Experimental Investigation on Autogenous Tungsten Inert Gas (TIG) Welding of AISI 1020 Mild Steel

A Thesis Submitted to

National Institute of Technology, Rourkela

In Partial fulfillment of the requirement for the degree of

Master of Technology

In

Mechanical Engineering

By

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Rourkela -769008

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CERTIFICATE

This is to certify that the thesis entitled "**Experimental Investigation on Autogenous Tungsten Inert Gas (TIG) of AISI 1020 Mild Steel**" being submitted by Pankaj Ahirwar (213ME2400) for the partial fulfillment of the requirements of **Master of Technology degree** in **Production Engineering** is a bonafide thesis work done by him under my supervision during the academic year 2014-2015 in the Department of Mechanical Engineering, National Institute of Technology Rourkela, India.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date:

Place: Rourkela

Dr. Manoj Masanta
Assistant Professor
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Pankaj Ahirwar

Abstract

Tungsten Inert Gas welding is also known as Gas Tungsten Arc Welding (GTAW), is an advance arc welding process become a popular choice when a high level of weld quality or considerable precision welding is required. However, the major problems of TIG welding process are its slow welding speed and limited to lower thickness material in single pass. 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. Activated flux has also been used to improve the weld depth. After performing welding by maintaining different gap between the plates to be welded, weld bead geometry and tensile strength of the weld has been investigated. It is observed that, by maintaining an appropriate gap full penetration welding of plate is possible which gives strength almost similar to base material.

Keywords - Tungsten Inert Gas welding, Activated flux, Tensile test, Hardness test and A - TIG welding process.

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Chapter 1

Introduction

Welding is a process of joining two similar or dissimilar metals by fusion, with or without application of pressure and with or without use of filler metal. Weldability of the material depends upon various factors like the metallurgical changes that occur due to welding, change in hardness of material, in and around the weld and the extent of cracking tendency of the joint. A range of welding processes have been developed so far using single or combination of factors like pressure, heat and filler material used.

1.1 Classification of Welding processes

I. Homogeneous welding
II. Heterogeneous welding
III. Autogenous welding

I. Homogeneous welding – Welding of thick plates using filler metal used as per needs according to thickness of plate. The filler material used to provide better strength to the joint. In this process filler material is same as base metal. Different types of homogeneous welding process commonly used are:

a) Arc welding – Filler material generally used as consumable electrode for manual arc welding and metal inert gas welding.
b) Gas welding – An external filler rod is required for gas welding.
c) Plasma arc welding – In case of Plasma arc welding also an external filler rod is necessary for welding.
d) Thermit welding – In case of thermit welding a molten material from some chemical reaction is added.

In case of homogeneous welding solidification occurs directly by growth mechanism without nucleation stage.

II. Heterogeneous welding – A filler material different from the base material is used for welding. The solidification in heterogeneous weld takes place in two stages *i.e.* nucleation and growth.

Since, Homogeneous and Heterogeneous welding process required external filler material therefore an arrangement for this filler rod feeding (in case of automated system) make the process complex and costly.

III. Autogenous welding – A weld joint can be developed just by melting of edges of plates or sheets. This type of welding used especially if plate thickness is less than 5 mm. No filler is added during autogenous welding. All types of solid phase welding, resistance welding and fusion welding without filler rod corresponding thin category of welding are examples of this category. Following are the some specific advantages of autogenous welding process:

- Suitable for high production rate.
- Heating of the workpiece is confined to very small parts which results in less distortion.
- Possible to weld dissimilar metals as well metal plates of different thickness.
- High speed welding is possible.
- Since no external material is used, the process is very economical.
- Since no filler rod is used, process can be automated easily.

Various types of Autogenous welding process

a) Resistance welding – Among these process resistance welding is limited for specific application and not useful for thick plate and complicated shape. Further for welding different thickness plate different diameter electrode is required.
b) Laser beam welding – Laser Beam Welding process is very expensive process not for small industry.
c) Electron Beam Welding – Similar to Laser Beam Welding process, Electron Beam Welding process is also very expensive process.
d) Friction Stir Welding – Friction Stir Welding is mainly limited to low melting temperature and soft material.
e) Gas welding without filler rod
f) TIG welding without filler rod

1.2 Tungsten Inert Gas welding

Tungsten Inert Gas welding is also known as Gas tungsten arc welding (GTAW), is an arc welding process that uses a non-consumable tungsten electrode to produce arc. The welded area is protected from atmospheric contamination by an inert shielding gas (argon or helium), and a filler is normally used to weld thick plate. The electrode is no consumable since its melting point is about 3400°C. In tungsten electrode 1 to 2% thorium and zirconium are added to improve electron emission, arc stability and current carrying capacity. A constant current welding power supply produces energy which is conducted across the arc through a column of highly ionized gas and metal vapors known as plasma. Heat input in GTAW does not depend on the filler material rate. Consequently, the process allows a precise control of heat addiction and the production of superior quality welds, with low distortion and free of spatter.

1.2.1 Principle of TIG welding

In TIG welding process, the electrode is non consumable and purpose of it only to create an arc. The heat-affected zone, molten metal and tungsten electrode are all shielded room atmospheric contamination by a blanket of inert gas fed through the GTAW torch. Fig. 1 shows schematic diagram of the working principle of TIG welding process. Welding torch consist of light weight handle, with provision for holding a stationary tungsten electrode. In the welding torch, the shielding gas flows by or along the electrode through a nozzle into arc region. An electric arc is created between electrode and the workpiece material using a constant current welding power source to produce energy and conducted across the arc through a column of highly ionized gas and metal vapors. The electric arc produce high temperature and heat can be focused to malt and join two different parts of workpiece.

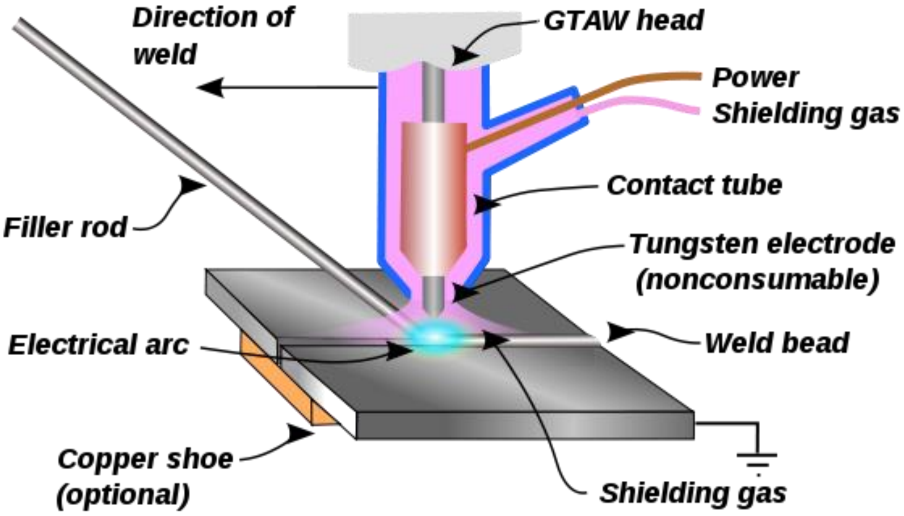


Fig. 1 Schematic diagram of working principle of TIG welding [Ref. 1]

1.2.2 Different types of welding current

Both the direct current (DC) and alternating current (AC) may be used for TIG welding. When the work is connected to the positive terminal of DC welding machine and the negative terminal to an electrode the welding set up is said to have straight polarity. When work is connected to negative and electrode to positive terminal then the welding set up is said to have reversed polarity.

Table 1 Comparison of different welding current polarities [Ref. 3]

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

1.2.3 Advantages of TIG welding process

- Concentrated arc produced for control heat input to the workpiece. It resulting in a narrow heat-affected zone.
- This process is done without use of flux, therefore no slag formation during welding process.
- No Sparks or Spatter because of no transfer of metal across the arc during TIG welding.
- Compared to other arc welding processes like flux cored welding, fewer amounts of fumes or smokes are produced.
- Welding of thin material is possible.
- Welding dissimilar type material is possible.
- Welding of different types of metal and metal alloys are possible by proper control
- Welding of different types of metal and metal alloys is possible.

1.2.4 Disadvantages of TIG welding process

- Low travel speeds than other welding processes to make the process slow.
- Low filler material deposition during welding compare to other arc welding process.
- High skills are required for manual welding process.
- Welding equipment cost is higher than other arc welding process.

1.2.5 Areas of application of TIG welding

TIG welding is often used for jobs that demand high quality welding such as for instance.

- The offshore industry
- The petrochemical industry
- Power plants
- The chemical industry
- The food industry
- The nuclear industry
- Automobile
- Aerospace

1.3 Welding process parameters of TIG welding

1. Welding current – Constant current type power source are used for TIG welding process. The preferred polarity for TIG welding process depends upon the type of workpiece material being welded. Direct Current (DC) with straight polarity is used for Cu alloy and stainless steel. DC with reverse polarity is used for magnesium. The Alternating Current (AC) is more versatile in welding for steel and aluminium. Fixed current mode varies the voltage to maintain a constant arc current.

2. Arc voltage - This can be fixed or adjustable depending on the equipment used for TIG welding. Some metals require a specific voltage range for welding. A high initial voltage is required for easy arc initiation. It also allows for a greater range of working tip distance between electrode and workpiece. Too large voltage, can lead to greater variability in workpiece quality.

5. Shielding Gas – Shielding gas is required for TIG welding to protect weld area from atmospheric contamination. If atmospheric gases (oxygen and nitrogen) are come in contact

with tungsten electrode, arc or welding metal cause fusion defect and porosity. Various shielding gases are available including mixtures of argon, helium and hydrogen. Mostly argon is used as a shielding gas for TIG welding. The choices of shielding gas affect depth of penetration, surface weld profile, strength, brittleness and hardness.

4. Gas flow rate – A uniform flow of inert gas is required to shield the molten metal. Gas flow rate can vary, proper selection of flow rate is required for ensure weld quality and improve efficiency. The value of gas flow rate is dependent on the thickness of the workpiece material to be welded. Lower flow rate required for manual welding than automatic welding process.

5. Welding speed – The amount of energy transferred per unit length of weld is inversely proportional to the welding speed. Maximum value of welding current with low speed provides maximum heat energy to the weld. Compare with the high welding speed in TIG welding low welding speed reduces the tendency of porosity.

1.4 Autogenous TIG welding

A weld joint produced by melting the contact edge surfaces and subsequently solidifying it at room temperature (without addition of any filler metal) is called “autogenous weld”. Thus, the composition of the autogenous weld metal corresponds to the base metal only. However, autogenous weld is crack sensitive when solidification temperature range of the base metal to be welded is significantly high. TIG welding process performed without application of filler material is known as autogenous TIG welding process. Autogenous TIG welding is preferred especially for less than 5 mm thick plate. The advantages of this process are that, it is economical process as compare to heterogeneous or homogenous welding process as no edge preparation and filler material are required. Figure 2 shows schematic diagram of autogenous TIG welding process.

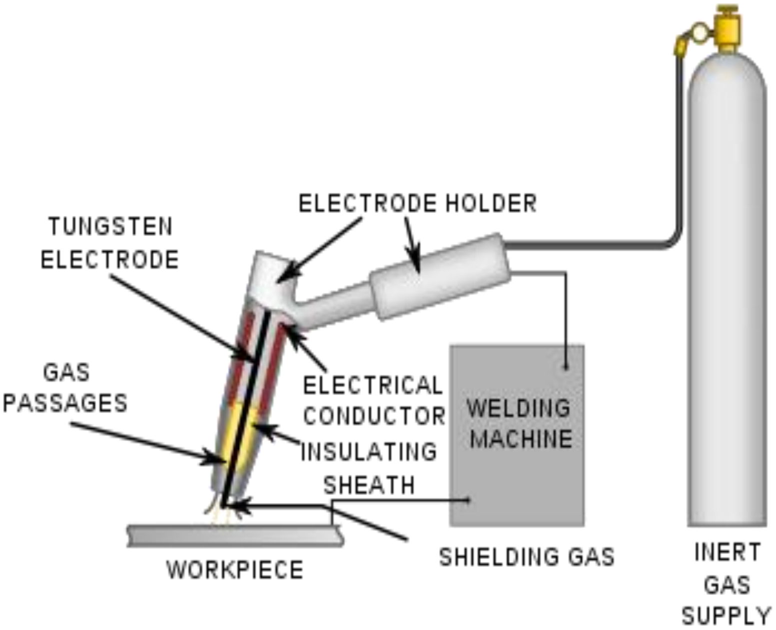


Fig. 2 Schematic diagram of Autogenous TIG welding [Ref. 1]

1.5 TIG welding on Mild Steel

TIG welding is widely used for fabrication of different types of materials like aluminum, mild steel and stainless steel. Maximum 6 mm thick mild steel plate can be weld by TIG welding. Mild Steel weld by TIG welding is more precise and cleaner than other arc welding process like manual arc welding or Metal Inert Gas welding. Mild steel is ductile material and can be easily machined. Welding of mild steel plate required to give different structural shape to produce various machine components. TIG welding is capable of achieving highest qualities weld and most versatile. TIG welding provides high integrity that is required at the root and in conjunction with weld speed. TIG welding machine are available in high current rating as well as low current rating. TIG welding provides 150 A to 350 A range of current which is useful for welding of thick mild steel plate. Table 2 and 3 shows mechanical properties and percentage composition of mild steel respectively.

Table 2 Mechanical properties of Mild Steel [Ref. 5]

Mechanical Property	**Mild Steel**
Density	7.85 g/cc
Young's Modules	190 - 210 GPa
Tensile strength	394.7 MPa
Carbon percentage	< 1.5 % C
Hardness	111 HB
Yield strength	294.8 MPa

Table 3 Percentage composition in Mild Steel [Ref. 8]

Alloy	**Percentage (%)**
Chromium	0.069
Nickel	0.01
Carbon	0.18
Manganese	0.8
Sulphur	0.04
Phosphorus	0.04
Silicon	0.4
Fe	Balance

1.5.1 Applications of Mild steel

- Mild steel materials are available in a variety of structural shapes and easily welded into tube, tubing and pipe. Mild steel pipes are used for pipelines in gas and oil industry.
- Mild steel has balance strength and ductility and good wear resistance so used in automobile industries, large structures, forging, nozzle and automotive components.
- Mild steel is used to produce dissimilar joint with stainless steel, application of this dissimilar joint in thermal power industry.
- Welding of mild steel plate is required to give different shapes to produce various machine components.

Chapter 2

Literature Review

TIG welding is widely used for different types of metal & alloy and still lots of research work is going for better performance by TIG welding process.

Krishnan et al. [6] done experiment to analyze the microstructure and oxidation resistance at different regions in the mild steel weld by TIG welding. During welding process a sharp change in the microstructure due to complex thermal cycle and rapid solidification was observed. This micro-structure change also affects the mechanical properties and oxidation resistance of the mild steel weld. Autogenous TIG welding was performed on 12 mm thick mild steel with 200 A current, 19 V voltage and 100 mm/min welding speed. Finer grain size was obtained at weld metal and heat affected zone.

Raj and Varghese [7] predict the distortion developed during TIG welding of low carbon steel. In their study, have developed three dimensional finite element model like longitudinal, angular or transverse distortion. Distortion in welding produced due to non-uniform heating and cooling. To validate the model welding was performed with welding current 150 A, electrode gap 3 mm, gas flow rate 25 l/min, electrode diameter 0.8 mm and Argon as shielding gas. They concluded that, maximum distortion occurs at surface opposite to the weld and along X direction of weld compare to other two directions.

Abhulimen and Achebo [8] performed experiments to identify the economical welding parameters using Response surface methodology (RSM) during TIG welding of mild steel pipe. Welding Parameters considered were gas flow rate 25 to 30 l/min, welding current 130 to 180 A, arc voltage 10.5 to 13.5 volt and argon as shielding gas. Results showed that, by using TIG welding of mild steel maximum tensile and yield strength of 542 MPa and 547 MPa was achieved respectively.

Mishra et al. [9] have done comparison of mechanical properties between TIG and MIG welded dissimilar joints. Mild steel and stainless steel dissimilar material joints are very common structural application. These dissimilar joints provide good combination of mechanical properties like corrosive resistance and tensile strength with lower cost. Welding parameters considered for MIG welding were welding current 80-400 A and voltage 26-56 volt. TIG welding was performed with 50-76 A current & 10-14 volt voltage. TIG welded dissimilar joint provide better tensile strength because of less porosity. Both dissimilar joint have best ductility & yield strength for TIG and MIG welding.

Fujii et al. [10] developed an advanced activated TIG welding method for deep penetration of weld joint. Maragoni convection induced on the molten pool by surface tension gradient. In order to control Maragoni convection small amount of oxidizing gas was used. Welding process done with welding current 160 A, welding speed 0.75 mm/s, electrode gap of 1mm and $Ar\text{-}O_2$ shielding gas. They observed that Maragoni convection changes from inward to outward and weld shape become wide and shallow.

Kuo et al. [11] investigate effect of oxide fluxes during TIG welding of 6 mm thick dissimilar joint between mild steel and stainless steel. The Cao, Fe_2O_3, Cr_2O_3 and SiO_2 fluxes were used in powder form. These powders were mixed with acetone to produce paint. Before welding a thin layer of flux was brushed onto the surface of the joint to be welded. TIG welding was performed with welding speed 150 mm/min, welding current 200 A and gas flow of 12 l/min. The result indicates that surface appearance of TIG welds produced with oxide flux formed residual slag. TIG welding with SiO_2 flux powder can increase joint penetration and weld to depth ratio.

Vikesh et al. [12] studied the effect of activated flux on TIG welding process. They focused on the effect of penetration in mild steel by TIG welding process. Compare to other arc welding process it having small depth of penetration. An activating flux powder is used to avoid this problem. Taguchi optimization is used to optimize welding process parameters using activating TIG welding method on mild steel. They observe from experimental result that improves in depth of penetration at weld zone with increase weld current. Depth of penetration is inversely proportional to the travel speed.

Pal and Kumar [13] studied the effect of activated TIG welding on wear properties and dilution percentage in medium carbon steel welds of 12 mm thick plate. TiO_2 and Cr_2O_3 fluxes were used in powder form. Flux powder was uniformly mixed with acetone and brushed onto the surface of joint to be welded. DC current and straight polarity was used with constant welding speed. A single pass TIG welding was performed with 180A welding current. The result indicated that TiO_2 flux coated weld increased the dilution on base metal as compare to Cr_2O_3 flux coated weld.

Nayee et al. [14] studied the effect of oxide based fluxes on metallurgical and mechanical properties of weld joint. Tungsten inert gas welding process is used to produce welds between 6mm thick mild steel and stainless steel plate with activating flux. In this investigation ZnO, TiO_2 and MnO_2 powder were used. Welding process performed with welding current 200 A, arc voltage 12.5 V and welding speed of 55 mm/min. Highest width to depth ratio get under $TiO_2$and ZnO fluxes compare to conventional TIG welding process. Among all three fluxes TiO_2 shows lowest angular deformation.

Ruckert et al. [15] show that during TIG welding process application of activated fluxes improve weld penetration and process competitiveness. They summaries the investigations on TIG welding of stainless steel, plain carbon steel, aluminum and titanium using activating flux. Welding process performed with 150 A & 175 A current and 15 cm/min welding speed. It was revealed that fluxes based on fluorides contribute to enhanced weld penetrations of titanium and SiO_2 flux for stainless steel, plain carbon steel and aluminum. The importance of flux homogeneity, flux composition and profile are shown to be primordial in determining width to depth ratio of weld.

Dhanda et al. [16] done experiment to show the effect of activated fluxes on mild steel welds. Maximum 2 to 3 mm thick plates of stainless steel and carbon steel can be weld with TIG welding under autogenous mode. The activating flux welding process is considered as feasible alternative to increase process productivity. Grade 91 steel is used as a workpiece material. A TIG welding was applied on P91 steel in which oxide powders CaO, ZnO, Fe_2O_3, TiO_2, MnO_2 and CrO_3 were used as flux material to produce a bead on plate weld. This method is responsible for increase in depth of penetration and also reduction in weld width. Heat input was increased with use of activated fluxes.

Fujii et al. [17] done comparative study of strength characteristics of mild steel and cast iron weld using various welding process. An important contribution would be made to fabrication industry through capability being available for joining of cast iron to mild steel using welding process. Selection of welding processes and consumables was based on the welding technologists and skilled welding operatives in industrial welding. Four commonly used welding processes (Gas welding process, metal arc welding process with a covered electrode, Metal Active Gas welding and TIG welding) were finally selected for production of specimens. The test specimens produced with metal active gas welding show good elongation and high tensile strength.

Mahajan et al. [18] studied the effect of mechanical arc oscillation on the weld metal grain structure in mild steel using TIG welding. For same welding parameters columnar grain were observed in the weld without arc oscillation and smaller sized grain observed in weld with arc oscillation. Mild steel weld grain structure is affect by various welding parameters like arc voltage, welding current, welding speed and types of welding process. It was found that higher strength for weld with oscillation compare to without arc oscillation on weld. Hardness of weld specimen with arc oscillation was less than without arc oscillation on weld.

Pasupathy and Ravisankar [19] have done optimization of tungsten inert gas welding parameters using Taguchi technique for dissimilar joint of low carbon steel and aluminium. Welding current, welding speed and distance between work material and electrode were used as input parameters in three level for optimization of the process.

Dye et al. [20] observe quasi steady state phase evolution and transient stresses produced around the TIG welding torch in plain carbon steel during TIG welding process. The dimensions of tubes were 203 mm in diameter and 3.2 mm in thickness. The TIG welding process performed under autogenous mode and DCEN condition. Input welding parameters were 35 A current, 14 V voltage& 0.5 mm/s welding speed. This technique is also applied to identify materials where stress state is require to modified for minimize cracking. Experiment shows that compression in HAZ just behind TIG welding torch is observed.

Vasiri et al. [21] done experiment to determine arc efficiency of TIG welding by calorimetric method. A water cooled calorimeter was designed to measure arc efficiency. TIG welding process was performed using two polarities (DCEN and DCEP) with 5 mm arc length on mild steel. The principle of water cooled method is based upon heat transfer from workpiece to water. TIG welding was done with 250 A current DC power source. Experimental results show that arc efficiency decreases with increment in arc length. Arc efficiency is not affected by gas flow rate. It is also independent from welding current.

Meng et al. [22] performed experiment to obtain high welding speed by using TIG and metal active gas (MAG) hybrid arc welding of mid steel. The effect of welding parameters on weld appearance and speed were analyzed through orthogonal experiment. Mechanical properties and microstructure of the welded specimen were tested. These specimens were compared with conventional MAG weld. Hybrid arc welding process was performed with welding current 350 A, gas flow rate of 9.5 l/min on 2.5 mm thick mild steel plate. Hybrid arc welding achieve 3.5 m/min welding speed under condition of high quality of weld. Mechanical property of hybrid arc weld is greater than conventional MAG weld.

Zuber et al. [23] performed experiment to investigate the effect of oxide based flux on 8 mm thick austenitic stainless steel plate. They show the effect on welding distortion, hardness value, ferrite number and depth of penetration on weld. SiO_2 flux is used in powder form mixed with acetone and paint of bead plate. The experimental result showed that this technique can increase depth of penetration at weld zone. Hardness value of weld increased due to the high temperature of joint. Welding distortion was more under autogenous mode but with the application of flux angular distortion of weld sample seems to be reduced.

2.1 Motivation and Objectives of present works

From the literature review it is observed that, though TIG welding is mainly performed on stainless steel and other high quality materials, however for precision quality welding to be done on mild steel component this process will be useful when welding performed in automated system as well as without using any filler rod. During autogenous TIG welding for not using any filler material, it is found that penetration depth or melt depth restricted to certain depth, when welding performed on thick plate. Using activated flux some work was reported for TIG welding on dissimilar materials as well as for stainless steel which improve the penetration of welding to some extend. Further during autogenous TIG welding without using filler rod, when plates are kept side by side and no gap provided between them, the depth of penetration or melting depth is also limited to a certain value, since molten material does not flow towards the bottom side of the joint. Therefore, for proper flow of molten material towards the bottom of the joint, a suitable gap must be maintained for autogenous TIG welding. On the basis of above observation, in the present work autogenous TIG welding has been performed conventionally and using activated flux. Further to get an optimum gap between the plates for TIG welding of 5 mm thick mild steel plate different gap value has been considered. Following are the detail objective of the present work.

- To perform autogenous TIG welding of 5 mm thick mild steel plate (AISI 1020) without using any filler rod and study the effect of welding current and welding speed.
- To study the weld depth and width and micro structure of the weld area obtained after TIG welding for different welding condition

- To study the effect of various welding parameter like arc voltage, welding current and welding speed.
- To perform TIG welding of 5 mm thick mild steel plate using a layer of TiO_2 coating (activated flux).
- To perform TIG welding of 5 mm thick mild steel plate by maintaining different gap between the plates to be welded.
- To measure the tensile strength of the weld joint.
- To measure macro-hardness of welding zone.

Chapter 3

Experimental planning and procedure

For the present work total experiments were performed in three different phases

In first phase autogenous TIG welding of 5 mm thick mild steel plates were performed without using any filler rod at different welding current and scan speed condition to see the effect of welding & speed and to obtain a current and speed range for approximate welding.

In second phase TIG welding of 5 mm thick mild steel plate was performed after applying a layer of TiO_2 flux and compared the weld properties with the welding done without flux.

In third phase, TIG welding was performed by maintaining different gap between the workpieces to be welded and study the effect of this gap on the welding performance mainly weld bead geometry and tensile strength of the weld.

3.1 Experimental setup

For the present project work an autogenous welding set up has been developed to perform welding with a fixed velocity without the application of filler material. A movable vehicle is used to hold TIG torch. The distance between workpiece and torch tip will remain constant the welding process. The speed of movable vehicle is controllable and can be varied according to the requirement of the welding speed and amount of heat required. Figure 3 shows experimental setup for present work. The welding setup for autogenous TIG welding process consists following components:

1. Welding torch
2. Electrode
3. Power supply
4. Inert gas supply unit
5. Work holding device
6. Movable vehicle holding the welding torch
7. Rail Track

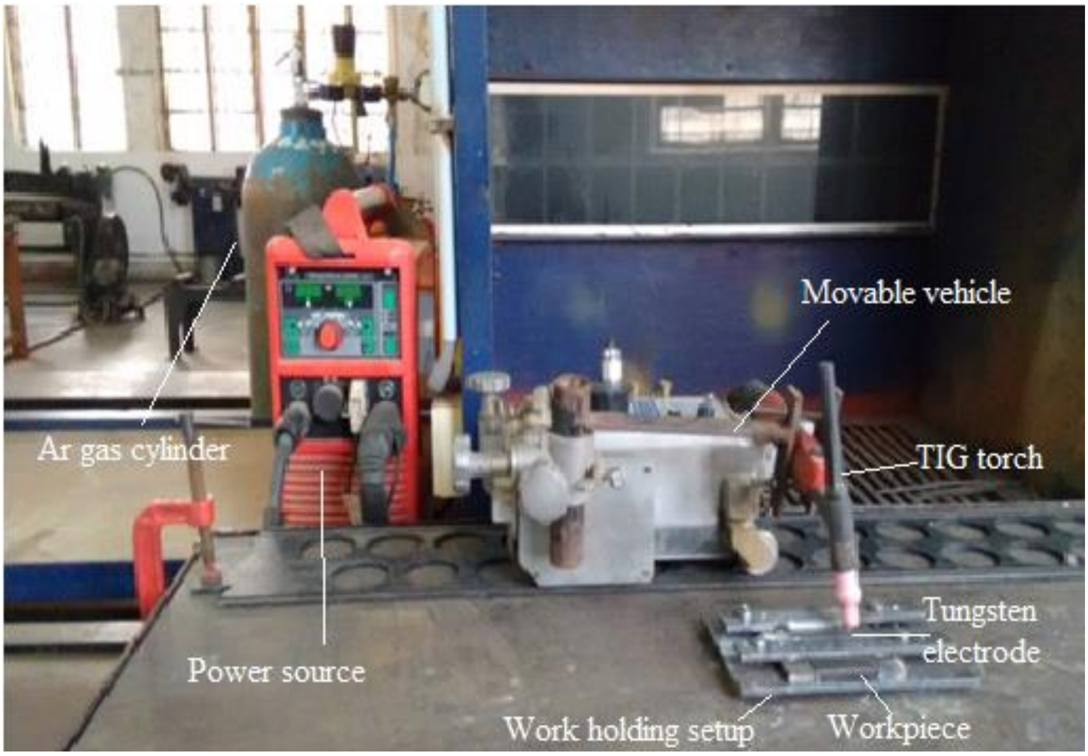


Fig. 3 Experimental setup of TIG welding

1. Welding torch – TIG welding torch is capable for both automatic and manual operation. The automatic and manual torches are similar in construction. The manual torch has a handle while the automatic torch normally comes with a mounting rack. The internal metal parts of a torch are made of hard alloys of copper or brass in order to transmit current and heat effectively. The size of the welding torch nozzle depends on the amount of shielded area desired. The main purpose of TIG torch is to carry the welding current and shielding gas to the weld. For present work a manual torch has been fixed with the movable tracker using clamp arrangement to make it automated. Figure 4 shows welding torch of autogenous TIG welding setup.

Fig. 4 Welding torch

2. Electrode – A non consumable tungsten electrode is used in TIG welding process. The tungsten electrode held firmly in the center of the torch and around the electrode a constant flow of shielding gas. The electrode used in GTAW is made of tungsten or tungsten alloy due to its highest melting temperature among the pure metals. Tungsten electrode is surrounded by a gas nozzle. This gas nozzle is generally made of ceramic material. For present experiment 2.4 mm diameter tungsten electrode has been used.

3. Power source – A constant current power source is used for TIG welding process. Direct current with straight polarity is used for welding of mild steel plate. Work material is connected to the positive terminal of DC welding machine and negative terminal to an electrode holder, this welding condition is said Direct Current with straight polarity. The DC power supply used for TIG can be steady or pulsed. For present work DC power supply in steady condition has been used where current is fixed and consequently voltage can vary to maintain a stable arc.

4. Inert gas supply unit – A gas cylinder is used to supply Argon gas to the welding torch. Argon gas is supplied from gas cylinder with a suitable gas flow rate. Gas flow is controlled by regulator and valve. The purpose of supplying inert gas is to shield the weld zone in order to protect it from atmospheric contamination which leads to welding defects. For present experiment gas flow in the range 12-15 l/min has been flown.

5. Movable vehicle – A movable setup is used to provide constant welding speed for TIG welding operation. This movable tractor is used to hold the welding torch. It also help in maintaining a proper gap between tip of the tungsten electrode and welded area of the workpiece. Manually it is difficult to maintain a constant weld speed and gap between electrode and workpiece. So with the help of a portable moving tractor welding speed and gap between workpiece and electrode can be easily controlled. Figure 5 shows a movable vehicle to hold the welding torch.

Fig. 5 Movable vehicle holding the welding torch

6. Work holding setup – It is used to hold the workpiece material. Proper clamping is require to hold the workpiece during welding process, so that during heating and cooling workpiece should not bend. Further if welding done by keeping the workpiece directly on metal plate heat will flow by conduction method and does not concentrate in the welding zone. Therefore work holding device designed in such a way that just below the weld zone of plate some gap is maintained. Figure 6 shows setup of work holding device.

Fig. 6 Work holding device

7. Rail track – Vehicle is move over this rail track in a straight path. Rail track is properly clamped by C clamp with the table.

3.2 Calibration of welding speed

Before start the welding process speed of the movable vehicle was calibrated to get a required welding speed and establish different speed values are shown in table 4.

Table 4 Welding speed on movable tractor

Sl. No.	Number on equipment	Welding speed (mm/s)
1.	1	2.33
2.	1.5	2.96
3.	2	3.5

3.3 Single pass autogenous TIG welding on Mild steel plate

In this phase of experiment, to study the feasibility of autogenous welding on 5 mm mild steel plate, TIG welding has been performed without using any filler rod. 5 mm thick mild steel plates were cut in 50 mm x 50 mm dimension with the help of band saw. The edges to be welded were grinded with surface grinding machine, so that proper contact is possible between the plates to be joined. Other surfaces were also polished with emery paper (silicon carbide) to remove all impurities from the surface and to provide require surface finish.

After the sample preparation mild steel plates were fixed in the work holding device with proper clamp through bolts. Direct Current (DC) with direct polarity (negative electrode and positive workpiece) was used to perform welding. Zirconiated tungsten electrode of 2.4 mm diameter was used as electrode. Three different current value and scan speed has been selected as shown in the table 5 and total 9 experiments were performed.

Table 5 Welding parameters for autogenous TIG welding of mild steel

Dimension of mild steel	50mm x 50mm x 5mm
Welding speed	2.33 mm/s, 2.96 mm/s and 3.5 mm/s
Arc voltage	14 – 15 V
Welding current	170 A, 190 A & 210 A
Gas flow rate	12 l/min
Current type	DC (positive workpiece& negative electrode)
Distance between tip and weld center	3 mm
Shielding gas	Argon

Table 6 Experimental planning for autogenous TIG welding of mild steel

Exp. No.	Welding current (A)	Welding speed (mm/s)
1	170	2.33
2	170	2.96
3	170	3.5
4	190	2.33
5	190	2.96
6	190	3.5
7	210	2.33
8	210	2.96
9	210	3.5

3.3.1 Sample preparation for study the weld bead geometry

After performing the TIG welding of mild 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 weld zone. These welded specimens were cut with the help of wire electro discharge machine. After cutting the samples, polishing & chemical etching were performed at the weld cross section, before taken the optical image. Specimens were prepared by usual metallurgical polishing method using different grit size SiC polishing paper and subsequent diamond paste polishing. Nital solution consist of ethyl alcohol (97%) and conc. HNO_3 (3%), has been used for etching the weld cross section by dipping the polished surface in it for 10 sec. Melting depth or weld penetration was checked for each weld sample from the change in microstructure using an optical microscope.

3.3.2 Sample preparation for tensile testing

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 an INSTRON Universal Testing Machine (UTM) with maximum load capacity of 600 KN. 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.

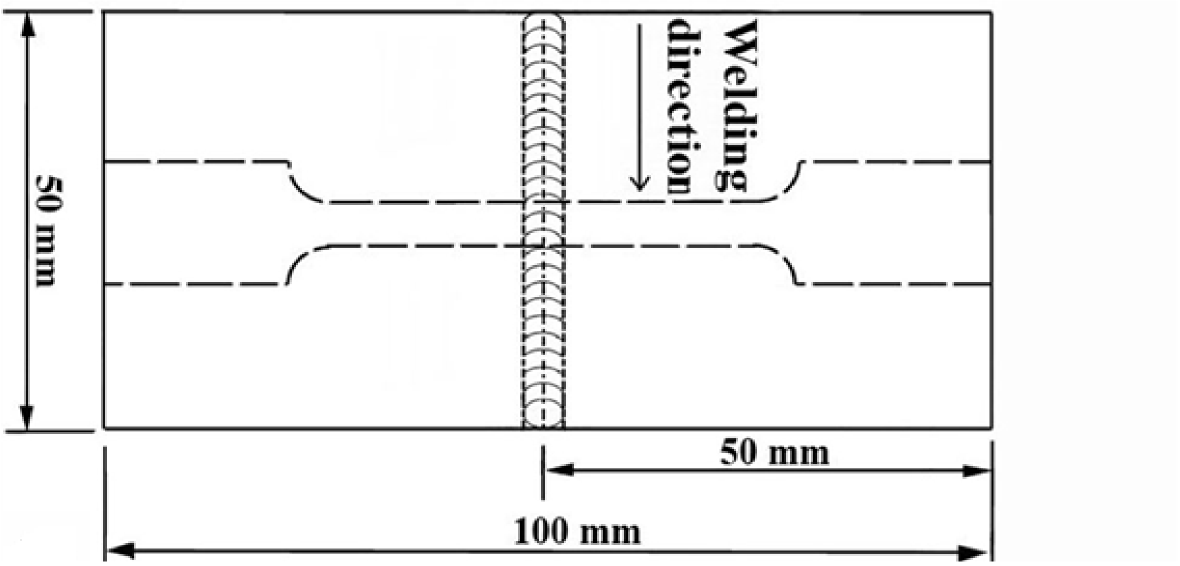


Fig. 7 Schematic Diagram of specimen for tensile testing

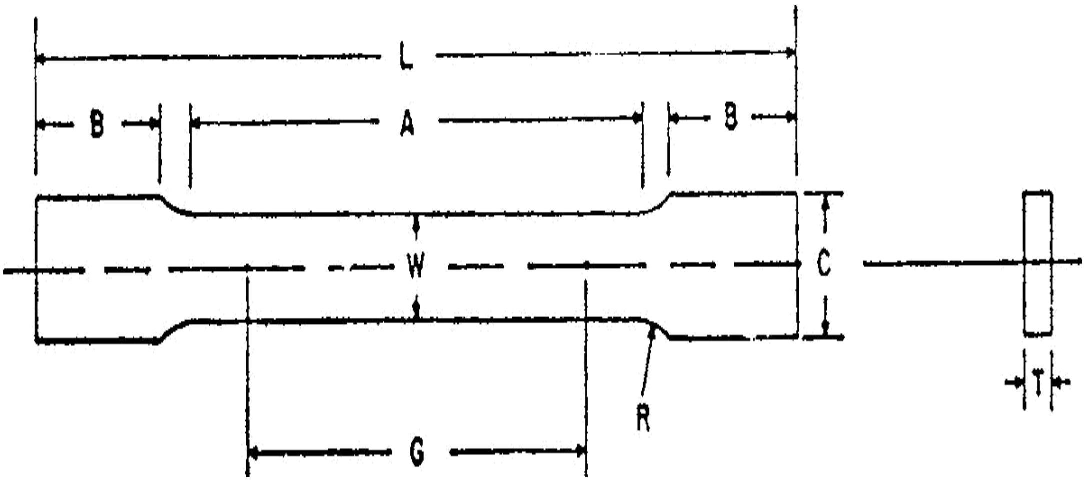


Fig. 8 Schematic diagram for 5 mm thick plate as per ASTM E8 standard [Ref. 4]

Table 7 Dimension for tensile test as per ASTM E8 standard [Ref. 4]

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

Fig. 9 INSTRON Universal Testing Machine (UTM)

3.4 TIG welding process with TiO_2 Flux

TIG welding provides high quality weld and good weld bead surface. However, compare to other arc welding processes like plasma arc welding and submerged arc welding, TIG welding exhibit low penetration/melting depth in the workpiece. Therefore, it is required to improve the penetration/melting depth of TIG welded joint. This can be done with the help of inorganic powders generally called ‘Activated flux’. Applications of activated fluxes in various arc welding process for ferrous, non-ferrous and dissimilar materials gives higher penetration compared to the welding done without using flux. The presence of flux narrow the arc concentrated energy in to a small area and reduces surface tension of the molten pool. This results in increases the depth of penetration of the weld joint.

Activated flux is prepared using single component of any oxides (Cao, Fe_2O_3, TiO_2, Zno, MnO_2 and Cr_2O_3) in powdered form or mixture of these powders. Activated flux then added in a liquid solvent like acetone of 5 to 10 ml of the flux powder and stirred to make it has homogenous paste, ready to be applied on the weld surfaces. A coating approximate 0.1 mm thick was applied to the surface of strip using a paint brush (10-12 mm) width prior to the welding.

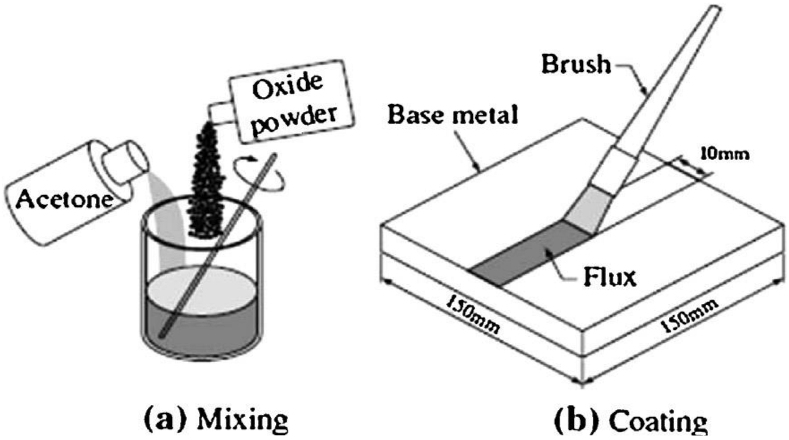


Fig. 10 Schematic diagram for preparation of flux [Ref. 16]

On the basis of these specific advantages of activated flux in this phase of experiment TiO_2 has been used as flux material to perform the welding of mild steel plate and effect of it during welding has been studied. Rutile TiO_2 powder has been used as flux material in the present work. Prior to welding the TiO_2 powder was uniformly mixed with acetone to make a paint like solution. Both TiO_2 and acetone of 10 ml of solution were properly mixed to form flux. Using a small paint brush a thick layer of this TiO_2 flux solution then painted on the surface to be weld. The layer should be sufficient thick so that flux appears opaque. Then the welding performed with 210 A current and three different speeds as described in table 8.

Table 8 Welding parameters for TIG welding of TiO_2flux coated mild steel

Dimension of mild steel	50mm x 50mm x 5mm
Welding speed	2.33 mm/s, 2.96 mm/s and 3.5 mm/s
Welding current	210 A
Arc voltage	14 – 15 volt
Current type	DC (positive workpiece& negative electrode)
Distance between tip & weld center	3 mm
Gas flow rate	12 l/min
Shielding gas	Argon
Activated flux	TiO_2
Electrode diameter	2.4 mm

3.5 TIG welding of mild steel by varying gap between workpieces to be welded

It has been observed from the previous experiments that, during autogenous TIG welding of thick mild steel plates either using flux or without flux, when plates are kept side by side and no gap provided between them, the depth of penetration or melting depth is limited to a certain value and molten material does not flow towards the bottom side of the joint. It is found from the literature, that during welding using filler rod, for the flow of molten material proper grooving is provided or some gap is maintained between the plates to be weld. Therefore, in this work, in order to increase the depth of penetration in weld, TIG welding was performed by maintaining a gap between the workpiece to be welded. An attempt has also been made to study the effect of gap between the plates during autogenous TIG welding of mild steel for using no filler rod.

In conventional TIG welding method depth of penetration is low at weld zone in thick mild steel plate. For the purpose of increment of the depth of penetration in weld TIG welding was performing with maintain gap between workpiece. All this results increase in depth of penetration. The 100 mm length welds were obtained along welding direction without application of wire or filler material. Total 9 experiments were performed and welding shown in table 9. Welding process done with constant speed and same value of fixed parameters as conventional autogenous TIG welding process.

Table 9 Experimental planning for TIG welding of mild steel

Exp. No.	Welding current (A)	Gap between workpiece (mm)
1	180	0.5
2	180	0.75
3	180	1
4	190	0.5
5	190	0.75
6	190	1
7	200	0.5
8	200	0.75
9	200	1

Chapter 4

Results and discussion

4.1 Welded specimen performed by conventional autogenous TIG welding

Figure 11 shows TIG welded specimens performed with three different welding current and welding speeds.

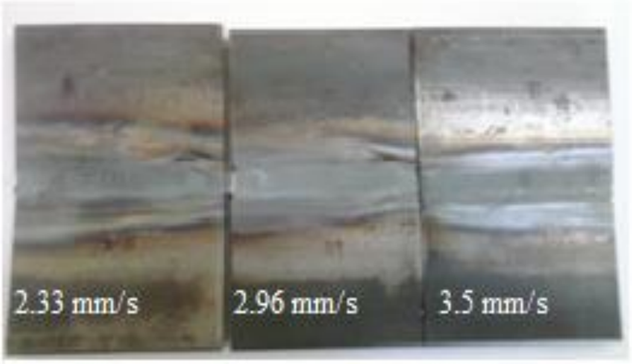
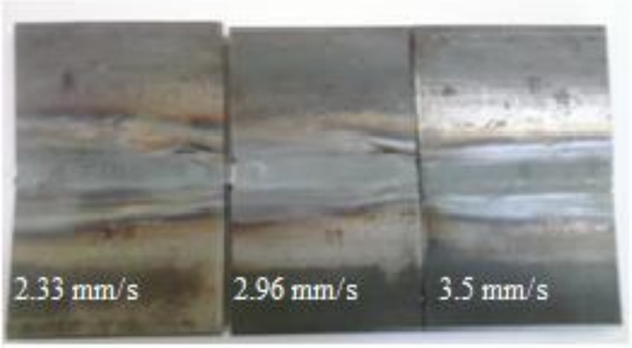
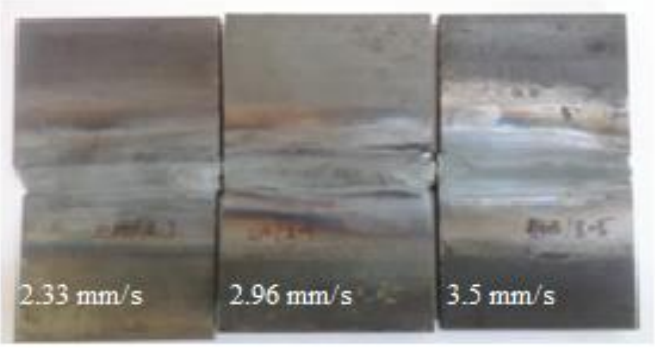
Sl. No.	Welding current	Welded sample at different speed
1	170 A	
2	190 A	
3	210 A	

Fig. 11 Welded specimens performed with 3 different speed and current setting by conventional autogenous TIG welding process

Macroscopic inspection of the samples produced from 9 experiment clearly reveal that weld joints formed with 170 A current for different welding speed didn’t satisfy the requirements of the welding. Therefore, these particular samples were discarded for further study. The remaining samples were considered for further testing, which has been described below.

4.1.1 Optical Image at weld zone by conventional autogenous TIG welding process

Fig. 12 shows optical microscopic image at cross section of weld zone by autogenous conventional TIG welding process performed with 190 A and 210 A welding current and three different speeds. The images show that, melting of the weld zone is not fully done for all different current and scan speed combination. Further, it is seen that, weld melt pool depth is larger for higher current (210 A). It is also seen that, as scan speed increase for a particular current value, melt depth reduce.

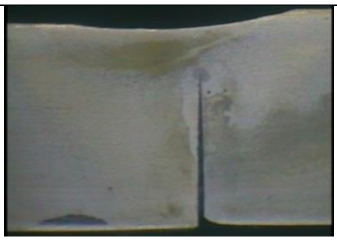
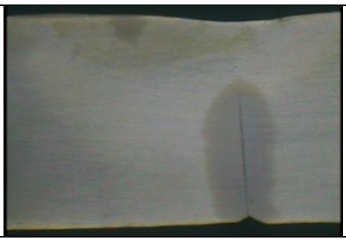
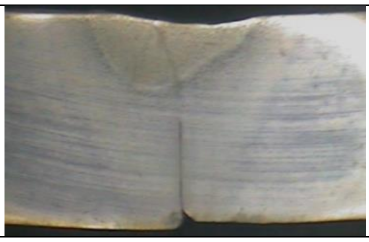
Current Speed (mm/s)	190 A	210 A
2.33 mm/s		
2.96 mm/s		
3.5 mm/s		

Fig. 12 Optical microscopic Image at cross section of weld by conventional autogenous TIG welding process

4.1.2 Weld bead geometry at cross section of weld zone by conventional autogenous TIG welding

Table 10 Width and depth of weld zone of TIG welded sample by conventional TIG welding

Sl. No.	Current (A)	Speed (mm/s)	Width (mm)	Depth (mm)
1	190	2.33	6.3	2.34
2	190	2.96	5.75	1.28
3	190	3.5	5.88	1.59
4	210	2.33	7	2.47
5	210	2.96	5.85	2.09
6	210	3.5	6.17	1.91

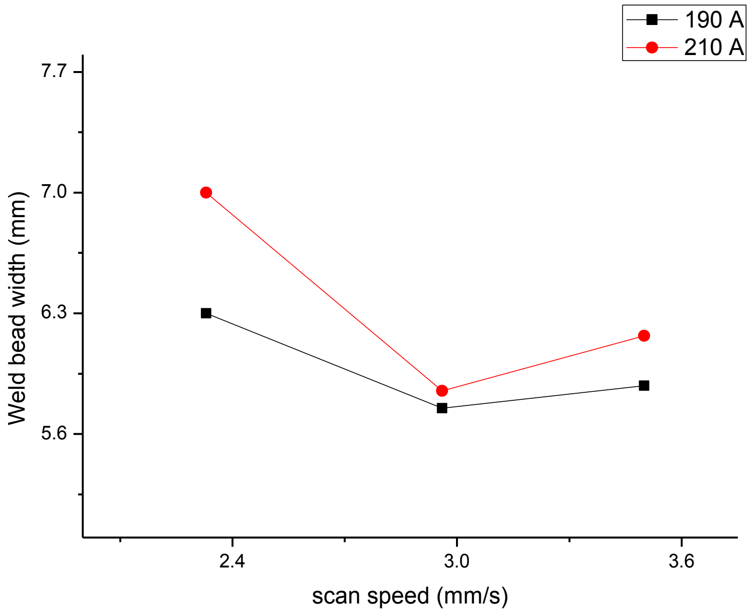


Fig. 13 Variation of weld bead width against scan speed for different welding current

Figure 13 shows the variation of weld bead width against scan speed for 190 A and 210 A welding current of welded specimen. The maximum welding width obtained at minimum welding speed and maximum current. It was normally observed that weld bead width increases as current increases but decreases with increment in welding speed.

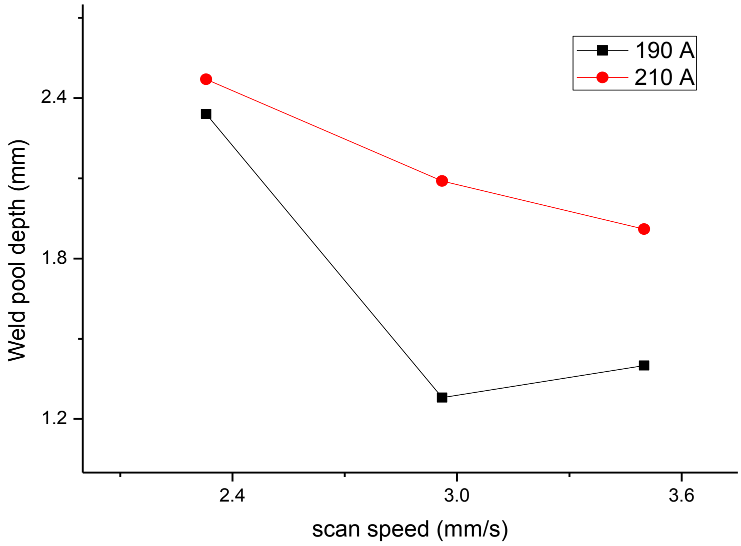


Fig. 14 Variation of weld pool depth against scan speed for different welding current

Figure 14 shows the variation of weld pool depth against scan speed for different welding current of TIG welded specimen. Low welding speed and high current provide high heat input to the workpiece, so the depth of penetration was maximum at this condition. The maximum weld pool depth was 2.47 mm, obtained at 210 A welding current and 2.33 mm/s scan speed.

Depth of penetration obtained in the above experiment was still small for proper applicability of the welding technique. Hence, more literature was studied and it was established that, depth of penetration can be further improved if activated flux is used during the welding process. Based on this, experiments were conducted again with an addition of activation flux utilization.

4.2 Welded specimens performed by activated TIG welding process

It was clearly observed from first set of experiment and results, that combination of maximum welding current and minimum speed provide high heat input to the workpiece material. However, maximum depth of penetration was obtained at this condition. Second set of experiment performed with the use of TiO_2 flux and 210 A welding current for three different welding speeds.TiO_2 activated TIG welding process performed with 210 A current and three different speeds shown in figure 15.

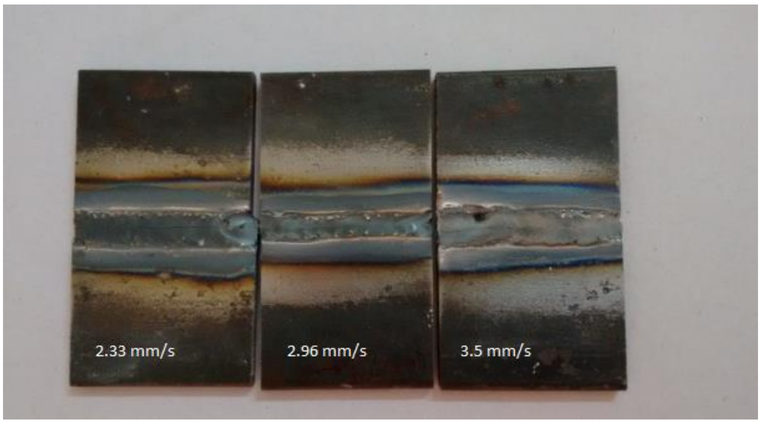
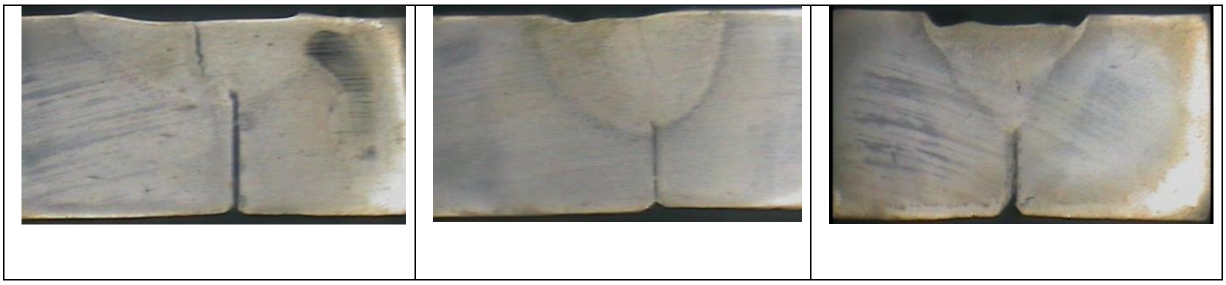


Fig. 15 TIG welded specimen with TiO_2 flux at 210 A current

4.2.1 Optical Image at weld zone of specimen performed by activated TIG welding process

Figure 16 shows optical microscopic image at weld zone performed by TiO_2 flux coated autogenous TIG welding process with 210 A current and different scan speed.



(a) 2.33 mm/s (b) 2.96 mm/s (c) 3.5 mm/s

Fig. 16 Optical microscopic Image at weld zone of TIG welded specimen with use of TiO_2 flux

From the optical image it is observed that, melt pool depth is relatively larger for using TiO_2flux, but still full penetration welding was not obtained. Further, for using TiO_2 flux on the melt pool zone some crack has been form. This crack may reduce the strength of the welding. Similar observation was done by some other researcher for using activated flux in welding of different type of steel in TIG welding [11, 12, 13].

4.2.2 Weld bead geometry at cross section of weld zone by TIG welding with TiO_2 flux

Table 11 Width and depth of weld zone of TIG welding with TiO_2 flux

Sl. no.	Current (A)	Speed (mm/s)	Width (mm)	Depth (mm)
1	210	2.33	7.16	2.65
2	210	2.96	5.52	3.09
3	210	3.5	6.28	2.95

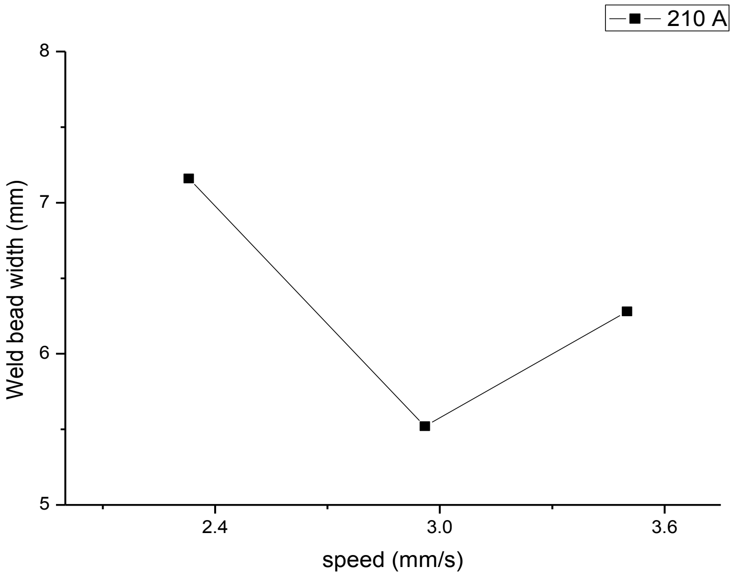


Fig. 17 Variation of weld bead width against scan speed for 210 A welding current

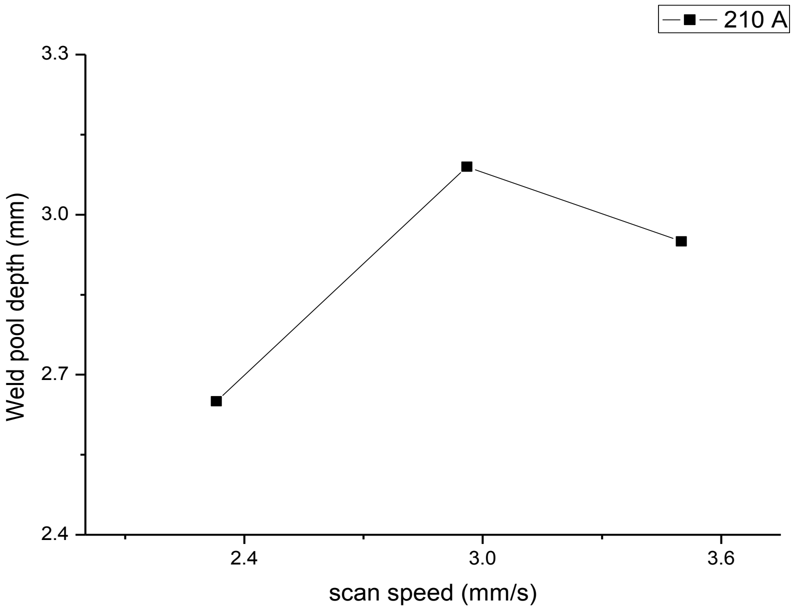


Fig. 18 Variation of weld pool depth against scan speed for 210 A welding current

Fig. 17 shows the variation weld bead width against scan speed for 210 A welding current of TiO_2 flux coated weld specimen. It was observed that welding width decreases with increment in welding current. The maximum weld bead width obtained at minimum welding speed.

Fig. 18 shows the variation of weld pool depth against scan speed for 210 A welding current of TiO_2 flux coated weld specimen. At minimum welding speed high heat input provided to the workpiece material, so the depth of penetration is inversely proportional to the scan speed. The depth of penetration of workpiece decreases with increment in welding speed.

In normal welding condition generally at lower scan speed depth of penetration is increases due to high heat input, but for using activated flux (TiO_2) add the upper surface of the plate most of the heat absorbed by the surface and at lower scan speed a wider melt pool is formed. As a result welding depth is reduced.

Table 12 indicates measurement value of depth of penetration for both without using flux and with using flux TIG welded sample. It was observed that the higher depth of penetration obtained for flux coated sample.

Table 12 Comparison of depth of penetration between without flux weld and with flux weld sample

Sl. No.	Current (A)	Speed (mm/s)	Depth (mm) without flux	Depth (mm) with flux
1	210	2.33	2.47	2.65
2	210	2.96	2.09	3.09
3	210	3.5	1.19	2.95

With the application of flux, desirable results, i.e. increase in depth of penetration was obtained. However, it was seen that material was unable to flow and weld properly as no gap was maintained between the components to be welded. To further improve the welding technique and facilitate optimum flow of the material, it was decided to maintain a suitable gap between the components. Taking this condition into account, more experiments were conducted to study the effect of welding gap kept between the welding sub-parts on the output response. In this regard, it is relevant to mention that, no study was reported on the effect of gap maintained between the workpieces to be welded by autogenous TIG welding process.

4.3 Welded specimens performed welding by varying gap between workpiece

In this set of experiment, suitable gap between workpiece was maintained for proper flow of material towards the bottom of the joint. Figure 19 shows welded specimens of mild steel performed by three different current and gap between workpiece to be welded. No flux is used for this set of experiment to avoid any crack on the weld zone.

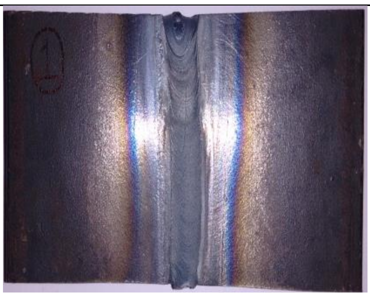
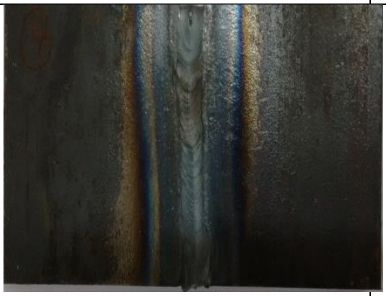
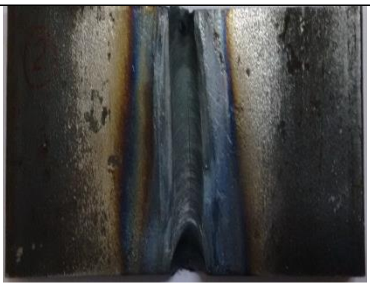
Welding current Gap between work piece	180 A current	190 A Current	200 A Current
0.5 mm			
0.75 mm			
1 mm			

Fig. 19 TIG welded specimens by varying gap between workpiece

4.3.1 Optical microscopic Image at weld zone performed welding by varying gap between workpieces

Figure 20 shows the optical microscopic image at weld zone of TIG welding done with different welding current and gap between workpiece. From the cross-sectional view, it becomes easier to understand the effect of welding parameters on the depth of penetration. It highlights the condition in which most efficient weld is obtained. For gap 0.5 mm melting is not done fully but when gap is maintained 0.75 mm, it has is seen that for using 200 A current full penetration welding was obtained. Again for using 1 mm gap full penetration welding was obtained for the sample processed with 190 A and 200 A welding current.

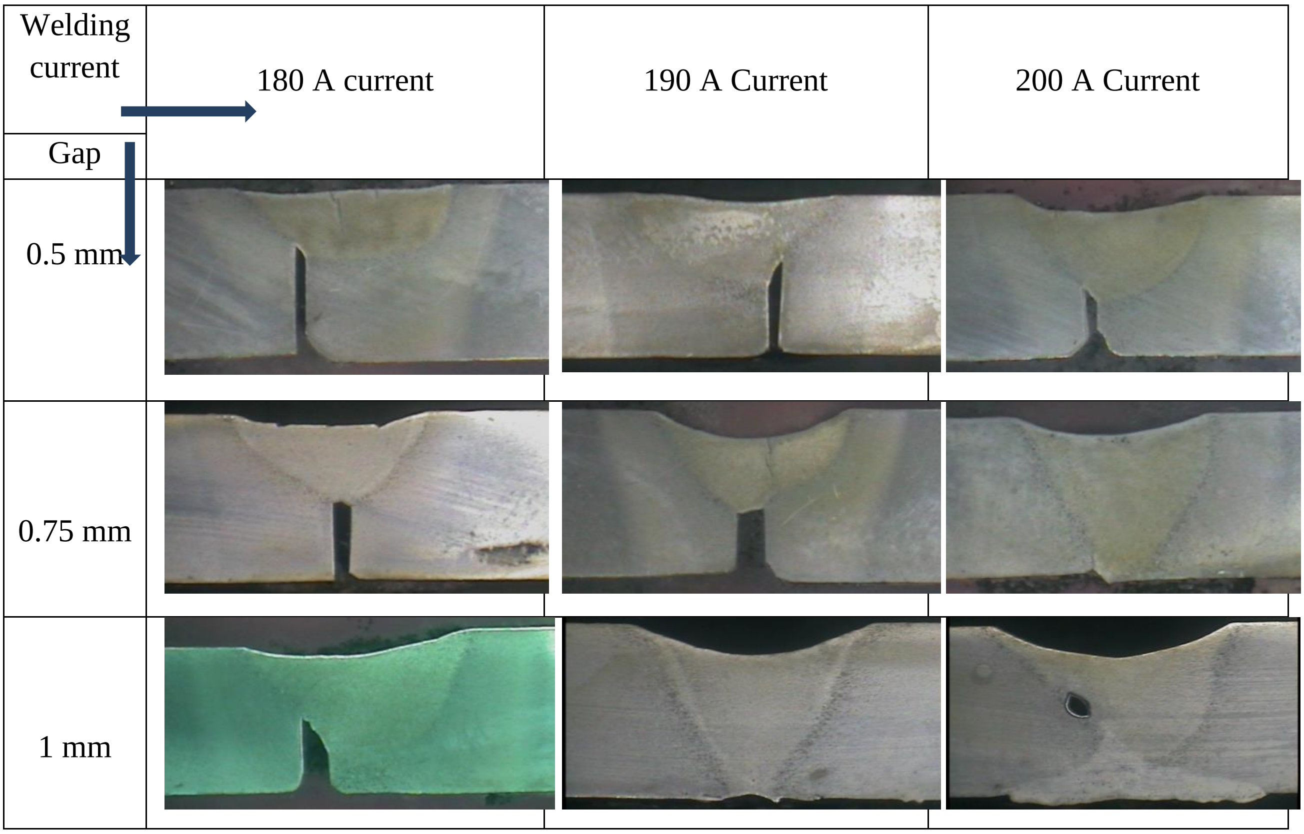


Fig. 20 Optical microscopic Image at weld zone of TIG welding done with different welding current and gap between workpiece

4.3.2 Weld bead geometry of weld zone

Measurement value of weld width, weld pool depth and crater form of welded sample at weld zone processed with different welding current and gap maintain between workpiece

Table 13 Measurement of width, depth and crater of welded sample at weld zone for different current and gap maintain between workpiece

Sl. no.	Current (A)	Gap (mm)	Width (mm)	Depth (mm)	Crater (mm)
1	180	0.5	5.85	2.26	0.29
2	180	0.75	6.05	2.83	0.4
3	180	1	6.2	4.21	0.51
4	190	0.5	6.37	2.47	0.42
5	190	0.75	6.13	3.05	0.76
6	190	1	6.5	4.88	0.9
7	200	0.5	6.52	3.46	0.71
8	200	0.75	6.34	4.61	0.86
9	200	1	6.94	4.98	0.98

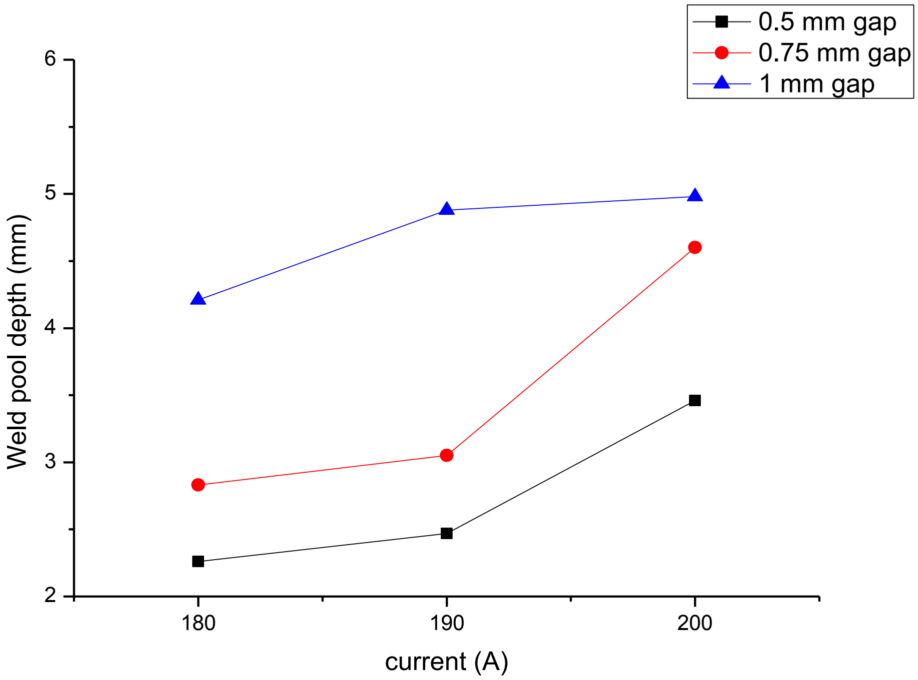


Fig. 21 Variation of weld pool depth against welding current for different gap between workpiece to be welded

Figure 21 indicates the variation of weld pool depth against welding current for different gap between workpiece to be welded. It has been observed that with the increase in current, weld pool depth increases. Current is directly proportional to the heat input according to relation

$H=I^2RT$. So when current increases heat input increase and it melts the material and flows down in the gap, leading to the melting of adjacent layer of material thereby increasing the depth of penetration. The maximum depth of penetration was observed at 200A current in all the three gap condition.

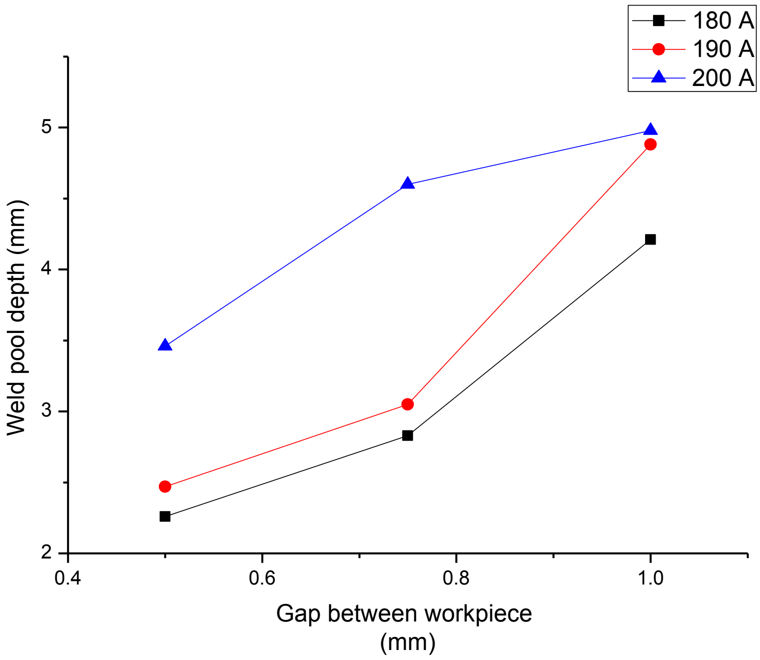


Fig. 22 Variation of weld pool depth against gap between workpiece to be welded for different welding current

Fig. 22 represents the variation of weld pool depth against gap between workpiece to be welded for different welding current. To enhance proper welding operation, the gap between two metals should be neither too small nor too large. When welding was done without any gap the molten material did not get any space to flow and only convective metal flow within the melt pool occurred, that restrict the depth of penetration. However, molten material can flow within the gap and reach to bottom portion when a proper gap was maintained. The maximum depth of penetration is observed at 1 mm gap between workpiece to be welded.

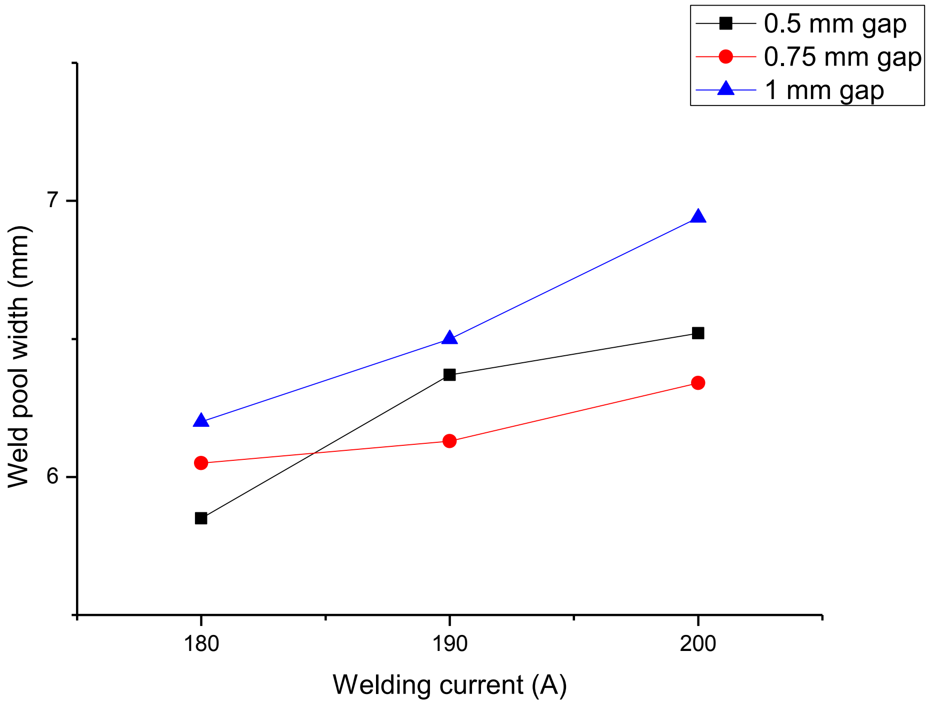


Fig. 23 Variation of weld bead width against welding current for different gap between workpiece to be welded

Fig. 23 shows the variation of weld bead width against welding current for different gap between workpiece to be welded. From the figure it can be seen that the value of welding width is increased with increment in applied welding current. Because of high current, crater was formed and welding width was large. The maximum welding width in this experiment was 6.94 mm at 200 A current.

Fig. 24 shows the Variation of weld bead width against gap between workpiece to be welded for different welding current. From the graph it can be clearly seen that width increases as the gap increase. As gap was varied in this experiment (0.5 mm, 0.75 mm and 1 mm), this gap value is also contribute in the increment of width of the welded zone.

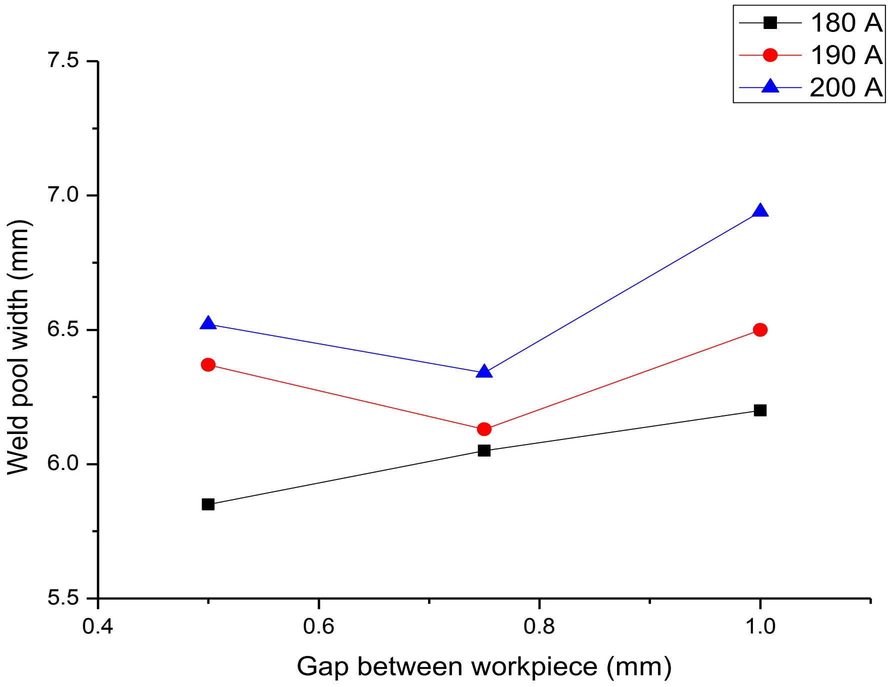


Fig. 24 Variation of weld bead width against gap between workpiece to be welded for different welding current

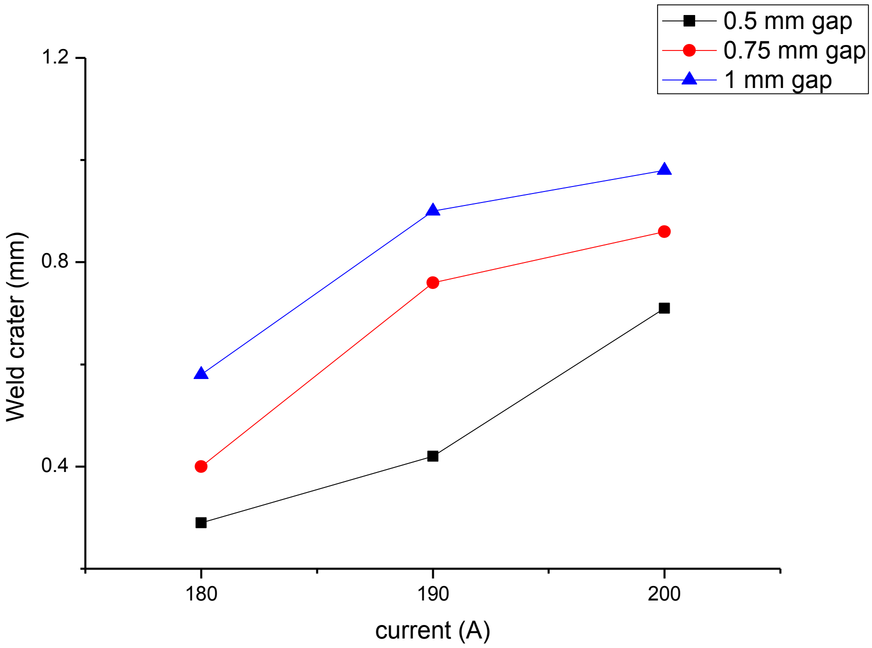


Fig. 25 Variation of weld crater against welding current for different gap between workpiece to be welded

Fig. 25 shows the Variation of weld crater against welding current for different gap between workpiece to be welded. It was observed that with the increase in current, crater increases at constant gap. At high current due to high heat input to the workpiece some amount of material from the top surface evaporated. Further flow of material within the gap make a concave surface on the workpiece. This is called crater in welding. As current increase this crater depth increases.

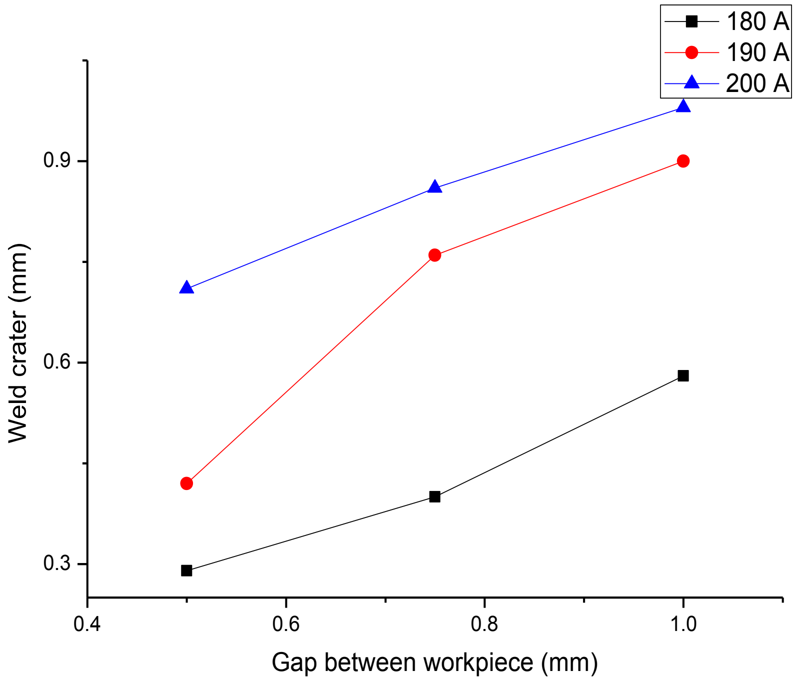


Fig. 26 Variation of weld crater against gap between workpiece to be welded for different welding current

Fig. 26 shows variation of weld crater against gap between workpiece to be welded for different welding current. In present work no filler material has been used and also maintained gap between workpiece. When the material melts, it fills up the gap between the workpiece. It was observed that with the increases in gap volume of void space between two welding workpiece also increases.

4.4 Tensile testing

In order to compare the strength of the welding joint at different welding conditions, tensile testing of welded specimen was performed using UTM. From previous two set of experiments it was established that higher depth of penetration was obtained at maximum current and minimum welding speed. Keeping this in mind, specimens with high current were more suitable for further analysis. Neither conventional TIG welded specimen nor activated

TIG welded specimen provide better strength. The results of the test suggest that weld joint obtained are not strong enough which motivated the third set of experiments.

Fig. 27 shows specimen for tensile testing and Table 14 shows the maximum tensile strength value of weld with welding condition.

Fig. 27 Tensile testing specimen

Table 14 Tensile strength at weld joint by TIG welding of varying gap between workpiece

Sl. No.	Welding current (A)	Gap between workpiece (mm)	Tensile strength (MPa)
1	180	0.5	115.95
2	180	0.75	225.21
3	180	1	264.54
4	190	0.5	319.10
5	190	0.75	346.38
6	190	1	501.173
7	200	0.5	442.98
8	200	0.75	395.45
9	200	1	617.22

Fig. 28 shows the variation of tensile strength against gap between workpiece to be welded for different welding current of weld sample. It has been observed that the increase in gap between workpiece to be welded, tensile strength of weld workpiece increases. This is mainly due to the higher penetration of welding for higher welding gap maintain between workpiece.

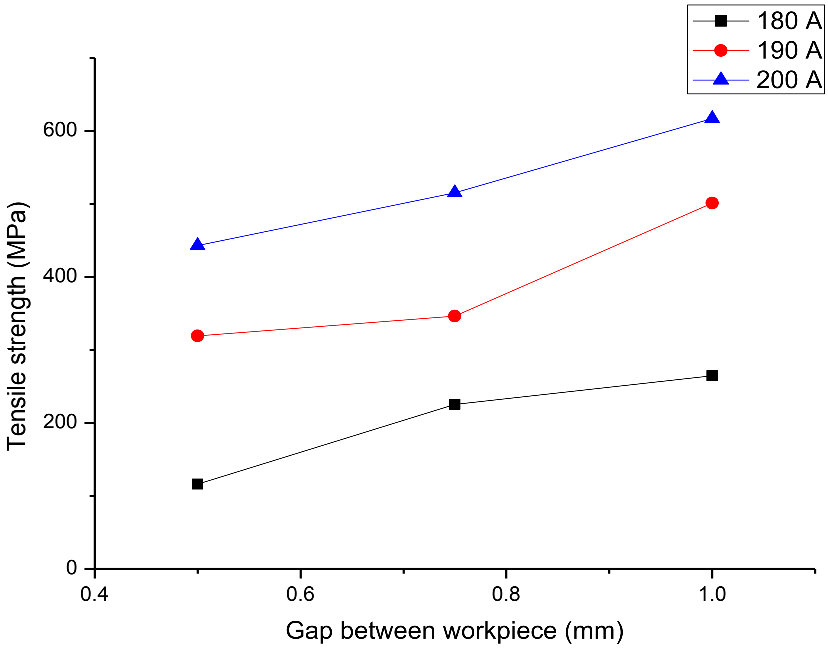


Fig. 28 Variation of tensile strength against gap between workpiece to be welded for different welding current

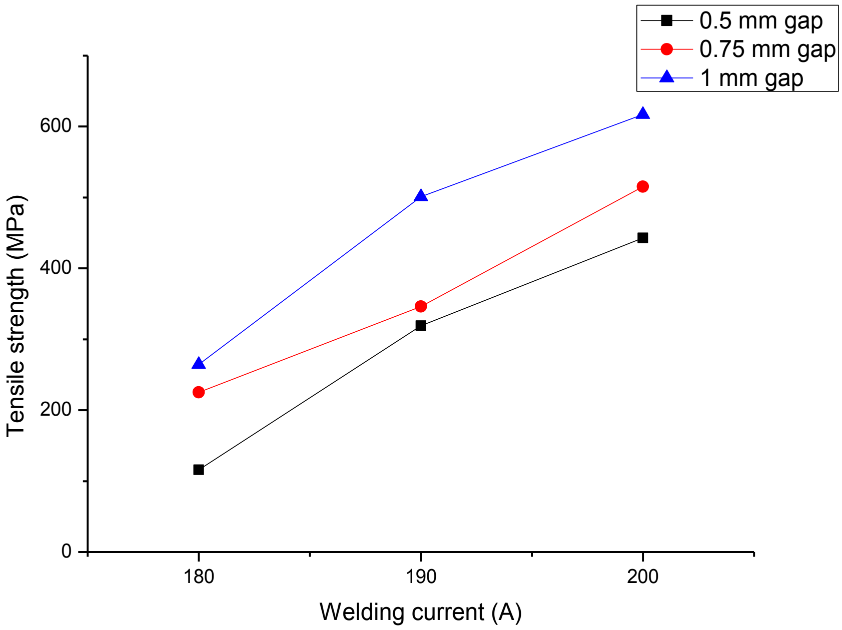


Fig. 29 Variation of tensile strength against welding current for different gap between workpiece to be welded

Similarly, Fig. 29 shows the variation tensile strength against welding current for different gap between workpiece to be welded. It has been observed that, with the increase in current tensile strength of weld workpiece increases. In this experiment autogenous for higher value of current heat input must be high. From the optical image it is seen that with the increase of current penetration depth increases. Higher penetration depth contributes for better strength.

4.5 Vickers Hardness test

Hardness of the welded zone was measured for selective specimen at the cross section. Hardness test was performed using Vickers Hardness tester with 0.3 kgf minimum load capacity. Fig. 30 shows the hardness value at the welded zone, heat affected zone and base material for the sample processed with 200 A current and 0.75 mm gap. Table 15 shows Hardness value for some representative samples.

Table 15 Hardness value for sample

Sample No.	Welding current (A)	Welding speed (mm/s)	Gap between workpiece (mm)	Hardness value at molten metal zone	Hardness value at heat affected zone	Hardness value at base material zone
1	190	2.33	0.5	192.6 HV	158.5 HV	149 HV
2	200	2.33	0.75	198.5 HV	176.8 HV	146.4 HV

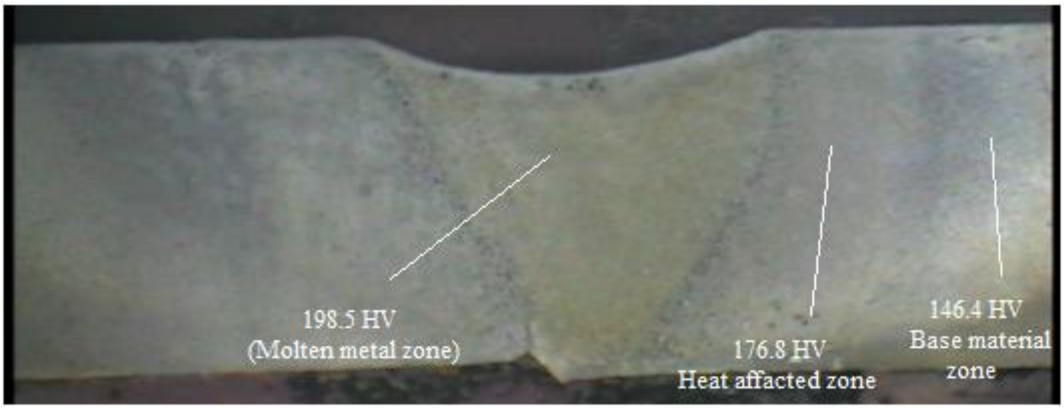


Fig. 30 Hardness value of sample at weld zone processed with 200 A current and 0.75 mm gap

It is observed from figure that hardness value decrease towards the base material zone. Average hardness values at molten metal zone for 190 A and 200 A current are 192.6 HV and 198.5 HV respectively. So it can say that approximate range of micro-hardness is 190 HV to 200 HV at molten metal zone for TIG welded samples.

Chapter 5

Conclusions

Findings of the present investigation can be summarized into following points

- 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.
- When the same procedure is repeated with additional utilization of TiO_2 flux, depth of penetration increases in comparison to the conventional welding, but some crack on the weld zone was observed for using flux.
- With constant welding speed, another set of experiments were done by maintaining a gap between workpiece to be welded. It is observed that, with a gap of 1 mm, defect-free welding with proper material flow obtained throughout the joint for higher welding current.
- Comparing the three methods of TIG welding, depth of penetration and tensile strength of weld joint is maximum when adequate gap is maintained between the components to be welded.
- From the graphs plotted, it can be inferred that welding width and depth increases with increase in welding current and gap maintained between the components to be welded.

5.1 Future aspects

If welding is possible with minimum welding speed, depth of penetration will increase. Optimum gap maintain between two workpieces to be welded so obtained higher melting depth. All these result to provide better strength to the weld joint.

TIG welding process performed with using filler material so thick plate weld and provides higher depth of penetration and better strength.

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