# ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIALS

ENGINEERING

**An Experimental study on the effects of welding parameters of tungsten inert gas welding on stainless steel plate**

A Thesis submitted in Partial Fulfillment of the Requirement for the award of the Degree of Master of Science in Manufacturing Engineering

BY

**YESUFEKADE FENETIE**

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Co-Advisor:- Mr. Tariku Desta

MECHANICAL DESIGN AND MANUFACTURING ENGINEERING PROGRAM

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# CANDIDATES'S DECLARATION

I hereby declare that the work which is entitled as "**An experimental study on the effects of welding parameters of TIG welding on Stainless steel plate**" is presented in partial fulfillment of **Master of Science in Manufacturing Engineering**. It is my own work which I accomplished for my master degree and executed from November, 2016 to May, 2017 with a supervision of Dr. J.Bhaskaran and Mr.Tariku Desta Department of Mechanical and Vehicle Engineering, Adama Science and Technology University, Ethiopia.

All relevant resources of information used in this thesis have been duly acknowledged.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval.

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| (Co-Advisor) | Date |

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Approved by board of Examiners

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# ABSTRACT

Tungsten Inert Gas welding is also known as Gas Tungsten Arc Welding (GTAW), is an advanced arc welding process which become a popular choice when a high level of weld quality or considerable precision welding is required. Other arc welding processes have limited quality when they are compared to TIG welding processes. The choice process depends on several factors; such as the compositional range of the material to be welded, thickness of the base materials and type of current. To improve welding quality of stainless steel plate speed control set up has been developed during welding process. Various welding tests have been carried out to optimise best combination of process parameters in practice. Effect of welding speed and welding current on the tensile strength of the weld joint has been investigated. Optical microscopic analysis has been done on the weld zone to evaluate the effect of welding parameters on welding quality. Micro-hardness value of the welded zone has been measured at the cross section to understand the change in mechanical property of the welded zone. The results of the TIG welding process show that, maximum depth of penetration was obtained with parametric combination of minimum welding speed and maximum current. Hardness value of the weld zone change with the distance from weld centre due to change of microstructure. At lower welding speeds and high welding current strength is more due to more intensity of current.



**Keywords**: *TIG Welding System, Micro hardness Test, Tensile Test, stainless steel plate.*

# ABBREVIATIONS

| S no. | Abbreviation | Description |
|---|---|---|
| 1 | TIG | Tungsten Inert Gas |
| 2 | GTAW | Gas Tungsten Arc Welding |
| 3 | HV | Vicker’s Hardness |
| 4 | DC | Direct Current |
| 5 | AC | Alternating Current |
| 6 | DCEN | Direct Current Electrode Negative |
| 7 | DCEP | Direct Current Electrode Positive |
| 8 | HAZ | Heat Effected Zone |
| 9 | SS | Stainless steel |
| 10 | BM | Base metal |
| 11 | WM | Weld metal |

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# CHAPTER ONE

# 1. INTRODUCTION

Welding is a permanent joining process used to join different materials like metals, alloys or plastics, together at their contacting surfaces by application of heat and or pressure. During welding, the work-pieces to be joined are melted at the interface and after solidification a permanent joint can be achieved. Sometimes a filler material is added to form a weld pool of molten material which after solidification gives a strong bond between the materials. Weldability of a material depends on different factors like the metallurgical changes that occur during welding, extent of oxidation due to reaction of materials with atmospheric oxygen and tendency of crack formation in the joint position. Proper design of the joint is critical. Selection of the specific process requires an understanding of the large number of available options, the variety of possible joint configurations, and the numerous variables that must be specified for each operation. If the potential benefits of welding are to be obtained and harmful side effects are to be avoided, proper consideration should be given to the selection of the process and the design of the joint. Generally, the quality of a weld joint is strongly influenced by process parameters during the welding process. In order to achieve high quality welds a good selection of the process variables should be utilized.

## 1.1 Types of welding process [27]

Based on the heat source used welding processes can be categorized as follows.

### 1.1.1 Arc Welding

In arc welding process an electric power supply is used to produce an arc between electrode and the work-piece material to joint, so that work-piece metals melt at the interface and welding could be done. Power supply for arc welding process could be AC or DC type. The electrode used for arc welding could be consumable or non-consumable. For non-consumable electrode an external filler material could be used.

### 1.1.2 Gas Welding

In gas welding process a focused high temperature flame produced by combustion of gas or gas mixture is used to melt the work pieces to be joined. An external filler material is used for proper welding. Most common type gas welding process is Oxyacetylene gas welding where acetylene and oxygen react and producing some heat.

Other fuel gases are also employed in the place of acetylene. The temperature ranges for different fuel gases are given in Table 1.1.

| Fuel gases | Max.Temp $^0$c | Neutral Temp $^0$c |
|---|---|---|
| Acetylene | 3300 | 3200 |
| Mythyl acetylene Propadiene | 2900 | 2600 |
| Propylene | 2860 | 2500 |
| Propane | 2780 | 2450 |
| Methane | 2740 | 2350 |
| Hydrogen | 2870 | 2390 |

Table 1.1 Temperature ranges for different fuel gases

Oxy-acetylene welding process can be used for joining a variety of metals. Oxygen gas is produced from commercial liquefaction of air. The liquid air is allowed to boil and when nitrogen and argon escape, pure liquid oxygen is left with. The gas is compressed in cylinders at a pressure of 15 MPa. Acetylene gas (C2H2) is produced by the reaction of calcium carbide (CaC2) with water (H2O). CaC2 + 2H2O = C2H2 + Ca (OH) 2. Acetylene gas has the tendency to explode if the pressure is increased. So the gas is dissolved in acetone (CH3–CO–CO3) liquid which acts as a solvent for the gas. One volume of acetone can absorb about 25 volume of acetylene per atmosphere. The acetylene gas is usually compressed at 1.7 MPa. The acetylene cylinder will be packed with porous calcium silicate, so that the liquid is distributed in fine form and the gas is aborbed in an effective way. The cylinders are fitted with fusible safety plugs made of a low melting alloy (melting point around 97°C) which will allow the gas to escape if the cylinders are exposed to excessive heat.

### 1.1.3 Resistance Welding

In resistance welding heat is generated due to passing of high amount current (1000–100,000 A) through the resistance caused by the contact between two metal surfaces. Most common types resistance welding is Spot-welding, where a pointed electrode is used. Continuous type spot resistance welding can be used for seam-welding where a wheel-shaped electrode is used.

Typical examples of this type of joining are spot and seam welding where sheet metals are pressed together at the joint by copper alloy electrodes and, projection welding where the metal itself is shaped so that local contact at the joint concentrates the current flow, thereby producing heat. Electro-slag welding which makes vertical joints, is in effect a continuous casting process employing electric resistance heating of a bath of molten slag carried above the weld pool. Electric resistance welding is a nonfusion welding process. Heat is generated when high electric current is passed through a small area of the two contacting metal surfaces. The heat H generated is given by $H = I^2 \times R \times t$ where I is current, R is resistance of the interface and t is the time of application of current. When the rise in temperature is sufficient, a large pressure is applied at the heated interface to form a weld joint. The process variables are: current, time of application of current, pressure, duration of pressure applications, materials to be welded and their thickness

There are five main types of resistance welding:

*(a)* Spot welding

*(b)* Seam welding,

*(c)* Projection welding,

*(d)* Upset butt welding and

*(e)* Flash butt welding

### 1.1.4 High Energy Beam Welding

In this type of welding a focused energy beam with high intensity such as Laser beam or electron beam is used to melt the work pieces and join them together. These types of welding mainly used for precision welding or welding of advanced material or sometimes welding of dissimilar materials, which is not possible by conventional welding process.

#### A. Electron beam welding

Electron beam welding is a process in which the heat required to produce fusion is obtained from the impact of a high velocity high density stream of electrons on the work piece. Upon impact the kinetic energy of the electrons is converted to thermal energy causing both vapourisation and melting. The vapourisation of the material beneath the beam enables the beam to penetrate into the material to be welded, with the beam and the vapour forming a hole. As the beam moves along the joint, the molten metal flows round the hole leaving the welded joint in the wake of the beam. The EB weldings have depth to width ratio of more than 10:1 due to the extremely high heat concentration. The beam is very narrow, less than 0.25 in diameter and the welding speed is high. Initial cost of EBW machine is very high. Further, EBW can be used only in an automatic operation owing to high speed of welding. However, significant machine time and material saving can be achieved by EBW.

**B. Laser beam welding**

Laser beam welding is a high energy density welding process with low heat input. A wide variety of metals and alloys can be welded by this process. The heat source is a focussed beam of high energy monochromatic and coherent stream of photons and this process does not require vacuum chamber. The welding unit consists of

*(a)* Laser generator

*(b)* Power supply

*(c)* Capacitor bank

*(d)* Microscope

### 1.1.5 Solid-State Welding

Solid-state welding processes do not involve melting of the work piece materials to be joined. Common types of solid-state welding are ultrasonic welding, explosion welding, electromagnetic pulse welding, friction welding, friction-stir-welding etc.

### 1.1.6 Detail of Arc Welding

Among all these types of welding processes arc welding is widely used for different types of materials. Common types of arc welding process are:

**A) Shielded Metal Arc Welding (SMAW) or Manual Metal Arc Welding**

This is most common type arc welding process, where a flux coated consumable electrode is used. As the electrode melts, the flux disintegrates and produces shielding gas that protect the weld area from atmospheric oxygen and other gases and produces slag which covers the molten filler metal as it transfer from the electrode to the weld pool. The slag floats to the surface of weld pool and protects the weld from atmosphere as it solidifies. Shielded metal arc welding (SMAW) is common and versatile method used for joining shapes that cannot be easily set up for automatic welding methods. In this method a solid electrode with an extruded backed-on-coating material is used. The arc is struck by short circuiting the electrode with the work piece. Welding current is chosen according to the electrode diameter, type of electrode, and the kind of welding job. The arc voltage is determined as function of the arc length. In MMA it will be very difficult to keep a uniform arc length. When welding with basic electrodes, where metal transfer causes short circuit, the dynamic short circuit current has to be limited to avoid evaporation and blowing a part of the drop. The weight of the weld metal deposited per unit time is proportional to the current intensity. The electrodes are thoroughly dried or baked after production, because moisture will cause an unstable arc, heavy spatter and porosity in the weld metal.

The coating of the electrode has got several functions:

*(a)* Electrode material burns off faster than the coating flux that forms a crucible and this shields the arc from the atmosphere.

*(b)* Flux removes the impurities from the molten metal.

*(c)* A gaseous envelope developed by the decomposition of the ingredients of the flux covers the molten weld pool, thereby protecting it from atmospheric contact.

*(d)* During cooling, the slag formed on the top of the weld metal acts as a protective cover against contamination by the atmosphere.

*(e)* It provides alloy addition to the weld metal.

Flux also helps to (a) start and maintain the arc, (b) deoxidise and refine the weld metal, (c) helps to control the weld bead profile and reduce the weld spatter, (d) control viscosity of the slag so that vertical and overhead welding is made possible. Arc voltage and current intensity, thermal energy and mode of metal transfer are controlled by the coating. The electric power source can be AC transformer or DC generator. Carbon steels from 3 mm to 60 mm can be welded easily with work piece as one polarity. Power sources of constant current type having drooping characteristics are used for MMAW process. Power sources of the constant voltage type are not suitable.

The heat developed by the arc is given by W (joules) = V (volt) × A (amps) × t (sec)

If the arc is travelling at a speed of S mm/minute, the heat input rate (HIR) of the arc will be HIR = V × A × 60/S Joules/mm length of the joint. Though AC or DC power source can be successfully used, DC power source is suitable for all types of electrodes. With AC source some non-ferrous type and a low hydrogen ferritic type electrodes may not give a stable arc. Both starting and maintaining a short arc will be easier with DC power. Vertical and overhead welding on thick sections will be easier with DC. In DC straight polarity (*i.e.* electrode negative) can be used for MMAW of all steels; but not for non-ferrous metals. With straight polarity, more of the arc heat is concentrated on the electrode and consequently melting and deposition rates are higher, welding is more rapid and the work piece is less susceptible to distortion. Reverse polarity (electrode positive) is used with basic low hydrogen electrodes and for most non-ferrous metals.

**B) Gas Metal Arc Welding (GMAW) or Metal Inert Gas or Active Gas Welding**

In this type of welding process a continuous and consumable wire electrode is used. A shielding gas generally argon or sometimes mixture of argon and carbon dioxide are blown through a welding gun to the weld zone. Gas metal arc welding is a gas shielded process that can be effectively used in all positions. The shielding gas can be both inert gas like argon and active gases like argon-oxygen mixture and argon-carbon-di-oxide which are chemically reactive. It can be used on nearly all metals including carbon steel, stainless steel, alloy steel and aluminium. Arc travel speed is typically 30-38 cm/minute and weld metal deposition rate varies from 1.25 kg/hr when welding out of position to 5.5 kg/hr in flat position. MIG welding is a well-established semi-automatic process. Continuous welding with coiled wire helps high metal depositions rate and high welding speed. MIG gives less distortion and there is no slag removal and its associated difficulties like interference with accurate jigging. Because of the good heat input control, MIG can be used for non-ferrous welding with good results. However, since the torch has to be very near to the job, there is a constraint where accessability is limited. Spatter is high and so deposition efficiency is less. Absence of slag in solid wire welding processes allows a higher cooling rate of the weld zone and hence joints made with the process on hardenable steels are susceptible to weld metal cracking. The filler wire is generally connected to the positive polarity of DC source forming one of the electrodes. The work piece is connected to the negative polarity. The power source could be constant voltage DC power source, with electrode positive and it yields a stable arc and smooth metal transfer with least spatter for the entire current range. AC power source gives the problem of erratic arc. So is DC power source also with electrode negative. Power sources are rated at 60 per cent duty cycle for semi-automatic and at 100 per cent duty cycle for automatic continuous operation with maximum amperage of 600 amps and 1000 to 2000 amps respectively. AC constant voltage power source, pulsed current constant voltage power source or pulsed current power source with voltage feedback controlled wire system are also in practice. Among these, constant voltage power source is generally used. With a constant voltage power source, the welding current increases when the electrode feeding rate is increased and decreases as the electrode speed is decreased, other factors remaining constant. When the current value is increased the melting rate of the electrode will also increase. Inert gas usually argon, helium or a suitable mixture of these is used to prevent the atmosphere from contacting the molten metal and HAZ. The core of the gas column ionized by the arc heat helps to maintain the arc. The metal transfer is accomplished by *(a)* Short circuit transfer (dip transfer), *(b)* Globular transfer. *(c)* Spray transfer:

## C) Plasma welding

Plasma means a gas that has been heated to a sufficiently high temperature so that it is transformed into an ionised condition and is able to conduct an electric current. Plasma arc welding is an inert gas non-consumable electrode welding method, uitilizing a transferred, constricted arc. As the orifice gas passes through the torch to the work piece, it is heated by the arc, gets ionized and passes through the arc constricting nozzle at an accelerated rate. Since too powerful a jet would cause a turbulence in the molten puddle, the jet effect on the work piece is softened by limiting gas flow rates through the nozzle. Since this flow alone may not be adequate to protect the molten puddle from atmospheric contamination, auxiliary shielding gas is provided through an outer gas cup on the torch.

The salient features of plasma arc process are:

*(a)* Narrow weld beads and HAZ

*(b)* Greater penetration and less distortion

*(c)* Less heating of surrounding parent metal and less current required than TIG.

*(d)* Less arc wandering.

PAW process as compared to TIG process has the following advantages:

*(a)* Greater concentration of energy

*(b)* Improved arc stability at low currents

*(c)* Higher heat content

*(d)* Higher velocity of plasma

*(e)* Less sensitivity to variations of arc length

*(f)* Solid backing is avoided by adopting keyhole technique

*(g)* No tungsten contamination.

However, in PAW

*(a)* Equipment cost is high

*(b)* Life of constricting nozzle is short

*(c)* Consumption of inert gas is increased.

## D) Submerged arc welding

Carbon and alloy steels and copper alloys can be welded by this process; generally applied for plate thickness above 10 mm. Best suited for automatic welding in boilers, pressure vessels, ship building where high quality welds for larger thickness plates are required. This process is generally used for flat and horizontal positions. Not suitable for cast iron. With U-type of grooves, narrow gap welding can be carried out by this process and, plates as thick as 300 -

400 mm can be welded. In such cases of pressure vessel cylinders and pipes made of large thick plates, automatic submerged arc process is preferred.

**E) Gas Tungsten Arc Welding (GTAW) or Tungsten Inert Gas (TIG)**

GTAW or TIG welding process is an arc welding process uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmosphere with a shielding gas generally Argon or Helium or sometimes mixture of Argon and Helium. A filler metal may also feed manually for proper welding. GTAW most commonly called TIG welding process was developed during Second World War. With the development of TIG welding process, welding of difficult to weld materials e.g. Aluminum and Magnesium becomes possible. The use of TIG today has spread to a variety of metals like stainless steel, mild steel and high tensile steels, Al alloy, Titanium alloy. Like other welding system, TIG welding power sources have also improved from basic transformer types to the highly electronic controlled power source today.

## 1.2 Basic mechanism of TIG welding

TIG welding is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmosphere by an inert shielding gas (argon or helium), and a filler metal is normally used. The power is supplied from the power source (rectifier), through a hand-piece or welding torch and is delivered to a tungsten electrode which is fitted into the hand piece. An electric arc is then created between the tungsten electrode and the work piece using a constant-current welding power supply that produces energy and conducted across the arc through a column of highly ionized gas and metal vapours. The tungsten electrode and the welding zone are protected from the surrounding air by inert gas. The electric arc can produce temperatures of up to 20,000$^{o}$C and this heat can be focused to melt and join two different part of material [27]. The weld pool can be used to join the base metal with or without filler material. Schematic diagram of TIG welding and mechanism of TIG welding are shown in fig 1.1 & fig 1.2 respectively.

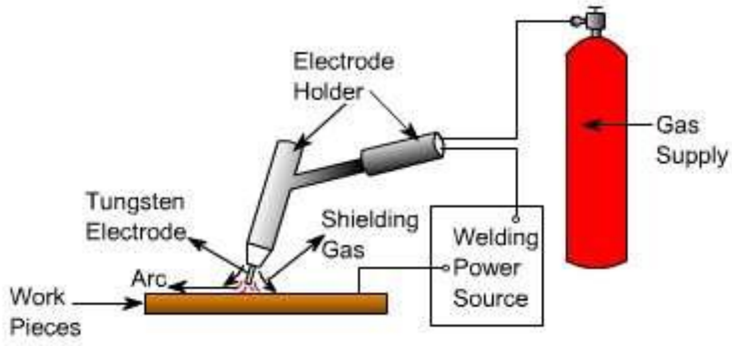


Figure 1.1 Schematic Diagram of TIG Welding System [27]

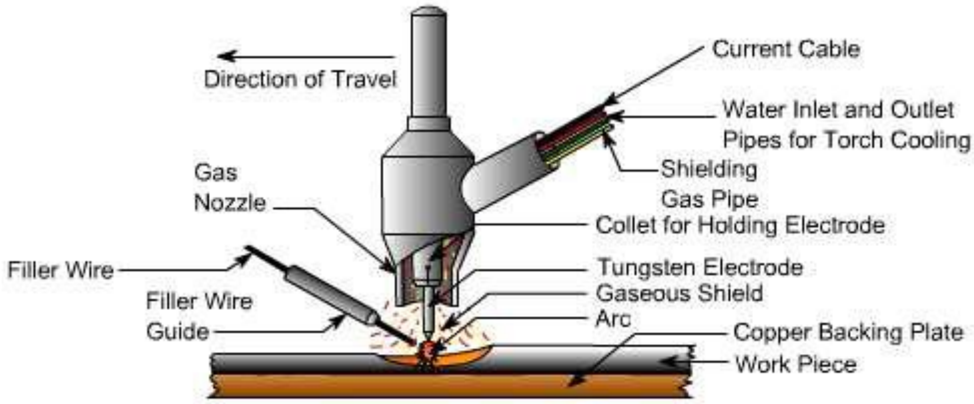


Figure. 1.2 Principle of TIG Welding [27]

Tungsten electrodes are commonly available from 0.5 mm to 6.4 mm diameter and 150 - 200 mm length. The current carrying capacity of each size of electrode depends on whether it is connected to negative or positive terminal of DC power source. The power source required to maintain the TIG arc has a drooping or constant current characteristic which provides an essentially constant current output when the arc length is varied over several millimeters. Hence, the natural variations in the arc length which occur in manual welding have little effect on welding current. The capacity to limit the current to the set value is equally crucial when the electrode is short circuited to the work piece, otherwise excessively high current will flow, damaging the electrode [27].

## 1.3 Types of welding current used in TIG welding

**a. DCSP (Direct Current Straight Polarity**): In this type of TIG welding direct current is used. Tungsten electrode is connected to the negative terminal of power supply. This type of connection is the most common and widely used DC welding process. With the tungsten being connected to the negative terminal it will only receive 30% of the welding energy (heat). The resulting weld shows good penetration and a narrow profile. DCSP setting is used for all metals except light metals. Mainly used on Stainless Steel, Mild Steel, Nickel, Copper, Titanium

b. DCRP (Direct Current Reverse Polarity): In this type of TIG welding setting tungsten electrode is connected to the positive terminal of power supply. This type of connection is used very rarely because most heat (70%) is on the tungsten, thus the tungsten can easily overheat and burn away. DCRP produces a shallow, wide profile and is mainly used on very light material at low Amp. DCRP mainly used on thin Material

**c. AC (Alternating Current):** It is the preferred welding current for most white metals, e.g. aluminium and magnesium. The heat input to the tungsten is averaged out as the AC wave passes from one side of the wave to the other. On the half cycle, where the tungsten electrode is positive, electrons will flow from base material to the tungsten. This will result in the lifting of any oxide skin on the base material. This side of the wave form is called the cleaning half. As the wave moves to the point where the tungsten electrode becomes negative the electrons will flow from the welding tungsten electrode to the base material. This side of the cycle is called the penetration half of the AC wave forms.

**d. Alternating Current with Square Wave**: With the advent of modern electricity AC welding machines can now be produced with a wave form called Square Wave. The square wave has better control and each side of the wave can give a more cleaning half of the welding cycle and more penetration

**e. ACHF:** This setting is used for light metals such as aluminum and magnesium. It has two benefits; the frequency oscillation of the welding current breaks up surface oxidation and only places 50% of the heat on the work piece. Mainly used on: Aluminum, Magnesium

| Sl. No. | Property | DC, electrode positive | DC, electrode negative | AC |
|---|---|---|---|---|
| 1 | Penetration | shallow | Deep | Intermediate |
| 2 | Heat generation | 2/3rd at electrode, 1/3rd at workpiece | 1/3rd at electrode, 2/3rd at workpiece | 50% on both |
| 3 | Metal deposition rate | High | Low | Intermediate |
| 4 | Thickness of work | Thin sheets | Thick sheets | Intermediate |
| 5 | Stable smaller arc | Easier | Easier | Difficult |
| 6 | Arc blow | serve | Serve | Intermediate |

Table 1.2 Comparison of different welding current polarities [6].

## 1.4 Electrode for TIG welding

Pure tungsten electrodes can be used for TIG welding. Pure Tungsten is generally identified with a green tip. Used for non-ferrous metals such as aluminum, brass, and copper. Normally run on ACHF (High Frequency) with a shiny ball 1.5 times the diameter of the electrode. The ball is formed by putting the machine on DCRP and striking an arc on a piece of copper. Thoriated and zirconiated types give easier starting and better arc stability and are generally preferred. 1% Thoriated Tungsten is generally identified with a yellow tip. Used on all steels and cast iron. To grind, use a clean wheel and make certain all grinding marks go in the same direction as the shielding gas will flow. Use a rounded point for cast iron and a sharp point for steels. Thoriated tungsten electrodes contain 2% thoria (thorium oxide) and are used for dc welding. 2% Thoriated Tungsten is generally identified with a red tip. Applications are the same as the 1% Thoriated Tungsten. Zirconium Tungsten is generally identified with a brown tip. This specialized electrode is primarily used where X-ray quality welds are needed on stainless steel, titanium, and root passes on pipe systems. Zirconiated tungsten electrodes contain 2% zirconia (zirconium oxide) and are recommended for Ac welding of aluminium. The diameter of the electrode is chosen to match the current. The minimum current depends on arc stability. The maximum current a given diameter of electrode can carry is determined by the onset of overheating and melting. Rare Earth is used exactly as Thoriated Tungsten. Rare earth electrodes generally last longer and perform equal to or better than Thoriated Tungsten. Rare earth tungstens are superior to thoriated types, as rare earths emit no radioactive isotopes [2].

**COLOR CODE FOR TUNGSTEN ELECTRODES**

| Designation | | Chemical Composition Impurities ≤ 0.1% | | |
|---|---|---|---|---|
| ISO 6848 | AWS A5.12 | OXIDE ADDITIVE | TUNGSTEN | TIP COLOR |
| WT20 | EWTh-2 | $ThO_2$: 1.70–2.20% | 2% THORIATED | Red |
| WP | EWP | ~~~~~~ | PURE | Green |
| WL15 | EWLa-1.5 | $LaO_2$: 1.30–1.70% | 1.5% LANTHANATED | Gold |
| WC20 | EWCe-2 | $CeO_2$: 1.80–2.20% | 2% CERIATED | Gray |
| WL20 | EWLa-2 | $La_2O_3$: 1.80–2.20% | 2% LANTHANATED | Blue |
| WZ8 | EWZr-8 | $ZrO_2$: 0.70–0.90% | 0.8% ZIRCONIATED | White |
| LaYZr™ | EWG | $La_2O_3$: 1.3–1.7%; $Y_2O_3$: 0.06–0.10%; $ZrO_2$: 0.6–1.0% | 1.5% LANTHANATED 0.8% YTTRIATED 0.8% ZIRCONIATED | Chartreuse |

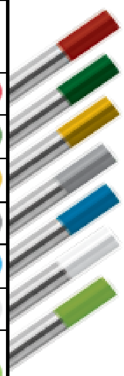

Table 1. 3 Color code for Tungsten electrode [2]

**TUNGSTEN ELECTRODE CHARACTERISTICS**

| Tungsten | Color Code | Characteristics |
|---|---|---|
| Pure | Green | Provides good arc stability for AC welding. Reasonably good resistance to contamination. Lowest current carrying capacity. Least expensive. Maintains a balled end. Used on transformer based machines only. |
| 2% Ceriated | Gray | Similar performance to thoriated tungsten. Easy arc starting, good arc stability, long life. Possible replacement for thoriated. |
| 2% Thoriated | Red | Easier arc starting. Higher current capacity. Greater arc stability. High resistance to weld pool contamination. Difficult to maintain balled end on AC. |
| 1.5% Lanthanated | Gold | Similar performance to thoriated tungsten. Easy arc starting, good arc stability, long life, high current capacity. 1.5% possible replacement for thoriated. 2% possible replacement for Pure. |
| 2% Lanthanated | Blue | Similar performance to thoriated tungsten. Easy arc starting, good arc stability, long life, high current capacity. 1.5% possible replacement for thoriated. 2% possible replacement for Pure. |
| .8% Zirconiated | White | Excellent for AC welding due to favorable retention of balled end, high resistance to contamination, and good arc starting. Preferred when tungsten contamination of weld is intolerable. Possible replacement for Pure. |
| LaYZr™ | Chartreuse* | Best for use on automated or robotic applications. Runs cooler than 2% Thoriated with longer life. Low to medium amperage range. |

Table 1.4 Characteristics of tungsten electrode [2]

## 1.5 TIG welding has a number of advantages and disadvantages

A. Advantages [6].

1. Excellent heat control allows joining of thin sections without burn through.
2. The heat source and the addition of filler metal are separately controlled.
3. TIG can be used on almost all metals including aluminum, magnesium and titanium.
4. It is a very precise method and produces the best appearance of any process.
5. The weld is finished as welded with no slag. Typically no cleanup is needed.
6. Narrow concentrated arc

B. Disadvantages [6].

1. It is the slowest of welding processes.
2. Exposure of the hot filler rod to the atmosphere can cause contamination.
3. Inert gas and tungsten electrode add to the cost.
4. Equipment costs are higher than other welding equipment.

## 1.6 Applications of TIG Welding

The TIG welding process is best suited for metal plate of thickness around 5- 6 mm. Thicker material plate can also be welded by TIG using multi passes which results in high heat inputs, and leading to distortion and reduction in mechanical properties of the base metal. In TIG welding high quality welds can be achieved due to high degree of control in heat input and filler additions separately. TIG welding can be performed in all positions and the process is useful for tube and pipe joint. The TIG welding is a highly controllable and clean process needs very little finishing or sometimes no finishing. This welding process can be used for both manual and automatic operations. The TIG welding process is extensively used in the so-called high-tech industry applications such as:

1. Nuclear industry
2. Aircraft
3. Food processing industry
4. Maintenance and repair work
5. Precision manufacturing industry
6. Automobile industry
7. The offshore industry
8. The petrochemical industry
9. Power plants, the chemical industry and Aerospace.

## 1.7 Process parameters of TIG welding

The good weldment needs high tensile strength, good surface finish and hardness. In order to produce any product with desired quality by welding, proper selection of process parameters is essential. The parameters that affect the quality and outcome of the TIG welding process are given below.

**a) Welding Current**

Higher current in TIG welding can lead to splatter and work piece become damage. Again lower current setting in TIG welding lead to sticking of the filler wire. Sometimes larger heat affected area can be found for lower welding current, as high temperatures need to applied for longer periods of time to deposit the same amount of filling materials. Fixed current mode will vary the voltage in order to maintain a constant arc current.

**b) Welding Voltage**

Welding Voltage can be fixed or adjustable depending on the TIG welding equipment. A high initial voltage allows for easy arc initiation and a greater range of working tip distance. Too high voltage, can lead to large variable in welding quality.

**c) Shielding Gases (Inert Gases)**

The choice of shielding gas is depends on the working metals and effects on the welding cost, weld temperature, arc stability, weld speed, splatter, electrode life etc. It also affects the finished weld penetration depth and surface profile, porosity, corrosion resistance, strength, hardness and brittleness of the weld material. Argon or Helium may be used successfully for TIG welding applications. For welding of extremely thin material pure argon is used. Argon generally provides an arc which operates more smoothly and quietly. Penetration of arc is less when Argon is used than the arc obtained by the use of Helium. For these reasons argon is preferred for most of the applications, except where higher heat and penetration is required for welding metals of high heat conductivity in larger thicknesses. Aluminium and copper are metals of high heat conductivity and are examples of the type of material for which helium is advantageous in welding relatively thick sections. Pure argon can be used for welding of structural steels, low alloyed steels, stainless steels, aluminium, copper, titanium and magnesium. Argon hydrogen mixture is used for welding of some grades of stainless steels and nickel alloys. Pure helium may be used for aluminium and copper. Helium argon mixtures may be used for low alloy steels, aluminium and copper. 100% Argon – most commonly used 25% Helium & 75% Argon – Mixture used when deeper root penetration and reduced porosity are desired.

Warning: Helium content greater than 25% may cause arc instability, when TIG welding

The flow rate of the gas is an important aspect of producing good TIG results.

Argon is generally preferred for the following reasons:

1. Easier arc starting.
2. Better arc stability (smoother arc).
3. Better cleaning of metals when used in AC mode.
4. Heavier than helium and therefore provides better coverage in drafty areas.
5. Less expensive than helium.

Exact gas selection depends on the type of work being done. Argon is the usual choice of maintenance welding shops. Argon is the best choice for aluminum, especially the 1100 grades. A mixture of 75% argon and 25% helium is best when welding austenitic stainless (308, 316, 304, etc.).

**d) Welding speed**

Welding speed is an important parameter for TIG welding. If the welding speed is increased, power or heat input per unit length of weld is decreases, therefore less weld reinforcement results and penetration of welding decreases. Welding speed or travel speed is primarily control the bead size and penetration of weld. It is interdependent with current. Excessive high welding speed decreases wetting action, increases tendency of undercut, porosity and uneven bead shapes while slower welding speed reduces the tendency to porosity.

Arc travel speed (ATS) in welding experiment can be computed by the following formula.

ATS (mm/min) = Measured Weld Length in millimeters x 60 Measured Time in Seconds.

**Constant parameter**

1. Work Piece Thickness
2. Tungsten electrode diameter
3. Gap between electrode tip and work piece
4. Welding technique (Down hand welding)

**Input Parameter**

1. Welding Current
2. Welding Voltage
3. Gas Flow Rate
4. Welding speed

## 1.8 Welding of stainless steel and stainless steel alloy

Most stainless steels are considered to have good weldability and may be welded by several welding processes including the arc welding processes, resistance welding, electron and laser beam welding, friction welding and brazing. For any of these processes, joint surfaces and any filler metal must be clean. The coefficient of thermal expansion for the austenitic types is 50% greater than that of carbon steel and this must be considered to minimize distortion. The low thermal and electrical conductivity of austenitic stainless steel is generally helpful in welding. Less welding heat is required [5].

## 1.9 Stainless steel

Stainless steel is a generic name for a number of different steels used primarily due to their corrosion resistance characteristic. Stainless steel is low alloy steel with a high percentage of chromium that is not less than 10.5%. Rust resistant is there because there is an oxide of chromium on the surface of the steel. The chromium present in stainless steel has great affinity for oxygen and forms a film of chromium oxide on the surface. Stainless steel does not readily corrode, rust or stain with water as ordinary steel does, but despite the name it is not fully stain-proof, most notably under low oxygen, high salinity, or poor circulation environments. It is also called corrosion-resistant steel or CRES when the alloy type and grade are not detailed, particularly in the aviation industry. The choosing of stainless steel in usually based on rust and heat resistant, mechanical properties, fabrication abilities, availability and cost. Mostly, rust resistant and mechanical properties are the main factor for choosing stainless steel. Stainless steel differs from carbon steel by the amount of chromium present. Unprotected carbon steel rusts readily when exposed to air and moisture. This iron oxide film (the rust) is active and accelerates corrosion by forming more iron oxide, and due to the greater volume of the iron oxide this tends to flake and fall away. Stainless steels contain sufficient chromium to form a passive film of chromium oxide, which prevents further surface corrosion and blocks corrosion from spreading into the metal's internal structure, and due to the similar size of the steel and oxide ions they bond very strongly and remain attached to the surface. Stainless steel is used where both the properties of steel and resistance to corrosion are required. Stainless steel base metals are grouped primarily into three classes depending on their crystal structure; austenitic (such as 302, 304, 308, 316, etc.), martensitic (such as 410, and 416), and ferritic (such as 409, and 430.). Austenitic grades are also available with a lowered carbon content (designated with an "L", such as 304L or 316L). These have in general, a higher resistance to corrosion in some definite environment, as well as a higher resistance to scaling at high temperature. Stainless Steel is iron-based alloy containing a minimum of 10.5% Chromium with or without other alloying elements. Based on the alloy content and the micro structure, stainless steels are classified into following three major categories [4].

**Austenitic**

This category of stainless steel contains 16 to 26% Chromium and 6 to22% Nickel. They are non- magnetic in annealed condition and have excellent corrosion resistance. They are not hardenable by heat treatment. However, they can develop high strength on cold working. They have excellent weldability, formability, hygiene factor and cryogenic properties. . On cold working they exhibit different degrees of magnetism. They are identified in the AISI 300 series.

**Ferritic**

This category of stainless steel contains 10.5 to 30% chromium without any Nickel. They are Ferro magnetic in nature and generally not hardenable by heat treatment. These steels possess good resistance to stress corrosion cracking and moderate weldability &formability. They are identified in the AISI 400 series.

**Martensitic**

This group contains 11 to 14% chromium without any nickel, but with a higher carbon content compared to the Austenitic and ferritic stainless steels. They are ferro-magnetic in nature and are hardenable by heat treatment. They possess moderate corrosion resistance and are identified in the AISI 400 series. Generally Stainless steels are alloys of iron, chromium, nickel, manganese, molybdenum, titanium, niobium, carbon and others just to mention the most important ones. Stainless steels include all the types of steel which are made corrosion resistant by alloying the steel with different alloying elements. TIG welding is an economically advantageous to welding of thinner stainless steels. It makes clean, smooth welds without porosities and craters possible even without welding from the backside. Welding is done in DC with negative polarity on the electrode. Ideally, austenitic stainless steels exhibit a single-phase, the face-centered cubic (F.C.C) structure, that is maintained over a wide range of temperatures. This structure results from a balance of alloying additions, primarily nickel, that stabilize the austenite phase from elevated to cryogenic temperatures. Because these alloys are predominantly single phase, they can only be strengthened by solid-solution alloying or by work hardening. Precipitation-strengthened austenitic stainless steels will be discussed separately below. The austenitic stainless steels were developed for use in both mild and severe corrosive conditions. Austenitic stainless steels are used at temperatures that range from cryogenic temperatures, where they exhibit high toughness, to elevated temperatures, where they exhibit good oxidation resistance. Because the austenitic materials are nonmagnetic, they are sometimes used in applications where magnetic materials are not acceptable. The most common types of austenitic stainless steels are the 200 and 300 series. Within these two grades, the alloying additions vary significantly. Furthermore, alloying additions and specific alloy composition can have a major effect on weld ability and the as-welded microstructure. Because of their physical properties, the welding behavior of austenitic stainless steels is different than the ferritic, martensitic, and duplex stainless steels. For example, the thermal conductivity of austenitic alloys is roughly half that of ferritic alloys. Therefore, the weld heat input that is required to achieve the same penetration is reduced. In contrast, the coefficient of thermal expansion of austenite is 30 to 40 percent greater than that of ferrite, which can result in increases in both distortion and residual stresses, due to welding. The molten weld pool of the austenitic stainless steels is commonly more viscous, or sluggish, than ferritic and martensitic alloys. This slows down the metal flow and wet ability of welds in austenitic alloys, which may promote lack-of-fusion defects when poor welding procedures are employed.

### 1.9.1 Austenitic stainless steel

Austenitic stainless steels have been used widely by the fabrication industry owing to their excellent high temperature and corrosion resistance properties. Some of the typical applications of these steel include their use as nuclear structural material for reactor coolant piping, valve bodies, vessel internals, chemical and process industries, dairy industries, petrochemical industries etc. Out of 300 series grade of these steels type 304 SS is extensively used in industries due to its superior low temperature toughness and corrosion resistance. One of the typical applications of type 304 SS include storing and transportation of liquefied natural gas (LNG), whose boiling point is 162 0C under 1 atmosphere.

### 1.9.2 Applications of austenitic stainless steel

SS 301**:** An austenitic stainless steel, it has the ability to attain high strength with some sacrifice of ductility through moderate or severe cold working. It can be used where high strength to weight ratio is required with good general corrosion resistance. By varying chemical composition within ASTM limits and temper rolling broad range of magnetic & mechanical properties can be achieved for a variety of applications. The susceptibility to carbide precipitation during welding restricts its use in many applications in favour of 304 grades. Transportation cars such as railway coaches, wagons, subway cars, electrical equipment and endless belts are some of the major applications where SS 301 is preferred [5].

**SS 301 L**

A Cr-Ni austenitic stainless steel, similar to SS301 with lower carbon (0.03%) and higher Nitrogen (0.20%), it has the ability to attain high strength without much sacrifice of ductility through moderate or severe cold working. It can be used where high strength to weight ratio is required with good general corrosion resistance & weldability. Broad range of mechanical properties with good weldability can be achieved by temper rolling.

**SS 304**

The most widely used austenitic stainless steel with a nominal composition of 18% Chromium & 8% Nickel it has excellent general corrosion resistance and forming characteristics. It finds application in transport, chemical, petrochemical and fertilizers industries, dairy, food processing, pharmaceutical industries, hospital equipment, cryogenic vessels, households as utensils & appliances, heat exchangers, machinery in paper, pulp, textile and beverage industries. In architectural applications it is used for panels, curtain walls, roofing etc. The weld ability of this grade is very good; it can be used in work hardened condition for uses requiring high strength.

**SS 304L**

An austenitic stainless steel similar to SS 304 but has lower carbon level (0.03% max). It is used in place of SS 304 for improved resistance to Intergranular corrosion and excellent Weldability. It is used for parts and structures which cannot be heat treated after welding. It has fewer tendencies to work hardened by cold working.

**SS-308**

Typical applications include stainless steel piping in refineries, oil and gas industries, and chemical plants. AISI Type 308 is an Austenitic Standard grade Stainless Steel. It is commonly called AISI Type 308 Chromium-Nickel steel or UNS S30800. It has increased chromium and nickel contents, thus increased corrosion resistance as compared to SS-304.

**SS 310**

This is an austenitic stainless steel with a higher Chromium and Nickel content. The restricted Carbon helps in better welding and formability. Because of their relatively high creep strength and mechanical properties at higher temperatures, these grades find applications where higher temperature and severe service conditions exist. They have high temperature scaling resistance but not good for high sulphur environments. Used for air heaters, annealing boxes, ovens, 20 carburizing boxes, fire box sheets, furnace linings, furnace stacks and dampers, gas turbine parts, heat exchangers, kiln linings, nozzle diaphragm assemblies for turbo jet engines, oil burner parts, paper mill equipment, oil refinery equipment and recuperater.

**SS 316**

It is a type of austenitic stainless steel with 2 to 3% Molybdenum to have improved corrosion resistance, particularly apparent for pitting and crevice corrosion resistance in chloride environment. This grade has good oxidation resistance. Continuous use at 425-860 0 C is not recommended due to carbide precipitation. Typical applications include architectural trims, marine exteriors, chemical processing equipment, food processing equipment, petroleum refining equipment, pharmaceuticals equipment, photographic equipment, pulp & paper processing equipment and textile finishing equipment. It has superior corrosion resistance as compared to other chromium-nickel steels when exposed to many types of chemical corrodents such as sea water, brine solutions etc. It is the second most common grade (after 304); the addition of molybdenum prevents specific forms of corrosion. It is used in the manufacturing and handling of food and pharmaceutical products where it is desirable to minimize metallic contamination. Type 316 is considerably more resistant to solutions of sulphuric acid, chlorides, bromides, iodides and fatty acids at high temperature.

**SS 316L**

This steel is similar to SS 316 with lower carbon level (0.03%) to have better corrosion resistance and Weldability. Low carbon content also reduces work hardening and improves ductility for cold forging, drawing etc., Low hot strength than SS316. Typical applications include food processing, chemical and petrochemical equipment, brewery equipment, coastal architectural panelling, laboratory equipments, heat exchangers, mining screens, chemical transportation containers etc.

### 1.9.3 Chemical composition

The following table shows various chemical composition present in stainless steel grades SS 304. This chemical composition used to determine at which category the plate is found.

| Base metal | Chemical composition | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Fe | C | Si | Mn | P | S | Cr | Mo | Ni | Cu |
| SS 304 | 71.5 | 0.074 | 0.50 | 0.88 | 0.016 | 0.016 | 18.38 | 0.044 | 8.29 | 0.029 |

Table 1.5 Chemical composition of the base material

**Effects of Alloying Elements and Impurities in Stainless Steels**

Carbon (C)

- A strong austenite former
- Added to some high strength alloys for hardening and strengthening effects.

Manganese (Mn)

- Austenite former.

Silicon (Si)

- A ferrite former
- Used to increase the corrosion resistance of austenitic steels
- Used to improve high temperature scaling resistance
- Used to improve resistance of high temperature steels to carburisation
- Promotes wetting by weld metal at 0,1 - 0,8%.

Chromium (Cr)

- A ferrite former
- Primary contributor to resistance to scaling and corrosion
- In the stainless steels, this element is used with little or no effect on high temperature strength and creep strength
- 12% chromium minimum essential for passivation.

Nickel (Ni)

- An austenite former
- Used to improve the general corrosion resistance against non-oxidising liquids
- Sometimes added in small amounts to straight chromium grades to improve the mechanical properties.

Molybdenum (Mo)

- A ferrite former
- Used to improve high temperature strength and creep resistance
- Used to improve general corrosion resistance of steels in non-oxidising media, and the resistance to pitting corrosion in all media.

Copper (Cu)

- Used to improve corrosion resistance of stainless steel in environments which are reducing rather than oxidising.

Niobium (Nb)

- A strong carbide former, used to stabilise austenitic stainless steels against the harmful precipitation of chromium carbides in the range of 480 - 820°C

- A strong ferrite former
- Added to some high strength alloys for hardening and strengthening effects
- Added to some martensitic straight chromium stainless steels to tie up the carbon and hence reduce the hardening tendency of the steels.

Titanium (Ti)

- A strong carbide former. Used to stabilise austenitic stainless steels against the harmful precipitation of chromium carbides in the range of 480 - 820°C
- A strong ferrite former
- Added to some high strength heat resisting alloys for its hardening and strengthening effects.

Cobalt (Co)

- Added to various alloys to impart strength and creep resistance at high temperatures.

Tungsten (W)

- Improves the high temperature strength and creep resistance of some high temperature alloys.

Nitrogen (N)

- A strong austenite former
- Used to minimise grain grown in high chromium straight chromium steels at high temperatures.

## 1.10 Problem statement

In manual TIG speed cannot be controlled so it is not considered as a parameter but in this present work welding speed controlled set up has been developed. The following input parameters are varied and their affect is analyzed by some experimental testing.

Input Welding Parameters

- Welding current

-Welding speed

- Gas flow rate

Output (Assessment of mechanical properties on weldment)

• Micro-hardness (Vickers) test

• Tensile testing

• Assessment of welded joints by using Optical microscope

•Weld Bead geometry (Bead width)

## 1.11 Objectives of the study

### 1.11.1 General Objective of the Study

The objective of the present study is to investigate the effect of welding parameters on the tensile strength of weld joint, micro hardness of the weld pool and microstructure of the weld zone at the cross section of the weld metal on 304 grade stainless steel using gas tungsten arc welding (GTAW) or tungsten inert gas welding (TIG) process.

### 1.11.2 Specific Objectives of the Study

In the present study an effort has been made to find best setting of input parameters of TIG welding to obtain better strength of SS plate.

- In this work to perform welding of stainless steel plate, speed controlled TIG welding setup has been made. Welding of the stainless steel plate has been done by changing the welding current and welding speed to get a high strength joint.
- Effect of welding speed and applied current on the tensile strength of weld joint, micro hardness of the weld and Optical microscopy images of the weld zone at the cross section has been investigated.

  Following tests and analysis work were carried out

  - Micro-hardness (Vickers) test
  - Tensile testing
  - Assessment of welded joints by using Optical microscope
  - Weld Bead geometry (Bead width)

## 1.12 Significance of the Study

The outcome of this study will give the better understanding the manufacturers to know the significance of welding parameters in TIG welding process. It will provide some guidelines that how to perform welding, experimental setup and expected result in correlation with welding parameters.

## 1.13 Scope of the Study

The scope of the study is to find out best combination of welding parameters on speed controlled set up of TIG welding of 4 mm stainless steel plate and analyzed the effect of welding parameters on the tensile strength of weld joint, micro hardness of the weld pool and Optical microscopy images of the weld zone at the cross section

## 1.14 Limitation of the study

The study of this experiment has been investigated the effect of welding parameters on stainless steel plate by TIG welding but the limitation is as summarized into following point

- Microstructure analysis may be carried on the welding joint by using SEM. etc to study the various grains but not in this experiment due to lack of facility.
- Tensile test and hardness test may also be carried with non-destructive tests such like radiography, ultrasonic tests etc. even though not performed in this experiment due to unavailability.

# CHAPTER TWO

## 2. LITERATURE REVIEW

### 2.1 Introduction

TIG welding is widely used for different types of metal & alloy and still lots of research work is going for the better performance of TIG welding process. The TIG welding process (or GTAW) is used when a good weld appearance and a high quality of the weld are required. A lot of research has been carried out throughout the world for predicting the strength and other mechanical properties of different kind of steel welded by TIG process. A brief review literature is being presented here.

**Saurabh Jetley. [4]** The study was to investigate the effects of various process parameters of tungsten inert gas welding on austenitic stainless steel SS-310 and SS-316. Four parameters namely welding current, type of gas, gas flow rate and included angle of weld plates during butt joint were varied at three levels. Orthogonal array L9 is used as per Taguchi Design of Experiments to finalise number of samples to be made for carrying out experimentation. Various welding tests like measuring the geometry of weld bead, bulk hardness test, dye penetration test, impact test, tensile test, micro-hardness test and chemical composition test of weld bead have been carried out on both materials to optimize best combination of process parameters in practice. The weld bead width for both materials depends on welding current and the type of shielding gas used in which current is most significant factor. On the other hand for weld bead height, the grove angle act as the most significant factor contributing to the result in a particular way and current is also having sub significant effect. Rockwell hardness test carried out on both material shows that there is no considerable variation in the values of hardness in the defined zone in comparison to base metal. Micro hardness test on both SS 310 and SS 316 shows that the current is the most significant factor affecting the micro hardness. Chemical composition result analysis for both material shows that there is a slight decrease in percentage composition of chromium because of formation of any compound in the welded region on account of tremendous heat generated during welding.

**Narender Bansal. [5]** The present study was investigate the welding aspects like weld bead geometry, micro hardness ,chemical composition of stainless steel (ss202 & ss304) during GTAW using three levels of welding current, shielding gas, gas flow rate to optimize the process following Taguchi experimental design. Bead width was measured and it was mainly depends on welding current. Micro hardness test showed that for ss304 the value of HVN was mainly dependent on welding current.

**Pankaj Ahirwar. [6]** In this work, autogenous TIG welding has been performed on 5 mm thick AISI 1020 mild steel plate without using any filler material. Wide range of welding current and scan speed has been tested for obtaining a full penetration welding. After performing welding, weld bead geometry and tensile strength of the weld has been investigated. It is observed that, by maintaining an appropriate combination of welding parameters penetration welding of plate is possible which gives strength almost similar to base material. The results of the conventional TIG welding process performed show that, maximum depth of penetration was obtained with parametric combination of minimum welding speed and maximum current. Depth of penetration and tensile strength of weld joint is maximum when adequate current is maintained at constant welding speed .From the experiment, it can be inferred that welding width and depth increases with increase in welding current.

**Ming Gao et al. [7]** The experiment conducted on CO2 laser-TIG hybrid welding with different shielding gas methods, is carried out on the 316L stainless plate. The results demonstrate that full weld penetration denoting efficient synergetic effect only can be obtained under the appropriate shielding gas parameters. The weld penetration of hybrid welding was determined by the plasma shape varying with the shielding gas parameters, especially the plasma height interacting with incident laser. The full penetrated weld cannot be generated by pure TIG torch method, but can be reached by the hybrid protecting method. The weld penetration of hybrid welding varies with the plasma shape determined by the shielding gas parameters, especially the plasma height interacting with incident laser. The higher the plasma height interacting with incident laser is the shallower is the weld penetration.

**Kanga et al. [8]** the effect of alternate supply of shielding gases in austenite stainless steel GTA welding was investigated. Basically two types of experiments were carried out. The former experiment was to measure the welding voltage waveforms to confirm the alternate supply of different gases in apparatus for alternate supply of shielding gases, and the latter one was to find the variations in welding distortion and welding speed with different types of shielding gases and type of gas supply. Discrete alternate supply of shielding gas is a new technology that alternately supplies the different kinds of shielding gases in weld zone. As a result, under the same welding conditions, compared with the welding by supplying pure argon, argon + 67% helium mixture by conventional method and the welding by supplying alternately pure argon and pure helium by alternate method showed the increased welding speed. Also, the alternate method showed the same welding speed with argon + 67% helium mixture without largely deteriorating of weld penetration. The alternate method with argon and helium compared with the conventional methods of pure argon and argon + 67% helium mixture produced the lowest degree of welding distortion. Argon (Ar) gas is the most commonly used shielding gas for GTA (gas tungsten arc) welding for aluminium and stainless. Helium (He) gas causes a high heat input due to high arc energy and thermal conductivity, and thus supports increasing welding speed and weld penetration. The alternate method with Ar and He presented the possibility of solving the problem of the increase in gas cost and welding distortion with the use of He in stainless steel welding.

**Shanping Lu et al. (9),** investigated the influences of argon and oxygen in helium base shielded GTA welding on the arc ignitability, bead protection and weld penetration by beadon-plate welding on SUS304 stainless steel. SUS304 stainless steel plates with a sulphur content of 0.002wt% pct and an oxygen content of 0.002wt% pct were used as the substrate with dimensions of 100mm×50mm×10mm. Experimental results show that the critical electrode tip work distance for arc ignition is increased from 1mm under pure He shielding to

5mm under He–50%Ar shielding. Small addition of oxygen content to the He–Ar mixed shielding can significantly change the weld shape from a wide shallow type to a narrow deep and the weld depth/width ratio can be doubled due to the change in the Marangoni convection from an outward to an inward direction. When the argon content in the He–Ar mixed shielding is below 30%, the shielding gas protection to the weld bead from the atmosphere is poor, and the weld bead surface is dirty and oxidized. Adding argon gas to helium gas can improve the arc ignitability of helium gas and make the arc stable because the Ar ionization energy (15.76 eV) is much lower than the He ionization energy (24.58 eV).

**Huang [10]** the study of the effects of activating flux in the weld morphology, arc profile, and angular distortion and microstructure of two different arc welding processes, namely, Gas Tungsten Arc Welding (GTAW) and Plasma Arc Welding (PAW) was carried out. The results showed that the activating fluxes affected the penetration capability of arc welding on stainless steel. An increase in energy density resulting from the arc constriction and anode spot reduction enhanced the penetration capability. The base material used in this study was austenitic stainless steel (AISI 304) with a chemical composition. The size of each specimen was 150 × 150 mm with a thickness of 5 mm. The specimens were roughly polished. Before welding, the flux powder was mixed with acetone to produce a paint-like consistency, and then a coating was brushed on the plate surfaces. Increasing the welding current decreased the cooling rate, therefore reducing the δ-ferrite content. Also, conventional GTAW was found to be a very high heat input process, thus exhibiting lower delta-ferrite content in a stainless steel weld.

**Tseng, Hsu. [11]** investigated the effect of activated tungsten inert gas (activated TIG) process on weld morphology, angular distortion, delta-ferrite content, and hardness of Type 316L stainless steels. Five kinds of oxide fluxes, MnO2, TiO2, MoO3, SiO2, and Al2O3, were used to study. An autogenous TIG welding was applied to 6 mm thick stainless steel plates through a thin layer of flux to produce a bead-on-plate welded joint. The oxide fluxes used were packed in powdered form. The experimental results indicated that the SiO2 flux facilitated root pass joint penetration, but Al2O3 flux led to the deterioration in the weld depth and bead width compared with conventional TIG process. Activated TIG welding can increase the joint penetration and weld depth to- width ratio, thereby reducing angular distortion of the weldment. To obtain high quality welds and stable weld arc, the activated TIG process requires large diameter electrodes to support a given level of the weld current. Activated TIG welding can increase the joint penetration and weld depth-to-width ratio, significantly reducing the angular distortion of the weldment. It was observed that the activated TIG welding increase the arc voltage thus the amount of heat input per unit length in a weld was also increased, and therefore the delta-ferrite content in weld metal increased.

**Squillace et al. [12]** carried out an investigation on microstructure and corrosion resistance of weld butt joints of AA 2024-T3. Two different welding processes were considered: a conventional tungsten inert gas (TIG) process and an innovative solid state welding process known as friction stir welding (FSW). Polarisation curve tests and electrochemical impedance spectroscopy were performed. In FSW joint, instead, lower temperatures involved in process and severe plastic deformations induced by tool motion allow rising of a complex situation: by a general point of view a slight decay of mechanical properties is recorded in nugget zone, flow arm and thermo-mechanically altered zone (TMAZ), while in heat-affected zone (HAZ), due to starting heat treatment of alloy under investigation, a light improvement of such properties is appreciated. Microhardness tests performed through the thickness of FSW joint allow pointing out the great differences among four different main zones: nugget zone (including flow arm), TMAZ, HAZ and unaffected zone (i.e. parent alloy). The first two zones were characterised by a general drop of mechanical properties, even though the nugget and flow arm zone show a slight recovery due to very fine grain structure, while the third one show a very slight increase.

**Cabello Munoz et al. [13]** investigated the comparative micro structural and mechanical characteristics of fusion welds (TIG) and solid-state welds (FSW) of Al–4.5 Mg–0.26 Scheattreatable aluminium alloy. Microstructures of base metal and welded zones are analyzed by optical (OM) and transmission electron (TEM) microscopy. Particular emphasis was laid on the evolution of hardening precipitates in welded areas. The corresponding mechanical properties are evaluated through micro hardness measurements and uniaxial tensile tests. The effect of a post-weld heat treatment on both microstructure and mechanical properties were also examined. The results suggest that hardening precipitates are comparatively more affected by the TIG than by the FSW process. This results in a substantial reduction of mechanical properties of TIG welds that can be partially recovered through a post-weld heat treatment. It appears that FSW joints exhibit higher mechanical properties than those obtained by A-TIG. Compared to base metal, YS of welded joints decreases by 20% for FSW and 50% for ATIG. This decrease is explained by a loss of strain hardening and a modification of Al3Sc hardening particles. The difference between friction stir welds and fusion welds is explained by a partial preservation of Al3Sc hardening particles in the case of FSW and a complete dissolution in the case of A-TIG.

**J.J. del Coz Díaz et al. [14]** in this study the thermal stress analyses were performed in the tungsten inert gas (TIG) welding process on two different stainless steel specimens in order to compare their distortion mode and magnitude. The finite element method including the birth and death technique is an efficient procedure to analyze the vertical displacement evolution at different plate locations in the welding process of stainless steels, as well as their angular deformation and longitudinal bending. The use of thermo graphic imaging in the context of TIG welding has been successfully demonstrated on a practical scale and helps to compare the thermal results in the subsequent numerical simulation at different locations and a specific time.

**Arivazhagan et al. [15]** carried out investigations to study the microstructure and mechanical properties of AISI 304 stainless steel and AISI 4140 low alloy steel joints by Gas Tungsten Arc Welding, Electron Beam Welding and Friction Welding. For each of the weldments, a detailed analysis was conducted on the phase composition, microstructure characteristics and mechanical properties. The results of the analysis showed that the joint made by EBW has the highest tensile strength (681 MPa) than the joint made by GTAW (635 Mpa) and FRW (494 Mpa). From the fractographs, it could be observed that the ductility of the EBW and GTA weldment were higher with an elongation of 32% and 25% respectively when compared with friction weldment (19%). Moreover, the impact strength of weldment made by GTAW is higher compared to EBW and FRW.

**Dongjie Li et al. [16]** in his present study compared double-shielded TIG method with the traditional TIG welding method under different welding parameters (i.e., speed, arc length and current). The strength of the Marangoni convection was calculated to estimate the influence of the welding parameters on the variations in weld pool shapes. The results show that changes in the welding parameters directly impact the oxygen concentration in the weld pool and the temperature distribution on the pool surface. The oxygen content and heat distribution on the weld pool surface are determinants of the pattern and strength of the Marangoni convection. Changes in the welding parameters directly change the heat input and the pattern of the Marangoni convection, thus controlling the shape of the molten pool. For the pure-He-shielded TIG process, the outward Marangoni convection was weakened with increasing oxygen content; thus, the D/W ratio increased slightly.

**Lothongkum et al. [17]** the TIG pulse welding parameters of 304L stainless steel sheet of 3 mm thickness in flat, vertical and overhead positions were investigated. The shielding gases were Ar, and Ar‡N2 (0±5%, v/v). The base and pulse currents in all welding positions were adjusted to achieve a weld bead contour corresponding to DIN 8563 class AS at 3.4 mm/s welding speed, 1 pulse/s pulse frequency and 55% on-time. In the vertical and overhead positions, gravitational force made the weld pool fall down, leading to undercut after solidification. With the appropriate welding parameters, the gravitational effect can be eliminated. It was found To gain a higher welding rate by increasing the welding speeds to more than 3.4 mm/s simultaneously with increasing pulse frequencies, pulse currents and base currents, was not successful.

**Balasubramanian et al. [18]** studied the effect of pulsed current Gas Tungsten Arc (GTA) welding parameters on corrosion behaviour of Ti–6Al–4V titanium alloy. Pulsed current gas tungsten arc welding was used to fabricate the joints. To optimize the number of experiments to be performed, central composite design was used. The investigation revealed increase in corrosion resistance with increase in peak current and pulse frequency up to an optimum value of the same and decrease in corrosion resistance beyond that optimum point. An increase in corrosion resistance with grain refinement was also detected. It was observed that effect of pulsing frequency and peak current had two regions with initially decreasing the corrosion rate and then increasing the corrosion rate irrespective of changes in base current and pulse on time. Current pulsing in GTAW lead to relatively finer and more equiaxed grain structure in titanium welds. The grain refinement due to current pulsing has resulted in increase in corrosion resistance. It is shown that out the four pulsed current parameters, peak current and pulse frequency are having predominant effect on corrosion properties.

**Correa et al. [19]** investigates the weldability of iron-based powder metal alloys Fe–Ni,
Fe–Ni–P alloys) using the pulsed gas tungsten arc welding process (GTAW) with three different filler metals (AWS R 70S-6, AWS R 309L, AWS R Fe–Ni). Results from this study indicate that powder metal Fe–Ni alloys may be successfully joined by pulsed GTAW with

filler metal of Fe–Ni alloy and mild steel in various thickness range (3–7 mm). Concerning to the powder metal Fe–Ni–P alloy, it may be joined by pulsed GTAW but a discerning selection of the filler metal and a careful control over the heat input. No excessive hardening was observed in the weld metal and HAZ of the powder metal Fe–Ni alloy as well as in the powder metal Fe–Ni–P alloy.

**Juang, Tarng. [20]** Presented the selection of process parameters for obtaining an optimal weld pool geometry in the tungsten inert gas (TIG) welding of stainless steel. Basically, the geometry of the weld pool has several quality characteristics, for example, the front height, front width, back height and back width of the weld pool. To consider these quality characteristics together in the selection of process parameters, the modified Taguchi method is adopted to analyze the effect of each welding process parameter on the weld pool geometry, and then to determine the process parameters with the optimal weld pool geometry. The optimization of process parameters can improve quality characteristics and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors.

**Benyounis et al. [21]** a comprehensive literature review of the application of various methods like design of experiment (DoE), evolutionary algorithms and computational networkare widely used to determine the welding input parameters that lead to the desired weld quality are have been discussed. Combining two optimization techniques, such as GA and RSM, would reveal good results for finding out the optimal welding conditions. Raveendra and Parmar have built mathematical models using the fractional factorial technique to predict the weld-bead geometry and shape relations (penetration, width, reinforcement height, and width to penetration ratio and percentage dilution). Andersen et al. have explained some concepts related to neural networks and how they can be used to model weld-bead geometry, in terms of equipment parameters, in order to evaluate the accuracy of neural networks for weld modelling. They carried out a number of simulations and they used actual GTAW data for this purpose. The data consisted of values for voltage, current, electrode travel speed and wire feed speed and the corresponding bead width, penetration, reinforcement height and bead cross-sectional area. The performance of neural networks for weld modelling was presented and evaluated using actual welding data. It was concluded that the accuracy of neural networks modelling is fully comparable with the accuracy achieved by more traditional modelling schemes.

**Nagesh, Datta [22]** explains an integrated method with a new approach for predicting the weld bead geometric descriptors and use of genetic algorithm for optimization of process parameters.

The properties of the welded joints are affected by a large number of welding parameters. . In an attempt to model the welding process for predicting the bead shape parameters, modelling and optimization of bead shape parameters in tungsten inert gas (TIG) welding process has been carried out. To optimize the process parameters for the desired front height to front width ratio and back height to back width ratio, genetic algorithmic approach has been applied. The proposed methods were found to be effective in determining the weld bead geometric descriptors for tungsten inert gas welding process.

**Dhas J et al. [23]** in his study has done a review on optimization of welding process.

According to him optimization of welding process parameters depend upon ability to measure and control the process variables involved in the welding process. An effective control of variables is required to obtain desired output. It is the simulation of welding process through finite element analysis which has made this possibility to measure and control the process variables. DOE is very good approach to conduct experiments in economical way. Taguchi method is extremely good as it is insensitive to variations in environmental conditions and other noise factors. Taguchi method uses special design of orthogonal arrays to study entire process parameters with small number of experiments. To analyse the results, Taguchi method uses a statistical measure of performance called signal to noise ratio, derived from electrical control theory.

**Bayraktar et al. [24]** study was undertaken with the objective of clarifying formability characteristics of welded thin sheet steels, such as Interstitial Free Steels (IFS) and Ferritic Stainless Steels (FSS) based on the LASER, TIG and resistance spot welding (RSW). The characterisation of basic parameters influencing formability of homogeneous; base metal (BMs) and welded parts (WPs) has been carried out. General micro structural observations indicate that a certain proportion of martensite is seen in the LASER welded parts of the nonstabilised grade of 430 and the amount of martensite is higher than that of TIG and RSW processes. The stabilised grades of 409 and 430Ti present entirely ferritic structure with a reasonable grain size. Correlation realized between the transition temperatures and deep drawability can be used for evaluating of the welding conditions and also of the material characteristics.

**Kumar, Shahi [25]** studied the influence of heat input on the microstructure and mechanical properties of gas tungsten arc welded 304 stainless steel. Three heat input combinations designated as low heat, medium heat and high heat were selected from the operating window of the gas tungsten arc welding process

(GTAW) and weld joints made using these combinations were subjected to micro-structural evaluations and tensile testing so as to analyze the effect of thermal arc energy on the microstructure and mechanical properties of these joints. The base material used were AISI 304

SS plates of sizes 200 mm x 100 mm x 6mm which were cut from a rolled sheet and the filler was 308 SS solid electrode of 3.15 mm diameter. The results of this investigation indicate that the joints made using low heat input exhibited higher ultimate tensile strength (UTS) than those welded with medium and high heat input. Significant grain coarsening was observed in the heat affected zone (HAZ) of all the joints and it was found that the extent of grain coarsening in the heat affected zone increased with increase in the heat input.

**Wang et al. [26]** investigated the effects of TIG Welding Parameters on Morphology and Mechanical Properties of Welded Joint of Ni-base Super alloy. The effect of welding parameters on the tensile strength and fracture were analyzed. Materials for experiments were plates of Ni-base super alloy; grade GH99, with a thickness of 1.2 mm and 1.5 mm respectively. The welding parameters were as follows: welding current 55~165A, welding speed 19-29cm/mm, impulse frequency 2~5Hz. Results show that the increase of welding current and the decrease of welding speed bring about the large amount of heat input in the welding pool and the enlargement of width and deepness of the welding pool.

**Prakash Mohan. [27]** to improve welding quality of Aluminum (Al) plate an automated TIG welding system has been developed, by which welding speed can be control during welding process. Welding of Al plate has been performed in two phases. During 1st phase of welding, single side welding performed over Al plate and during 2nd phase both side welding performed for Al plate by changing different welding parameters. Effect of welding speed and welding current on the tensile strength of the weld joint has been investigated for both type of weld joint. Optical microscopic analysis has been done on the weld zone to evaluate the effect of welding parameters on welding quality. Micro-hardness value of the welded zone has been measured at the cross section to understand the change in mechanical property of the welded zone.

## 2.2 GAPS IN LITERATURE

- Although many researchers have done testing and analysis on stainless steel grade SS310 and SS 316 but less work is done on welding parameters of TIG welding which is proposed in the present thesis work.
- No more work has been reported in the area of studying the welding speed controlled set up value in the weldment quality like mechanical properties and bead geometry of 304 stainless steel plate which is carried out in the present work.

# CHAPTER THREE

## 3. MATERIALS AND METHODOLOGY

### 3.1 Experimental setup

For proper welding, welding speed should be controlled, so that Speed controlled welding setup has been developed on lathe machine. The speed controlled welding setup with its main components is shown in figure 3.1.

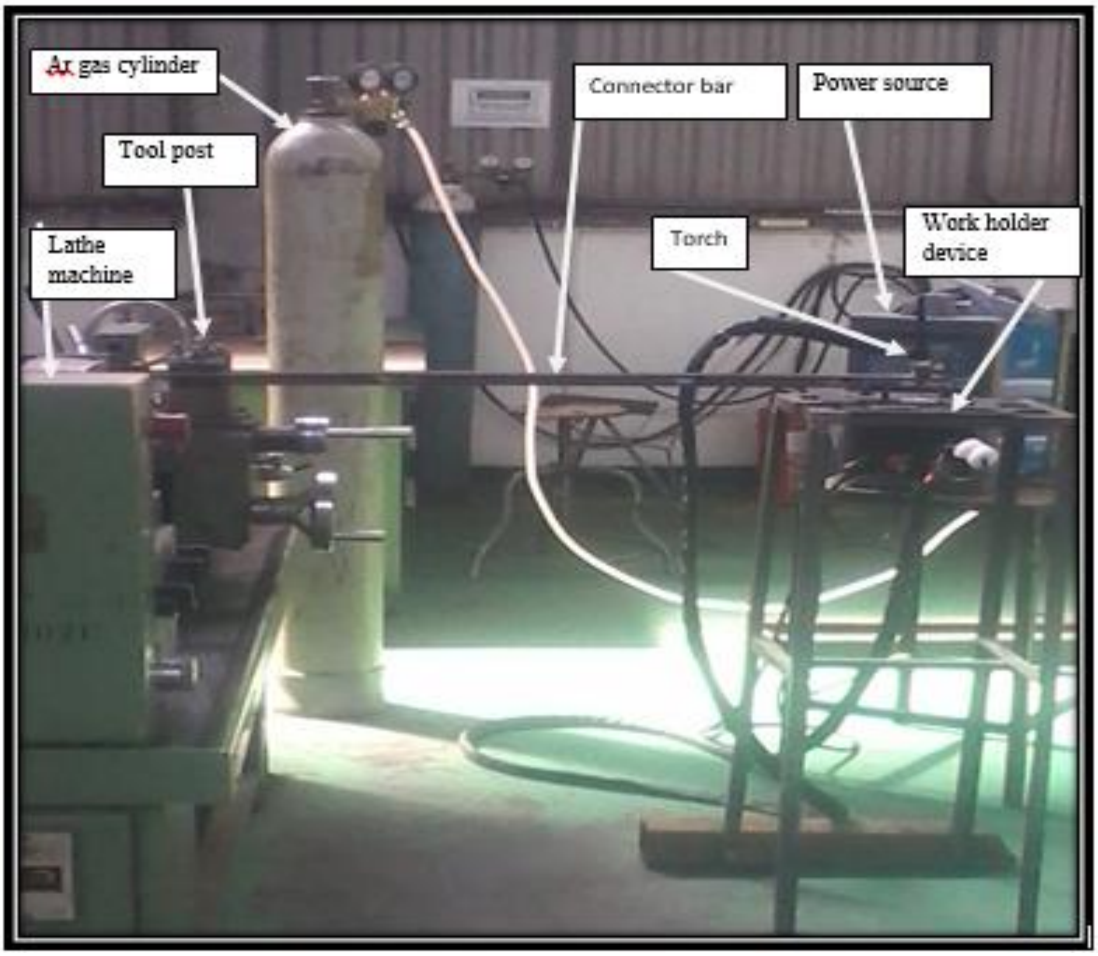


Figure. 3.1 – Experimental set-up for TIG welding

**a) Speed control unit (tool post)** – Here, speed control unit is a movable tractor which run with a predefined speed required for welding. TIG welding torch is fixed with strip steel which is connect with tool post (using a tool set as a clamp) so that during welding a stable and continuous arc form. Distance between the torch tip and work piece and angle of torch tip can also be control using the tool post. Movable tractor (tool post) is run in a particular speed over this rail in horizontal a straight line.

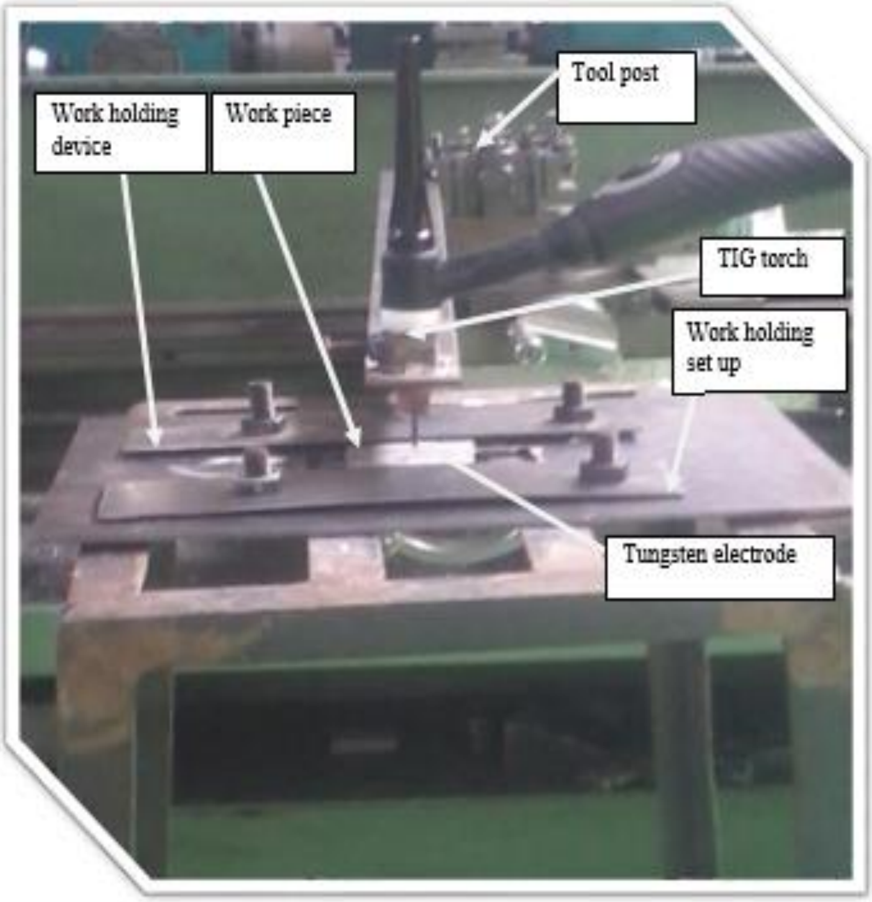


Figure 3.2 Tool post holding the welding torch

**b) TIG welding torch-** Torch is fixed with the movable tractor unit. A tungsten electrode is fixed in the torch and gas is flow through this. The torch was maintained at an angle approximate 90° to the work piece.

**c) TIG welding machine**– This is the main part of TIG welding setup by which controlled amount of current and voltage is supplied during welding. Smarty TX 250 model welding machine with current range 5-250 A and voltage up to 230 V, depending on the current setting has been used.

**d) Gas cylinder**- For TIG welding Ar gas is supplied to the welding torch with a particular flow rate so that an inert atmosphere formed and stable arc created for welding. Gas flow is control by regulator and valve.

**e) Work holding table**- a surface plate (made mild steel) is used for holding the work piece so that during welding gap between the tungsten electrode and work piece is maintained. Proper clamping has been used to hold the work piece.

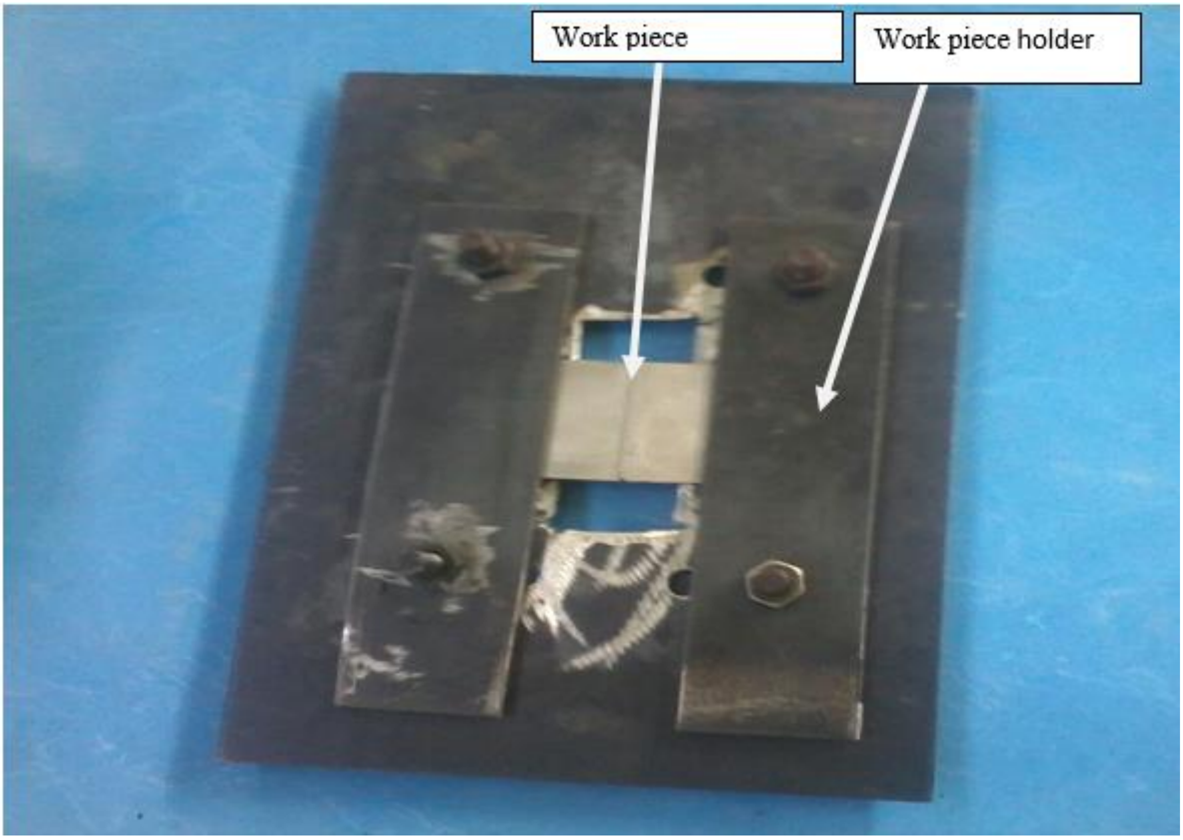


Figure 3.3 Work holding device

## 3.2 welding speed on the setup

Before performing the actual experiment a number of trial experiments have been performed to get the appropriate parameter range where welding could be possible.

| S.NO | Speed value (mm/s) |
| --- | --- |
| 1 | 4.2 |
| 2 | 5 |

Table 3.1 Speed value on speed controlled tractor (tool post)

## 3.3 Experimental procedure

1. In this phase of experiment, to study the feasibility of welding on 4 mm stainless steel plate, TIG welding has been performed without using any filler rod.
2. Stainless steel plates of 4 mm thick were cut in 50 mm x 50 mm dimension with the help of Wire cut Electro-discharge Machining (WEDM).
3. The edges to be weld was polished with emery papers of different grades (silicon carbide) to remove all impurities from the surface and to provide good surface finish. So that proper contact and wetting action between the plates to be joined.
4. After the sample preparation stainless steel plates were fixed in the work holding device with proper clamp through bolts.
5. Direct Current (DC) with direct polarity (negative electrode and positive work piece) was used to perform welding.
6. Thoriated tungsten electrode of 2.4 mm diameter was used as electrode [2]
7. For the experiment welding parameters selected are shown in table 3.2. Before performing the actual experiment a number of trial experiments have been performed to get the appropriate parameter range where welding could be possible and no observable defects like undercutting and porosity occurred.

| | |
|---|---|
| Dimension of stainless steel plate | 50mm x 50mm x4mm |
| Welding speed | 4.2 mm/s, 5 mm/s |
| Welding current | 120A-160A |
| Arc voltage | 17 -20V |
| Gas flow rate | 25 l/min |
| Current type | DC (negative electrode and positive work piece) |
| Distance between tip and weld center | 3 mm |
| Shielding gas | Argon |

Table 3.2 Welding parameters for TIG welding of stainless steel plate (SS304).

| Exp.No | Distance between tip and weld center (mm) | Gas flow rate (l/mim) | Welding current (A) | Welding speed (mm/s) |
|---|---|---|---|---|
| 1 | 3 | 25 | 120 | 4.2 |
| 2 | 3 | 25 | 130 | 4.2 |
| 3 | 3 | 25 | 140 | 4.2 |
| 4 | 3 | 25 | 150 | 4.2 |
| 5 | 3 | 25 | 160 | 4.2 |
| 6 | 3 | 25 | 120 | 5 |
| 7 | 3 | 25 | 130 | 5 |
| 8 | 3 | 25 | 140 | 5 |
| 9 | 3 | 25 | 150 | 5 |
| 10 | 3 | 25 | 160 | 5 |

Table 3.3 Experimental planning for TIG welding of stainless steel at constant Arc voltage.

## 3.4 Sample preparation for study the weld bead geometry

After performing the TIG welding of stainless steel plate, welded specimens were cut at the perpendicular to the weld scan direction with the dimension of 20 mm x 10 mm for taking optical microscope image of the welded zone. These welded specimens were cut with the help of wire electro discharge machine (WEDM). After that the samples were polished and chemical etched across the welded zone, before taken the optical image.

Specimens were prepared by usual metallurgical polishing technique using different grit size SiC polishing emery paper and also with diamond paste polishing. Nital solution was used as an etchant consist of ethyl alcohol (97%) and conc. $HNO_3$ (3%) and treated on the surface of welded zone. The penetration depth of weld was assessed by visual inspection.

## 3.5 Sample preparation for tensile testing

Mechanical testing plays an important role in evaluating fundamental properties of engineering materials as well as in developing new materials and in controlling the quality of materials for use in design and construction. If a material is to be used as part of an engineering structure that will be subjected to a load, it is important to know that the material is strong enough and rigid enough to withstand the loads that it will experience in service. As a result engineers have developed a number of experimental techniques for mechanical testing of engineering materials subjected to tension, compression, bending or torsion loading. The most common type of test used to measure the mechanical properties of a material is the tensile test. Tensile test is widely used to provide basic design information on the strength of materials and is an acceptance test for the specification of materials. Tensile strength test is one of the most common testing methods. It is used to determinate the behavior of a sample while an axial stretching load is applied. This test has to be performing under ambient or controlled conditions to determine the tensile properties of a material. Tensile testing is commonly used to determine the maximum load (tensile strength) that a material can withstand. For tensile testing of welded samples were cut into I shape as per ASTM E8. Tensile testing of the weld specimens were carried out in Universal Testing Machine (UTM). The tensile testing involved fixing the sample in UTM properly and then applying a gradually increasing force until shape transformation occurs in the specimen and it finally break. In this experiment two samples per test has been carried out.

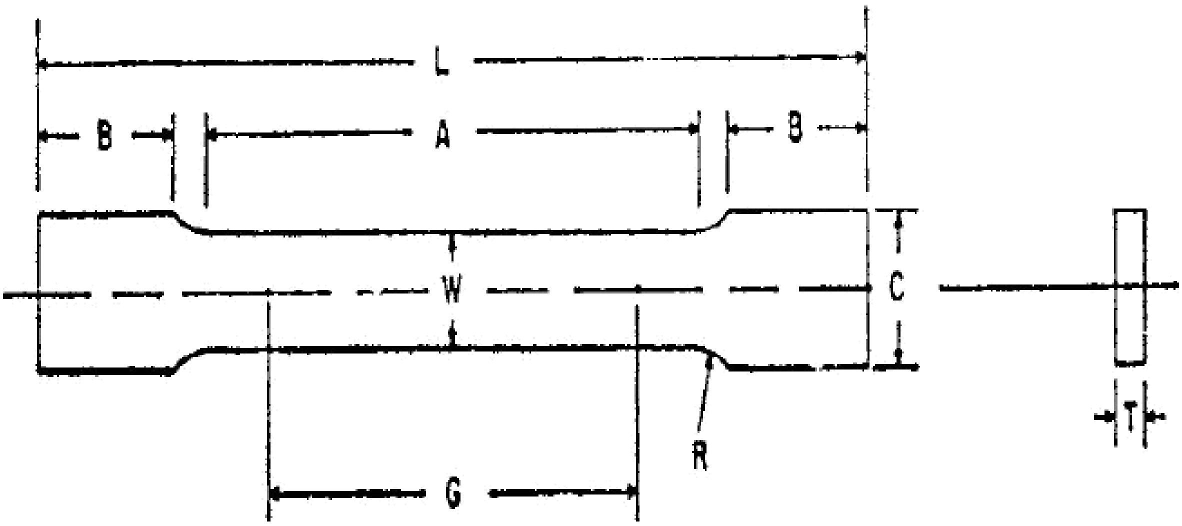


Figure 3.4 Schematic diagram for plate as per ASTM E8 standard

| | |
|---|---|
| Overall length (L) | 100 |
| Gauge length (g) | 25 |
| Width of grip section (C) | 10 |
| Length of grip section (B) | 30 |
| Radius fillet (R) | 6 |
| Width (W) | 6 |

Table 3.4 Dimension for tensile test as per ASTM E8 standard

## 3.6 Sample preparation for Hardness Testing

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. Hardness is not an intrinsic property of the material. The value of this property is the result of a defined measurement procedure, thus depending on the hardness method used; the hardness value will be different. All of the hardness tests involve the use of a specifically shaped indenter, significantly harder than the test sample. This indenter is press into the surface of the sample using a specific force. Either the depth or size of the indent is measured to determinate the hardness value. Hardness measurements are widely used for the quality control of materials because they are quick and considered to be non-destructive tests when the marks or indentations produced by the test are in low stress areas. There are many methods to determine the hardness, among those Vickers, Brinell and Rockwell hardness tests are frequently used. In this experiments Vikers's hardness test was used to assess the weldment quality. Vickers hardness is a measure of the hardness of a material, calculated from the size of an impression generates under load by a pyramid shaped diamond indenter. The diamond is pressed on the surface of material at loads ranging up to approximately 120 kilogram force and the size of the impression (not greater than 0.5 mm) is measured with the help of a calibrated microscope. The Vickers hardness number (HV) is calculated using the following formula:

$$HV = 1.854 (F/D2)$$

Where F being the applied load (measured in kilogram force) and D2 the area of the indentation (measured in square millimeters).

The Vickers hardness should be reported like 800 HV/10, which means a Vickers hardness of 800, was obtained using a 10kgf force. Extremely accurate readings can be observed in this test, which is one of the major advantages of the Vickers hardness test and just single type of indenter is used for each and every type of metals or surface treatments. A 20 mm x10 mm x 4 mm specimen were cut at the cross section for microstructural study and micro-hardness measurement from each sample. Before micro hardness measurement cross section of the welded specimen mounted and polished with 220, 600 and 1200 grit size polishing paper sequentially. Micro-hardness was measured with Vickers micro-hardness tester. In this experiment two samples per test has been carried out.

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 TIG welding experiments on Stainless steel

The below photo graphic image shows the variation in weld width and wettability with reference to two welding speed and five different current in TIG**.**

| Sample.no | current (A) | Welding speed (mm/s) | |
|---|---|---|---|
| | | 4.2mm/s | 5mm/s |
| 1 | 120 |  |  |
| 2 | 130 |  |  |
| 3 | 140 |  |  |

| | | | |
|---|---|---|---|
| 4 | 150 |  |  |
| 5 | 160 |  |  |

Figure 4.1 Welded specimens observation to assess the bead width for two different welding speed

### 4.1.1 Weld bead geometry at cross section of weld zone

Welding width for all the samples were measured by using digital vernier caliper as shown in table 4.1. The welding width then plotted against the applied welding current for different welding speed as shown in Figure 4.1. From the plot it is clearly seen that welding width increases almost linearly with increase of welding current.

| Sample No. | Current (A) | Speed ( mm/s) | Width (mm) |
|---|---|---|---|
| 1 | 120 | 4.2 | 4.14 |
| 2 | 130 | 4.2 | 6.22 |
| 3 | 140 | 4.2 | 6.70 |
| 4 | 150 | 4.2 | 7.04 |
| 5 | 160 | 4.2 | 7.63 |
| 6 | 120 | 5 | 4.98 |
| 7 | 130 | 5 | 6.82 |
| 8 | 140 | 5 | 7.05 |
| 9 | 150 | 5 | 7.66 |
| 10 | 160 | 5 | 8.04 |

Table 4.1 Width of weld zone in TIG welded samples

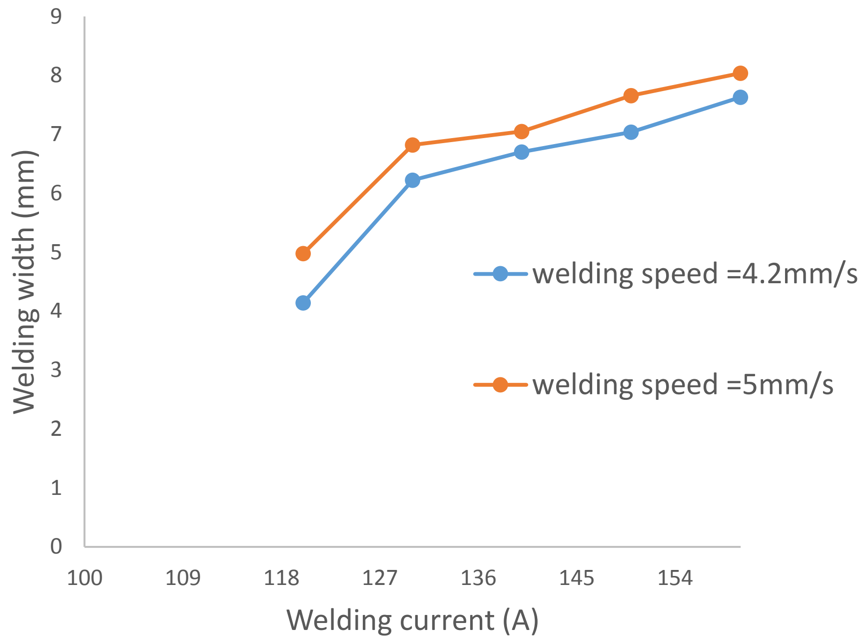


Figure 4.2 welded width of the samples with different welding speed and welding current

### 4.1.2 Optical microscopy images of the weld zone at the cross section

Figure. 4.3 shows optical microscopic image at cross section of weld zone by TIG welding process performed with different welding speed and current setting. The cross section of the weld zone shows a clear effect of the welding parameters like applied current and welding speed. So, the images show that, melting of the weld zone is not fully done for all different current and speed combination. But, it is seen that, weld melt pool depth is larger for higher current. It is also seen that, as speed increase for a particular current value, melt depth reduce. Depending on the welding speed and current setting this welding penetration is changed. It can be say from the observation of the figure that as welding current increases welding depth also increases for fixed value of welding speed. In another for a particular value of welding current welding depth found decreases as the welding speed increases .The visual observation of penetration depth is shown in the figure 4.3.

| Welding current (A) | Welding speed (mm/s) | |
|---|---|---|
| | 4.2 mm/s | 5 mm/s |
| 120 |  |  |
| 130 |  |  |
| 140 |  |  |
| 150 |  |  |

| | | |
|---|---|---|
| 160 |  |  |

Figure 4.3 optical microscopy photograph at the cross section of the welding done (after polishing the surface) with different current setting and welding speed

## 4.2 Micro-hardness test

Micro-hardness value of the welded zone was measured for all the welded specimens at the cross section to understand the change in mechanical property of the welded zone. Figure 4.4 shows micro-hardness value at the weld zone and table 4.2 shows the micro-hardness value at the welded zone taken from the centre of the welding zone towards the base material for different samples performed with different welding speed and welding current. From the graph it is found that for almost all the samples micro hardness value increases in the welding zone than the base material. After a certain distance these value reduces to the hardness of the base material for the sample processed with welding speed 4.2 mm/s and different current setting as shown in table 4.2. And for the welding done with welding speed 5 mm/s and different current setting micro-hardness value reaches to the micro-hardness value of base material after some distance from the center.

| Sample no | Welding current(A) | Welding speed(mm/s) | Hardness value at welded zone (HV) |
|---|---|---|---|
| 1 | 120 | 4.2 | 114 |
| 2 | 130 | 4.2 | 131 |
| 3 | 140 | 4.2 | 137 |
| 4 | 150 | 4.2 | 149 |

| | | | |
|---|---|---|---|
| 5 | 160 | 4.2 | 169 |
| 6 | 120 | 5 | 109 |
| 7 | 130 | 5 | 115 |
| 8 | 140 | 5 | 125 |
| 9 | 150 | 5 | 139 |
| 10 | 160 | 5 | 147 |

Table 4.2 Hardness value for sample at Welded zone

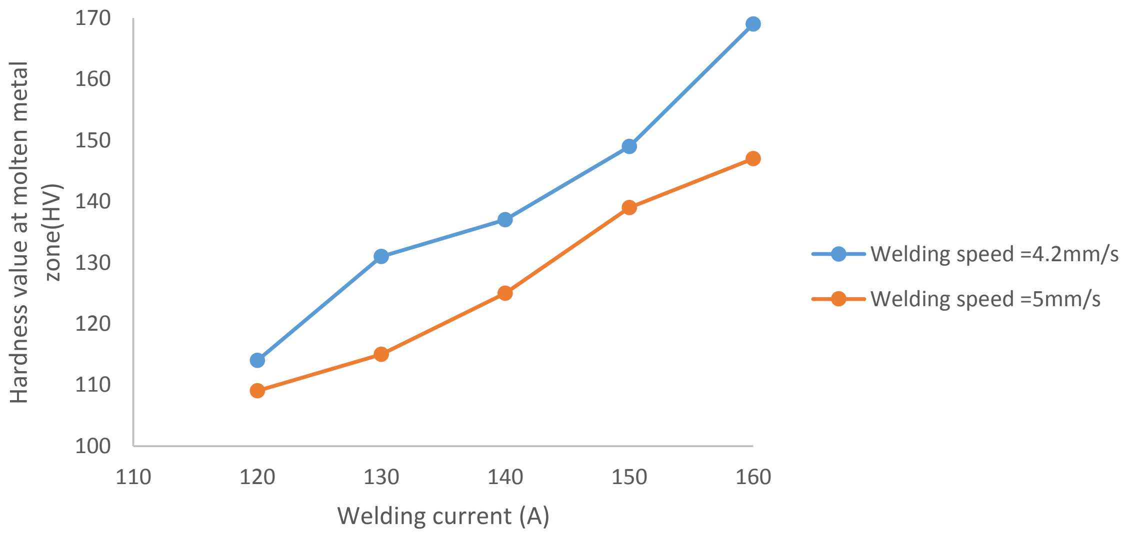


Figure 4.4 Vicker's Hardness (HV) value at welded zone, with welding speed 4.2 mm/s, 5mm/s and with different welding current.

| Sample no | Welding current(A) | Welding speed(mm/s) | Hardness value at molten metal zone (HV) | Hardness value at heat affected zone | Hardness value at base material zone |
|---|---|---|---|---|---|
| 1 | 120 | 4.2 | 114 | 103 | 98 |
| 2 | 130 | 4.2 | 131 | 116 | 105 |
| 3 | 140 | 4.2 | 137 | 117 | 106 |
| 4 | 150 | 4.2 | 149 | 129 | 119 |
| 5 | 160 | 4.2 | 169 | 140 | 131 |
| 6 | 120 | 5 | 109 | 100.5 | 97 |
| 7 | 130 | 5 | 115 | 105 | 99 |
| 8 | 140 | 5 | 125 | 117 | 108 |
| 9 | 150 | 5 | 139 | 129 | 120 |
| 10 | 160 | 5 | 147 | 127 | 110 |

Table 4.3 Comparative Hardness value at different three zones

## 4.3 Tensile test

In order to compare the strength of the welding joint at different welding conditions, tensile testing of welded specimen was performed using UTM. Table 4.4 shows the tensile strength value for all the welded joints produced at different welding speed and current setting. These values are much lower than the tensile strength of the base material. Tensile strength of the as received base material has been found 500 MPa. In Figure. 4.5 tensile strength of the welded joints are plotted against applied current for welding speed of 4.2 mm/s. From the graph also found that tensile strength value almost increasing for increasing current setting when welding speed is 4.2 mm/s. Similarly in Figure 4.6 tensile strength of the welded joints are plotted against applied current for welding speed of 5 mm/s. From this graph it is found that, welding done with 5 mm/s there is specific change of tensile strength due to change in current. Initially with increase current tensile strength of the welding increases. Comparing the figure 4.5 and 4.6 it is clearly seen that for almost all current setting condition tensile strength values of the welded joint performed with welding speed 4.2 mm/s are larger than the tensile stress values of the welded joint performed with welding speed 5 mm/s.

| Sample no | Welding current(A) | Welding speed (mm/s) | Tensile strength (Mpa) |
|---|---|---|---|
| 1 | 120 | 4.2 | 322.11 |
| 2 | 130 | 4.2 | 355.23 |
| 3 | 140 | 4.2 | 405.22 |
| 4 | 150 | 4.2 | 403.56 |
| 5 | 160 | 4.2 | 524.29 |
| 6 | 120 | 5 | 299.27 |
| 7 | 130 | 5 | 325.67 |
| 8 | 140 | 5 | 397.54 |
| 9 | 150 | 5 | 432.65 |
| 10 | 160 | 5 | 462.24 |

Table 4.4 Tensile strength value of different welded Samples

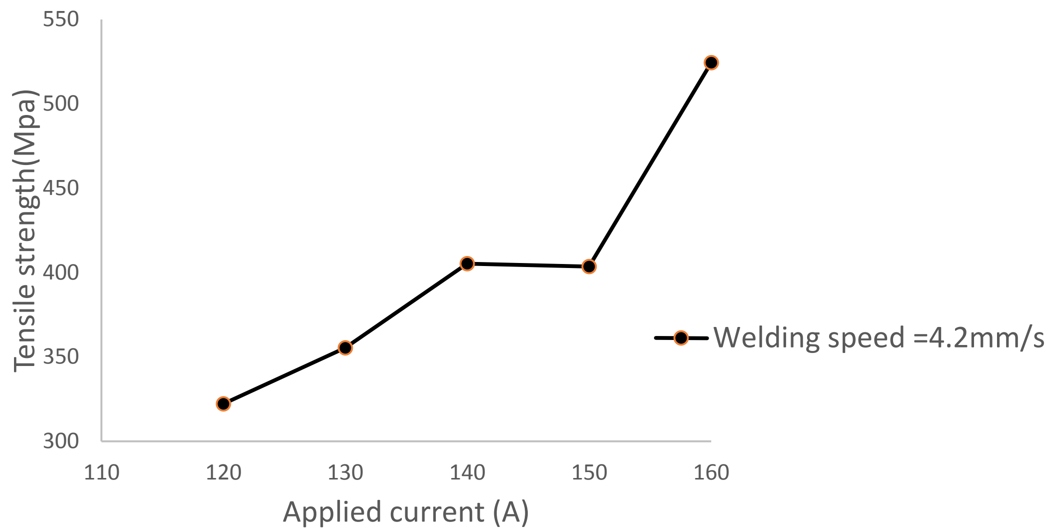


Figure 4.5 Tensile strength of the welded joint against applied current for welding speed of 4.2 mm/s.

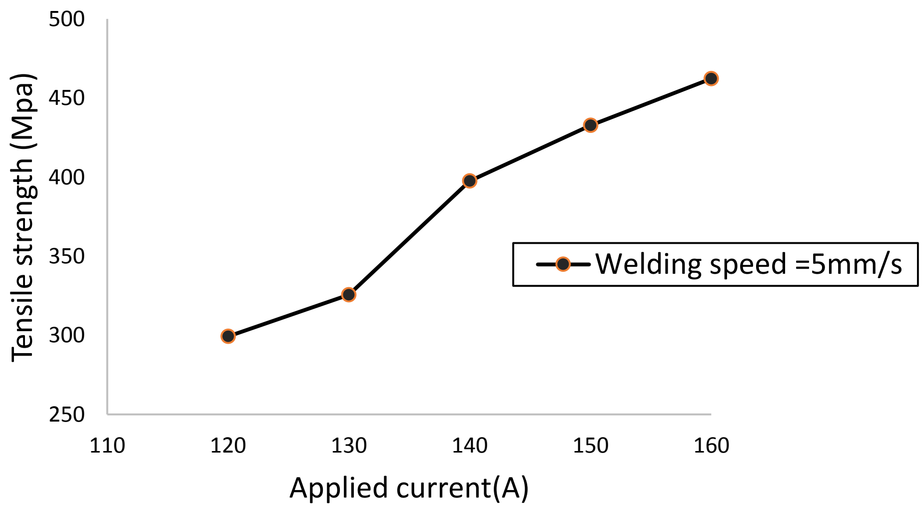


Figure 4.6 Tensile strength of the welded joint against applied current for welding speed of 5 mm/s.

# CHAPTER FIVE

# CONCLUSIONS

Findings of the present investigation can be summarized into following points

- Gas Tungsten Arc welding process parameters Welding Speed and Welding Current were important control on welding materials.
- TIG welding parameters has been affected the weld strength and hardness.
- The results of the TIG welding process performed show that, maximum depth of penetration was obtained with parametric combination of minimum welding speed and maximum current.
- From the graphs plotted, it can be inferred that welding width increases with increase in welding current.
- With welding speed controlled set up of TIG welding system uniform welding of stainless steel plate can be possible.
- Welding strength or tensile strength of the weld joint depends on the welding parameters like welding speed and welding current. With the increase in current, tensile strength of the weld joint increases.
- Hardness value of the weld zone change with the distance from weld centre due to change of microstructure.
- At lower welding speeds and high welding current strength is more due to more intensity of current.

## 5.1 Future scope

- In present work welding is performed without any filler material. A filler rod/wire feeding system can be included in the system so that by using filler rod/wire stiffener plate can be welded to improve the strength of weld. Welding setup can also be used for welding of some other materials.
- Microstructure analysis may be carried on the welding joint by using SEM, XRD. etc to understand better weldability and weld fusions at welded joints.
- The non-destructive tests such as radiography, ultrasonic tests etc can be used to study pinhole, hot tearing at different higher rating.

- Tensile test and hardness test may also be carried with non-destructive tests such like radiography, ultrasonic tests etc.
- Shielding gas composition carried to study its effect on various properties of stainless steel plate.

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