Study of Fusion Profile Development during Activated Tungsten Inert Gas Welding

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in

Production Engineering

By

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CERTIFICATE

I hereby declare that the thesis entitled "Study of Fusion Profile Development during Activated Tungsten Inert Gas Welding" is an authentic record of my work carried out as requirements for the award of the degree of **Master of Engineering** in **Production Engineering** at **Thapar University, Patiala** under the supervision of **Dr. Anirban Bhattacharya, Assistant Professor**, Mechanical Engineering Department, IIT Patna and **Dr. Tarun Kumar Bera, Associate Professor**, Mechanical Engineering Department, Thapar University Patiala during July, 2014 to July, 2016. No part of the matter embodied in this report has been submitted to any other university or institute for the award of any degree.

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It is certified that the above statement made by the student is correct to the best of my/our knowledge and belief.

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I also place on record, my sense of thankfulness to one & all who have directly or indirectly lent a helping hand to compile this report.

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Abstract

Welding which is widely used in joining same or different kind of materials each others. Different kind of welding techniques are used now days to join materials. Tungsten inert gas (TIG) welding is one of them which are known for its good appearance and quality. Main problem in this kind of welding is its depth of penetration which is very low. So, researchers developed a new technique which can improve its drawback for depth of penetration. Study of fusion profile development during activated tungsten inert gas welding (ATIG) is important for increasing depth of penetration of weld. In this work, both TIG and ATIG for SS304 steel by varying main factors in welding like current, time of weld and shielding gas were studied and compared. At higher current, the depth of penetration is also high for ATIG. The depth of penetration for TIG welding increases twice by using mixture of argon and hydrogen as hydrogen plays a significant role to increase in depth of penetration for TIG welding. TiO_2 shows best aspect ratio for all value of current and time. Values of aspect ratio are consistent for TiO_2 when current is varying at constant time.

Keywords: Activated Tungsten Inert Gas Welding, Flux, Process Parameters, Depth of penetration, Profile Development.

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Nomenclature

TIG- tungsten inert gas

ATIG- activated tungsten inert Gas

Ar – Argon

C – Current

w – Width

d- Depth

A – Ampere

Chapter 1

Introduction

1.1 Introduction

Welding is a process which is used to join two similar or different kinds of metals or thermoplastics. Sometimes a filler metal is added between the gap of two metal which are to be join and sometimes not. In most of welding process materials which are to be join firstly melts and then they fuse together to form a weld after cooling down. But sometimes joint is made simply by applying pressure when they are in plastic stage (materials will not be go into melting stage).Melting of materials are generally achieve by an arc and plastic stage by friction or electric current. So welding can be done in different ways according to our requirement and availability. Soldering and brazing is also a joining process but temperature in both of them is not as high as comparison to the welding. Also the joint obtain from these two process is temporary, but joint obtained by welding is permanent. In today's world application of welding is uncountable. Some examples are joining of railway tracks, joining of LPG cylinders, joining of boilers, joining of agriculture equipments. So without welding technique all this application will be not so economical and time to join them will also be more. Now we will classify the welding process as described below:

Classification of welding process

On the basis of pressure, welding can be classified mainly in two type

1. Pressure welding
2. Non pressure or fusion welding (source of weld will be arc mainly)

In first type of welding classification the main source of weld is friction and electric current. Weld is formed without adding any filler metal mainly. Welding techniques which comes under this are shown below by a figure 1.1.

And in second type of welding process welding is done by producing arc from electric source and gas. Filler metal is always used for joining thicker materials. Welding techniques which comes under this classification is shown below by figure 1.2.

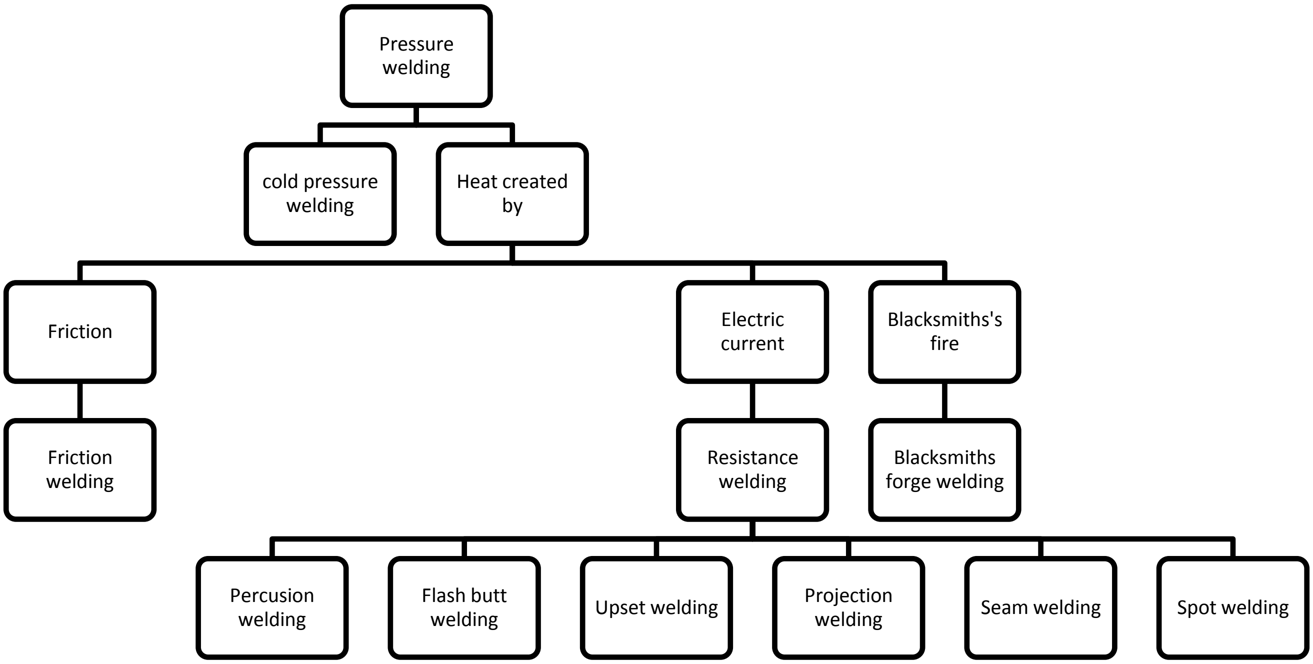


Figure 1.1: Classification of pressure welding

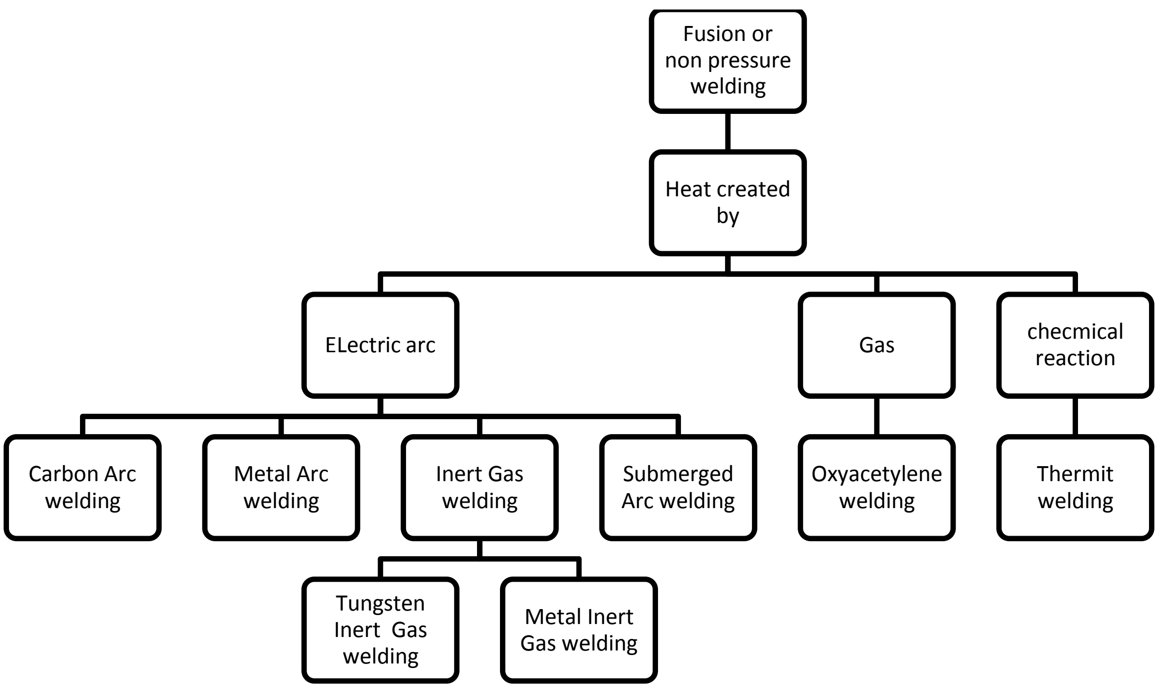


Figure 1.2: Classification of Fusion welding

1.2 Tungsten Inert Gas Welding

Tungsten inert gas welding (TIG) is a process that welds the metal by an arc initiation between tungsten electrode and metal. Tungsten electrode is non consumable so no need to change electrode again and again as in case of Metal Inert Gas welding in which electrode is consumable. An inert gas is coming through the nozzle having electrode tip inside it. At the time of welding when arc is appearing between electrode and metal at that time inert gas (i.e. Argon, helium etc) through the nozzle protects the welding pool from atmosphere. At the time of welding, pool is fully covered by the inert gas more effectively as comparison to the MIG welding because gas comes by pressure. Whole setup for TIG welding is shown below in fig 1.3.

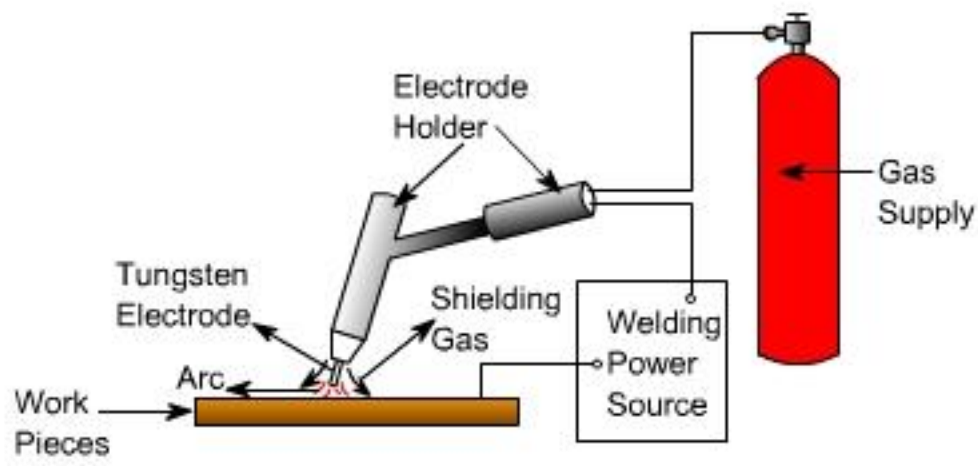


Figure 1.3 TIG welding setup (www.nptel.ac.in)

As shown in fig above one supply from power source is joined to work piece and one supply to the electrode. This supply makes one terminal positive and other terminal negative depends on our requirement (discuss in next sub section). Inert gas supply is done by the foot paddle which is joined to the electric source (not shown above). When electric supply is on then by pressing the foot paddle first and then a noise is produced at that time electrode is bring near to the work piece and to initiate the arc electrode is strike out with work piece and then a continuous arc is produced and we get our weld. Filler metal is used for welding thicker materials.

1.2.1 Polarity

Polarity is basically defines which part of the circuit is connected to which terminal and current. According to that, polarity used in TIG welding is of three types.

a. Direct current electrode negative (DCEN)
b. Direct current electrode positive (DCEP)
c. Alternating current

a. Direct current electrode negative

In this polarity electrode is connected to the negative terminal of the power source. It is also called straight polarity. Most commonly this polarity is used for getting deeper weld. Electrons are emitting through the electrode which is negatively charged towards the positively charged work piece with some momentum. To initiate electron from the electrode some energy is required which is called work function. When this emitted electron strikes with work piece then energy nearly equivalent to that is released. So that is why this polarity is good for deeper penetration (shown in fig 1.4). More energy is located at the work piece (70%) and less at electrode (30%). So overheating chances of electrode is also less in DCEN. So capacity of electrode is also higher in DCEN.

b. Direct current electrode positive

This polarity is also called as reverse polarity. In this polarity electrode is make positive and work piece become negative. Shallow and wide penetration is getting by this polarity as shown in fig 1.4 below. Electrons are emitted through the work piece so more heat (70%) is located at the electrode now. This polarity is basically used for oxide cleaning of work metal. At the time of welding positive ions from the shielding gas strikes to the weld surface and a clean surface is appear after welding. Since more heat is located at the electrode so efficiency of electrode is decrease. Chances of overheating are more in this polarity so cooling of it is required through coolant.

c. Alternating current

This polarity is intermediate stage of DCEN and DCEP. We get medium penetration by A.C (shown in fig 1.4). Half cycle do cleaning action of oxide layer of work surface and half do for deeper penetration. Heat located equally at electrode (50%) and work piece (50%). Capacity of electrode is also good in this polarity. Used mainly for welding aluminum alloy.

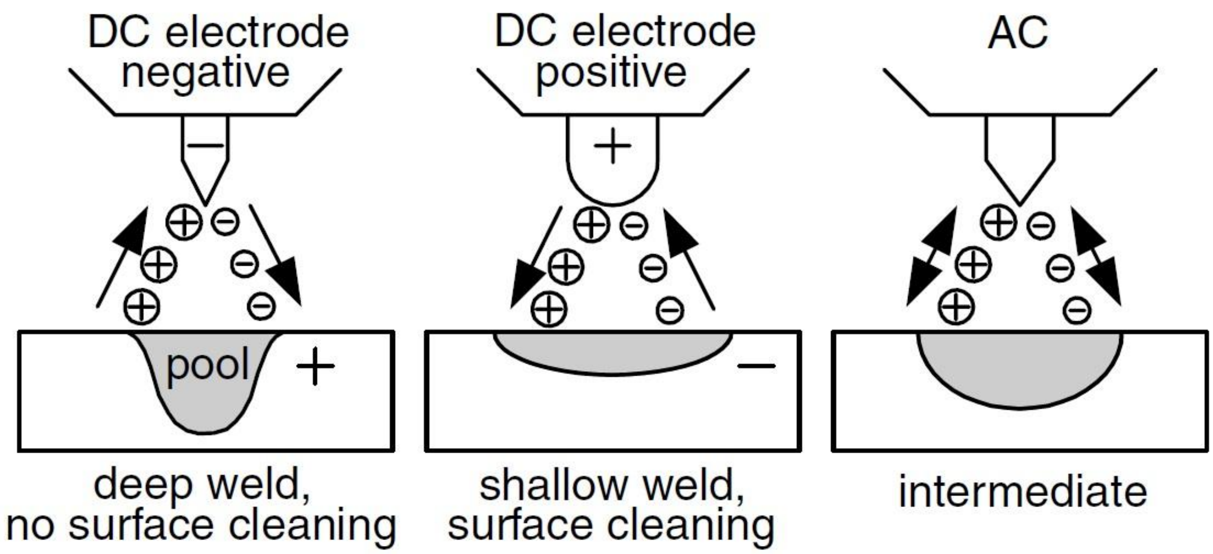


Figure 1.4 Different polarities in TIG welding (Sindo kou, Welding metallurgy)

1.2.2 Electrodes

A non consumable electrode is used in TIG welding. Tungsten electrode is best for this application. It has high melting point and high capacity. To increase the electron emissivity 2% of thorium or cerium coating is done at the tip of electrode. It also increases the resistance to contamination of tungsten when the temperature is high at the time of welding. Current carrying capacity is also higher in coated electrode tip.

1.2.3 Shielding Gases

Most commonly argon or helium is used as shielding gas in TIG welding. Properties of some shielding gases are given below in table 1.1.

As shown in table 1.1 molecular weight of Argon gas is higher as comparison to the helium so argon is more stable at the welding pool. Also ionization potential is also lower in Argon gas, so ionization of Argon can be done easily as compare to Helium. So Argon is more preferable then Helium. On the other hand more heat input can be done by Helium and Hydrogen. Sensitivity to variation in arc length is higher in case of Helium gas. So we can use Helium gas for thicker section and for automatic TIG welding.

Table 1.1: Properties of some shielding gases

Gas	Chemical symbol	Molecular weight	Ionization Potential
Argon	Ar	39.95	15.7
Carbon Dioxide	CO_2	44.01	14.4
Helium	He	4.00	24.5
Hydrogen	H_2	2.016	13.5
Nitrogen	N_2	28.01	14.5
Oxygen	O_2	32.00	13.2

1.2.4 Advantages

TIG welding is used in industry for getting high quality welds. Welding joints get by TIG welding are having best appearance as comparison to other welding process. Appearance of weld is awesome when it is achieved through TIG welding, that's why it is first choice of manufacturer when welding is doing on bike frames, automobiles. Argon and Helium which is used as shielding gas produces less fumes or smokes so visibility of working area is also good. So control on welding bead becomes easier. On the other hand you can weld with or without filler metal. For welding thicker metal filler metal can be used. We can weld also weld vertical joints very easily.

1.2.5 Disadvantages

In TIG welding deposition rate is very low. Heat input is very low in TIG welding. Excessive current input can cause overheating of tungsten electrode and can erode the welding pool at the time of welding. When joining thicker welds a skill worker is required for better hand eye coordination. Traveling speed is lower as comparison to the other welding techniques.

1.3 Stainless steel

Steel is an alloy of iron having different percentile of carbon in it. Depending on the percentage of carbon steel is mainly of three types given in table 1.2 below.

Table 1.2: Types of steel

Type of steel	Percentage of carbon
Mild steel	Up to 0.25 %
Medium carbon steel	From 0.25 to 0.45%
High carbon steel	From 0.45 to 1.5%

Sometimes chromium, nickel and tungsten like metals are also added in iron to make its alloy known as stainless steel and high speed steel. These metals in iron improve its corrosion resistivity, formability and looks. Iron becomes more shiny and hard. Stainless steel is having minimum of 10% of chromium which increases its corrosion resistivity. A layer of oxide is produces in stainless steel due to chromium which resist it to corrode.

Sometimes silicon, nickel and manganese is also added to increase its other properties i.e. formability and corrosion resistance is increased due to nickel and molybdenum. Due to its improved properties it is now used in various forms in various applications .i.e. domestics, agriculture, chemical industries, automobiles, medical and food and drink industries etc.

Classification of stainless steel:

Stainless steel is further divide in to five types given below:

a. Ferritic
b. Austenitic
c. Martensitic
d. Duplex
e. Precipitation hardening (PH)

a. Ferritic stainless steel

Ferritic steels are not good where welding of thick sections is done. So they are limited to thin section welding due to their lack of toughness in welds. Carbon is less than 0.10% in ferritic steels. Its structure is similar to low alloy steels. They have body centered structure. When high chromium and molybdenum is used then it can be used widely in sea water. This steel is having magnetic properties. They are having high resistance to stress corrosion cracking but their formability is not as good as comparison to the austenitic stainless steel. Some ferritic steels (i.e. 409 and 405) used in kitchen and exhaust systems. Some other examples of ferritic steels are 444 and 261. They are costly but they have high resistance to chlorides.

b. Austenitic stainless steel

Welding strength of austenitic steels is good as comparison to ferritic steel. In this kind of steel Nickel, manganese and nitrogen are added to improve the property of steel. Its structure is similar to the normal steel at high temperature which gives strength to it for weldability and formability. They are having faced centered structure. Chromium, molybdenum and nitrogen are added to improve its corrosion resistance. When it is work hardened to high strength level they don't loss their property of ductility and toughness at good level. They are normally non magnetic. All 300 series and 200 series grade steels are under this kind of steel. 300 series are having chromium and nickel and 200 series are having manganese, chromium, nickel and nitrogen.

c. Martensitic

These steels are having similar structure to ferritic steel but having high carbon in it. Carbon percentage is up to 1% in it. It is having good strength and medium corrosion resistivity. They are having low weldability. They are magnetic in nature. Some examples are 410 and 420 steel. Preheating is done some times to improve its weldability.

d. Duplex stainless steels

These steels are 50% austenitic and 50% ferritic. Their primarily used are in chemical plants and piping applications.

They are having high corrosion crack resistance as compare to austenitic steel. They are having some magnetic properties but less then ferritic steel due to the presence of 50% phase of austenitic steel. Chromium is 22-25% and 5% Nickel with molybdenum and nitrogen.

e. Precipitation Hardening

It is chromium-nickel based steel. Some other metal i.e. aluminum, copper and titanium is added to enhance its strength. When heat treatment is done, very fine particles form in the matrix of steel which increase its strength. They can be machined to intricate shapes. Some examples are 630,631 and 660 which provide high strength.

1.4 Activated TIG welding

It is a flux based TIG welding in which a layer of flux powder is painted on the surface of work piece which is to weld (as shown in figure 1.5 below). We all know the limits of TIG welding. It has lower deposition rate. It has Lower travel speed. It consumes more times as comparison to the other welding techniques. So to improve all its back points activated TIG welding is good solution to it.

Depth of penetration becomes 3 times more as comparison to the normal TIG welding. So to achieve good weld multi pass is not required in TIG welding. So lot of time can be saved in industry. So we can achieve fine appear strong weld by ATIG welding.

Chapter – 2

Literature review

2.1 Introduction

Welding is a vast field and it is a backbone of many manufacturing industries. TIG welding is known for its good surface appearance and many industries like automobiles and bike frame manufacturers using it. But big disadvantages of TIG welding are less penetration and welding is done in multi passes. So it consumes more time as comparison to other welding techniques. In today's world of competition value of time is very high. So to remove these disadvantages many researchers do study on TIG welding. After studying, researchers develop a flux based TIG welding which compensates these disadvantages. Here I read some of the research papers which I divided them in to basically three parts.

- Convection in arc welding pool
- Effect of ATIG in different steels
- Simulation comparison of ATIG weld pool

2.2 Literature review

2.2.1 Convection in arc welding pool

Oreper et al. [1983] did quantitative study on how convection and heat flow occurs in welding pool. After understanding role of different forces in welding pool they drive different governing equations and solved them numerically by putting them in finite difference form. Computer model used to solve was of MIT's IBM 370 digital. In this paper by changing the different parameter they find the major factor on which convective flow is mostly depend. They consider three factors mainly i.e. electromagnetic force, surface tension force and buoyancy force. They drive different run by varying input parameter and find their results. According to their results convective flow in weld pool is mostly depends on surface tension force. By putting surface tension force zero they find an inward flow of weld pool and depth of penetration become more.

So according to them surface tension force must be consider more to improve TIG welding. This paper was base for the further study on TIG welding.

Kou et al. [1986] demonstrated first time study on 3D convection in moving welding pool. Their work was further step to previous work of Oreper et al. [1983]. In previous work convective modeling is done on stationary welding pool. In this paper they work on 6061 aluminum alloy and shows effect of each force in welding pool separately and together. This paper shows that at the same current depth of penetration can be varied by changing flow of convection in welding pool. They also show that direction of flow of molten metal also effects macrosegregation and porosity in the welding. When direction of surface tension force is from outward to inward direction then porosity is less. Same is for macrosegregation.

Gadeon et al. [1990] showed in their study that the hydrogen content measured in a diffusible hydrogen test will be governed by three distinctly different phenomena: hydrogen absorption into the molten pool, hydrogen trapping or rejection from the solidification front, and hydrogen diffusion away from the solidified weld. These are separate occurrences which must be separately modeled in order to obtain a complete understanding of the hydrogen remaining in the weld. This study has attempted to separate out these various effects in order to determine the amount of hydrogen initially absorbed. Once this value is known, a new model can be developed in order to gain a greater understanding of the basic gas-metal reaction occurring in the weld pool and how this is affected by the welding arc.

Kim et al. [1992] showed in their study that how four driving force influence in welding pool by modeling. It was first time that to drive a model arc force is considered. Otherwise only three forces (surface tension force, buoyancy force Lorentz force) were used by the previous papers to drive a model on convection pool. Deformation of weld pool surface occurs by the arc pressure shown in their study. Deformation of welding pool is not so effected when current was 100 A. It deforms the weld pool very small. But at higher current deformation is very large and drag force become dominant in convective pool flow. Drag becomes higher and it effects the weld pool convection. Stream line flow of welding pool was shown separately for both flat and deformed surface at different currents level and then comparison was done. When current was high deformation become more so due to the domination of drag force effect of electromagnetic force reduces. This was done because surface area becomes higher so flow of the surface became higher same for the surface forces. So it results in shallow penetration of weld pool.

Dong et al. [2007] used nickel based alloy (nimonic 203) for their study. In their study they used three types of flux which are TiO, TiO_2, and Ti_2O_3. According to them arc constriction and reverse Marangoni is the main factors of increasing penetration in the TIG welding. They talked about the critical value of flux that should be put on the surface of work piece. Depth of penetration increasing more when the flux quantity is low and not so high but penetration start to become low when quantity become high. So quantity of flux should not be above the critical value. Simulation was also done and comparison was done and result was quite close.

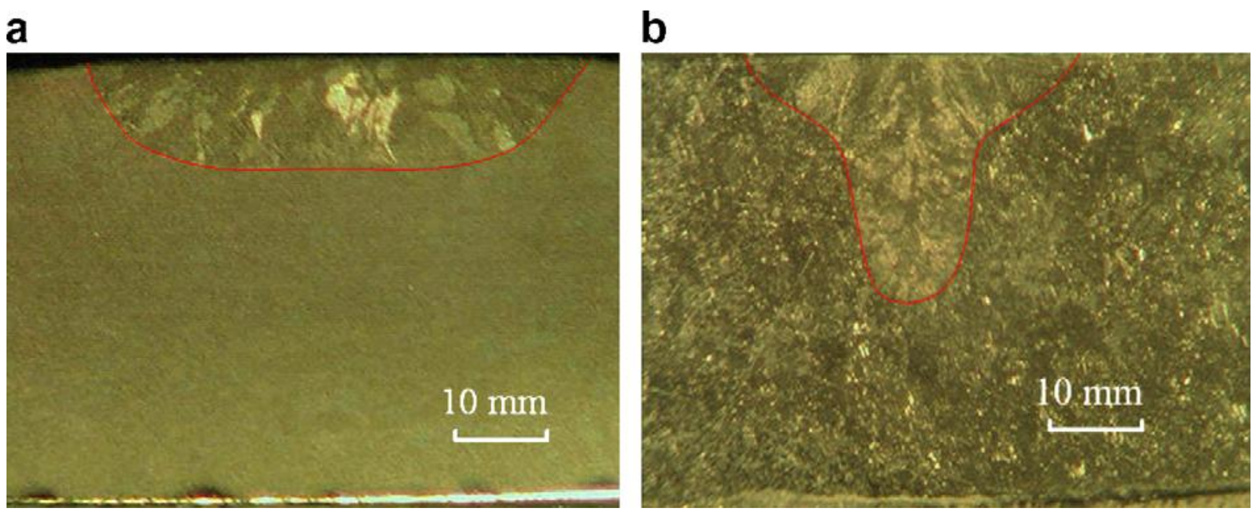


Figure 2.1 Comparison of TIG and ATIG welding

According to them reverse Marangoni convection is strong factor to increase the penetration of welding. As shown in figure 2.1 above.

Morisada et al. [2013] did their study on new idea of change the direction of convection pool. In all previously work, depth of penetration of welding pool was increasing by using active flux. In this study they developed CA-TIG welding technique. In which depth of penetration is increasing by using oxygen from the atmosphere. Oxygen is flowed in the welding pool by using aspiration effect. The schematic diagram of CA-TIG (cap active tungsten inert gas welding) is shown below in figure 2.2.

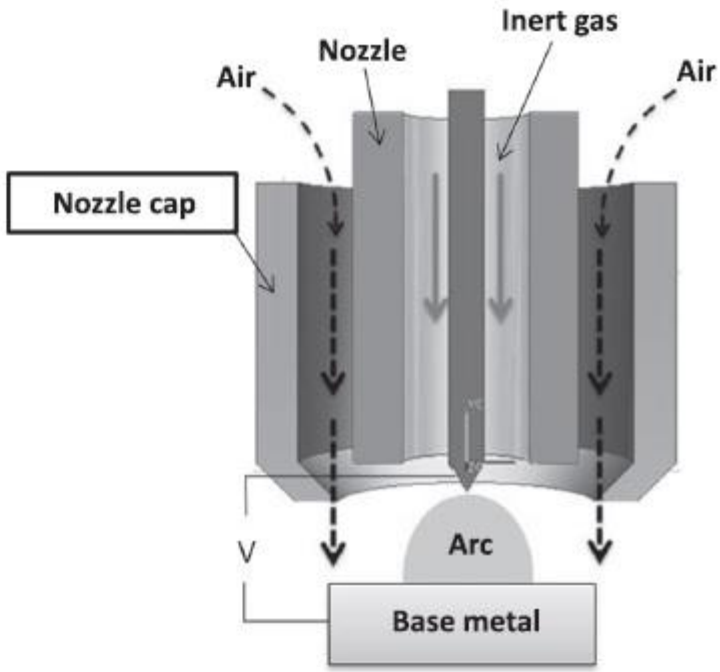


Figure 2.2: Schematic diagram of CA-TIG welding [Morisada et al. [2013]

Depth of penetration was increasing three times as comparison to the simple TIG welding. Active oxygen which comes from the environment has negligible effect on the tungsten electrode.

2.2.2 Effect of ATIG on different steel welding

Chern et al. [2010] did their study of characteristics of duplex stainless steel. They check the effect of ATIG welding on the surface appearance, angular distortion, and depth of penetration, mechanical properties and microstructure of stainless steel 2205. The effect was very positive in ATIG welding as comparison to the conventional TIG welding. Depth of penetration was increasing 3 to 4 times. Angular distortion was very low (almost zero in SiO_2). Fumes formation was very less in ATIG welding. Plasma column and anode root can determine morphology of activated TIG welding. As shown in figure 2.3

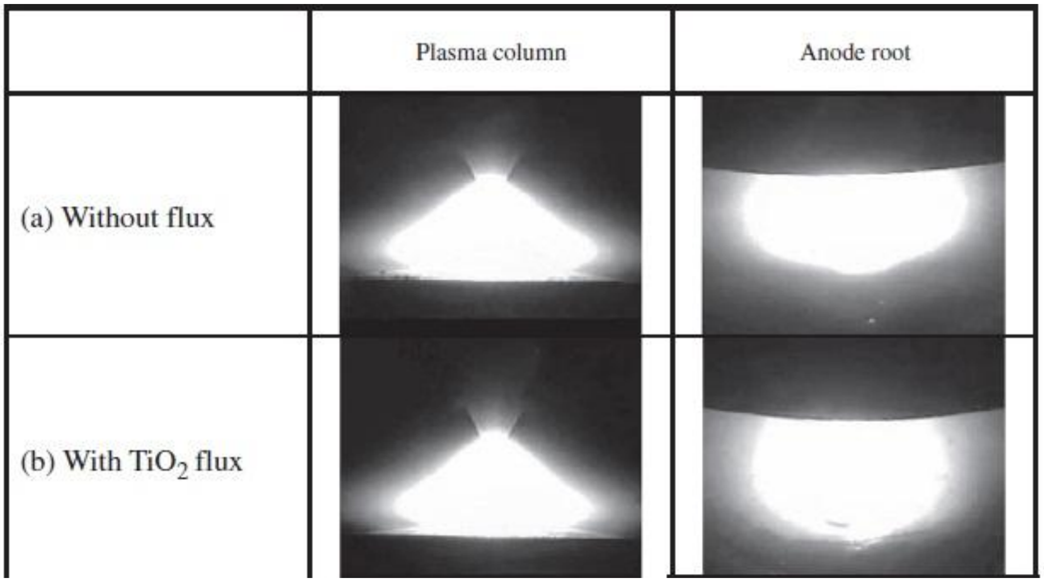


Figure 2.3: Plasma column and anode root [Chern et al. [2010]

Dhandha et al. [2014] did their study on P91 (9% chromium + 5% molybdenum) steel. P91 steel applications are in high temperature component of power plants, petrochemical and nuclear power plants. It is used due to its superior mechanical strength like tensile strength, creep rupture strength and corrosion resistance. They study the effect of ATIG welding on the surface appearance and depth of penetration on P91 steel. They used six different powders (CaO, Fe_2O_3, TiO_2, ZnO, MnO_2 and CrO_3) for their study and found different results for each of them. All was superior to the simple TIG welding. They used semiautomatic setup for welding results. Based on many trials they found four (Fe_2O_3, ZnO, MnO_2 and CrO_3) out of six are suitable for weld at 200 A and 100 mm travel speed. Aspect ratio was found to 0.95, 0.83 and 0.85 in case of ZnO, MnO_2, and CrO_3 respectively as comparison to 0.23 in TIG welding.

Nair et al. [2014] did their study on the finding the optimization parameter in ATIG welding for duplex stainless steel (DSS). DSS is used in many applications for its superior quality like strength and corrosion resistance. And a welding joint can change its property due to thermal effects of HAZ. There should be proper balance of austenite and ferrite in welding zone so that property of DSS not changes. So an optimization is done with ATIG welding for getting deeper penetration and balanced ferrite and austenite composition. Optimization is done by applying ANOVA and Pooled ANOVA techniques by considering electrode gap, travel speed, current and voltage. These are found to be 1 mm, 130 mm/min, 140 ampere and 12 volt respectively. When welding is done by these parameters on DSS they get balanced austenitic and ferritic composition.

Bhattacharya et al. [2015] did comparative study on different steel i.e. AISI 304, AISI 316, Duplex 2205 and AISI 4340. 14 types of different fluxes were used to find the effect of them on surface appearance and depth of penetration. Also effect of different shielding gases or their composition was studied in their research work. For example argon, 95% argon + 5% hydrogen and 70% argon + 30% helium were used to study their effects. Oxide based oxides show their significant effects on welding morphology. Depth of penetration increase 300% as comparison to the simple TIG welding. On the other hand fluoride based flux like KBr and KCl are having insignificant effects on welding morphology. When argon and hydrogen or argon and helium used with flux based welding they get noticeable increase in depth of penetration more than argon flux based welding.

Ramkumar et al [2015] checked the weldability, microstructure and tensile strength of AISI 430 ferritic stainless steel with or without flux. Effect of current on depth and width of penetration is shown by using flux or without flux is shown. Depth of penetration was more when current was increasing. Microstructure shows presence of austenite, ferrite and cluster of Martensite in fusion zone for all cases. After welding presence of low carbon Martensite make the sample harder in all cases in comparison to the parent metal. Joint strength was found more as comparison to the parent metal by welding with or without flux.

Cai et al. [2015] shows the effect of cerium oxide on 800 MPa super steel. The effect of cerium oxide on depth of penetration, microstructure and mechanical strength was investigated. When the content of cerium oxide was increasing from 0 to 15% on the same way depth of penetration was increasing but it passed the value of 15 % the depth of penetration was start to decrease. Optimum value of cerium oxide is found to be 15%. At the value of 15% due to the formation of acicular ferrite is reached maximum so as with low temperature impact, strength and micro hardness. At value less or more then this formation of proeutectoid ferrite is increasing and the mechanical properties of welding materials is start to Detroit

Bhattacharya et al. [2015] found the effect of different current value in ATIG welding. They used AISI 304, AISI 316 and duplex stainless steel for their research. Micro hardness comparison was also done for both flux and without flux welding. Results show no effect on both the cases. Presence of oxygen in TiO_2 helps in arc constriction due to which increase in energy density and due to which depth of penetration become high. Microstructure was also studied, according to which more austenite is present in welding of 304 and 316 steel at optimum value of current and moderate rate of gas flow. When hydrogen is used with argon as shielding gas then it increasing the heat conduction and melting efficiency and results in deeper penetration.

2.2.3 Simulation comparison of weld pool

Zhang et al [2010] did their study with the help of different setup like high speed camera, simulation (PHOENIC software) module and x-ray transmission video transmission system. In their study the role of flux powder to increase the depth of penetration and compare the results with conventional TIG welding. Effect of Marangoni convection is higher as comparison to the arc constriction in the weld pool. Fluid flow in the pool was capture by the x-ray transmission video observation system. As show in fig 2.4 below

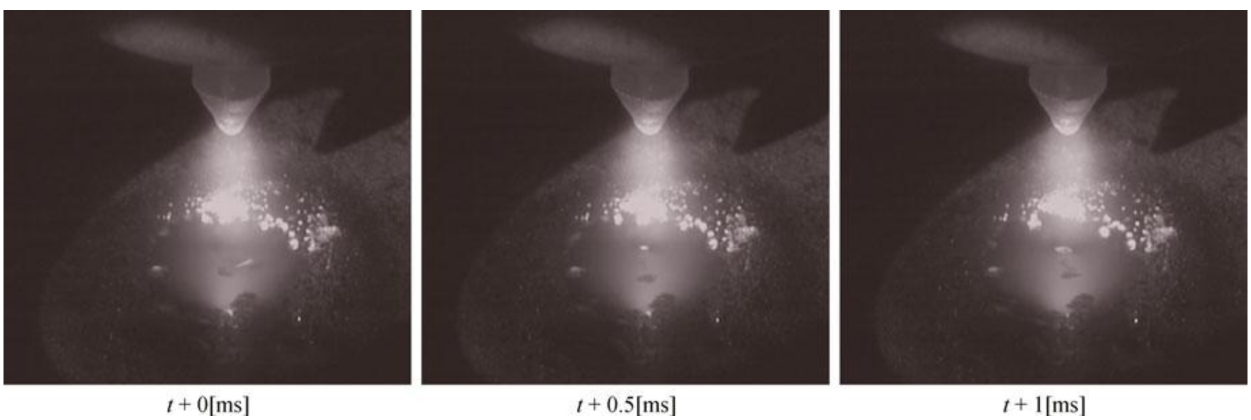


Figure 2.4: observation of molten pool during ATIG welding (Zhang et al [2010])

A tracer is placed on the surface of work piece and its motion and direction is observed for both TIG and ATIG welding with high speed camera. The direction of tracer was from outer edge to inward in ATIG welding. Temperature distribution in TIG and ATIG welding is compare with PHOENIC software.

Berthier et al. [2012] did their work to develop a model to find the effect of Marangoni convection in TIG. A 2d axis symmetrical model is developed to show the results by considering and not considering Lorentz force both. Two layers were painted on work piece together and then observe the effect of the pool. Pool is diverging towards the TIG side of welding. In their second paper they used optical emission spectroscopy to observe the result of arc constriction with different flux powder and their mixture. Arc constriction was maximum when single flux powder was used as shown in figure 2.5 below. Fluorides are having no significant effect in welding pool convection.

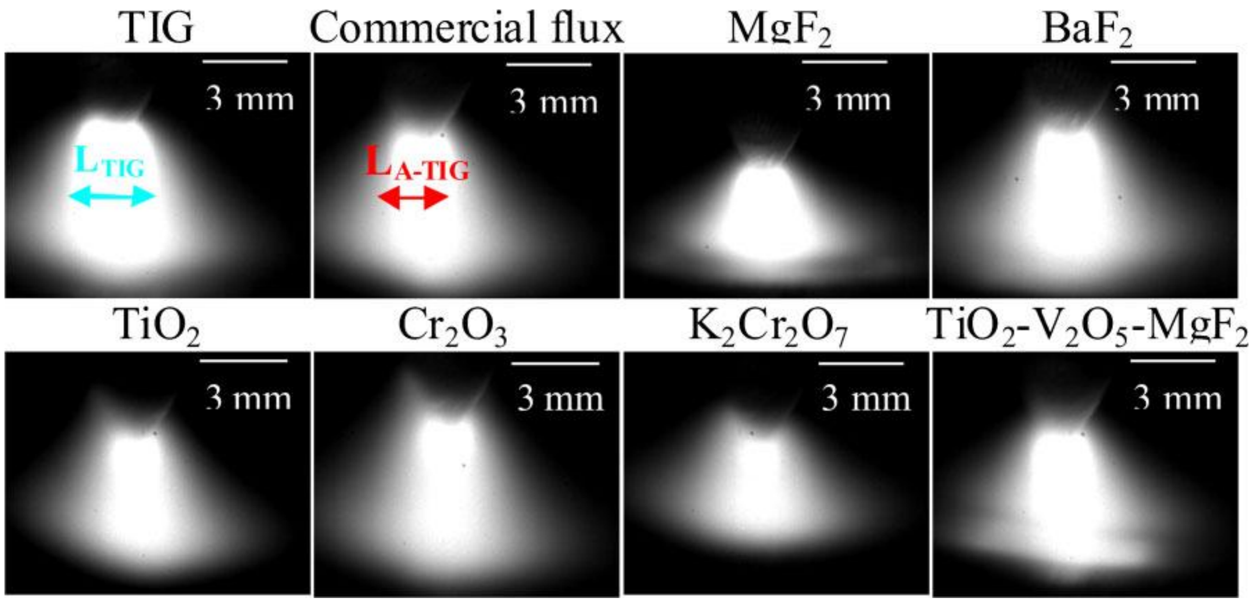


Figure 2.5: observation of plasma for TIG and ATIG (Berthier et al. [2012])

2.3 Summary of literature review

In literature review we studied different research papers TIG welding and improvement of this technique was done by implying a layer of flux on workpiece. This is named as activated tungsten inert gas welding (ATIG). Role of different studies are different but their main objective was how the direction of convective pool is changed. First of all convection in the welding pool is done by different forces are discussed. Oreper et al. [1983] were first who discussed about these forces. They consider only three forces i.e. surface tension force, Lorentz force and buoyancy force. Then in further study done by Kim et al. [1992], they consider fourth force arc pressure and its effect on the weld pool convection. Out these four forces which force or forces are playing main role to increase the depth of penetration. As done by Dong et al. [2007] by taking different fluxes. Lorentz force and Surface tension force was playing main role to increase the depth of penetration. They also discuss about the quantity of flux which should not cross a critical value because after that depth of penetration was start to decrease. Some researchers also tried to develop some more easy way to increase the depth of penetration i.e. Morisada et al. [2013] developed CA-TIG welding. Oxygen which act as active element in weld pool is directly taking by the nozzle attached to the welding electrode. Oxygen was directly taking by the environment by aspiration effect. Results were very significant by this technique.

Various kind of steel is used in industry for its better strength and superior quality. So it is required to find a best technique to weld it without changing its quality. TIG welding is best fit for it but depth of penetration is very low in it so several studies were done to increase its depth and quality with active flux welding. Chern et al. [2010] used duplex steel with ATIG welding in their research and Dhandha et al. [2014] used P91 steel. Both studies check the surface appearance, microstructure, creep crack resistance and depth of penetration by using different fluxes. Mostly single argon gas is used as shielding gas but some researchers also used mixture of gases like Argon and Hydrogen which further increase depth of penetration more than ATIG with single argon i.e. Bhattacharya et al. [2015]. As quantity of flux is main drawback for the ATIG welding so there should be an optimize value it. Cai et al. [2015] tried out to find optimum value of cerium when welding of 800 MPa super steel. Optimum value of cerium content was 15%. Beside the experimental research some simulation work was also done by researches i.e. Zhang et al [2010]. Comparison of experimental work is done with simulated results. Tracers were used to capture the movement of welding pool in both TIG and ATIG welding by high speed cameras.

2.4 Scope and objectives of present work

Steel is widely used in industries for its superior quality like appearance, strength etc. All these are first requirement for customers. Main industries which are using steels are automobiles, bike frames manufacturing etc uses steels for its superior quality. But area of their selling product requires good surface appearance and strength. So to join them we require a welding technique which does not affect its properties and appearance. TIG welding is best fit for their requirement. But main drawback of TIG was lesser depth of penetration in case of steel. So many researchers did their research on different steel so that TIG can make best for welding steel. Some used different fluxes, some used different shielding gas and some did different modification like CA-TIG to improve the weldability for steel. Based on all that we did our research in this field and our objectives are following:

1) Effect of different currents values on SS304 steel with or without different flux and compare with each other.
2) Effect of different shielding gases on SS304 steel with or without flux with different current values and compare them.

Chapter 3

Methodology

3.1 Introduction

We did experimental work on SS304 steel which is used widely in various applications. Both TIG and ATIG welding is done on steel at different current values using a TIG welding setup. Firstly we did our work at different current values with argon (100%) as shielding gas using five fluxes i.e. SiO_2, MoS_2, CrO_3, TiO_2 and NiO_2. Then compare all of them with TIG welding and then welding is done with argon and hydrogen (95% + 5%) as a shielding gas and then compare them with TIG welding. Firstly we will compare all results for single gas and then we will compare the results for both gases each other. For calculating the result we did many procedures which are discussed below one by one.

3.2 Material

Material used was SS304 whose specifications were (100mm×75mm×12mm). After that we used atomic absorption spectrometer (shown in figure3.1 below) for calculating its chemical composition. Before calculation we slightly rub our piece with emery paper to removes the dirt and slag layer from the surface of workpiece. After that we put our workpiece on the atomic absorption spectrometer and we run three tests for calculating its chemical composition. Major source in its composition were Chromium, nickel and some manganese also. All values are given below in table 3.1

Figure 3.1: Atomic absorption spectrometer

Table 3.1: Chemical composition of SS304 steel

Element	Burn 1	Burn 2	Burn 3
Fe	70.2	69.8	69.7
C	0.160	0.0393	0.201
Si	0.450	0.406	0.451
Mn	1.14	1.13	1.14
P	0.0320	0.0547	0.0244
S	0.0279	0.0163	0.0319
Cr	18.7	19.4	19.2
Mo	0.264	0.278	0.257
Ni	8.24	8.09	8.11
Al	0.0641	< 0.0010	0.0875
Co	0.134	0.141	0.135
Cu	0.410	0.398	0.400
Nb	0.0158	0.0153	0.0113
Ti	0.0234	0.0177	0.0241
V	0.0466	0.0477	0.0432
W	0.0579	0.0458	0.0562

Chromium improves the corrosion resistance of steel and also increases the resistance to oxidation at higher temperatures. Nickel is added to promote the austenitic structure in steel. It also improves the weldability, ductility and toughness of steel.

3.3 Welding setup

TIG as well as A-TIG welding are performed on tungsten inert gas welding machine (Make: TECHNOWELD MDX – 300, INDIA) available at Central Workshop and shown in the Fig. 3.2. DC power source is used with static volt-ampere (V-I) characteristics of the drooping type, that is, of the constant current type.

The basic equipments used are:

1. Welding torch

2. Power supply
3. Shielding gas
4. Electrode

Figure 3.2: welding setup for TIG

Process parameters used are:

- Current used – 170 amp, 190 amp, 210 amp
- Voltage – 20-25 volt
- Shielding gas- Argon, mixture of argon and hydrogen (95% +5%)
- Electrode- Tungsten
- Gas flow rate- 12 l/m
- Material used- SS304 steel

3.4 Preparation of workpiece

Before welding of workpiece it is firstly rubbing with brush grinder to remove grime layer from the surface. When surface gets shiny appearance it is then cleaned with acetone. After that preparation of flux layer is start. For making a paste of flux firstly we take a glass plate. Then we clean it properly by acetone. After that we take a flux powder of which we want to make a layer. We are using five powders which are SiO_2, MoS_2, CrO_3, TiO_2 and NiO_2. We put small quantity of powder in glass plate then it is mix with small quantity of acetone to make it paste like structure. After that this paste like structure is painted with a small brush of width 10 mm on workpiece surface (shown in figure3.3 below). Then we wait for evaporation of acetone. After evaporation of acetone it makes a dry layer of flux on surface of workpiece. Now our work piece is ready to weld.

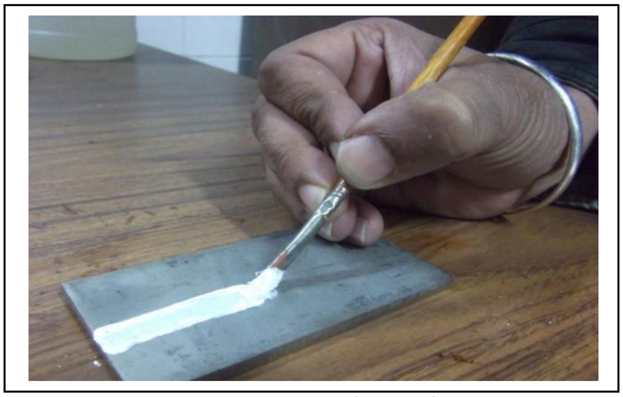
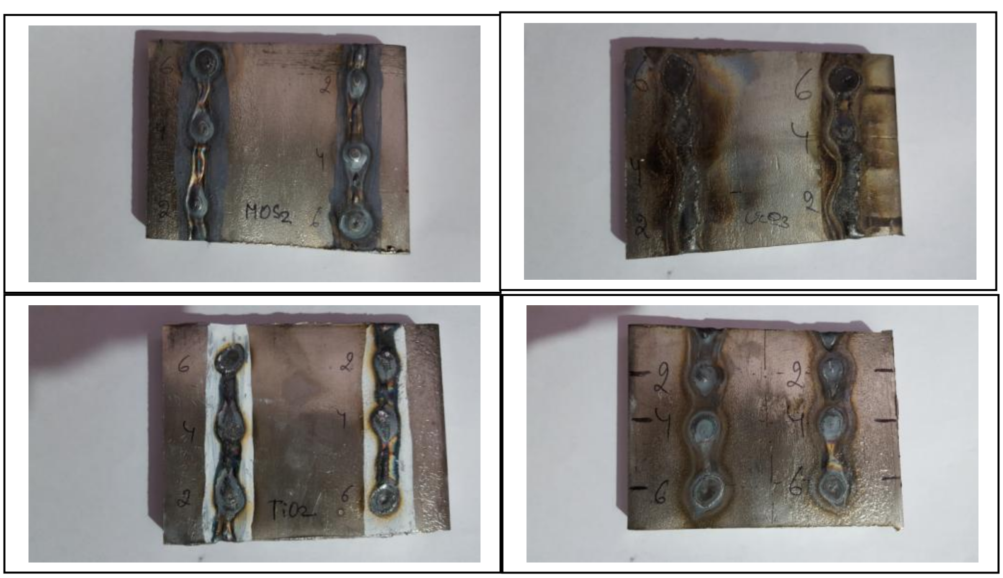


Figure 3.3: Painting surface of workpiece

3.5 Welding of work piece

When layer of flux become dry after that workpiece are taken in to the work shop and current is set according to our requirement. We used three different values of current i.e. 170 A, 190 A, 210 A for comparing the results. Firstly we used only Argon as shielding gas at all three currents. Voltage and gas flow rate remains constant. Only variables are time and current. We make three different bead of weld for 2 sec, 4 sec and 6 sec at each current value. One of them is shown below in figure 3.4.



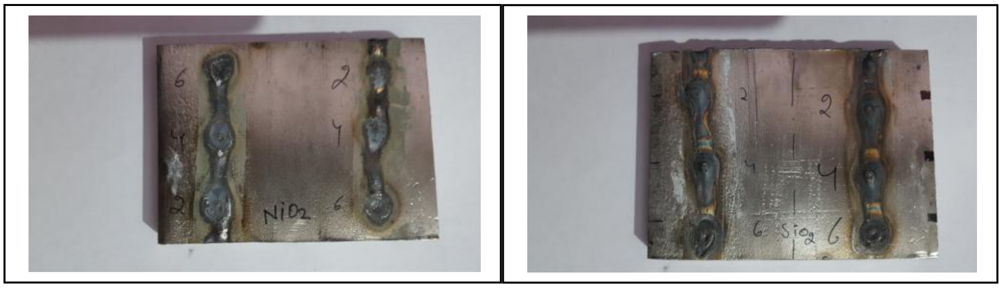


Figure 3.4: Welding bead appearance on surface of work pieces using flux and without flux for 2 sec, 4 sec and 6 sec (at current- 190 A).

In figure 3.4 above all workpiece bear name of flux powder used for welding. One which is not bearing name is without flux powder. After welding with argon only, welding is done with argon and hydrogen mixture also.

3.6 Preparation of sample

After welding done for argon and argon + hydrogen, work pieces were taken into cutting shop. All beads were cut from the centre and collected separately for each current and flux. Cutting is done with disc cutter using to cut steel pipes. After cutting they converted in to small pieces of samples. All samples are then taking in to surface grinder (shown in figure 3.5 below) shop to make welding surface flat and smooth.

Figure 3.5: Surface grinder (www.ronmack.com.au)

After grinding each piece they are further polish with polishing machine. Polishing is done with emery paper of grit 220, 600, 1000 and 2000 respectively. After polishing the etching of surface is done with etchant [Carpenter SS etchant ($FeCl_3$ + $CuCl_3$ + Ethanol + HCl + HNO_3)]. After etching surface shows a bead appearance on it. After that measurement of depth and width of penetration is done with the help of leica microscope (shown in figure 3.6 below).

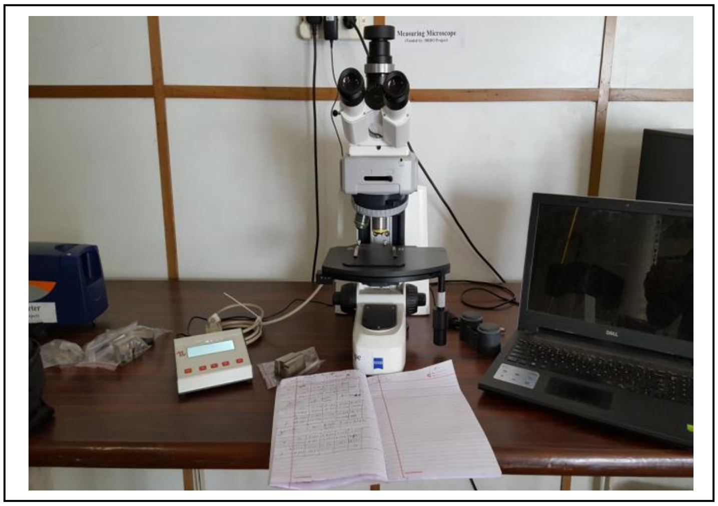


Figure 3.6: Leica microscope

We also calculate 10 to 12 points on outer profile of welding bead observe in leica microscope to generate a profile in excel.

Chapter 4

Results and discussion

4.1 Introduction

Main aim of this chapter is to compare the results of welding bead for different value of current at different time. Effect of different shielding gases is also compared. Comparisons of different flux and different shielding gas is done with the help of images capture by S6 edge android phone and curves made by taking points from leica microscope. Now we will compare all results and discussion will be done on that.

4.2 Results of welding with argon as shielding gas (TIG and ATIG)

4.2.1 For current of 170 A

When welding of SS304 is done at 170 A it is found that depth of penetration is very low even for welding at 6 sec. Results of depth of penetration without flux are shown below in table 4.1.

Table 4.1: Depth and width values for TIG and ATIG welding at 170 A current.(w= width, d= depth)

Time	Without flux (mm)		With SiO_2 (mm)		With TiO_2 (mm)		With MoS_2 (mm)		With CrO_3 (mm)		With NiO_2 (mm)	
In sec	w	d	w	d	w	d	w	d	w	d	w	d
2	4.88	1.46	6.32	2.49	5.23	2.49	6.47	2.18	6.19	2.58	4.17	1.76
4	8.47	1.49	7.64	4.01	6.95	3.31	8.60	2.80	7.12	3.24	7.42	2.10
6	8.67	1.67	8.47	4.10	6.99	3.86	8.72	3.35	9.13	3.82	8.42	3.15

As shown in the table value of depth and width is more in flux based welding as comparison to the TIG welding. For 2 sec maximum results are found for Sio2 and TiO2 and CrO3.effect of NiO2 is not so high. Bead appearance is also shown below in figure 4.1 below. As shown in fig appearance of bead is so clear for ATIG welding.

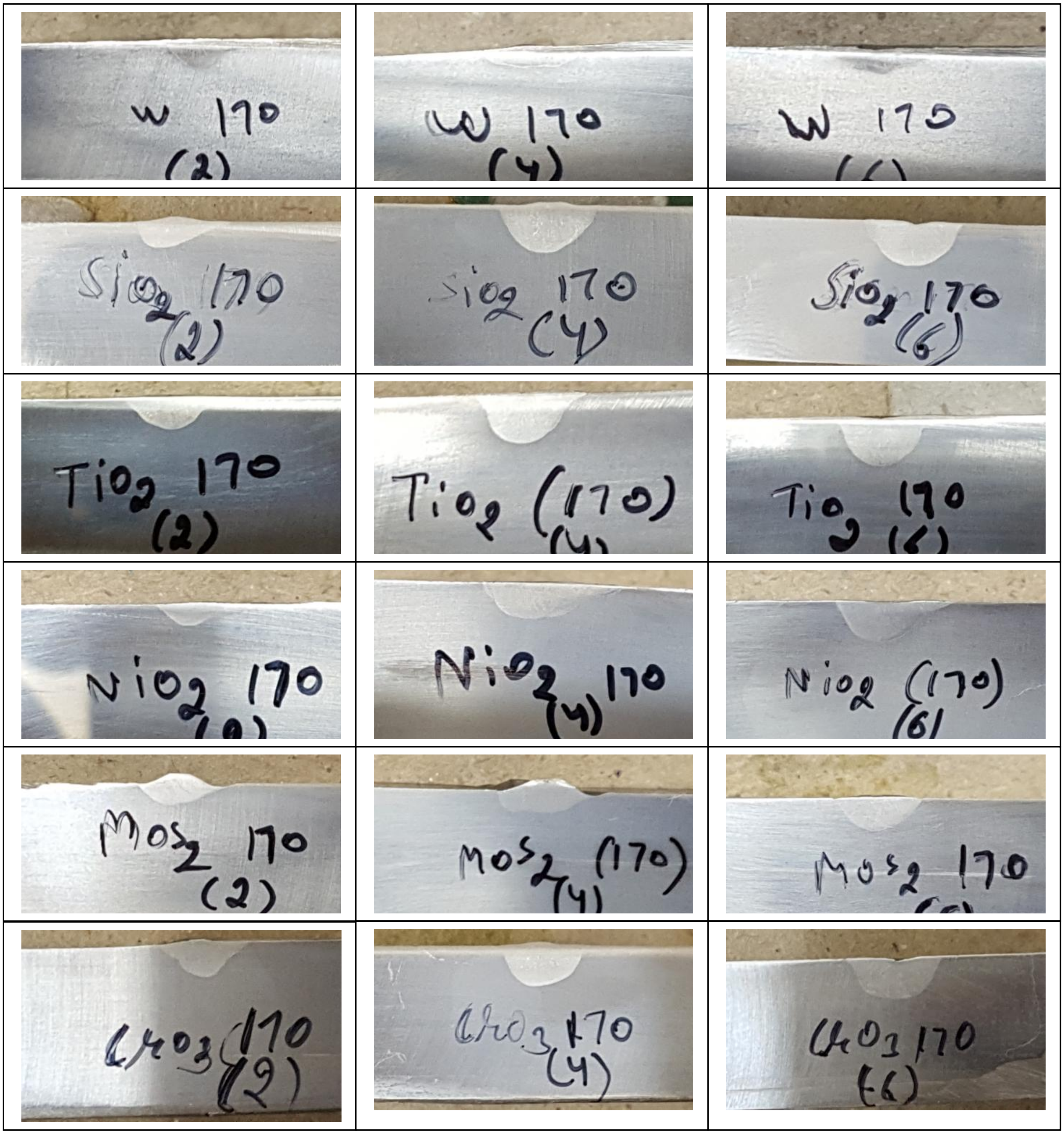


Figure 4.1: Bead appearance for TIG and ATIG welding samples for 2 sec, 4 sec and 6 sec at current- 170 A

As we can see depth of penetration at this current value for TIG welding is 1.46 mm for 2 s but in case of ATIG welding it increases 160 % to 170%. At this current value in TIG welding depth of penetration is increasing marginally but width is increasing more. So to welding at this value of current TIG welding optimize value is 2 sec after that weld become more shallow as shown above in figure 4.1. But for ATIG welding each one shows significant increase in depth of penetration with respect to width. So it can be economical to get more width at more time. For showing the effect of variation of time we draw the profile curves for each type of welding. All of them are shown below one by one.

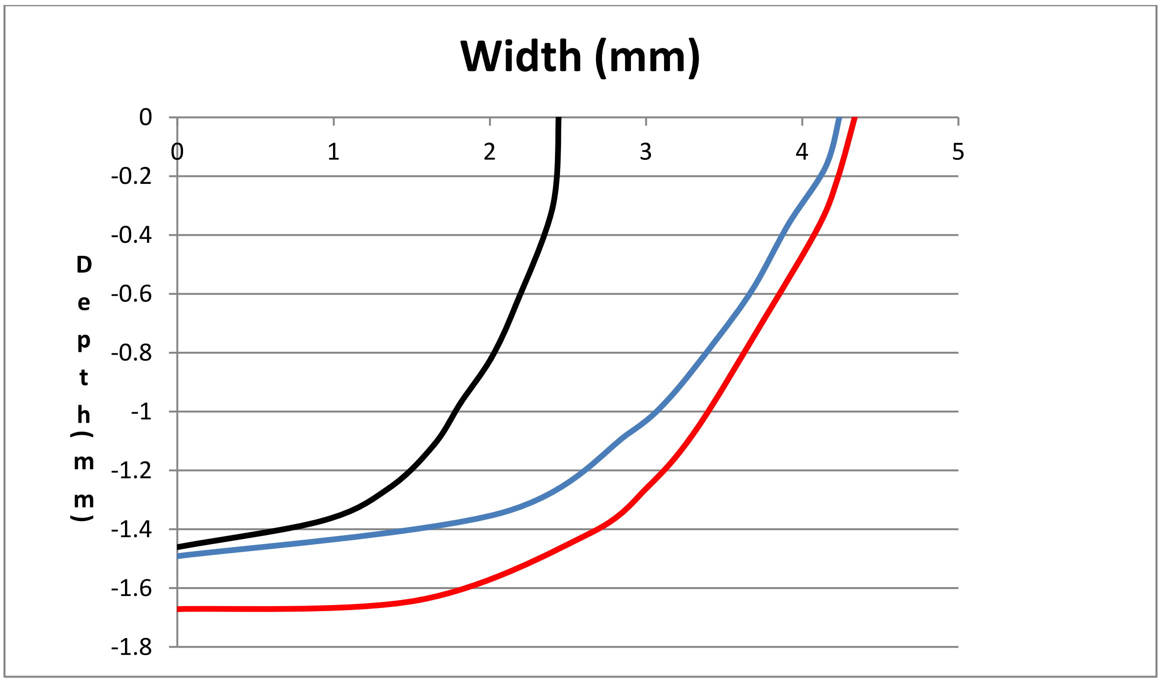
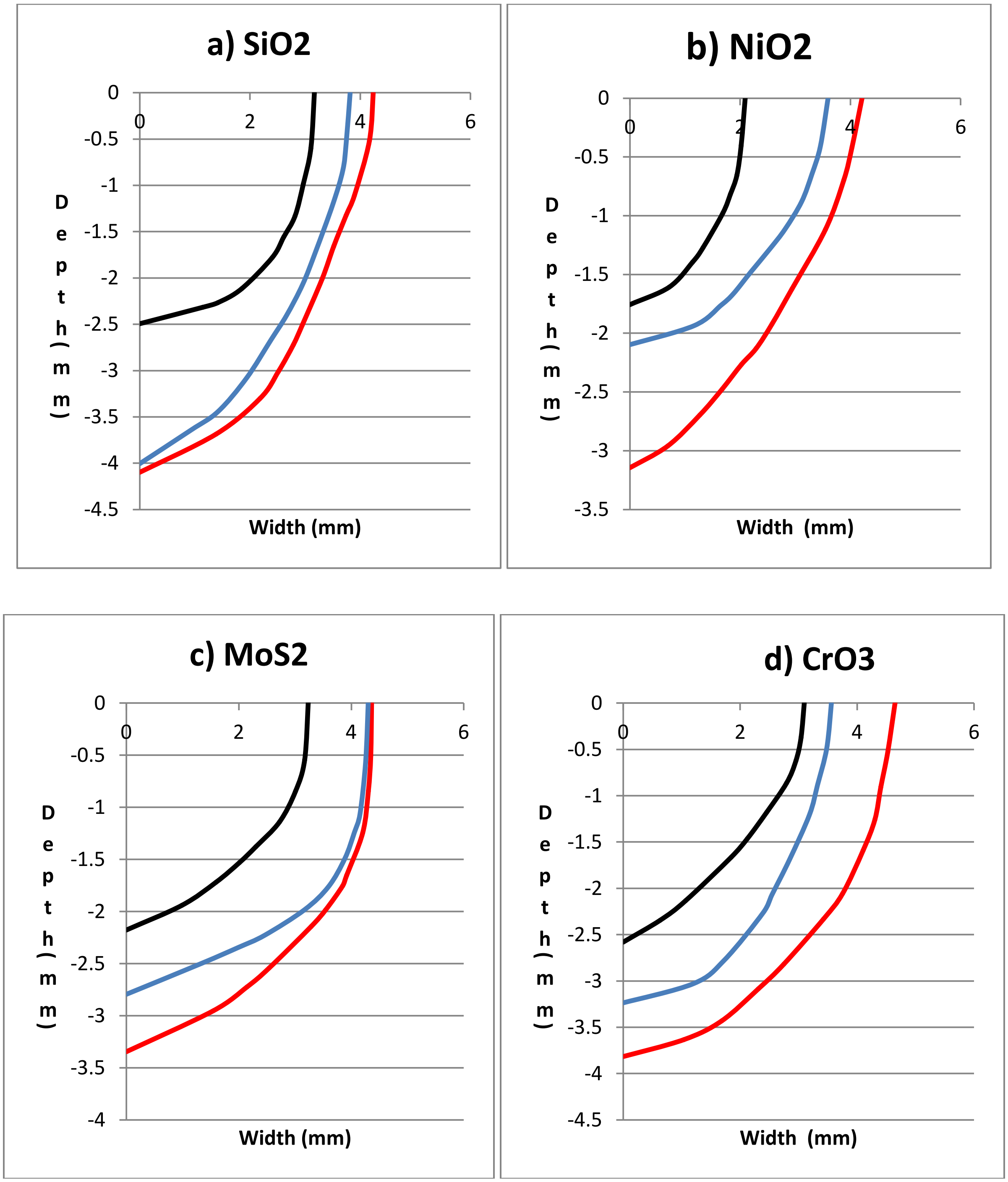


Figure 4.2: Profile curves for TIG welding at 170 A of current for 2 sec (black), 4 sec (blue) and 6 sec(red) (compare with values in table)

Now from profile curve we can easily check the variation for TIG welding. For 2 sec width of bead is nearly half of width for 4 sec and 6 sec. But depth is marginally increasing. Now we will show profile curves for ATIG welding for different flux.

The profile curve for TiO2 shown below is showing that by increasing time after 2 sec width is not decreasing but depth is increasing. So weld starts to become narrow. So it is significant to get deeper penetration for increasing time at this value of current for TiO2. As shown in figure 4.3 below.

The comparison of profile curve we draw for SiO2, TiO2, Cro3 and NiO2 for 2, 4 and 6 sec also shows same effect as shown by TiO2. By increasing time at 170 A. so if we want dipper penetration in ATIG we can increase the time at same current of value.



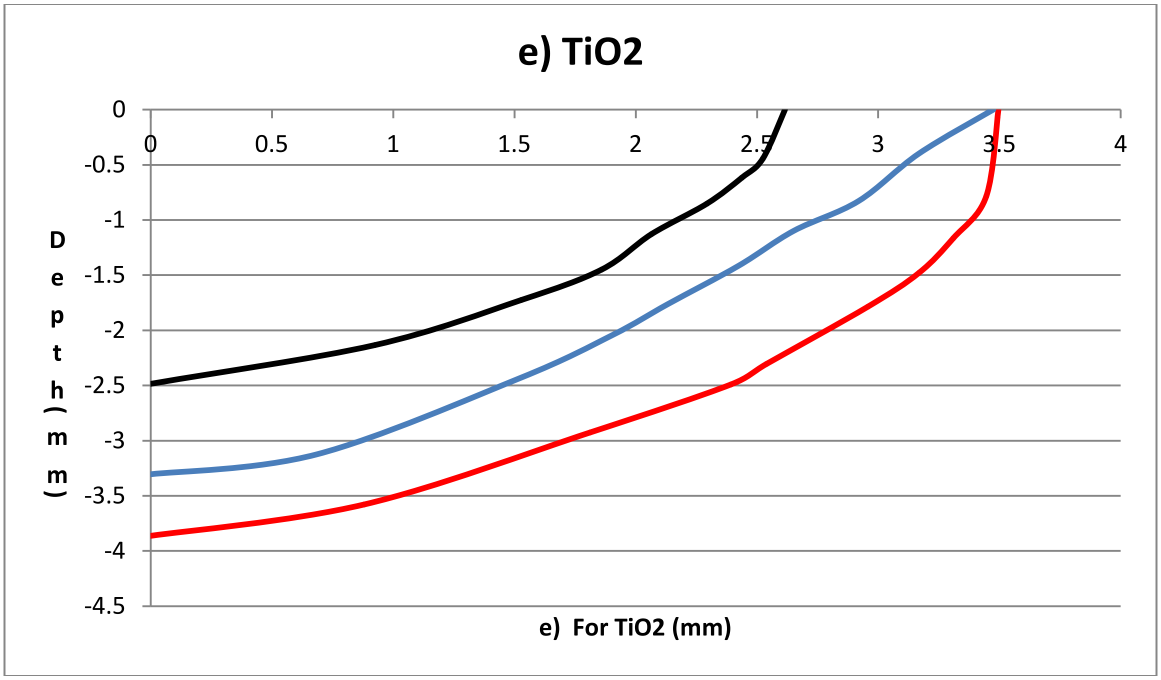


Figure 4.3: Profile curves (a, b, c, d, and e) for ATIG welding for different fluxes. (Current- 170 A) (Black- 2 sec, Blue- 4 sec, Red- 6sec)

So flux implementation increase the depth of penetration significantly by increasing the time but without flux after some time bead start to become shallow instead of narrow as in ATIG welding.

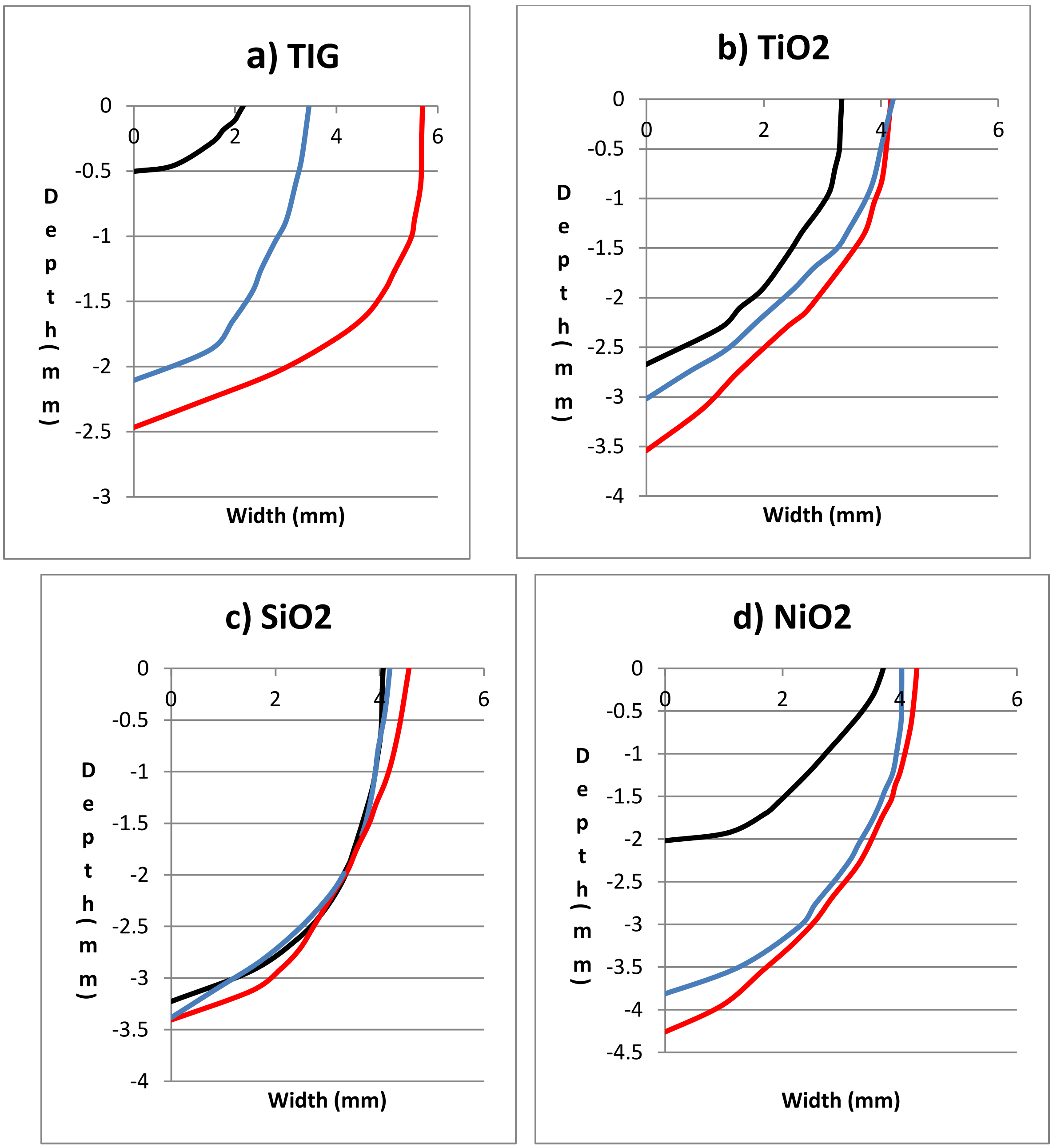
4.2.2 For current 190 A

Now we will discuss about the variation for 190 A for TIG and ATIG. First of all we will compare their depth and width for different time by table shown below in 4.2.

Table 4.2: Depth and width values for TIG and ATIG welding at 190 A current (w= width, d= depth)

Time	Without flux (mm)		With SiO_2 (mm)		With TiO_2 (mm)		With MoS_2 (mm)		With CrO_3 (mm)		With NiO_2 (mm)	
In sec	w	d	w	d	w	d	w	d	w	d	w	d
2	4.33	0.50	8.13	3.23	6.66	2.67	7.02	3.18	8.23	2.41	7.44	2.05
4	6.92	2.11	8.39	3.38	8.42	3.02	8.18	3.58	9.83	2.43	8.07	3.81
6	11.41	2.47	9.12	3.41	8.34	3.54	9.82	4.37	8.87	3.65	8.59	4.26

Values shown above in the table 4.2 indicates significant role of flux for getting depth and width. Mostly results are same as for 170 A. Value of current is higher so arc area is also higher due to this for 2 sec depth of penetration for TIG welding is lower as comparison to 170 A. Effect of variation of time by profiles for TIG and ATIG are shown below in figure 4.4 below.



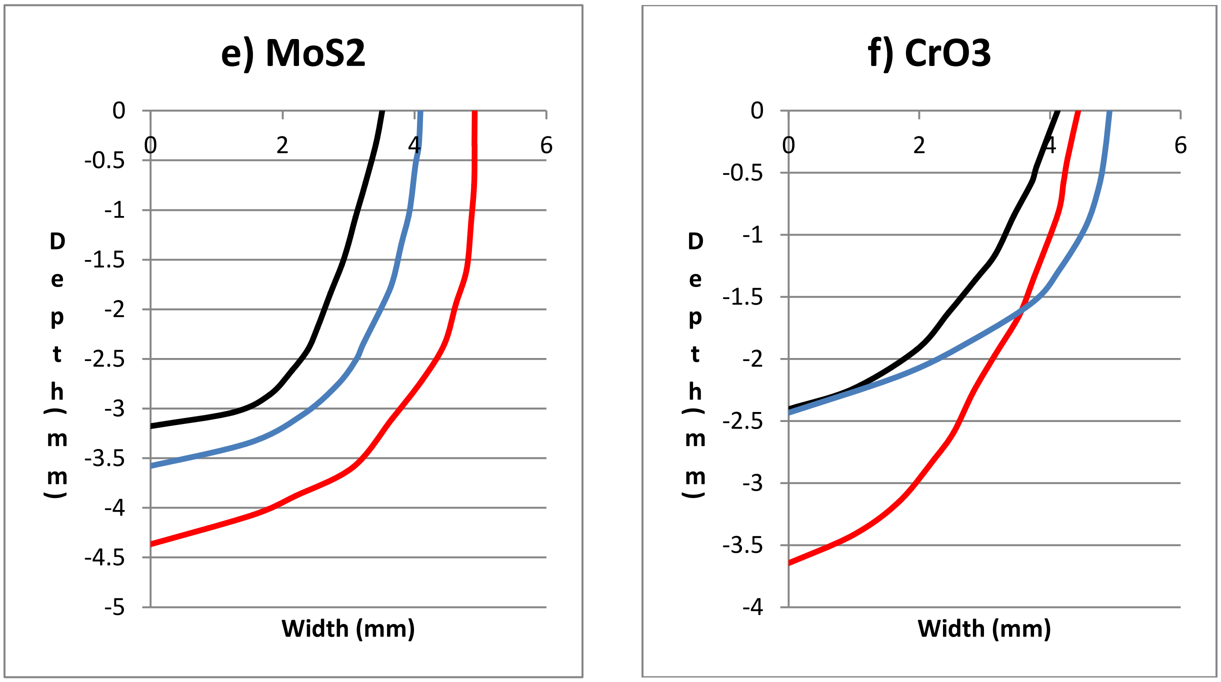
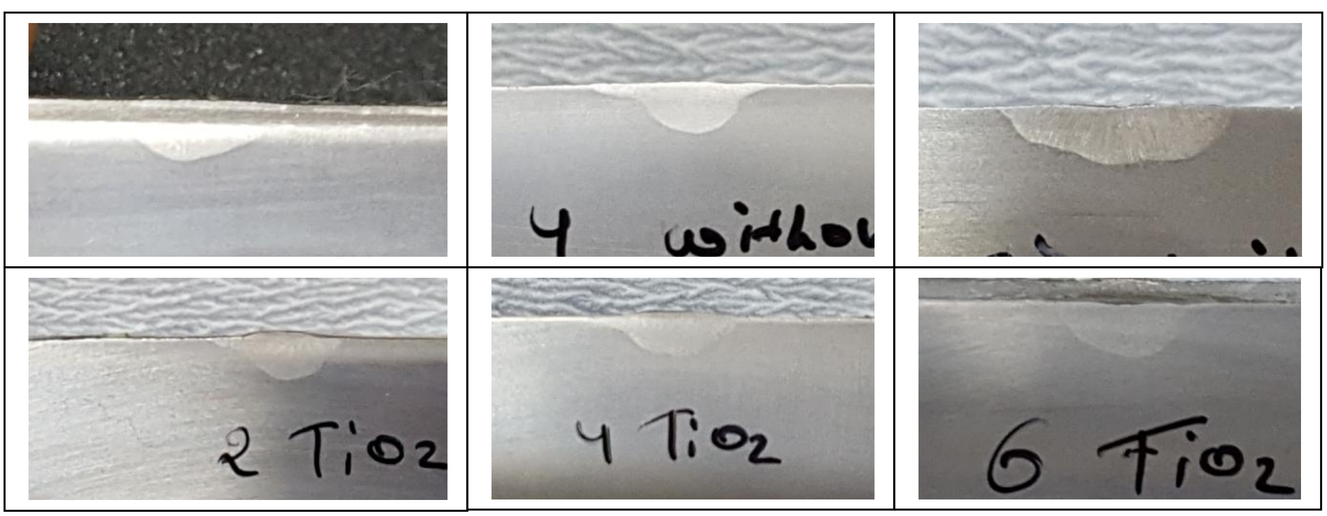


Figure 4.4: Profile curves (a, b, c, d, and e) for TIG and ATIG welding for different fluxes. (Current- 190 A) (Black- 2 sec, Blue- 4 sec, Red- 6sec)

How depth and width is varying can be clearly shown by the profile curve. We can compare different time value for different fluxes. What is the effect of time at same current can be seen by these profile curves clearly. Bead appearance for TIG and ATIG is shown below in figure 4.5.



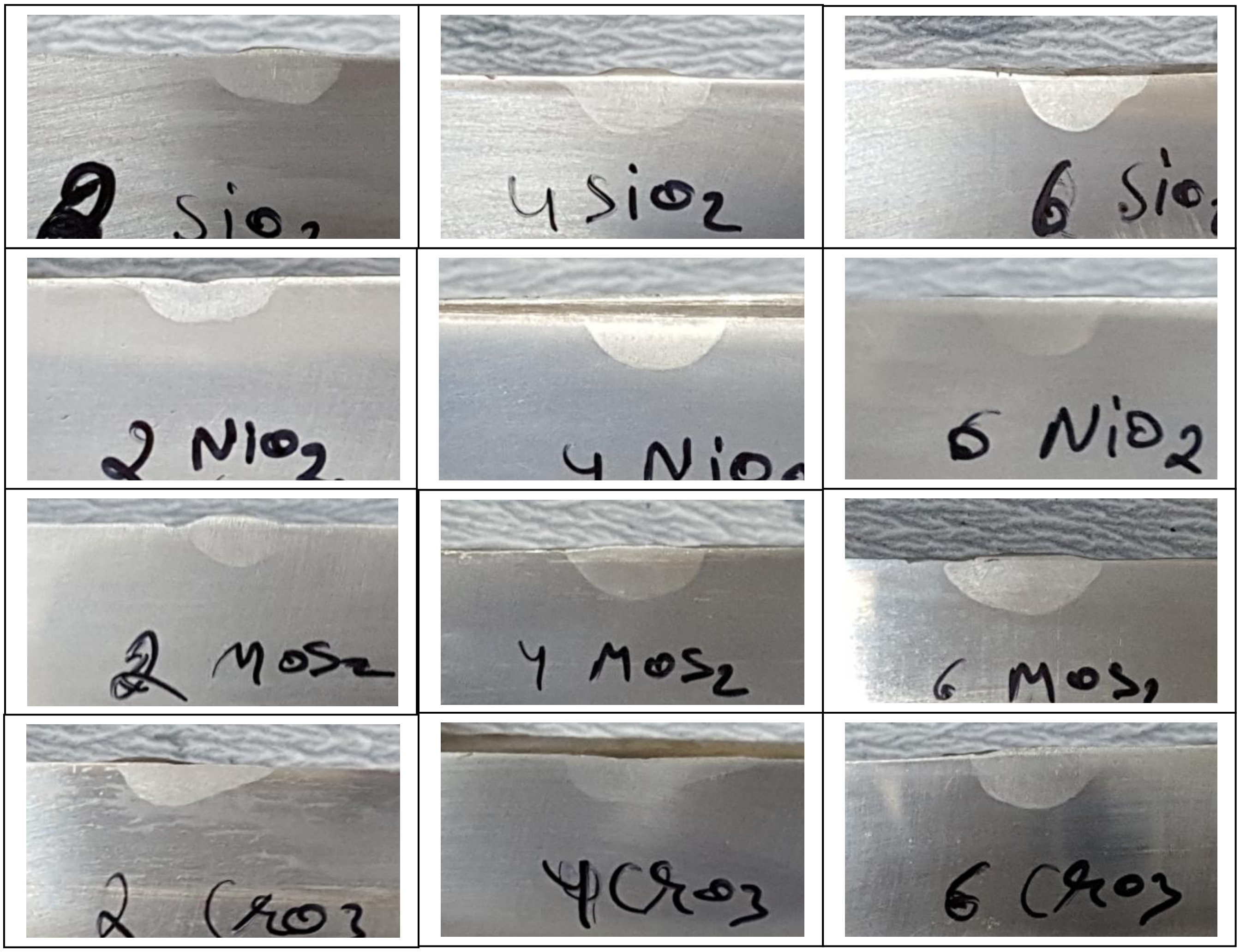


Figure 4.5: Bead appearance for TIG and ATIG welding samples for 2 sec, 4 sec and 6 sec at current- 190 A

The depth of penetration can be more for 2 sec in TIG welding. Here we get only 0.5 mm for 2 sec. This can be happened due to human error i.e. deviation of hand while welding or may be due to not maintained gap between workpiece and electrode. This will be discussing further in article of discussion.

4.2.3 For current of 210 A

After taking values for 170 and 190 A we take a high value of current to see the effect on TIG and ATIG welding. Taking current constant we varies the time again for 2, 4 and 6 sec for checking the variation of TIG and ATIG so we are comparing effect of time and flux both. For this we make a table like earlier and check the value in table 4.3 below.

Table 4.3: Depth and width values for TIG and ATIG welding at 210 A current (w= width, d= depth)

Time	Without flux (mm)		With SiO_2 (mm)		With TiO_2 (mm)		With MoS_2 (mm)		With CrO_3 (mm)		With NiO_2 (mm)	
In sec	w	d	w	d	w	d	w	d	w	d	w	d
2	7.39	2.88	7.75	3.63	6.59	3.39	7.22	2.81	6.82	3.26	7.53	2.78
4	10.41	2.31	7.95	5.08	8.98	4.61	8.48	3.63	9.69	4.05	7.51	4.79
6	12.73	2.36	12.26	3.68	9.60	4.87	9.78	3.81	10.29	3.76	9.34	5.15

As shown in above table depth of penetration for SS304 steel for 210 A of current is increasing significantly for ATIG welding but in TIG welding weather we are going to increase time depth of penetration is very low. Instead of depth, width of welding bead increasing continuously. So weld becomes shallower. Only result for 2 sec is comparable to ATIG welding but weathers us increasing time weld bead become shallower. There is one deviation in result for SiO2 for 6 sec. This can be happen because of fewer gaps between electrode and workpiece. Because at higher current value arc pressure dominate the electromagnetic force and it results in shallow penetration [Kim et al. [1992]. We get this kind of results several times which will be shown further in different results. Profiles of TIG and ATIG welding are shown in figure 4.6 below one by one.

As shown below in different profiles generated with the help of leica microscope helps to compare the bead variation at different time of welding. How depth and width varying with time can be compare through this. Bead appearance of welding at 210 A for TIG and ATIG welding are shown below for different time in fig 4.7.

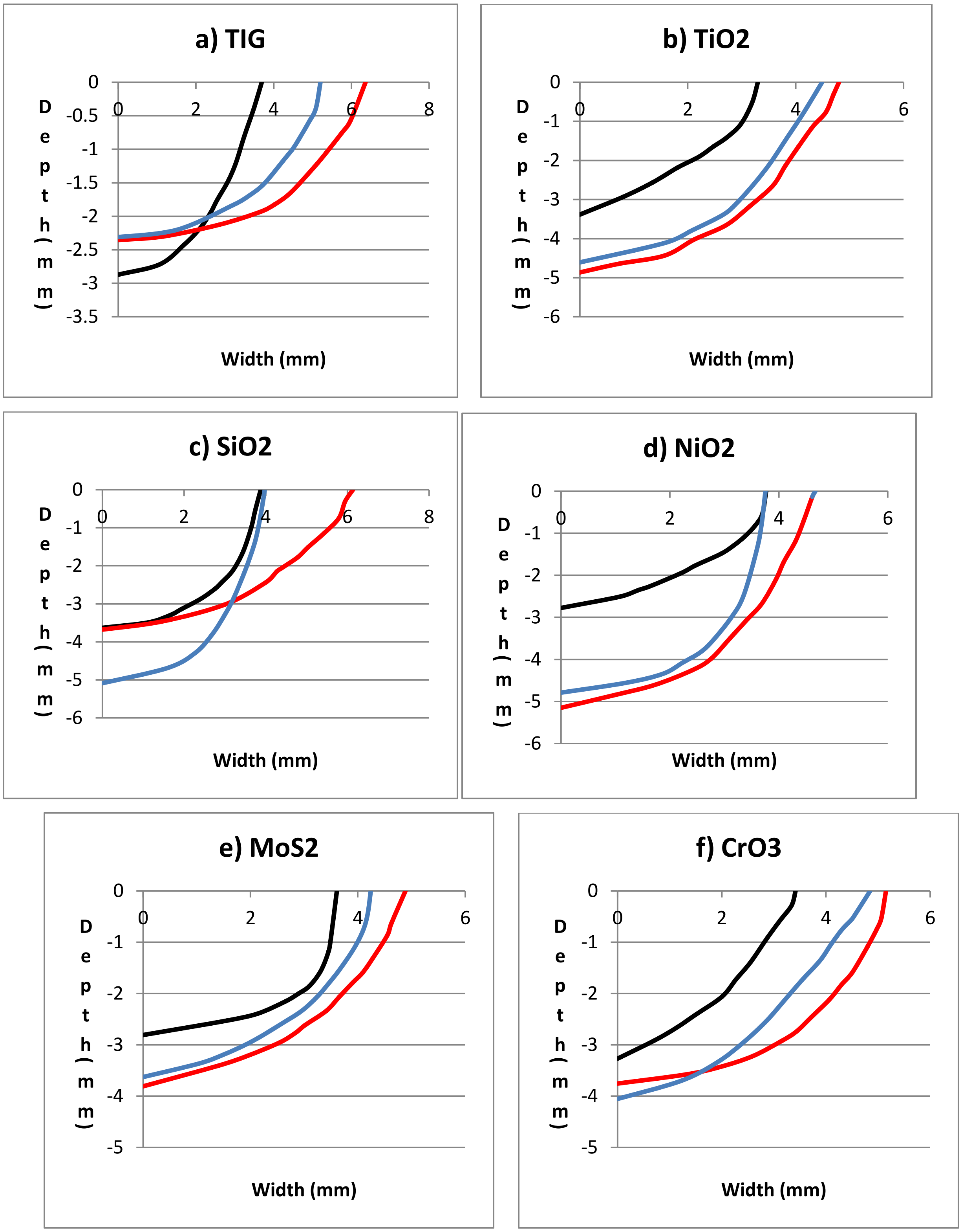


Figure 4.6: Profile curves (a, b, c, d, and e) for TIG and ATIG welding for different fluxes. (Current- 210 A) (Black- 2 sec, Blue- 4 sec, Red- 6sec)

Figure 4.7: Bead appearance for TIG and ATIG welding samples for 2 sec, 4 sec and 6 sec at current- 210 A

All above results were regarding to the argon as shielding gas. Now we will see results for mixture of argon (95%) and hydrogen (5%).

4.3 Results of welding with argon and hydrogen as shielding gas (TIG and ATIG)

Argon is used as shielding gas widely in industries in TIG welding. In our above results it was found that flux based TIG welding with argon increase depth of penetration 150 to 250% for SS304 steel. Now we will show the effect of hydrogen gas in TIG welding with or without flux and will compare with above values for argon. We will compare effect of hydrogen for different flux and different time also as done in above case. Now we will show results at different current values using argon and hydrogen as shielding gas.

4.3.1 For current 170 A

After welding with argon and hydrogen we measure the depth and width of each bead which are given below in table 4.4.

Table 4.4: Depth and width values for TIG and ATIG welding at 170 A current (w= width, d= depth)

Time	Without flux (mm)		With SiO_2 (mm)		With TiO_2 (mm)		With MoS_2 (mm)		With CrO_3 (mm)		With NiO_2 (mm)	
In sec	w	d	w	d	w	d	w	d	w	d	w	d
2	8.66	1.98	6.88	2.15	6.52	3.30	9.00	3.14	8.75	2.77	8.52	2.43
4	9.43	3.03	9.70	3.37	7.60	3.32	8.54	3.32	10.18	3.07	9.90	3.45
6	8.38	3.32	8.32	3.88	9.27	3.94	9.70	4.73	8.67	4.34	10.19	3.94

As shown in table above effect of ATIG welding is not so high for higher time. We can see clearly that welding without flux improve so much, we can compare the result the results with table number 4.1. By comparing we can see the welding depth increasing to 34, 103 and 99 % for 2, 4 and 6 sec respectively. Bead becomes narrower as comparison to TIG welding with argon only. Effect on ATIG welding is also seems when comparing with table 4.1. 20 to 25 % increase is further get by mixing hydrogen. Now we will show profile curves below in figure 4.8 for TIG and ATIG welding at 170 A of current.

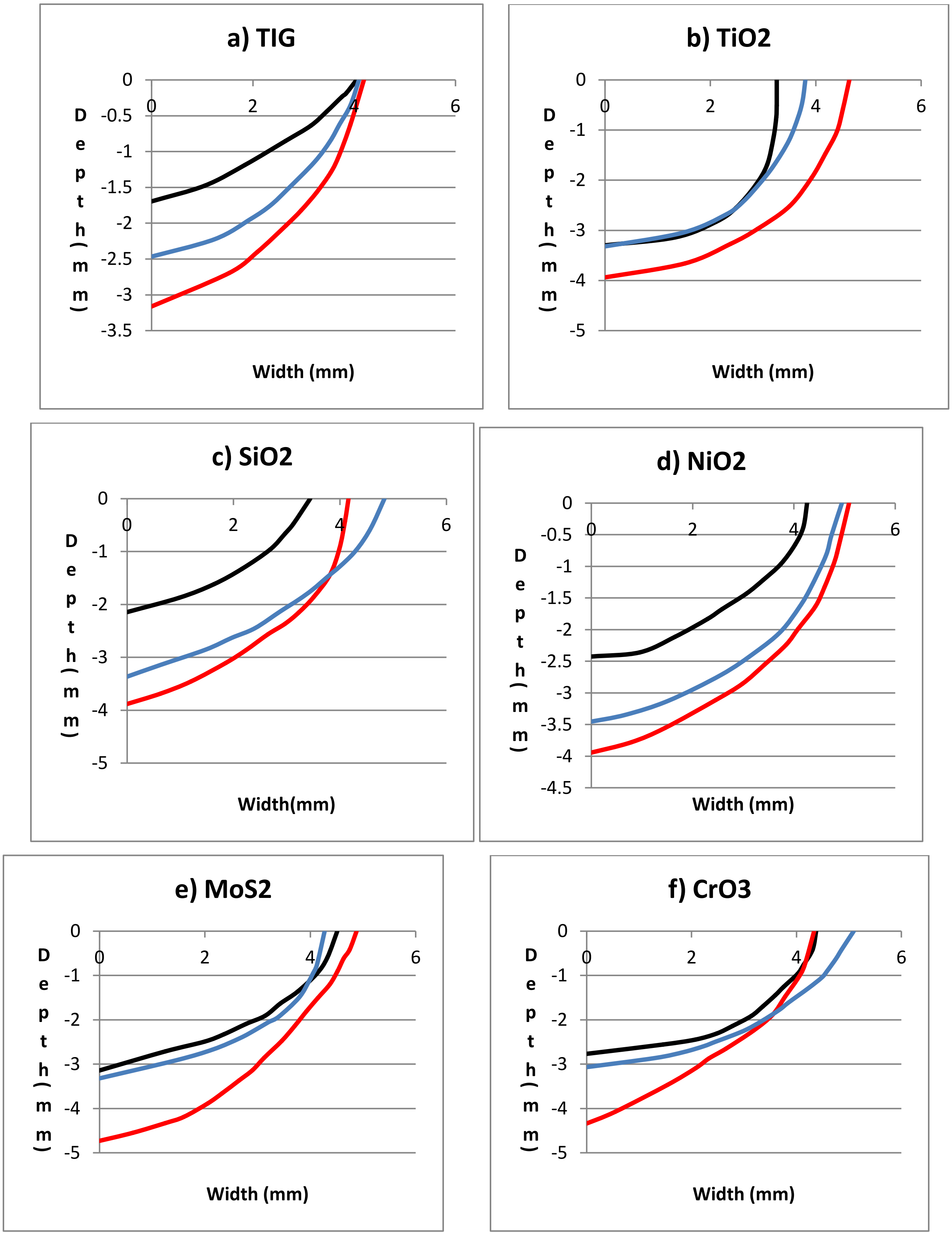


Figure 4.8: profile curves for TIG and ATIG welding at 170 A of current (Black- 2 sec, Blue- 4 sec, Red- 6sec)

Effect of increasing the time shows largely in TIG welding only (shown above in profile curves).

Figure 4.9: weld bead appearance for TIG and ATIG welding

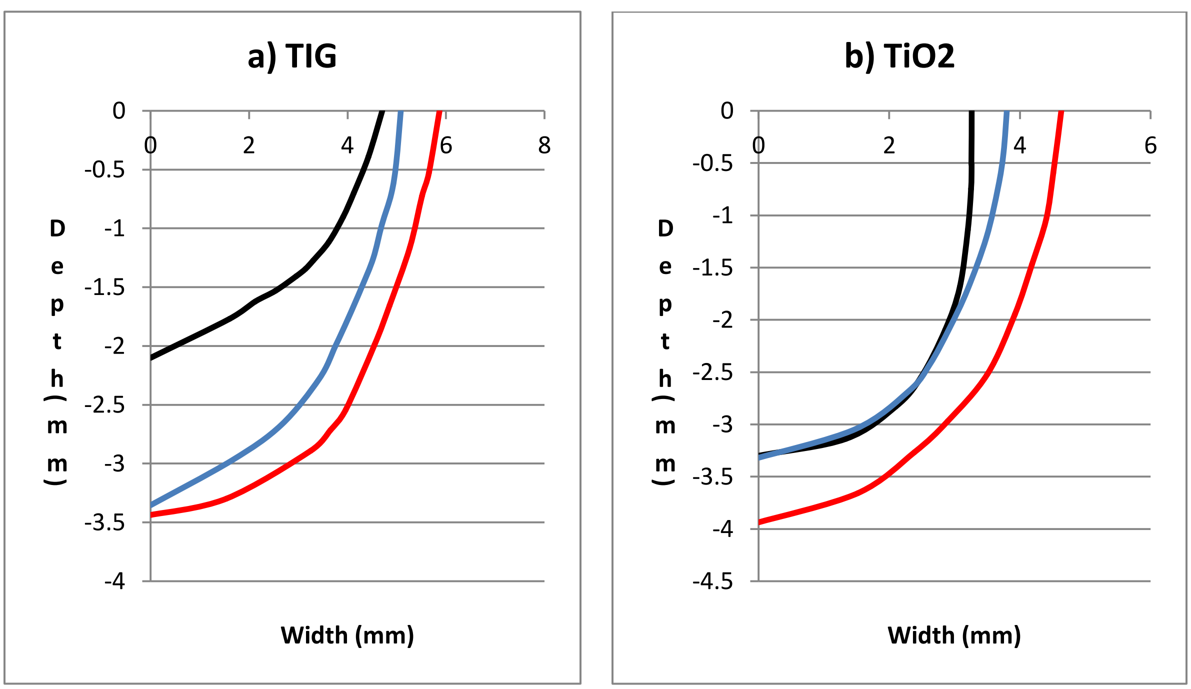
4.3.2 For current 190 A

Now we will discuss results from 190 A of current. Values for width and depth of penetration are given below in Table 4.5 below.

Table 4.5: Depth and width values for TIG and ATIG welding at 190 A current (w= width, d= depth

Time	Without flux (mm)		With SiO_2 (mm)		With TiO_2 (mm)		With MoS_2 (mm)		With CrO_3 (mm)		With NiO_2 (mm)	
In sec	w	d	w	d	w	D	w	d	w	d	w	D
2	9.40	2.10	8.25	3.14	7.35	3.23	6.81	3.63	9.02	3.13	8.61	2.79
4	10.16	3.34	9.98	3.48	7.99	4.49	9.65	4.45	11.31	4.03	12.08	3.19
6	11.73	3.44	11.89	4.31	9.24	4.83	10.00	4.57	9.76	4.30	11.63	4.52

Now we can compare these values at 190 A with welding results which we get by argon as shielding gas only. Depth of penetration increase 60 % as comparison to the welding done by single argon only. ATIG welding is also improved up to 27 % in some fluxes i.e. SiO2 for 6 sec. Now we will show profile curve in figure 4.10 below.



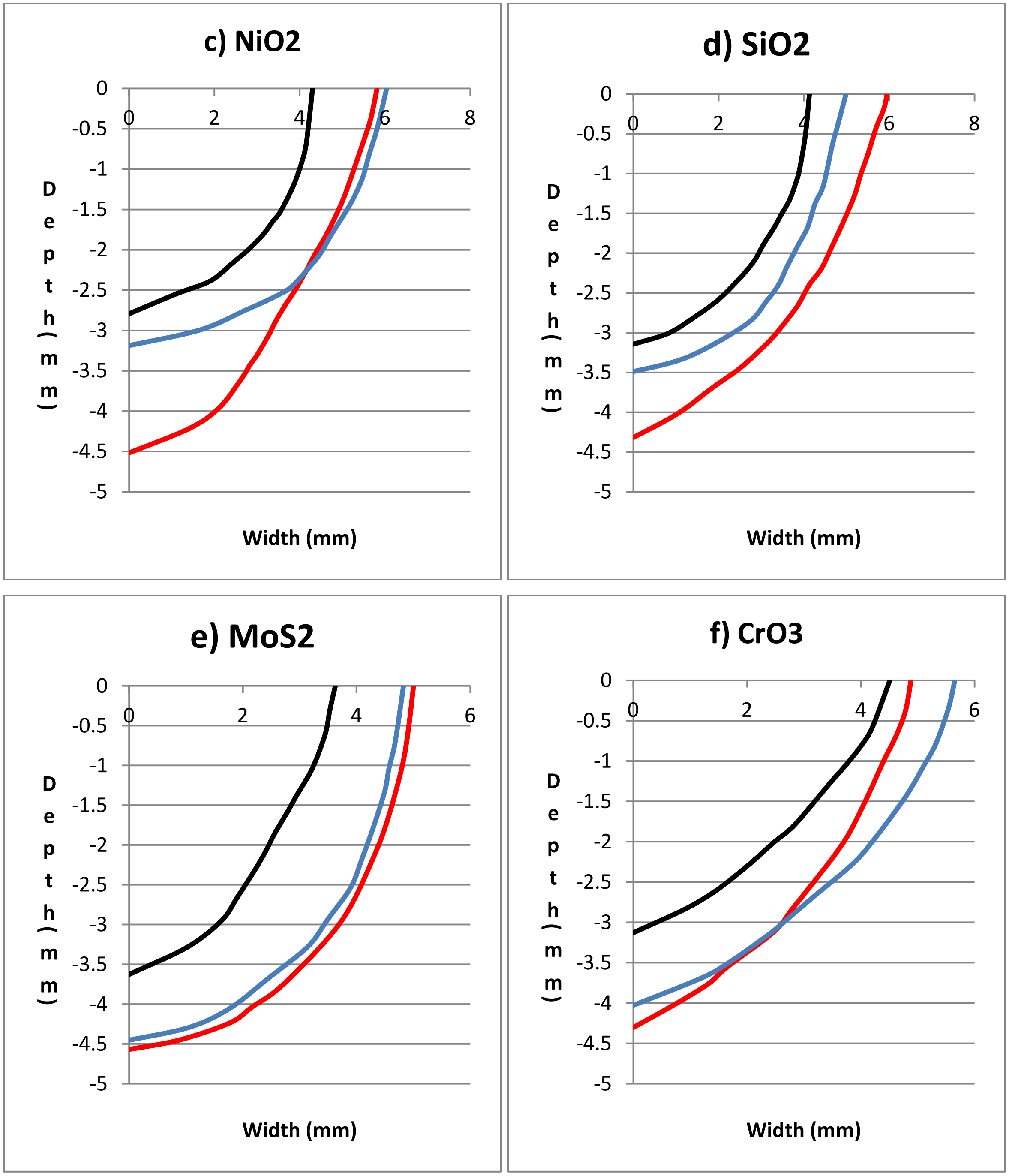


Figure 4.10: Profile curves for TIG and ATIG welding at 190 A (Black- 2 sec, Blue- 4 sec, Red- 6sec)

The significant effect of hydrogen is shown above by numerical and profile curves. Now we will show the bead of samples which are capture by Samsung Galaxy S6 edge smart phone. Images of bead for 2, 4 and 6 sec are shown below in figure 4.11.

Figure 4.11: Bead appearance of TIG and ATIG welding at 190 A of current

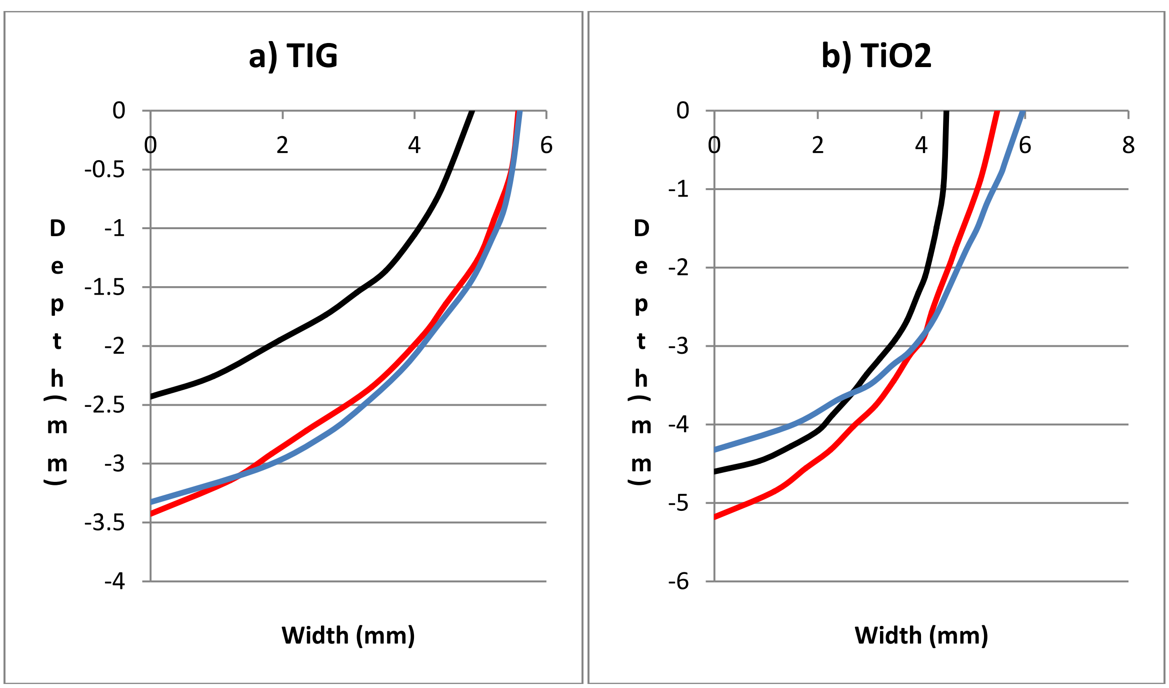
4.3.3 For current 210 A

Now we will compare the result for 210 A. All values for this are written in table 4.6 below. These values are then comparing with simple argon as shielding gas TIG and ATIG welding.

Table 4.6: Depth and width values for TIG and ATIG welding at 210 A current (w = width, d= depth)

Time	Without flux (mm)		With SiO_2 (mm)		With TiO_2 (mm)		With MoS_2 (mm)		With CrO_3 (mm)		With NiO_2 (mm)	
In sec	w	d	w	d	w	d	w	d	w	d	w	d
2	9.75	2.43	10.93	3.57	8.97	4.60	12.65	3.40	10.43	2.67	11.80	2.43
4	11.20	3.33	11.62	4.35	11.92	4.32	12.54	4.33	12.09	2.80	13.88	3.91
6	11.46	3.70	11.37	5.78	10.98	5.18	12.07	5.05	10.71	4.27	14.08	4.01

All the values in the table proof the significant role of hydrogen in welding of SS304 by TIG and ATIG welding. Value of TIG welding results with argon and hydrogen as shielding gas having equivalent to ATIG welding results at 190 A. we also observe the effect of arc pressure in some value due to high current and smaller gap between electrode and workpiece i.e. for Cro3 at 4 sec. So use of hydrogen with argon as a shielding gas shows very positive effect on TIG welding. At higher current values even we don't need of flux for up to 4 mm of depth weld in SS304. Profiles curves for TIG and ATIG welding are shown below in figure 4.12.



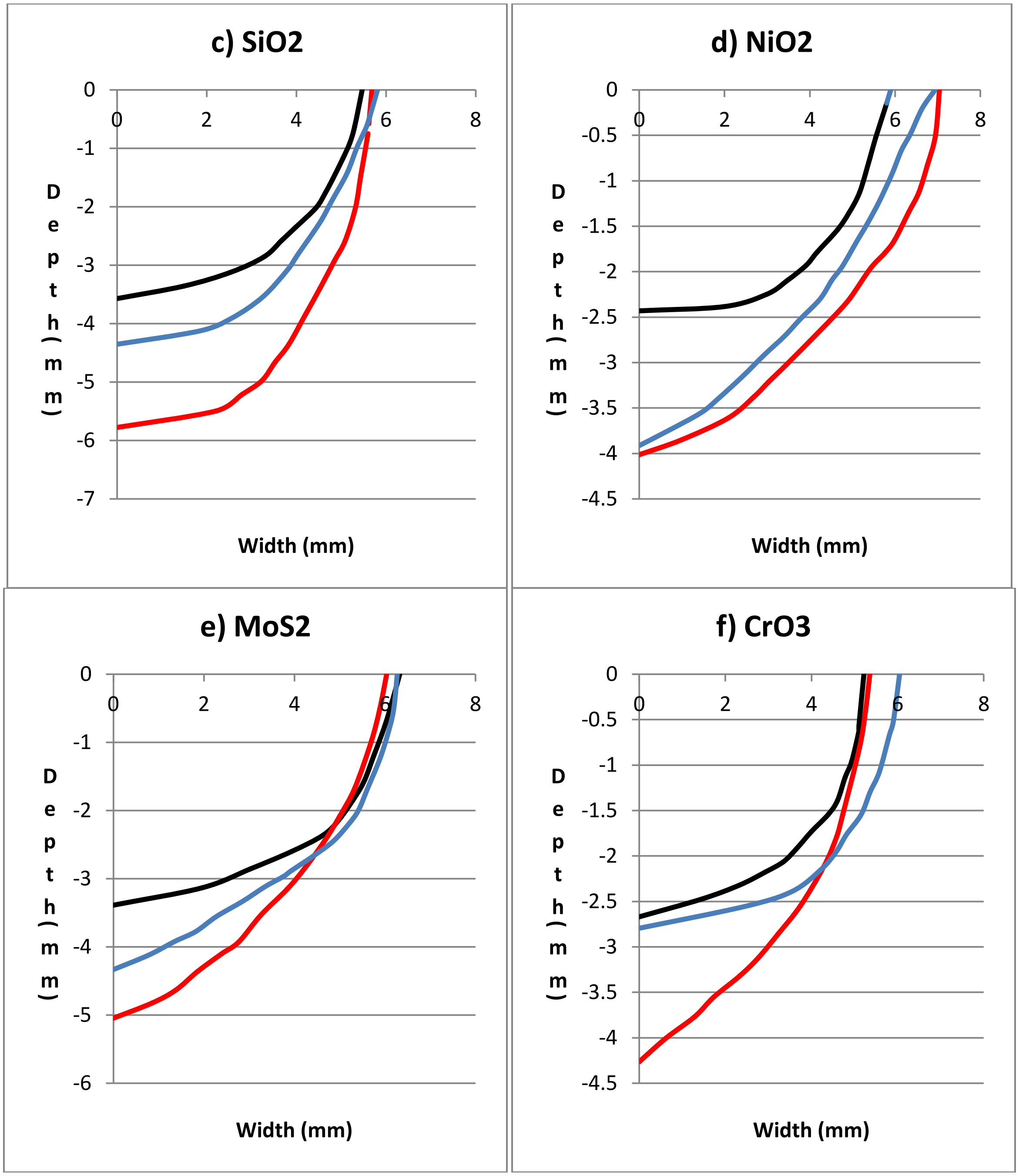


Figure 4.12: profile curves for TIG and ATIG welding at current 210 A (Black- 2 sec, Blue- 4 sec, Red- 6sec

Different profile curves shows that at 210 A of current by using argon and hydrogen as shielding gas width of bead is not varying so much. Only effects occur for depth of penetration. With increasing time depth is increasing not width. Now we will show bead of all samples for 210 A of current in figure 4.13 below

Figure 4.13 Bead appearances for TIG and ATIG welding at 210 A current.

Now we will discuss the above experimented result in our next article one by one. What is the effect and why it is happing will be discuss one by one our variable elements were time, current and shielding gas. What is the main effect of each variable will be discussed in discussion part.

4.4 Discussion

In all our experimentation our main variables are current, time and shielding gas. Effects of all these three variables are shown in results above. Now we will discuss all of them one by one.

4.4.1 Effect of current and time for argon as shielding gas

For checking the effect of current we keep the other variable constant. As we see previously in result section it was clear that depth of penetration was higher 2 to 3 times from previous value. Now for 2 sec of current we will see effect of current for each TIG and ATIG welding. As shown in table 4.7 below.

Table 4.7: Comparison of TIG and ATIG welding for different value of current (for 2sec)

C	Without flux (mm)		With SiO2 (mm)		With TiO2 (mm)		With MoS2 (mm)		With NiO2 (mm)		With CrO3 (mm)	
A	w	d	w	d	W	d	w	d	w	D	w	d
170	4.88	1.46	6.32	2.49	5.23	2.49	6.47	2.18	4.17	1.76	6.19	2.58
190	4.32	0.50	8.13	3.23	6.66	2.67	7.02	3.18	7.44	2.05	8.23	2.41
210	7.39	2.87	7.75	3.6	6.59	3.39	7.22	2.81	7.53	2.78	6.83	3.26

d= depth, w= width, C= current, A= ampere

From the above comparison we can see clearly depth of penetration become nearly double for ATIG welding. At 190 A of current for TIG welding we get very low depth of penetration this can be happen due to human error i.e. increase or decrease of distance between electrode tip or workpiece. If we talk about aspect ratio which is equal to depth divide by width, this is greater at 210 A of current. Maximum aspect ratio we getting is 0.51 in case of TiO2. For TIG welding it was 0.39 at 210 A of current. If we talk about depth only, it is increasing when current is increasing at 2 sec.

Now we will compare value when time of bead is 4 second. We will get aspect ratio for all three current and will compare at 4 sec. Value of depth and width of bead is shown below in table 4.8.

4.8: Comparison of TIG and ATIG for different value of current (at 4 sec).

C	Without flux (mm)		With SiO2 (mm)		With TiO2 (mm)		With MoS2 (mm)		With NiO2 (mm)		With CrO3 (mm)	
A	w	d	w	d	W	d	w	d	w	D	w	d
170	8.47	1.49	7.64	4.01	6.95	3.31	8.60	2.78	7.42	2.10	7.12	3.24
190	6.92	2.11	8.39	3.38	8.42	3.02	8.18	3.58	8.07	3.81	9.83	2.43
210	10.4	2.31	7.95	5.1	8.98	4.61	8.48	3.63	7.51	4.79	9.69	4.05

d= depth, w= width, C = current, A= ampere

At 4 sec of time we can see clearly depth of penetration is increasing from 2 sec. we can compare values from table 4.7. When time of welding is increasing from 2 to 4 sec, there is no significant increase in the value of depth of penetration of welding pool for TIG welding. Only width of penetration is increasing more. So aspect ratio become less when time is increasing from 2 to 4 sec for all value of current. Aspect ratio at 2 sec for at 170 A for TIG was 0.29 and at 4 sec it becomes 0.17. Also for TIG aspect ratio at 2 sec for 210 A was 0.39, but at 4 sec it becomes 0.22. So bead becomes shallower when time is increasing also. At constant time, when current is increasing, depth of penetration is also increasing both for TIG and ATIG welding. At 170 A and 210 A for different flux we get nearly 3 times more aspect ratio i.e. 0.476, 0.455 in TiO2, CrO3 respectively. When current is increasing from 170 A to 210 A, aspect ratio is also increasing. Now we will compare values for 6 sec of time in table 4.9 below.

Table 4.9: Comparison for TIG and ATIG for different values of current (at 6 sec)

C	Without flux (mm)		With SiO2 (mm)		With TiO2 (mm)		With MoS2 (mm)		With NiO2 (mm)		With CrO3 (mm)	
A	w	d	w	d	W	d	w	d	w	D	w	d
170	8.67	1.67	8.47	4.10	6.99	3.86	8.72	3.35	8.42	3.15	9.30	3.82
190	11.40	2.46	9.12	3.41	8.34	3.54	9.82	4.37	8.59	4.26	8.87	3.65
210	12.7	2.36	12.2	3.6	9.60	4.87	9.78	3.81	9.34	5.15	10.2	3.76

d= depth, w= width, C= current, A= ampere

Depth of penetration is increasing by increasing the time from 2 to 6 sec for ATIG welding. But for TIG again values of width is increasing more than values of depth. So for TIG welding after value it is not significant for TIG to increase time and current when using argon as shielding gas we can compare these values from table 4.1 to 4.3 for variation of time also. Again aspect ratio is further reduced when time is increased more. Depth of penetration become more when current is increasing from 170 to 210 A at 6 sec of time. Some values for ATIG at higher current are lesser then previous value. This is because at higher value of current when distance between tip of electrode reduced then arc pressure start to dominate the electromagnetic force. Due to this surface of weld pool becomes more flat and bead start to become shallow (Kim et al. [1992]). For example SiO2 at 210 A for 6 sec is shown in table 4.9 above.

4.4.2 Effect of current and time for mixture of hydrogen as shielding gas

Now we will compare values of depth and width of penetration when shielding gas is mixture of both argon and hydrogen. First of all for 2 sec of time values are written in table 4.10 below

Table 4.10: Comparison of TIG and ATIG for different value of current (at 2 sec)

C	Without flux (mm)		With SiO2 (mm)		With TiO2 (mm)		With MoS2 (mm)		With NiO2 (mm)		With CrO3 (mm)	
A	w	d	w	d	W	d	w	d	w	D	w	d
170	8.09	1.98	6.88	2.15	6.52	3.30	9.00	3.14	8.52	2.43	8.75	2.77
190	9.403	2.10	8.25	3.14	7.35	3.23	6.81	3.63	8.61	2.80	9.02	3.13
210	9.75	2.43	10.9	3.5	8.97	4.60	12.6	3.40	11.7	2.43	10.4	2.67

d= depth, w= width, C= current, A= ampere

Now from table we can see directly that values are improved when mixture of gases is used. For example for TIG welding depth of penetration is improved significantly for all values of current. We can compare profile for both kind of shielding gas as shown in figure 4.14 below.

Above values which are given in table above 4.10 are compared with value of table 4.7. We can compare all of them by drawing profile for each value at 170 A of current as shown in figure 4.14. We can see variation clearly by curve easily and how profile is varying for each value.
Now we will show all variation at 2 sec of time for each current value.

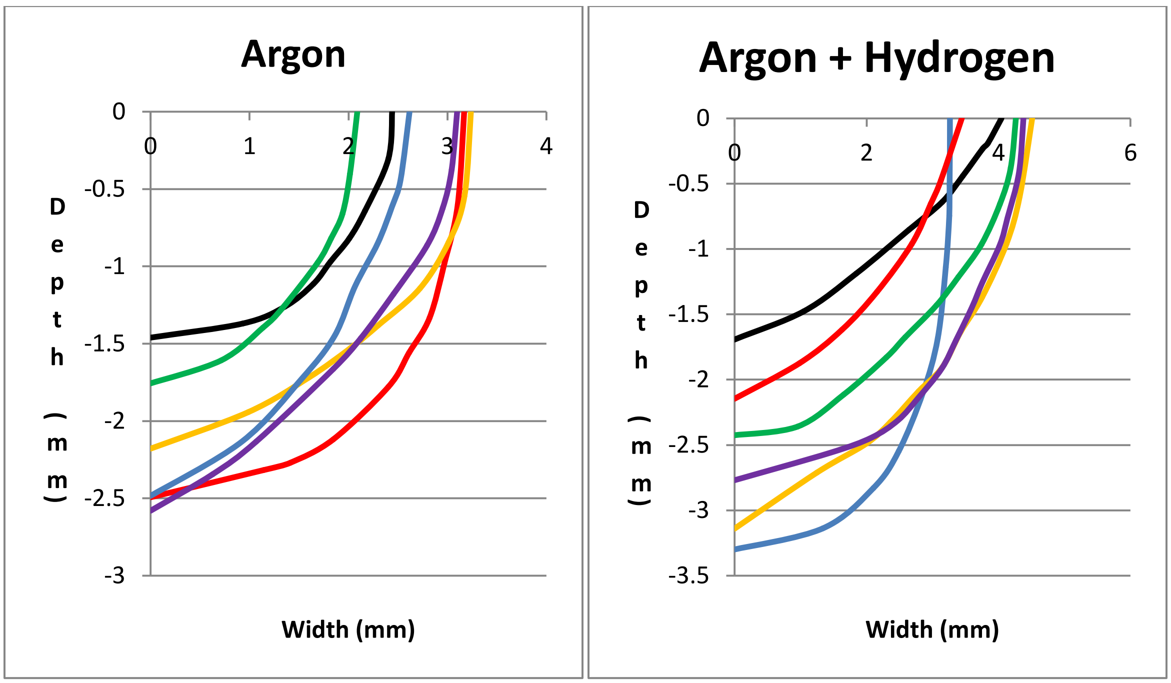


Figure 4.14: Comparison between both types of shielding gas for 2 sec and current- 170 A (Black- without flux, Blue- TiO2, Red- Sio2, Green- NiO2, Orange- MoS2, Purple- CrO3)

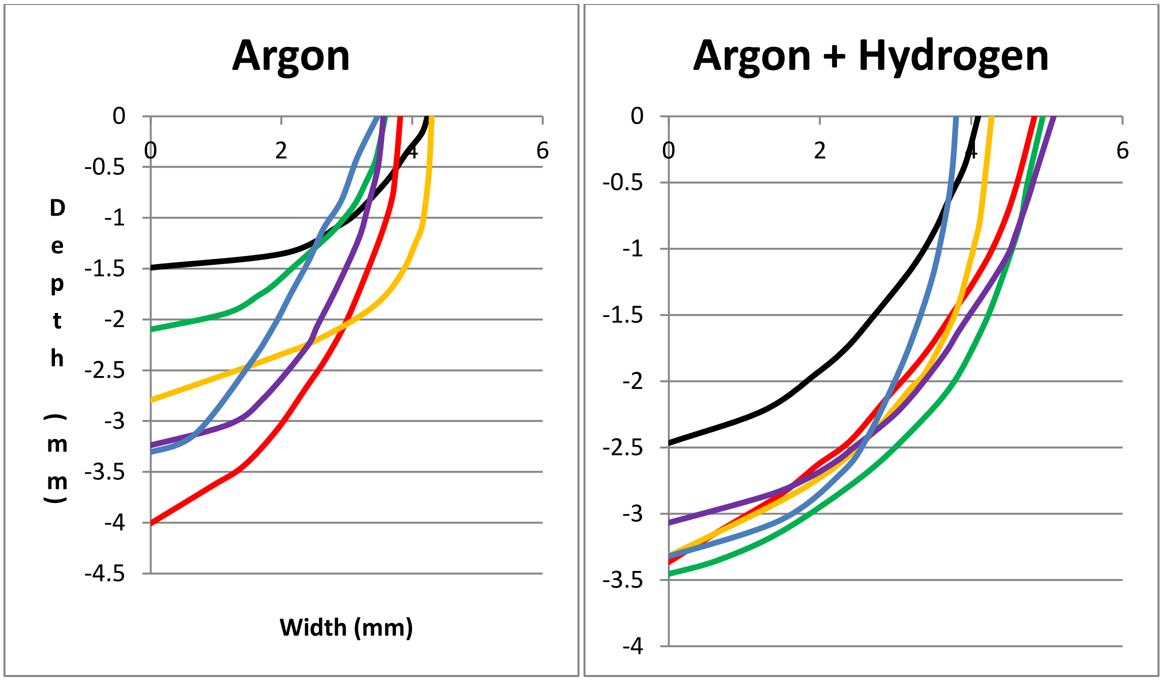


Figure 4.15: Comparison between both types of shielding gas for 4 sec and current- 170 A (Black- without flux, Blue- TiO_2, Red- SiO_2, Green- NiO_2, Orange- MoS_2, Purple- CrO_3)

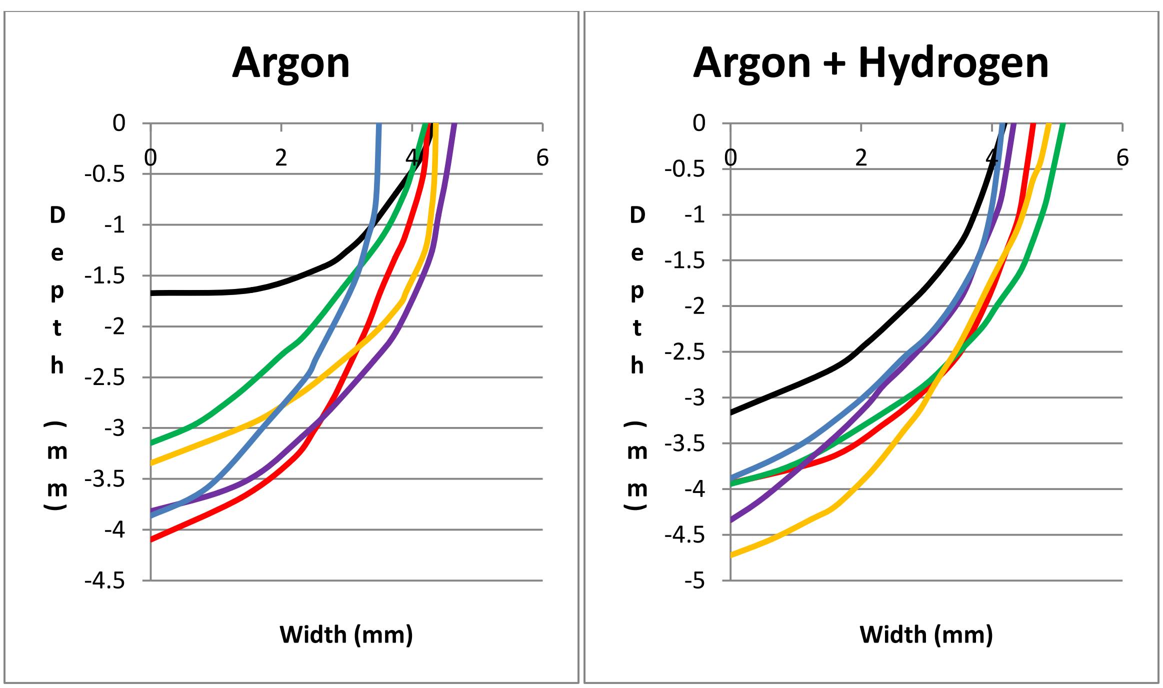


Figure 4.16: Comparison between both types of shielding gas for 6 sec and current- 170 A (Black- without flux, Blue- TiO_2, Red- SiO_2, Green- NiO_2, Orange- MoS_2, Purple- CrO_3)

Now we can clearly create the difference between all the profile for 170 A of current and can be compare with argon and hydrogen mixture as a shielding gas. The above profile can help to differentiate both for TIG and ATIG and effect of shielding gas on depth and width of penetration. Weather we are using argon or mixture of argon and hydrogen all profiles depth value are greater than black curve which is for TIG welding (without flux) and when we compare for shielding gas we can compare both curve profiles with each other.

When we are using mixture of gases variation between TIG and ATIG is not so high for depth of penetration, as seen in case of argon only. We get symmetry for mixture of gases when time is increasing for constant current. As seen from the curve profiles. Now when current is increasing to 190 A of value, here also curve profiles are closer to each other as compare to single argon only by increasing time from 2 to 6 sec .profile curve is very closer to ATIG curve profiles. This is shown below in figures 4.16 to 4.18

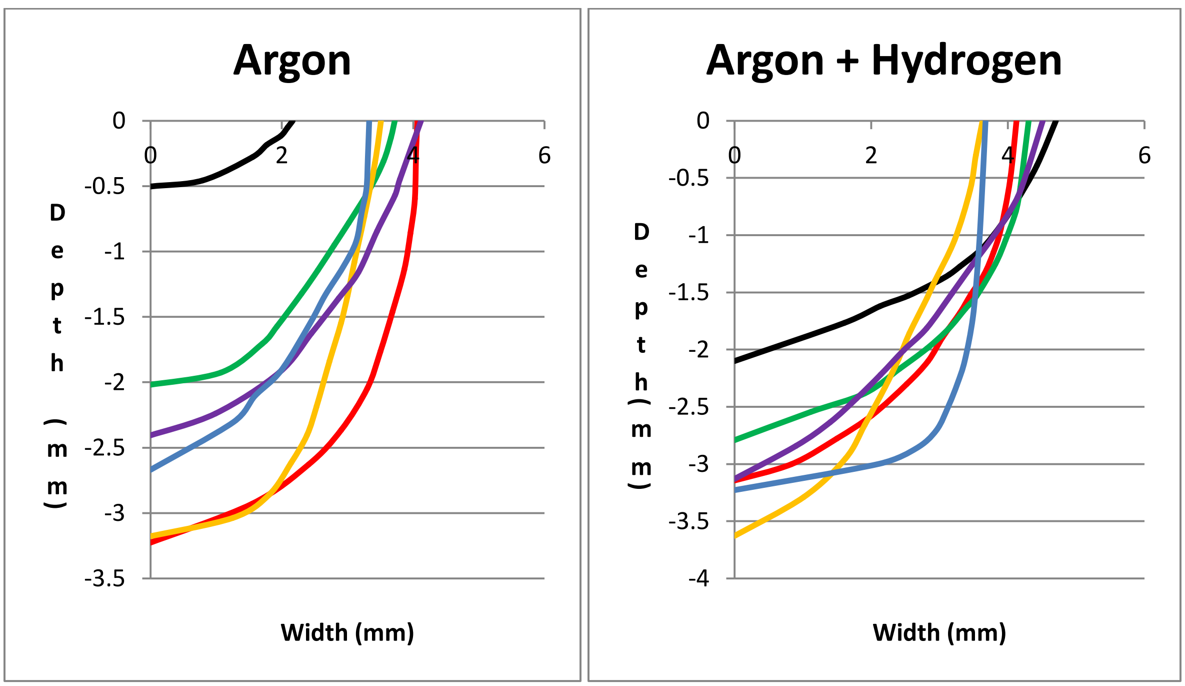


Figure 4.17: Comparison between both types of shielding gas for 2 sec and current- 190 A (Black- without flux, Blue- TiO2, Red- Sio2, Green- NiO2, Orange- MoS2, Purple- CrO3)

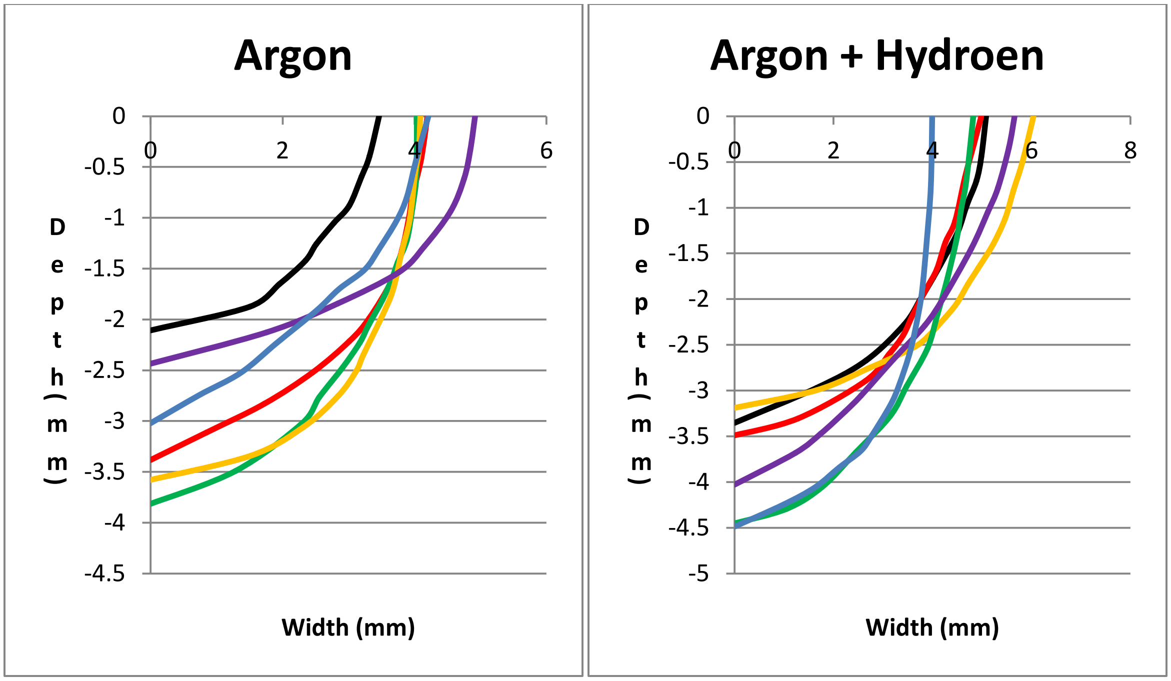


Figure 4.18: Comparison between both types of shielding gas for 4 sec and current- 190 A (Black- without flux, Blue- TiO2, Red- Sio2, Green- NiO2, Orange- MoS2, Purple- CrO3)

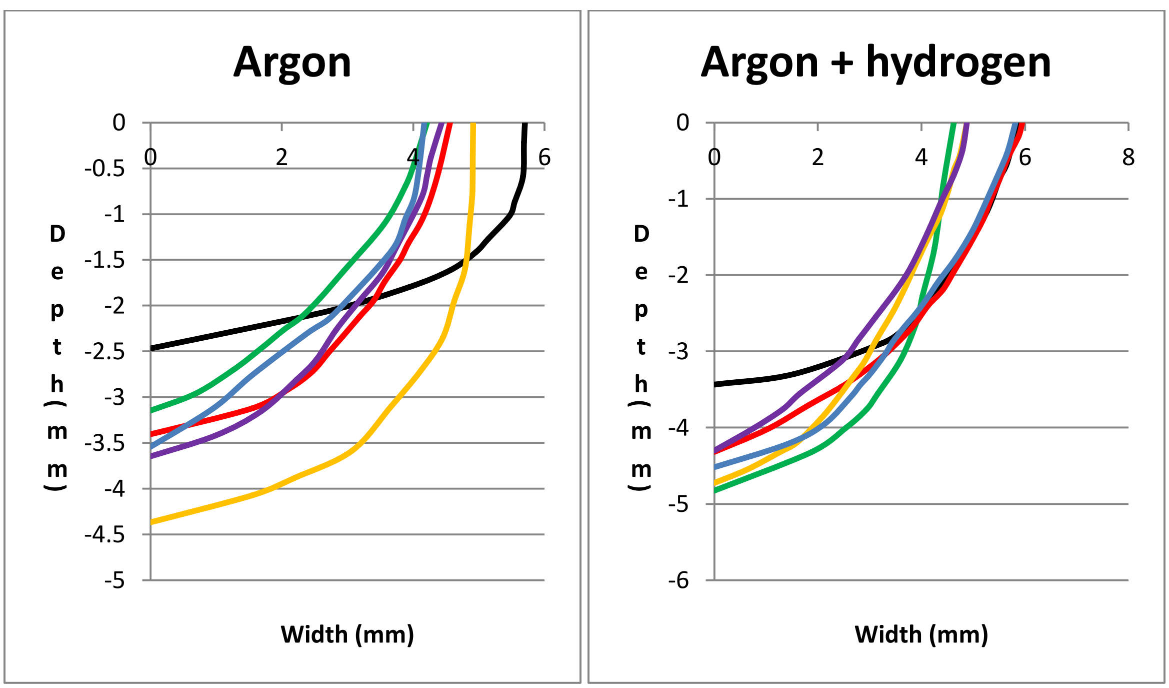


Figure 4.19: Comparison between both types of shielding gas for 6 sec and current- 190 A (Black- without flux, Blue- TiO2, Red- Sio2, Green- NiO2, Orange- MoS2, Purple- CrO3)

Now from above figures we can easily clarify the difference between TIG and ATIG with respect to current, time and shielding gas. Numeric values for depth and width are given below in Table 4.11 below.

Table 4.11: Comparison of TIG and ATIG welding for different current at 4 sec.

C	Without flux (mm)		With SiO2 (mm)		With TiO2 (mm)		With MoS2 (mm)		With NiO2 (mm)		With CrO3 (mm)	
A	w	d	w	d	W	d	w	d	w	D	w	d
170	9.43	2.47	9.7	3.37	7.60	3.32	8.54	3.32	9.9	3.45	10.18	3.07
190	10.16	3.35	9.98	3.48	7.99	4.49	9.65	4.45	12.08	3.19	11.31	4.03
210	11.2	3.33	11.6	4.35	11.9	4.32	12.5	4.2	13.88	3.91	12.1	2.8

d= depth, w= width, C= current, A= ampere

Now we will draw profile curve for 6 sec of value for different value of current. Shown below in figure 4.20 to 4.22.

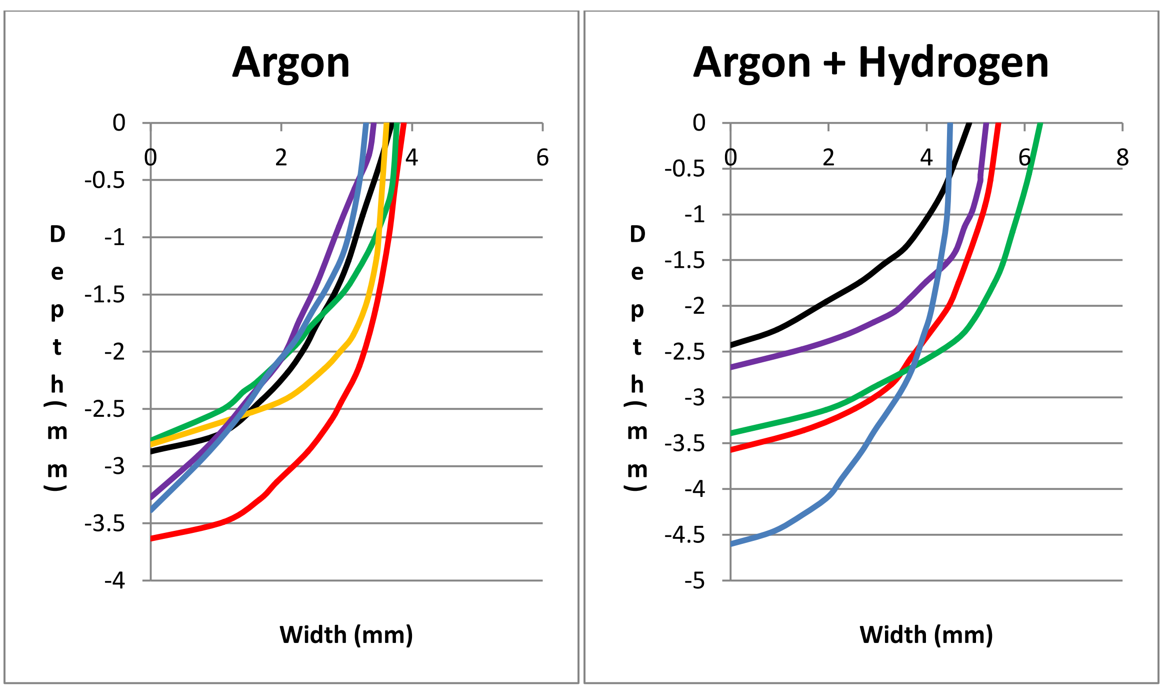


Figure 4.20: Comparison between both types of shielding gas for 2 sec and current- 210 A (Black- without flux, Blue- TiO2, Red- Sio2, Green- NiO2, Orange- MoS2, Purple- CrO3)

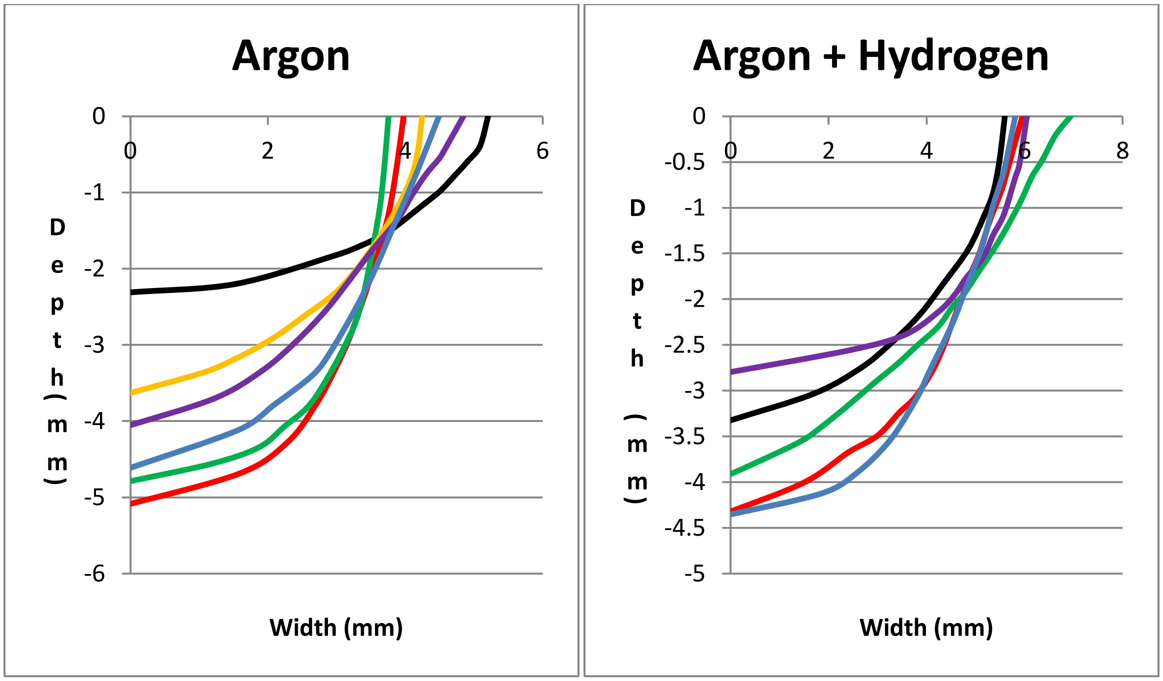


Figure 4.21: Comparison between both types of shielding gas for 4 sec and current- 210 A (Black- without flux, Blue- TiO2, Red- Sio2, Green- NiO2, Orange- MoS2, Purple- CrO3)

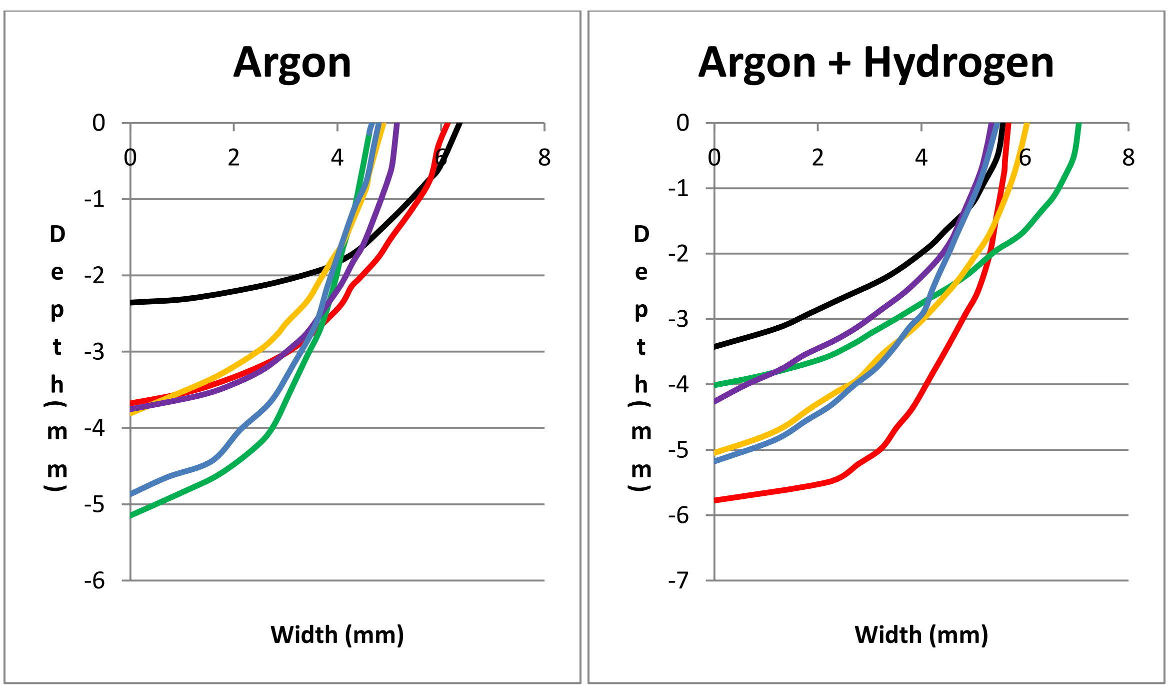


Figure 4.22: Comparison between both types of shielding gas for 6 sec and current- 210 A (Black- without flux, Blue- TiO2, Red- Sio2, Green- NiO2, Orange- MoS2, Purple- CrO3)

Numerical values for above profile curves are given in table 4.12 below for argon and hydrogen as shielding gas. From table 4.12 we can say that when current is increasing for constant value of time depth of penetration is also increasing.

Table 4.12: Comparison of TIG and ATIG welding for different value of current at 6 sec

C	Without flux (mm)		With SiO2 (mm)		With TiO2 (mm)		With MoS2 (mm)		With NiO2 (mm)		With CrO3 (mm)	
A	w	d	w	d	w	d	w	d	w	d	w	d
170	8.38	3.32	8.23	3.88	9.27	3.94	9.7	4.73	10.19	3.94	8.67	4.34
190	11.73	3.44	11.89	4.32	9.24	4.83	10.0	4.57	11.63	4.52	9.76	4.30
210	11.47	3.7	11.3	5.78	10.9	5.18	12.1	5.4	14.08	4.01	10.7	4.27

So above discussion are sufficient to compare all the value and to get conclusion from that. We can compare bead appearance, profile curve variation and depth and width of penetration for different value of current, time and shielding gas.

Chapter 5

Conclusion and scope for future work

5.1 Introduction

In our study we draw different table and charts to compare each of the factors like current, time and shielding gas to find their effect. These three factors are having major role in welding. We calculate different value of effect by taking steel as a workpiece. We take SS304 steel because of its uses in our environment. Its superior quality makes it important for several industries like automobile, power plant etc. For joining of steel we want a technique which cannot affect its properties due to heating effect and for better appearance. TIG welding was good option for industries that fulfill their requirement. But main problem in TIG was its depth of penetration which is low for steel. So after many researches they found a technique which was flux based TIG welding. It increases its depth of penetration 2 to 3 times and avoids the multi pass for desired depth of penetration. In this way we tried out to find some data both for TIG and ATIG welding. Data collected from our results and discussion concluded following information in conclusion.

5.2 Conclusion

Table 5.1: Effect of current and time for TIG welding (Argon only)

TIG WELDING (Argon)						
Current	2 sec		4 sec		6 sec	
Ampere	Depth	Width	Depth	Width	Depth	width
170	1.46	4.88	1.49	8.47	1.67	8.67
190	0.50	4.32	2.11	6.92	2.47	11.41
210	2.87	7.39	2.31	10.41	2.36	12.73

1. As shown from the table above, by increasing the time at constant value of current there is very little effect on the depth of penetration but width is increase to nearly twice at first

then it is also increase little bit from previous value i.e. 190 A and 210 A. But when current is high like at 210 A depth is higher for smaller time but at high value of time width increases significantly then depth of penetration a shown above.

2. As shown above by increasing the current at constant time depth of penetration become more first then it reaches at optimize value. For example depth of penetration at 170 A is 1.49 mm at 4 sec but when current is increasing more to 190 A it becomes nearly twice and then for 210 A it increases little bit. This is true for all value of time. Value at 190 A for 2 sec is due to human error.

TIG WELDING (Argon +Hydrogen)						
Current	2 sec		4 sec		6 sec	
Ampere	Depth	Width	Depth	Width	Depth	width
170	1.98	8.66	3.03	9.43	3.32	8.38
190	2.10	9.40	3.35	10.16	3.44	11.73
210	2.43	9.75	3.33	11.2	3.7	11.46

3. As shown in the table above at constant value of time when current become higher depth of penetration is also higher. Same is true for constant current and increasing of time.
4. When we compare this value of table 4.14 with 4.13, we can see depth of penetration for TIG welding increases twice by using mixture of argon and hydrogen. So hydrogen plays a significant role to increase in depth of penetration for TIG welding. It increases the melting efficiency of arc so as to depth of penetration.
5. When we compare TIG welding with ATIG welding depth of penetration becomes 2 to 3 times as shown above in table 4.1 to 4.6. For example at 4 sec of time at 170 A of current value for TIG 1.49 mm and on the other hand for SiO_2 it was 4.01. This is happened due to reverse Marangoni effect of penetration.
6. It is not significant to increase current and time for simple TIG welding to increase depth of penetration because after some value depth increase marginally and width increases at higher rate. So weld becomes shallower. But for ATIG welding it is significant to increase time or current by keeping one of them is constant.

7. At higher value of current when distance between electrode tip and workpiece become smaller then a critical value arc pressure start to dominate the electromagnetic force results in shallow penetration (Kim et al. [1992]). So there is some critical value for distance between electrode and workpiece. Below or above which it effects the morphology of weld.
8. Profile curves show the variation of shape for bead at different factors.
9. TiO2 shows best aspect ratio for all value of current and time. Values of aspect ratio are consistent for TiO2 when current is varying at constant time.

5.3 Scope for future work

Scope for the future work can be following for TIG and ATIG welding:

- We can check effect of current and time for mixture of fluxes also.
- We did our study for 5% hydrogen and 95 % of argon but results can be found by varying this ratio. We can also go for mixture of argon and helium for different ratio.
- Instead of SS304, work can be done for different steel. Because there are many kind of using all around the word.
- Work can be done to get critical value of gap between electrode and work piece.
- What should be the critical value of flux, work can be done to find it.
- Mathematical modeling can be done to compare the effect of current and time with experimental results.

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