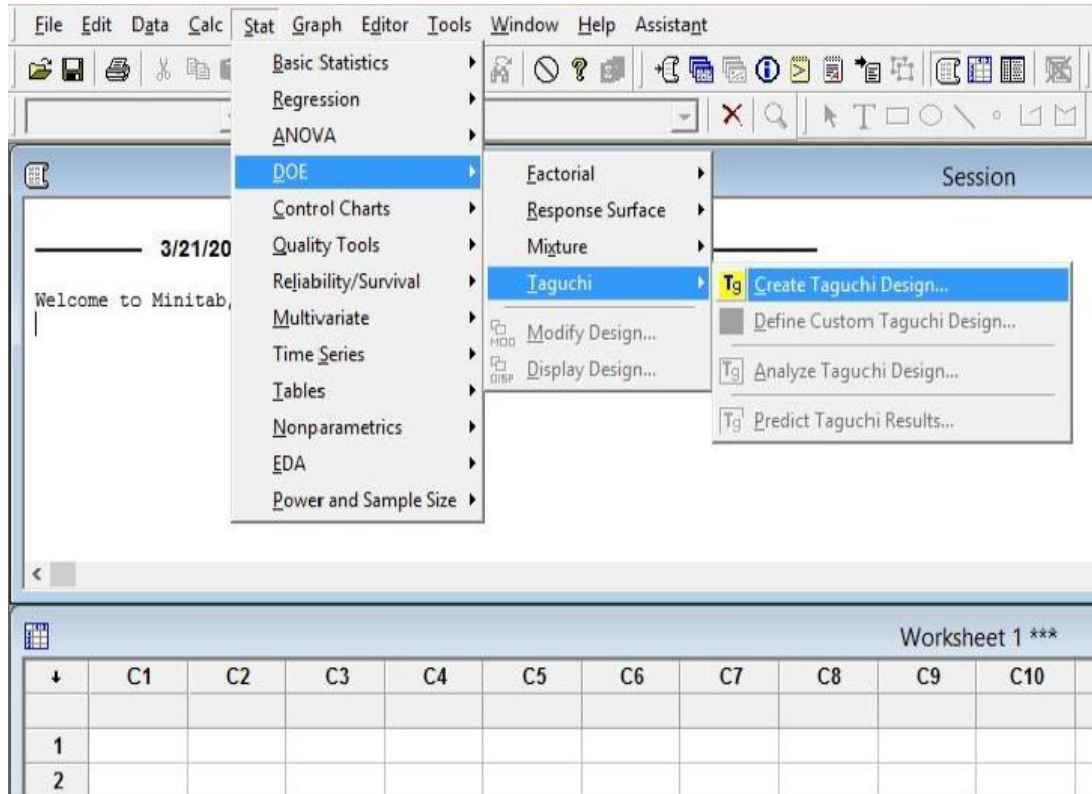


Figure 4.3. Select Stat/DOE/Factorial/Create Factorial Design.

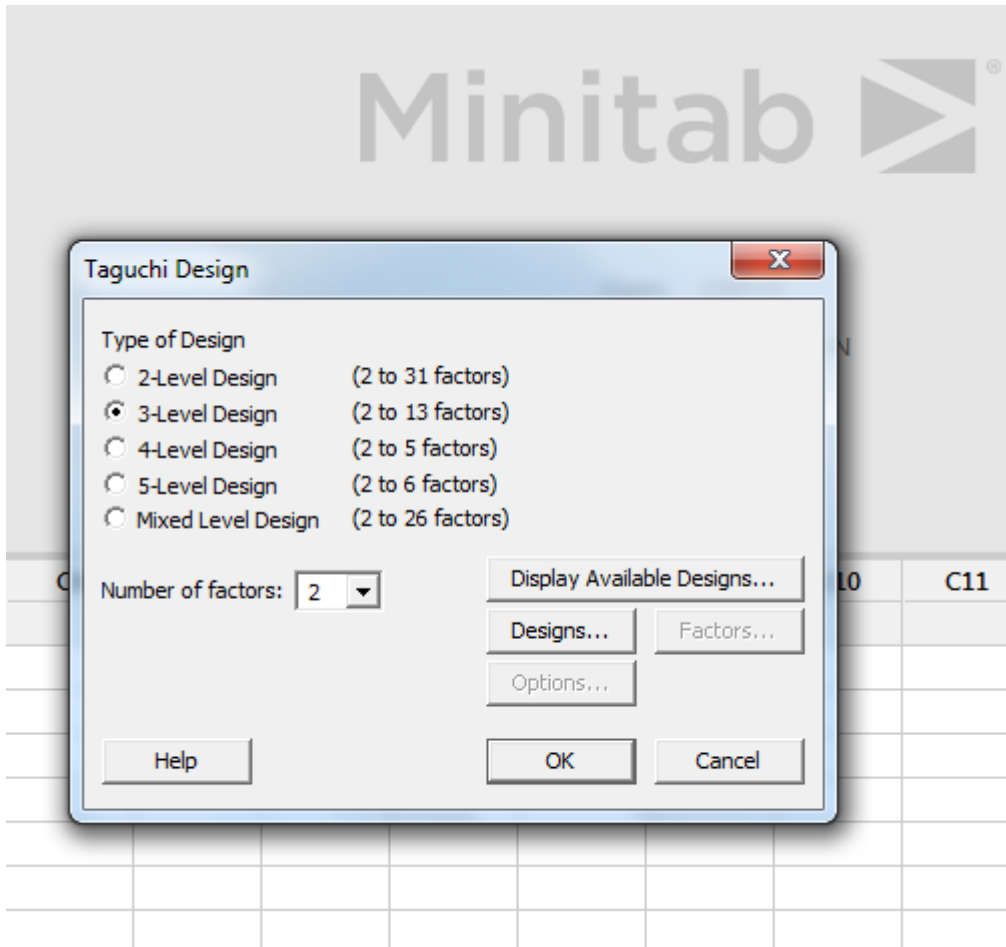
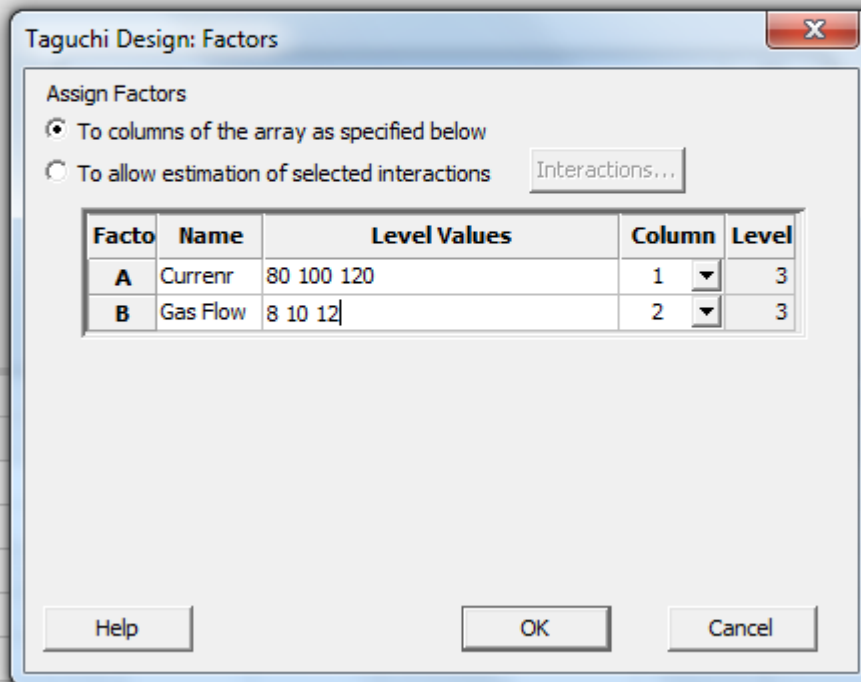


Figure 4.4. Second step Taguchi design.



C11

Figure 4.5. Fourth step, setting up the Taguchi design factors.

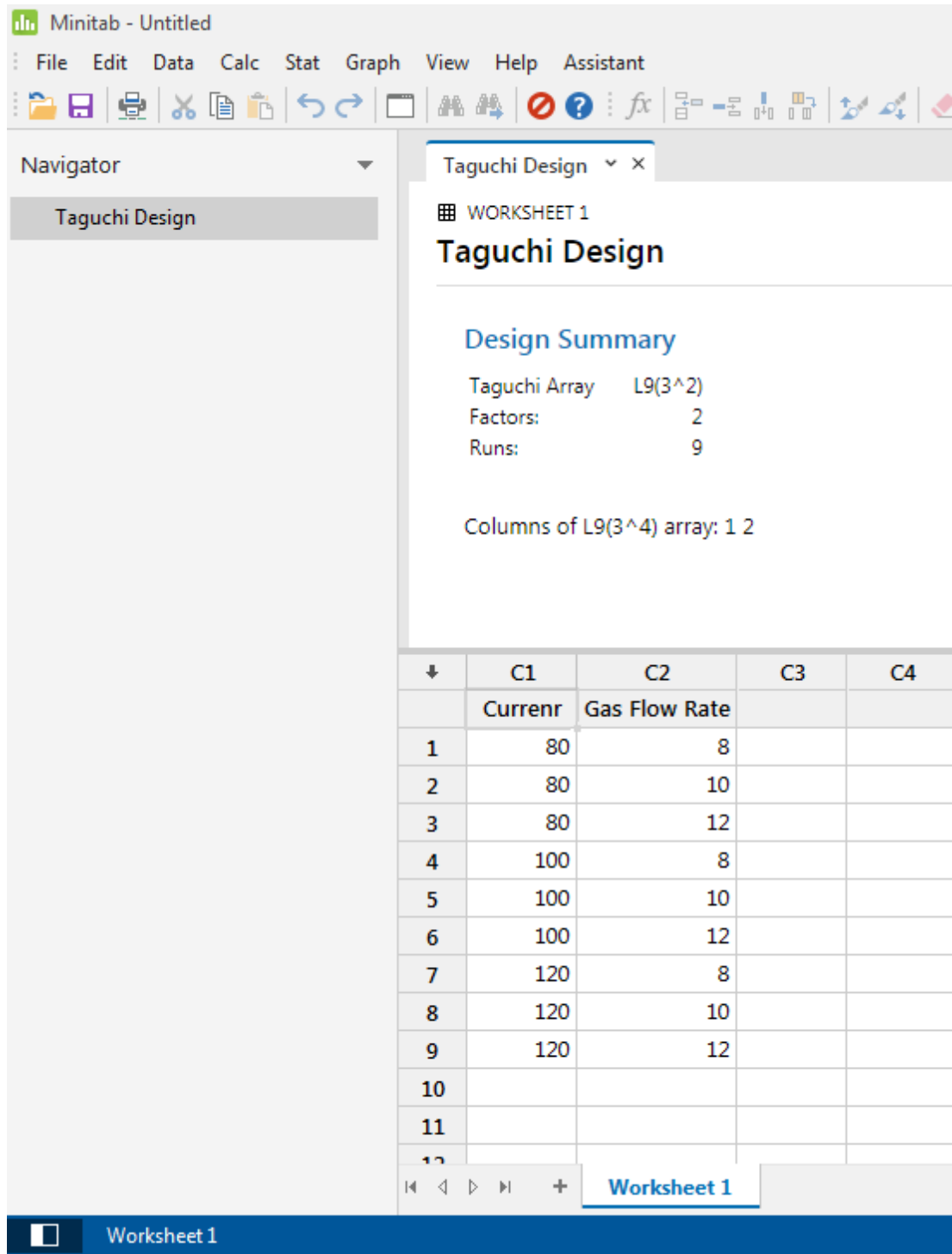


Figure 4.6. Welding parameters design.

Welding parameters as resulted by Minitab software shown in Table 4.1.

Table 4.1. Welding process parameters

Experiment no.	Gas flow Rate (Lit/min)	Current (Amp)
1	8	80
2	8	100
3	8	120
4	10	80
5	10	100
6	10	120
7	12	80
8	12	100
9	12	120

Table 4.2. welding process parameters.

Parameter	Range
Distance from tip to contact	4 mm
Voltage	10-15
Tungsten electrode	2.4 Diameter
Filler rod SS-304	1.6 mm Diameter
Gas flow rate Argon	8-12 L/M

4.3 TESTING

4.3.1 Tensile Test

Per ASTM standard has been used to tensile test, where size of the work piece is decided as per ASTM A370. Figure 4.7 shown welding sample prepared after machining. Table 4.3 shows tensile test results according to welding parameters. As showing, the best tensile test results recorded by sample No. 3, which welded by (8 gas flow rate and 120 current Ampere). Followed by sample No. 9 that welded by (12 gas flow rate and 120 current Ampere), while the lowest tensile results recorded by sample No. 8 which welded by (12 gas flow rate and 100 current Ampere).

Table 4.3. The tensile test results.

Experiment	no. Gas flow Rate Lit/min	Current Amp	Tensile Strength N/MM²
1	8	80	449.82
2	8	100	465.21
3	8	120	596.59
4	10	80	488.56
5	10	100	479.11
6	10	120	456.81
7	12	80	519.64
8	12	100	440.62
9	12	120	556.19

4.3.1.1 Taguchi Analysis

Table 4.4 shoes the S/N ratios and Mean 1 of Tensile Strength resulted by Minitab software.

Table 4.4. The tensile test results.

Experiment	no. Gas flow Rate Lit/min	Current Amp	Tensile Strength N/MM²	SNRA1	MEAN1
1	8	80	449.82	53.0608	449.82
2	8	100	465.21	53.3530	465.21
3	8	120	596.59	55.5135	596.59
4	10	80	488.56	53.7784	488.56
5	10	100	479.11	53.6087	479.11
6	10	120	456.81	53.1947	456.81
7	12	80	519.64	54.3141	519.64
8	12	100	440.62	52.8813	440.62
9	12	120	556.19	54.9045	556.19

Mean

Table 4.5 shows the graph of the main effects of the signal-to-noise ratios of the tensile strength, as shown in Table 4.5, while Table 4 shows the means response table. Figure 4.7 shows the main media effects according to gas and current flow.

Table 4.5. Response Table for Signal to Noise Ratios
Nominal is best ($10 \times \text{Log}_{10}(\bar{Y}^2/s^2)$)

Level	Current	GAS Flow Rate
1	*	*
2	*	*
3	*	*
Delta	*	*
Rank	1.5	1.5

Table 4.6. Response Table for Means

Level	Current	GAS Flow Rate
1	503.9	486.0
2	474.8	461.6
3	505.5	536.5
Delta	30.7	74.9
Rank	2	1



Figure 4.7. The main effects of means.

From Figure 4.7, it can be note that gas flow rate is highly effective as compared to the current.

Signal to Noise Ratios

The signal-to-noise ratio was calculated using Minitab, as Table 4.7 shows the response-to-noise-response schedule. Figure 4.8 illustrates the main effects of SN ratios for a tensile test. It can be note that gas flow rate is highly effective as compared to the current.

Table 4.7. Response Table for Signal to Noise Ratios
Larger is better

Level	Current	GAS Flow Rate
1	53.98	53.72
2	53.53	53.28
3	54.03	54.54
Delta	0.51	1.26
Rank	2	1

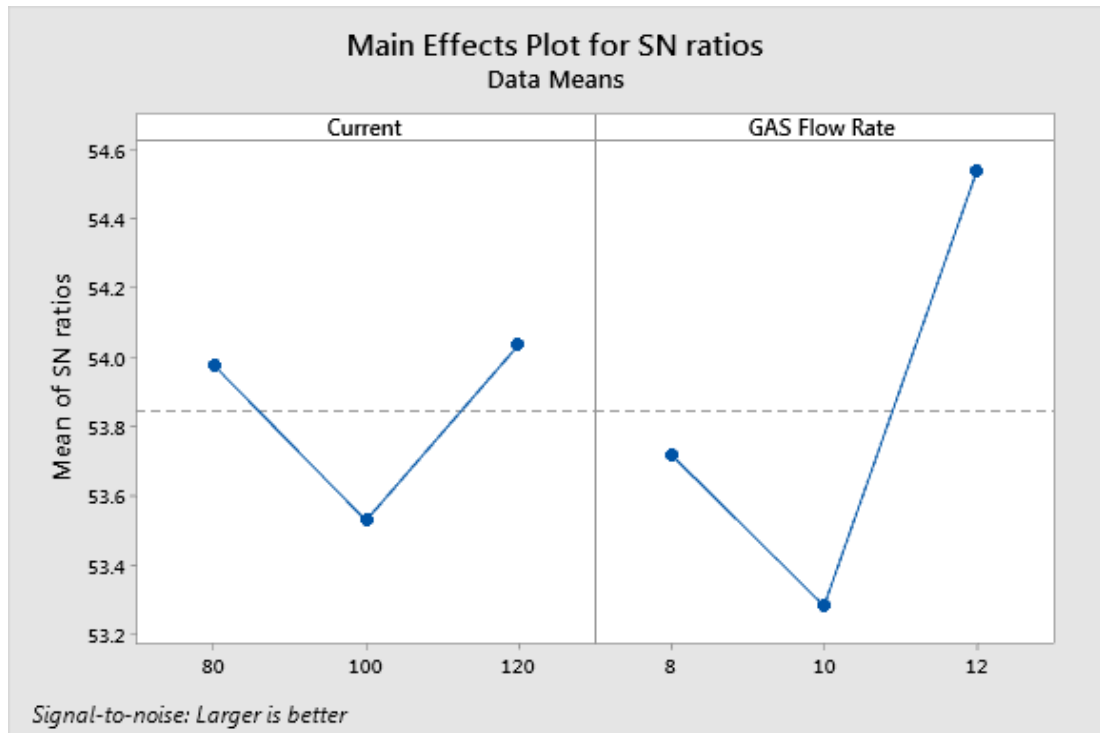


Figure 4.8. The main effects of SN ratios.

ANOVA Test

As same as Mean and S/n ratio, the ANOVA test has been done to carried out the highly effective factor (current or gas flow rate). Table 4.9 shows the factor information of tensile test, which is found that welding current is highly effective by recording 0.754 as P-Value, while gas flow rate recorded 0.329.

Table 4.9. The Factor Information of tensile test.

Factor	Type	Levels	Values
Current	Fixed	3	80, 100, 120
GAS Flow Rate	Fixed	3	8, 10, 12

Table 4.10. Analysis of Variance of tensile test by ANOVA Test.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Current	2	1786	893.1	0.30	0.754
GAS Flow Rate	2	8754	4376.8	1.49	0.329
Error	4	11770	2942.5		
Total	8	22310			

4.3.2 Hardness Test

The hardness test has been done on Rockwell hardness tester by pointer used 1/16", and force applied 100 kg. the best results recorded by sample No. 9 by 116 in weld metal and HAZ with (12 Gas flow rate and 120 welding current ampere).

Table 4.11. The hardness test results

Experiment	No. Gas flow Rate Lit/min	Current Amp	Hardness		
			Bas Metal	HAZ	Weld Metal
1	8	80	97	99	101
2	8	100	96	99	103
3	8	120	96	101	107
4	10	80	95	99	108
5	10	100	97	102	104
6	10	120	96	103	113
7	12	80	95	103	108

8	12	100	95	101	114
9	12	120	97	106	116

4.3.2.1 Taguchi Analysis

Table 4.12 shows the S/N ratios and Mean 1 of hardness test resulted by Minitab software.

Table 4.12. The Hardness Signal to Noise Ratio.

Experiment	No. Gas flow Rate Lit/min	Current Amp	Hardness Weld Metal	SNRA1	MEAN1
1	8	80	101	40.0864	101
2	8	100	103	40.2567	103
3	8	120	107	40.5877	107
4	10	80	108	40.6685	108
5	10	100	104	40.3407	104
6	10	120	113	41.0616	113
7	12	80	108	40.6685	108
8	12	100	114	41.1381	114
9	12	120	116	41.2892	116

Mean

Table 4.13 shows the response schedule for signal to noise ratios, and Table 4.14 shows the means response table. Figure 4.9 shows the main media effects according to gas and current flow. From figure, it can be note that welding current is highly effective as compared to the gas flow rate in hardness test.

Table 4.13. Response Table for Signal to Noise Ratios
 Nominal is best ($10 \times \text{Log}_{10}(\bar{Y}^2/s^2)$)

Level	Current	GAS Flow Rate
1	*	*
2	*	*
3	*	*
Delta	*	*
Rank	1.5	1.5

Table 4.14. Response Table for Means

Level	Current	GAS Flow Rate
1	103.7	105.7
2	108.3	107.0
3	112.7	112.0
Delta	9.0	6.3
Rank	1	2

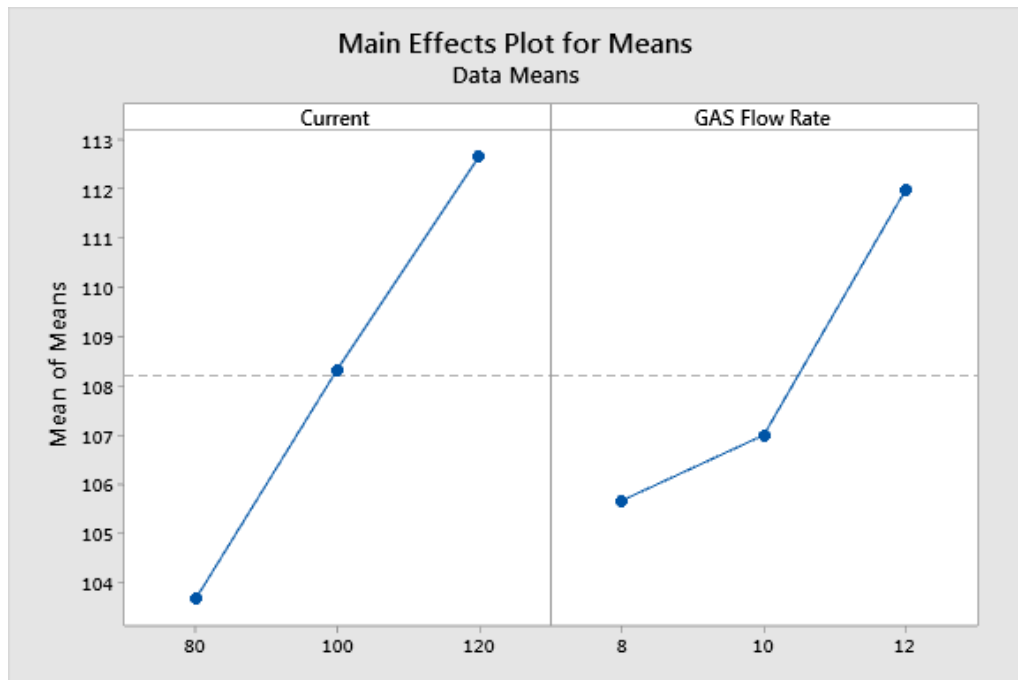


Figure 4.9. The main effects of means.

Signal to Noise Ratios

Signal to Noise Ratios has been calculated using Minitab software, where Table 4.15 shows response Table for Signal to Noise Ratio of hardness test. Figure 4.10 shows the main effects of SN ratios of hardness test. It can be note that welding current is highly effective as compared to the gas flow rate.

Table 4.15. Response Table for Signal to Noise Ratios

Larger is better.

Level	Current	GAS Flow Rate
1	40.31	40.47
2	40.69	40.58
3	41.03	40.98
Delta	0.72	0.51
Rank	1	2

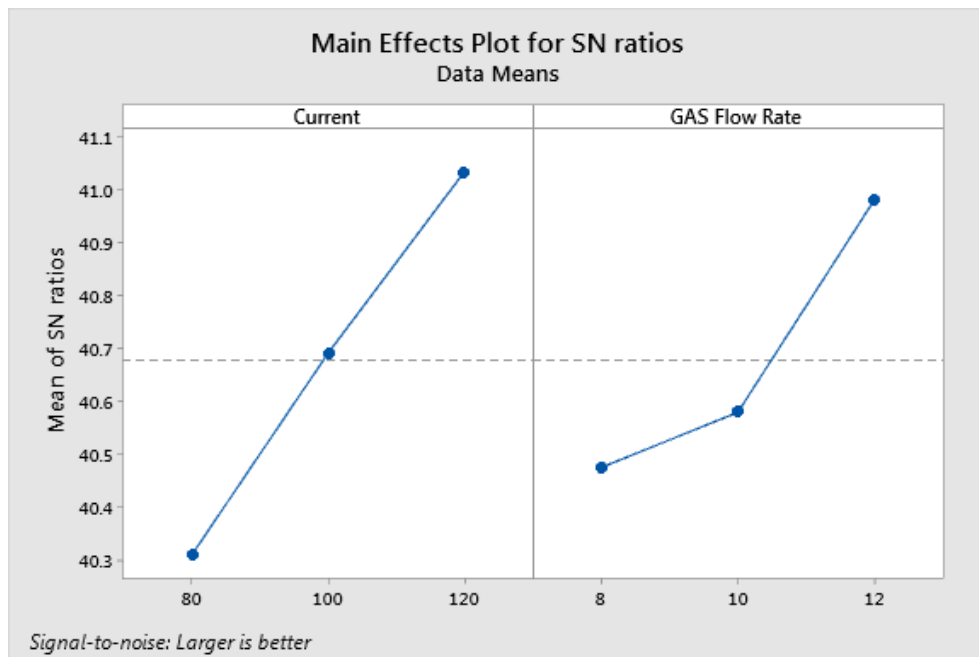


Figure 4.10. The main effects of SN Ratios.

ANOVA Test

As same as Mean and S/n ratio, the ANOVA test has been done to carried out the highly effective factor (current or gas flow rate) in hardness test. Table 4.16 shows the factor information of hardness test, which is found that welding gas flow rate is highly effective by recording 0.083 as P-Value, while welding current recorded 0.033.

Table 4.16. The Factor Information of hardness test.

Factor	Type	Levels	Values
Current	Fixed	3	80, 100, 120
GAS Flow Rate	Fixed	3	8, 10, 12

Table 4.17. The Analysis of Variance of hardness test by AVOVA Test.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Current	2	121.56	60.778	8.97	0.033
GAS Flow Rate	2	66.89	33.444	4.93	0.083
Error	4	27.11	6.778		
Total	8	215.56			

PART 5

CONCLUSIONS

5.1 CONCLUSIONS

This study aims to improve and verify the parametric effect of TIG welding on the tensile strength of various metals SS-304 and low carbon steel. This process will be carried out using theoretical and experimental work. In addition, the research aims to study various metal connections using the metal filling process. In general, different welding is used to make thermal power plants, pressure vessels and tubes in nuclear reactors and heat exchangers, and therefore, failure often occurs due to low tensile strength. The process designed using Minitab software. After survey and experimental work, there are some points that can be concluded, which as following:

- The best tensile test results recorded by sample No. 3, which welded by (8 gas flow rate and 120 current Ampere).
- In mean and Signal to Noise Ratios of Tensile Strength, it can be note that gas flow rate is highly effective as compared to the current. while in ANOVA Test of Tensile Strength is found that welding current is highly effective by recording 0.754 as P-Value, while gas flow rate recorded 0.329.
- The best hardness results recorded by sample No. 9 by 116 in weld metal and HAZ with (12 Gas flow rate and 120 welding current ampere).
- In mean and Signal to Noise Ratios of hardness, the main effects of SN ratios of hardness test. It can be note that welding current is highly effective as compared to the gas flow rate. While in ANOVA Test, is found that welding
- gas flow rate is highly effective by recording 0.0083 as P-Value, while welding current recorded 0.0033.
- The research adds new references in welding dissimilar metals for student and researchers.

5.2 FUTURE RECOMMENDATIONS

As future recommendation, these are some points that can be taken in the accounts:

- This work can be extended to study the effect of parameter on other responses such as heat affected zone (HAZ) and mechanical properties.
- This study could be applied on other metals.
- This study could be applied on other welding processes.
- This study could be used as references on study the effect of welding parameters on the heat affected zone, hardness and distortion.

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