STUDY THE EFFECTS OF WELDING PARAMETERS ON TIG WELDING OF ALUMINIUM PLATE

A Thesis Submitted

In the Partial fulfilment of the requirement for the degree of

Master of Technology

in

Production Engineering

By

PRAKASH MOHAN
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National Institute of Technology
Rourkela -769 008 (India)
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Under the supervision of

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2014

DECLARATION

I the undersigned solemnly declare that the report of work entitled **“Study the effects of welding parameters on TIG welding of Aluminum plate”** is based on my own work carried out during the course of my study under the supervision of Dr. M. Masanta.

I assert that the statements made and conclusions drawn are an outcome of the project work.

I further declare to the best of my knowledge and belief that the report does not contain any part of any work which has been already submitted for thesis evaluation in this University.

Name: Prakash Mohan

Roll no: 212me2332

DEDICATED TO

MY LOVING PARENTS

National Institute of Technology

Rourkela

CERTIFICATE

This is to certify that the thesis entitled "**Study the effects of welding parameters on TIG welding of Aluminium plate**" being submitted by Prakash Mohan (212ME2332) for the partial fulfilment of the requirements of **Master of Technology degree** in **Production Engineering** is a bona-fide thesis work done by him under my supervision during the academic year 2013-2014 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:

Dr. Manoj Masanta

Assistant Professor

Department of Mechanical Engineering

National Institute of Technology, Rourkela

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Prakash Mohan

Abstract

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

Keywords: Automated TIG Welding System, Micro hardness Test, Tensile Test

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Chapter 1

Introduction

Welding is a permanent joining process used to join different materials like metals, alloys or plastics, together at their contacting surfaces by application of heat and or pressure. During welding, the work-pieces to be joined are melted at the interface and after solidification a permanent joint can be achieved. Sometimes a filler material is added to form a weld pool of molten material which after solidification gives a strong bond between the materials. Weld ability of a material depends on different factors like the metallurgical changes that occur during welding, changes in hardness in weld zone due to rapid solidification, extent of oxidation due to reaction of materials with atmospheric oxygen and tendency of crack formation in the joint position.

1.1 Different *type of welding processes*

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

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

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

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

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

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

Arc Welding:

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

a) ***Shielded Metal Arc Welding* (SMAW) or Manual Metal Arc Welding:** This is most common type arc welding process, where a flux coated consumable electrode is used. As the electrode melts, the flux disintegrates and produces shielding gas that protect the weld area from atmospheric oxygen and other gases and produces slag which covers the molten filler metal as it transfer from the electrode to the weld pool. The slag floats to the surface of weld pool and protects the weld from atmosphere as it solidifies.

b) ***Gas Metal Arc Welding* (GMAW) or Metal inert or active gas welding (MIG/MAG):** In this type of welding process a continuous and consumable wire electrode is used. A shielding gas generally *argon or sometimes mixture of argon and carbon dioxide* are blown through a welding gun to the weld zone.

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

1.2 Basic *mechanism of TIG welding:*

TIG welding is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmosphere by an inert shielding gas (argon or helium), and a filler metal is normally used. The power is supplied from the power source (rectifier), through a hand-piece or welding torch and is delivered to a tungsten electrode which is fitted into the hand piece. An electric arc is then created between the tungsten electrode and the work piece using a constant-current welding power supply that produces energy and conducted across the arc through a column of highly ionized gas and metal vapours [1]. The tungsten electrode and the welding zone are protected from the surrounding air by inert gas. The electric arc can produce temperatures of up to 20,000^{o}C and this heat can be focused to melt and join two different part of material. The weld pool can be used to join the base metal with or without filler material. Schematic diagram of TIG welding and mechanism of TIG welding are shown in fig. 1 & fig. 2 respectively.

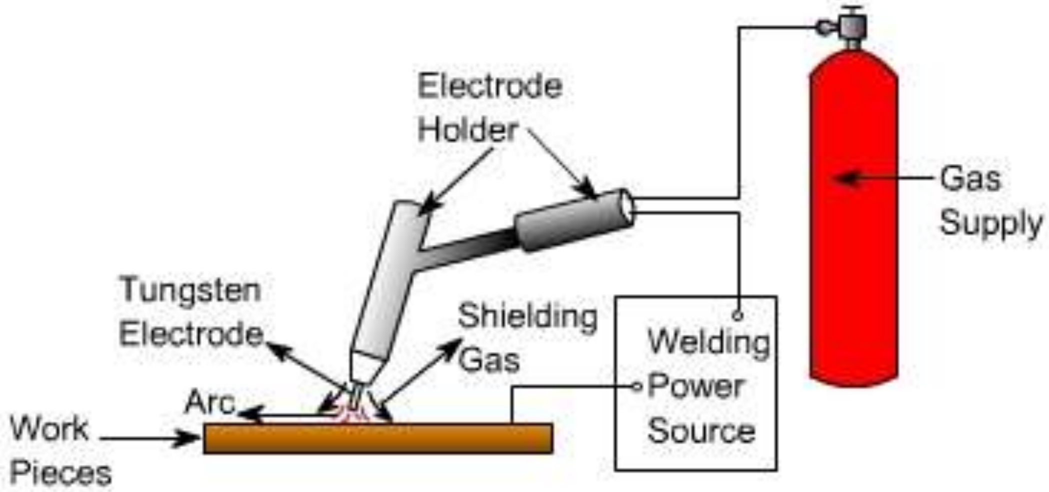

Fig 1: Schematic Diagram of TIG Welding System. [Ref*:* 1]

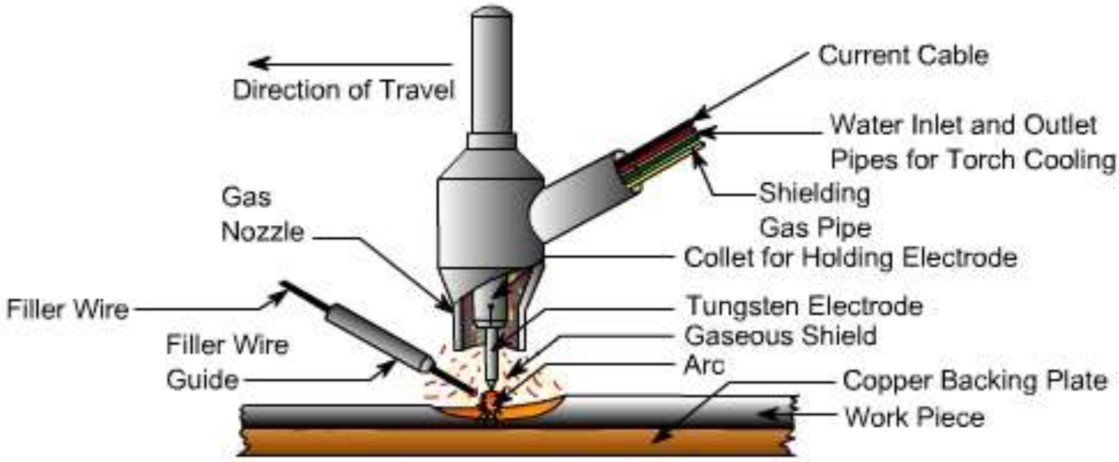

Fig. 2: Principle of TIG Welding. [Ref*:* 1**]**

Tungsten electrodes are commonly available from 0.5 mm to 6.4 mm diameter and 150 - 200 mm length. The current carrying capacity of each size of electrode depends on whether it is connected to negative or positive terminal of DC power source.

The power source required to maintain the TIG arc has a drooping or constant current characteristic which provides an essentially constant current output when the arc length is varied over several millimetres. Hence, the natural variations in the arc length which occur in manual welding have little effect on welding current. The capacity to limit the current to the set value is equally crucial when the electrode is short circuited to the work piece, otherwise excessively high current will flow, damaging the electrode. Open circuit voltage of power source ranges from 60 to 80 V.

1.*3 Types of welding current used in TIG welding*

a. **DCSP (*Direct Current Straight Polarity)***: In this type of TIG welding direct current is used. Tungsten electrode is connected to the negative terminal of power supply. This type of connection is the most common and widely used DC welding process. With the tungsten being connected to the negative terminal it will only receive 30% of the welding energy (heat). The resulting weld shows good penetration and a narrow profile.

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

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

d. ***Alternating Current with Square Wave:*** With the advent of modern electricity AC welding machines can now be produced with a wave form called Square Wave. The square wave has better control and each side of the wave can give a more cleaning half of the welding cycle and more penetration [2].

1.4 Advantages of TIG welding

TIG welding process has specific advantages over other arc welding process as follows -

I. Narrow concentrated arc

II. Able to weld ferrous and non-ferrous metals

III. Does not use flux or leave any slag (shielding gas is used to protect the weld-pool and tungsten electrode)

IV. No spatter and fumes during TIG welding

1.5 Applications of TIG Welding

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

I. Nuclear industry
II. Aircraft
III. Food processing industry
IV. Maintenance and repair work
V. Precision manufacturing industry
VI. Automobile industry

1.6 Process parameters of TIG welding

The parameters that affect the quality and outcome of the TIG welding process are given below.

a) Welding Current

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

b) Welding Voltage

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

c) Inert Gases:

The choice of shielding gas is depends on the working metals and effects on the welding cost, weld temperature, arc stability, weld speed, splatter, electrode life etc. it also affects the finished weld penetration depth and surface profile, porosity, corrosion resistance, strength, hardness and brittleness of the weld material. Argon or Helium may be used successfully for TIG welding applications. For welding of extremely thin material pure argon is used. **Argon** generally provides an arc which operates more smoothly and quietly.

Penetration of arc is less when Argon is used than the arc obtained by the use of Helium. For these reasons argon is preferred for most of the applications, except where higher heat and penetration is required for welding metals of high heat conductivity in larger thicknesses. Aluminium and copper are metals of high heat conductivity and are examples of the type of material for which helium is advantageous in welding relatively thick sections. Pure argon can be used for welding of structural steels, low alloyed steels, stainless steels, aluminium, copper, titanium and magnesium. Argon hydrogen mixture is used for welding of some grades of stainless steels and nickel alloys. Pure helium may be used for aluminium and copper. Helium argon mixtures may be used for low alloy steels, aluminium and copper.

d) Welding speed:

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

1.7 Properties and advantages of Al:

Aluminium is a very light weight metal (specific weight of 2.7 g/cm^3). Use of aluminium in automobile and aerospace reduces dead-weight and energy consumption. Strength of Aluminium can be improved as per the required properties for various applications by modifying the composition of its alloys. Aluminium is a highly corrosion resistant material. Different types of surface treatment can further improve its corrosion resistance property. Aluminium is an excellent heat and electricity conductor and in relation to its weight is almost twice as good a conductor as copper. This has made aluminium the most commonly used material in major power transmission lines.

Aluminium is ductile and has a low melting point. In a molten condition it can be processed in a number of ways. Its ductility allows products of aluminium to be basically formed close to the end of the product's design [3].

1.8 Welding of Aluminium and Aluminium alloy

Aluminium can be joined in many ways such as bolting, riveting (temporary joint) and welding (permanent methods). Aluminium and its alloys are welded in industry by a variety of methods.

Thermal conductivity of Aluminium is quite high; therefore heat is easily conducted away from the welding area. It is essential that the heat source is powerful enough to rapidly reach aluminium's melting point of 565 /650ºC. Coefficient of thermal expansion of Aluminium is also high compared to steel, so it is prone to distortion and stress inducement if the proper welding procedure is not followed. Aluminium is a reactive metal that quickly forms an oxide layer on the surface and strength of the weld area become weak. Therefore welding of Aluminium by conventional arc welding process is become difficult.

By understanding the welding characteristics and utilizing proper procedures Aluminium and its alloys could be easily weld. The most common commercial aluminium and aluminium alloy welding methods use an electric arc with either a continuously fed wire electrode [with DC current, with and without pulsed current] or a permanent tungsten electrode plus filler wire with AC current.

To ensure an acceptable weld quality, there are two basic factors to consider - breaking loose and removing the oxide film, and preventing the formation of new oxide during the weld process. It is essential that proper preparations and precautions always be taken before welding commences. The surfaces to be joined and the area around the weld zone [~50 mm] must be degreased using as solvent [acetone or toluene] and a clean cloth. The area must be clean and completely dry as grease and moisture can form gases and cause pores in the welded joint [4].

Chapter 2

Literature Review

2.1 TIG Welding :

Sanjeev kumar et. al [5] attempted to explore the possibility for welding of higher thickness plates by TIG welding. Aluminium Plates (3-5mm thickness) were welded by Pulsed Tungsten Inert Gas Welding process with welding current in the range 48-112 A and gas flow rate 7 -15 l/min. Shear strength of weld metal (73MPa) was found less than parent metal (85 MPa). From the analysis of photomicrograph of welded specimen it has been found that, weld deposits are form co-axial dendrite micro-structure towards the fusion line and tensile fracture occur near to fusion line of weld deposit.

Indira Rani et. al [6] investigated the mechanical properties of the weldments of AA6351 during the GTAW /TIG welding with non-pulsed and pulsed current at different frequencies. Welding was performed with current 70-74 A, arc travel speed 700-760 mm/min, and pulse frequency 3 and 7 Hz. From the experimental results it was concluded that the tensile strength and YS of the weldments is closer to base metal. Failure location of weldments occurred at HAZ and from this we said that weldments have better weld joint strength.

Ahmed Khalid Hussain et. al [7] investigated the effect of welding speed on tensile strength of the welded joint by TIG welding process of AA6351 Aluminium alloy of 4 mm thickness. The strength of the welded joint was tested by a universal tensile testing machine. Welding was done on specimens of single v butt joint with welding speed of 1800 -7200 mm/min. From the experimental results it was revealed that strength of the weld zone is less than base metal and tensile strength increases with reduction of welding speed.

Tseng et. al [8] investigated the effect of activated TIG process on weld morphology, angular distortion, delta ferrite content and hardness of 316 L stainless steel by using different flux like TiO_2, MnO_2, MoO3, SiO2 and Al_2O_3. To join 6 mm thick plate author uses welding current 200 Amp, welding speed 150 mm/min and gas flow rate 10 l/min. From the experimental results it was found that the use of SiO_2 flux improve the joint penetration, but Al_2O_3 flux deteriorate the weld depth and bead width compared with conventional TIG process.

Narang et. al [9] performed TIG welding of structural steel plates of different thickness with welding current in the range of 55 -95 A, and welding speed of 15-45 mm/sec. To predict the weldment macrostructure zones, weld bead reinforcement, penetration and shape profile characteristics along with the shape of the heat affected zone (HAZ), fuzzy logic based simulation of TIG welding process has been done.

Karunakaran et. al [10] performed TIG welding of AISI 304L stainless steel and compare the weld bead profiles for constant current and pulsed current setting. Effect of welding current on tensile strength, hardness profiles, microstructure and residual stress distribution of welding zone of steel samples were reported. For the experimentation welding current of 100-180 A, welding speed 118.44 mm/min, pulse frequency 6 Hz have been considered. Lower magnitude of residual stress was found in pulsed current compared to constant current welding. Tensile and hardness properties of the joints enhanced due to formation of finer grains and breaking of dendrites for the use of pulsed current.

Raveendra et. al [11] done experiment to see the effect of pulsed current on the characteristics of weldments by GTAW. To weld 3 mm thick 304 stainless steel welding current 80-83 A and arc travel speed 700-1230 mm/min. More hardness found in the HAZ zone of all the weldments may be due to grain refinement. Higher tensile strength found in the non-pulsed current weldments. It was observed that UTS and YS value of non-pulsed current were more than the parent metal and pulsed current weldments.

Sakthivel et.al [12] studied creep rupture behaviour of 3 mm thick 316L austenitic stainless steel weld joints fabricated by single pass activated TIG and multi-pass conventional TIG welding processes. Welding was done by using current in the range of 160-280 A, and welding speed of 80-120 mm/min. Experimental result shows that weld joints possessed lower creep rupture life than the base metal. It was also found that, single pass activated TIG welding process increases the creep rupture life of the steel weld joint over the multi-pass TIG weld joints.

Tetsumi Yuri et. al [13] investigated high cycle and low cycle fatigue properties of SUS304L, SUS316L steel and the effects of welding structure by TIG welding process. Welding was done with U-shaped groove and the weld was done by multi-passes with voltage of 8-10 V, a current of 120-210 A, and welding speed of 800 mm/min. From the experimental results it was revealed that in high-cycle fatigue tests, the ratio of fatigue strength to tensile strength of the weld metals is lower than that of base metal. However, in low-cycle fatigue tests, the fatigue lives of the weld metals were slightly shorter than that of base metals.

Norman et. al [14] investigated the microstructures of autogenous TIG welded Al-Mg-Cu-Mn alloy for a wide range of welding conditions. Welding was done with current in the range 100-190 A and welding speed 420-1500 mm/min. The fine microstructure was observed at the centre of the weld which was form due to higher cooling rate at the weld centre compared to the fusion boundary. It was observed that as the welding speed increases, the cooling rate at the centre of the weld also increases, producing smaller size dendrite structure.

Song et. al [15] successfully joined dissimilar metals of 5A06 Al alloy and AISI 321 stainless steel of thickness 3 mm by TIG welding-brazing with different filler materials. TIG welding–brazing was carried out by AC-TIG welding source with welding current 135 A, arc length 3.0–4.0mm, welding speed 120 mm/min and argon gas flow rate 8–10 lit/min. It was found hat addition of Si preventing the build-up of the IMC layer, minimising its thickness. The author also investigated **(Song et. al 2009)** spreading behaviour of filler metal on the groove surface and microstructure characteristics for butt joint. For the experimentation welding current in the range of 90-170 A and welding speed in the range of 100-220 mm/min, were used for 2 mm thick plate.

Wang et. al [16] studied the influences of process parameters of TIG arc welding on the microstructure, tensile property and fracture of welded joints of Ni-base super-alloy. For welding plate width of 1.2-1.5 mm, welding current in the range of 55-90 A, with variable welding speed in the range 2100-2900 mm/min was used. From experimental result it was observed that, the heat input increases with increase of welding current and decrease of welding speed.

Kumar and Sundarrajan [17] performed pulsed TIG welding of 2.14 mm AA5456 Al alloy using welding current (40-90) A, welding speed (210-230) mm/min. Taguchi method was employed to optimize the pulsed TIG welding process parameters for increasing the mechanical properties and a Regression models were developed. Microstructures of all the welds were studied and correlated with the mechanical properties. 10-15% improvement in mechanical properties was observed after planishing due to or redistribution of internal stresses in the weld.

Preston et.al [18] developed a finite element model to predict the evolution of residual stress and distortion dependence on the yield stress-temp for 3.2 mm 2024 Al alloy by TIG welding.

Akbar Mousavi et.al [19] analysed the effect of geometry configurations on the residual stress distributions in TIG weld from predicted data and compared it with data obtained by X-Ray diffraction method. Attempts were made to analyse the residual stresses produced in the TIG welding process using 2D and 3D finite element analysis. For welding of 10 mm thick 304 grade stainless steel welding current in the range 80-225 A, voltage 15 V, and welding velocity in the range of 90-192 mm/min were employed.

Ahmet durgutlu et.al [20] investigated the effect of hydrogen in argon as shielding gas for TIG welding of 316L austenitic stainless steel. They used current 115 A, welding speed 100 mm/min and gas flow rate 10 l/min for welding of 4 mm thick plate. For all shielding media, hardness of weld metal is lower than that of HAZ and base metal. Penetration depth, weld bead width and mean grain size in the weld metal increases with increasing hydrogen content. The highest tensile strength was obtained for the sample welded under shielding gas of 1.5%H_2–Ar.

Wang Rui et. al [21] investigated the effect of process parameters i.e. plate thickness, welding heat input on distortion of Al alloy 5A12 during TIG welding. For welding they used current (60-100) A, welding speed (800-1400) mm/min and thickness of w/p (2.5-6) mm. The results show that the plate thickness and welding heat input have great effect on the dynamic process and residual distortion of out-of-plane.

Dongjie Li et.al [22] proposed a double-shielded TIG method to improve weld penetration and compared with the traditional TIG welding method under different welding parameters i.e welding speed, arc length and current. They used gas flow rate 10 l/min, welding speed (90-300) mm/min, current (100-200) A and thickness of w/p 10 mm. The results show that the changes in the welding parameters directly impact the oxygen concentration in the weld pool and the temperature distribution on the pool surface.

Lu et. al [23] proposed a double-shielded TIG welding process for the welding of 9 mm thick Cr13Ni5Mo stainless steel by using pure He as inner shielding layer and mixture of He and CO_2 gas as the outer shielding layer. Welding current and welding speed considered for the experimentation in the range of 120-140 A and 90-300 mm/min respectively. The double–shielded TIG welding process display efficiency 2-4 times greater than that of traditional TIG welding. A change in the direction of the surface tension affects the fusion zone profile which results a larger weld depth. This process allows a high welding efficiency comparing with traditional TIG welding.

Urena et. al [24] investigated the influence of the interfacial reaction between the Al alloy (2014) matrix and SiC particle reinforcement on the fracture behaviour in TIG welded Al matrix composites. TIG welding was carried out on 4 mm thick AA2014/SiC/Xp sheets using current setting in the range of 37-155 A and voltage of 14-16.7 V. From experimental results it was found that, the failure occurred in the weld metal with a tensile strength lower than 50% of the parent material. Fracture of the welded joint was controlled by interface deboning through the interface reaction Layer. Probability of interfacial failure increases in the weld zone due to formation of Aluminium-carbide which lowers the matrix/reinforcement interface strength.

Sivaprasad et.al [25] performed TIG welding of 2.5 mm thick Nickel based 718 alloy using welding current in the range of 44-115 A, voltage 13-15 V and welding speed 67 mm/min. the influence of magnetic arc oscillation on the fatigue behaviour of the TIG weldments in two different post-weld heat treatment conditions were studied.

Wang Xi-he et. al [26] performed TIG welding of SiCp /6061 Al composites without and with Al-Si filler using He-Ar mixed as shielding gas. For the welding authors uses gas flow rate 6.9 l/min, welding speed 1800 mm/min, current-60 A. The results show that addition of 50 vol.% helium in shielding gas improves the arc stability, and quality of welding improves when the Al–Si filler is added. The microstructure of the welded joint shows non-uniformity with SiC particles distributing in the weld centre.

Qinglei et. al [27] analysed microstructure, element distribution, phase constituents and micro hardness for welding joint of Mo-Cu composite and 18-8 stainless steel plates of thickness 2.5 mm carried out by TIG welding process with Cr-Ni fillet wires. Welding has done with speed (49.8-64.2)mm/min, gas flow rate-8 l/min, arc voltage-(28-32) V and welding current -90 A. Formation of γ-Fe(Ni) phases and $Fe_{0.54}Mo_{0.73}$ compound must contributed to the high micro hardness. The results indicate that austenite and ferrite phases were obtained in the weld metal. The micro hardness near the fusion zone at Mo–Cu composite side increased from weld metal to fusion zone, and the peak value appeared near the boundary between fusion zone and Mo–Cu composite.

Lothongkum et. al [28] investigated the TIG welding of 3 mm thick AISI 316L stainless steel plate at different welding position. Pure argon gas and mixture of argon with nitrogen (1-4 vol.%) were used as shielding gas with a flow rate of 8 l/min during top and back sides of welds. Effects of welding speeds and nitrogen contents in argon shielding gas on pulse currents were study to achieve an acceptable weld bead profile with complete penetration. It was found that increasing nitrogen contents in argon gas decreases the pulse currents and increasing welding speed will increase the pulse current.

2.2 Problem identification and objective of the work

From the literature review, it is found that welding of Aluminium is a big challenge by conventional arc welding process. Again repeatability of welding depends on its control on welding speed and other processing parameters.

In this work to perform welding of 3 mm Aluminium plate, an automated TIG welding setup was made. Welding of the Aluminium plate was done by changing the welding current and welding speed to get a high strength joint. To get better strength welding of the Aluminium plate also done from both side. Effect of welding speed and applied current on the tensile strength of weld joint, micro hardness of the weld pool and macrostructure of the joint was analysed.

Chapter 3

Experimental Work and Methodology

3.1 Development of an automated TIG welding system

For proper welding and control on welding parameters mainly on welding speed an automated welding setup has been developed in-house. The automated welding setup with its main components is shown in fig. 3.

Fig. 3 – Experimental set-up for TIG welding

The welding setup consists mainly following parts

a) Speed control unit (movable tractor) – Here, speed control unit is a movable tractor which run with a predefined speed required for welding. TIG welding torch is fixed with it using a clamp in a particular angle so that during welding a stable and continuous arc form. Welding speed can be change using a regulator. Distance between the torch tip and work piece and angle of torch tip can also be control using the adjustable knob.

b) Rail track –Movable tractor is run in a particular speed over this rail track in a straight line.

c) TIG Welding torch- Torch is fixed with the movable tractor unit. A tungsten electrode is fixed in the torch and Ar gas is flow through this.

d) TIG welding machine– This is the main part of TIG welding setup by which controlled amount of current and voltage is supplied during welding. A Rectifier (made by FRONIUS) with current range 10-180 A and voltage up to 230 V, depending on the current setting has been used.

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

f) Work holding table- a surface plate (made of grey cast iron) is used for holding the work piece so that during welding gap between the tungsten electrode and work piece is maintained. Proper clamping has been used to hold the work piece.

g) The torch was maintained at an angle approximate 90° to the work piece.

3.2 Calibration of speed

Before start the experiment speed of the movable tractor was calibrated to get a required welding speed and found different speed value which is shown in table 1.

Table 1: Speed value on speed controlled tractor

Number on equipment	Speed value(mm/s)
1	2.5
1.5	3
2	3.50
2.5	4.0
3	4.5
3.5	5
4	5.5
4.5	6

3.3 Experimental planning and procedure:

For the present work, experimentation was done in two phase. In first phase, butt welding of Al plate (3 mm thickness) done at one side with different current setting and welding speed. In second phase, butt welding of Al plate done both side by varying welding speed and current setting.

3.3.1 Experimental procedure:

Commercial Aluminium plate of thickness 3 mm was selected as work piece material for the present experiment. Al plate was cut with dimension of 120 mm x 50 mm with the help of band-saw and grinding done at the edge to smooth the surface to be joined. After that surfaces are polished with emery paper to remove any kind of external material.

After sample preparation, Aluminium plates are fixed in the working table with flexible clamp side by side and welding done so that a butt join can be formed.

TIG welding with Alternate Current (AC) was used in experiments as it concentrates the heat in the welding area. Zirconiated tungsten electrodes of diameter 3.4 mm was taken as electrode for this experiment. The end of the electrode was prepared by reducing the tip diameter to 2/3 of the original diameter by grinding and then striking an arc on a scrap material piece. This creates a ball on the end of the electrode. Generally an electrode that is too small for the welding current will form an excessively large ball, whereas too large an electrode will not form a satisfactory ball at all.

For the first phase of experiment welding parameters selected are shown in table 2. Before performing the actual experiment a number of trial experiments have been performed to get the appropriate parameter range where welding could be possible and no observable defects like undercutting and porosity occurred.

Table 2: Welding parameters for 1st phase of experiments

Parameters	**Range**
Welding current	(100-140) A
Voltage	50 v
Speed	(3.5-4) mm/s
Distance of tip from weld centre	3 mm
Gas flow rate	(8-10) l/min.
Current type	AC
Dimension	120mm*50mm*3mm

After performing the welding, welded specimens were cut with dimension of 100 mm x 25 mm for tensile test, which were further cut in to I shape. Tensile test was performed with universal tensile testing machine (Instron-600) with maximum load capacity of 600 kN.

Further, a 10 mm x5 mm x3 mm specimen were cut at the cross section for microstructural study and micro-hardness measurement from each sample. Before micro-hardness measurement cross section of the welded specimen mounted and polished with 220, 600 and 1200 grit size polishing paper sequentially. Micro-hardness was measured with Vickers micro-hardness tester (LECO micro hardness tester LM 248 AT). Optical image of the cross section of the welded zone was taken with an optical microscope.

Table 3 : Experimental planning

Exp. No.	**Electrode Work piece Distance (mm)**	**Argon Gas flow rate (l/min)**	**Voltage (V)**	**Welding Speed (mm/s)**	**Current (A)**
1	3	8-10	50	3.50	100
2	3	8-10	50	3.50	110
3	3	8-10	50	3.50	120
4	3	8-10	50	3.50	130
5	3	8-10	50	3.50	140
6	3	8-10	50	4.0	100
7	3	8-10	50	4.0	110
8	3	8-10	50	4.0	120
9	3	8-10	50	4.0	130
10	3	8-10	50	4.0	140

Chapter 4

Result and discussion

Welding width for all the samples were measured and calculated average welding width as shown in table 4. Average value of welding width then plotted against the applied welding current for different welding speed as shown in Fig. 5. From the plot it is clearly seen that welding width increases almost linearly with increase of welding current.

Fig.4 shows the welded butt joint specimen, where welding performed with different welding speed and current setting as described in table 3.

Fig. 4–welded specimen performed with (a) welding speed 3.5 mm/s and welding current 100, 110, 120, 130 and 140 A for sample no 1, 2,3,4,5 respectively (b) welding speed 4 mm/s and welding current 100, 110, 120, 130 and 140 A for sample no 6,7,8,9,10 respectively

Table 4: Weld width

Sample no	Reading 1 (mm)	Reading 2 (mm)	Reading 3 (mm)	Avg. width (mm)
1	5.43	4.85	4.51	4.93
2	7.35	6.83	7.22	5.14
3	8.95	7.58	7.29	7.94
4	7.24	7.82	7.82	7.626
5	10.92	10.45	10.04	10.47
6	5.03	5.18	4.92	5.042
7	5.53	5.85	5.99	5.79
8	8.57	8.05	7.86	8.16
9	9.27	8.06	8.27	8.54
10	9.13	10.07	8.57	9.256

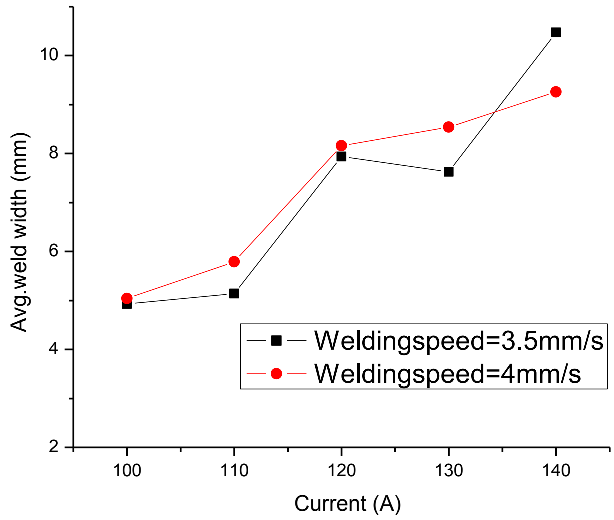

Fig. 5: welding width of the samples with different welding speed and welding current condition

Surface roughness of the weld zone for all the samples were measured and average surface roughness value was calculated from three reading which is tabulated in Table 5. Roughness value found in the range of 1.1 to 3.5 micron, is quite low for a welded specimen. Therefore it can be say that using an automated system good quality of welding is possible which may not require any further finishing operation. These roughness values are again plotted against applied current in fig. 6. But no specific effect of applied current on the surface roughness value has been observed.

Table 5: Surface roughness value for different welded samples

Sample No	Reading1 (μm)	Reading2 (μm)	Reading3 (μm)	Avg. Value (μm)
1	3.411	3.358	3.034	3.145
2	1.929	1.190	1.189	1.436
3	1.720	1.381	1.376	1.492
4	0.704	1.382	1.395	1.160
5	2.812	2.791	1.220	2.274
6	1.900	4.615	3.258	3.258
7	2.363	2.192	2.174	2.243
8	3.563	3.575	3.583	3.574
9	3.248	3.311	4.151	3.57
10	1.311	1.236	1.210	1.252

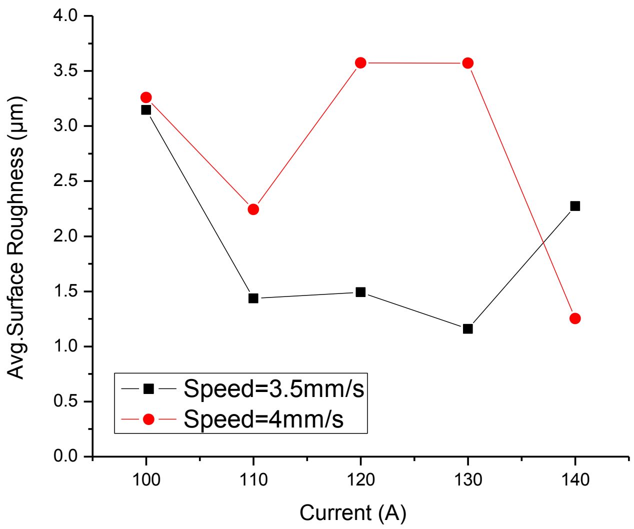

Fig. 6: Avg. surface roughness of the sample with different welding current and welding speed condition

4.1 Optical microscopy images of the weld zone at the cross section:

current	**Welding speed=** 3.50 mm/s	**Welding speed=**4 mm/s
100 (A)		
110 (A)		

120 (A)		
130 (A)		
140 (A)		

Fig. 7: Optical microscopy photograph at the cross section of the welding done with different current setting and welding speed

Fig. 7 shows the optical image of the welded zone at the cross section for the specimen prepared with different welding speed and current setting. From the images no specific change could be observed for the weld specimen. However, cross section of the weld zone shows a clear effect of the welding parameters like applied current and welding speed. Fig. 7 shows the optical photograph at the cross section of the welding performed with different current setting and welding speed. From the figure it can be seen that welding is not performed full depth of the work piece. Depending on the welding speed and current setting this welding penetration is changed. It can be say from the observation of the figure that as welding current increases welding depth also increases for fixed value of welding speed. Again for a particular value of welding current welding depth found decreases as the welding speed increases.

4.2 Micro-hardness test: Micro-hardness value of the welded zone was measured for all the welded specimens at the cross section to understand the change in mechanical property of the welded zone. Fig. 8 and 9 shows the micro-hardness value at the welded zone taken from the centre of the welding zone towards the base material for different samples performed with different welding speed and welding current. From the graph it is found that for almost all the sample micro hardness value increases in the welding zone than the base material and these values are in the range of 40 to 80 HV in the welded zone. After a certain distance these value reduces to the hardness of the base material for the sample processed with welding speed 3.5 mm/s and different current setting as shown in Fig. 8. However for the welding done with welding speed 4 mm/s and different current setting micro-hardness value reaches to the micro-hardness value of base material after 5 to 6 mm.

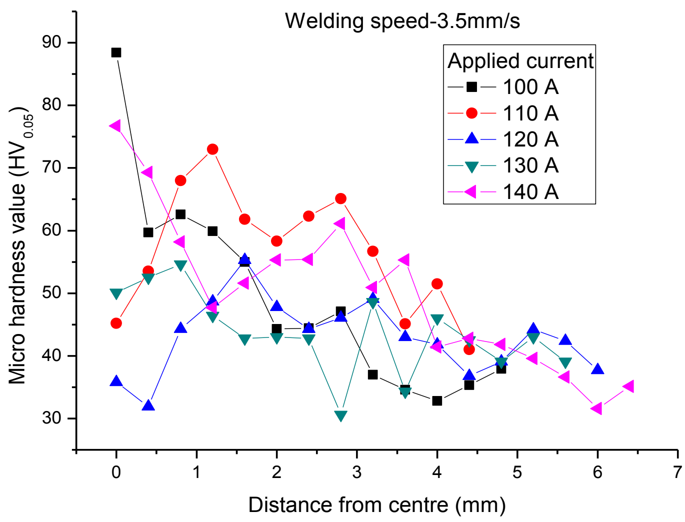

Fig.8: Micro-hardness value from the centre of the weld zone towards the base material for welding done with welding speed 3.5 mm/s and different welding current

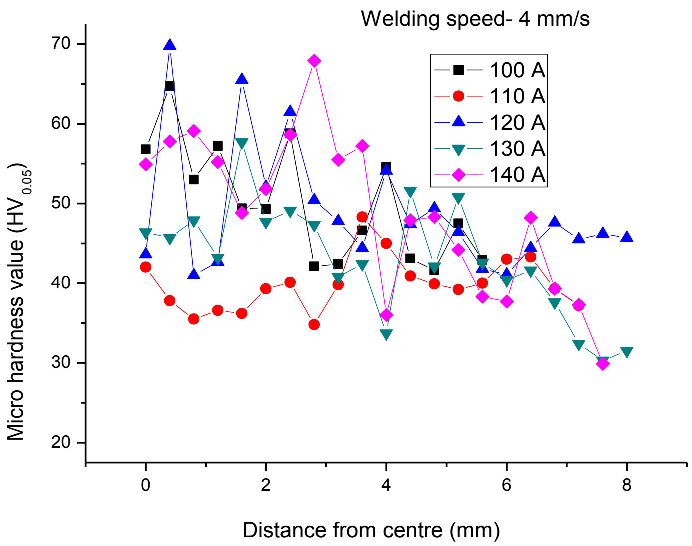

Fig. 9: Micro-hardness value from the centre of the weld zone towards the base material for welding done with welding speed 4 mm/s and different welding current

4.3 Tensile test:

Tensile test of the welded joint was performed with universal tensile testing machine (Instron) with maximum load capacity 600 kN. Load give with a speed of 1 mm/min.

Table 6 shows the tensile strength value for all the welded joints produced at different welding speed and current setting. These values are much lower than the tensile strength of the pure Aluminium. Tensile strength of the as received Aluminium has been found 132 MPa. In Fig. 10 tensile strength of the welded joints are plotted against applied current for welding speed of 3.5 mm/s. From the it is also found that tensile strength value almost increasing for increasing current setting when welding speed is 3.5 mm/s (except for welding current form 120 A to 130 A). Similarly in Fig. 11 tensile strength of the welded joints are plotted against applied current for welding speed of 4 mm/s. From this graph it is found that, welding done with 4 mm/s there is no specific trend in change of tensile strength due to change in current. Initially with increase current tensile strength of the welding increases upto 120 A and then this value decreases.

Comparing the fig. 10 and 11 it is clearly seen that for almost all current setting condition (except 120 A current setting) tensile strength values of the welded joint performed with welding speed 3.5 mm/s are larger than the tensile stress values of the welded joint performed with welding speed 4 mm/s.

Table 6: Maximum load at tensile strength and tensile strength value of different welded samples

Sample no	Load at tensile strength (N)	Actual tensile strength (MPa)
1	1719.36415	22.92486
2	1964.57603	26.19435
3	2878.42769	38.37904
4	2311.58920	30.82119
5	2927.50737	39.03343
6	1311.63038	17.48841
7	1285.78716	17.14383
8	3307.39478	44.09860
9	2258.41971	30.11226
10	1386.81158	18.49082

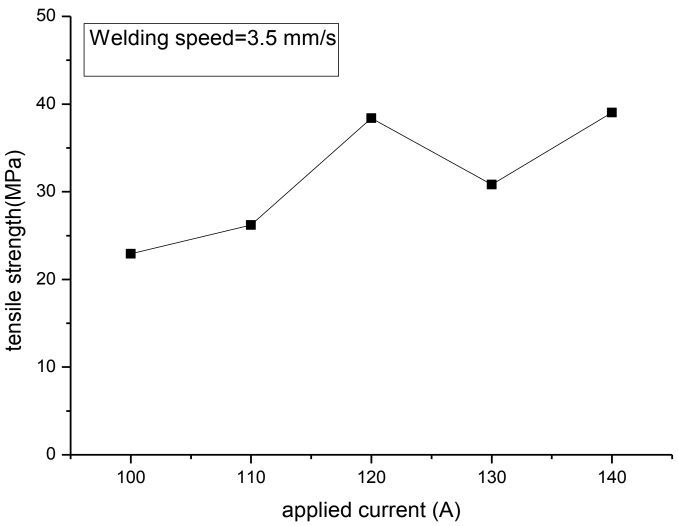

Fig. 10: Tensile strength of the welded joint against applied current for welding speed of 3.5 mm/s.

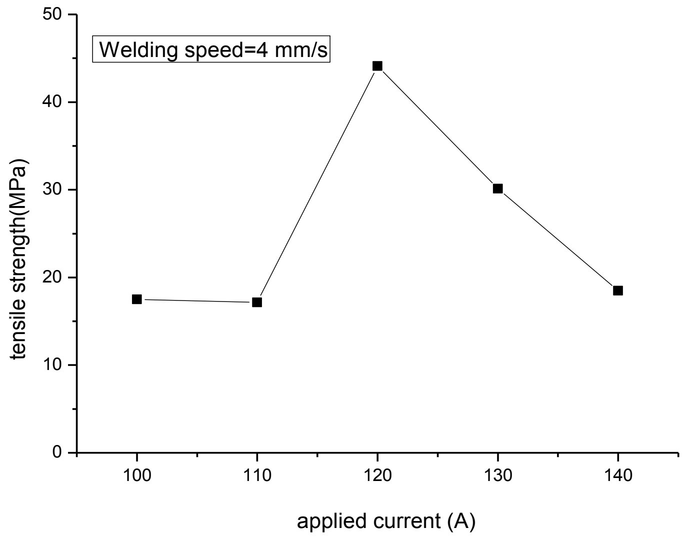

Fig. 11: Tensile strength of the welded joint against applied current for welding speed of 4 mm/s.

4.4: 2nd phase of experiment (both side joint):

After performing the 1st stage of experiments it was revealed that tensile strength of the weld joint is quite low and only part of the plate thickness got welded for the applied parameter setting.

Table 7: Experimental parameters for both sides welding by TIG welding

Exp. No.	Electrode Work piece Distance (mm)	Argon Gas flow rate (l/min)	Voltage (V)	Current (A)	Welding Speed (mm/s)
1	3	8-10	50	150	3.5
2	3	8-10	50	150	4
3	3	8-10	50	150	4.5
4	3	8-10	50	150	5
5	3	8-10	50	180	4.5
6	3	8-10	50	180	5
7	3	8-10	50	180	5.5
8	3	8-10	50	180	6

In 2nd phase of experiment welding done both side of plate. In this case, after performing welding at one side in butt condition, welding done at the other side with same parametric condition. Detail experimental condition for both sided welding is shown in table 7. For all the experiments, distance between electrode and work-piece kept constant at 3 mm, Ar gas flow rate was 8-10 l/min and applied voltage was 50 V. Welding done by changing welding current and welding speed as detailed in table 7.

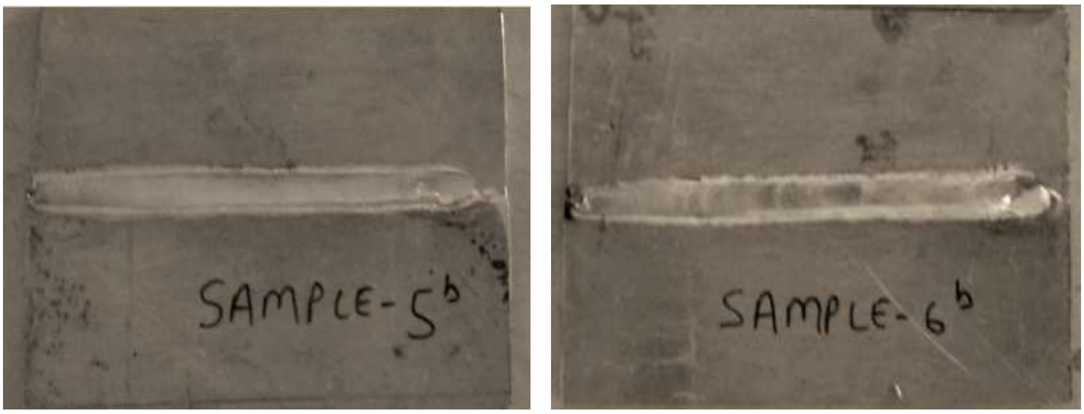

Fig: 12: Both side TIG welded samples prepared with (a) welding current 180 A, welding speed 3 mm/s (b) welding current 180 A, welding speed 3.5 mm/s

Fig. 12 shows the photograph of the both side TIG welded samples prepared with different current setting and welding speed. From these figure no specific difference could be observed.

4.4.1: Optical image at the cross section for both sided weld joints

Optical image at the cross section of the weld was taken by using an optical microscope after proper polishing. Optical photo graph at the cross section of the welded samples are shown in fig. 13. From these images it is observed that when welding performed at both sides joining take place throughout the thickness of the Aluminium plate.

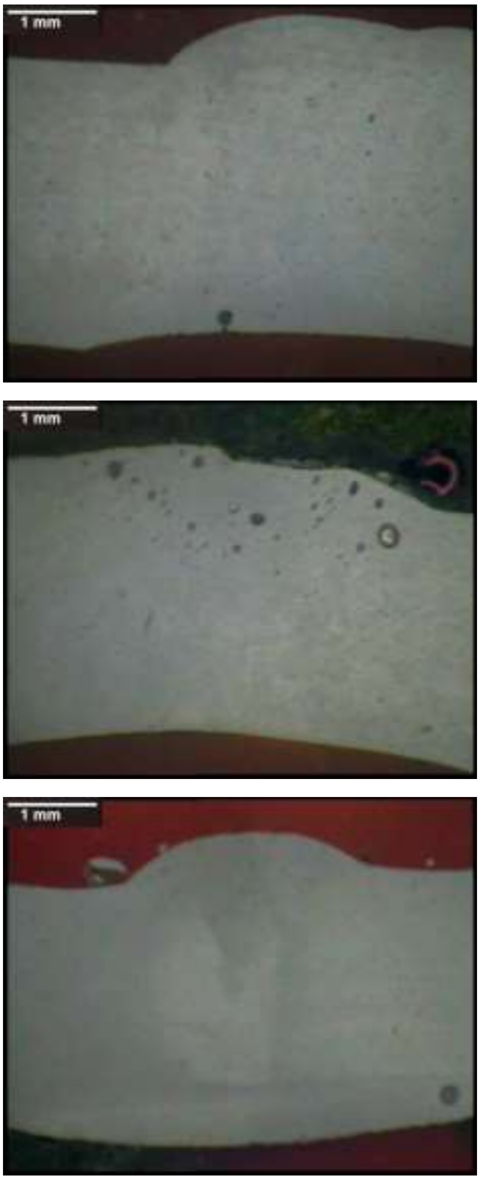

Fig. 13: Optical microscopy image of the welded zone at the cross section of both sided TIG welded Aluminium samples with current setting of 150 A and welding speed(a) 3.5 mm/s (b) 4 mm/s (c) 4.5 mm/s (d) 5 mm/s

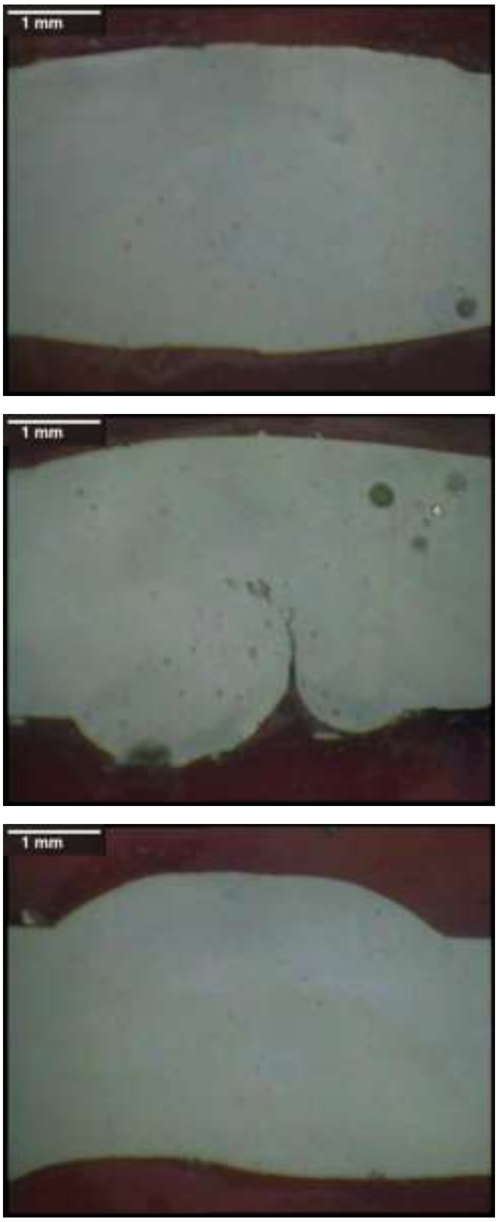

Fig. 14: Optical microscopy image of the welded zone at the cross section of both sided TIG welded Aluminium samples with current setting of 180 A and welding speed(a)4.5 mm/s (b) 5 mm/s (c) 5.5 mm/s (d) 6 mm/s

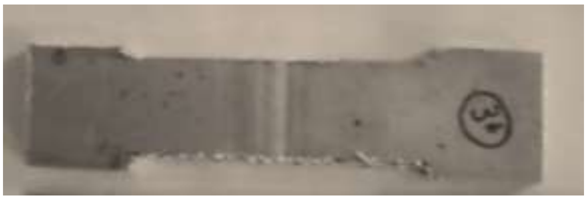

Fig 15: Tensile test specimen

Fig. 16: Tensile test machine during performing test

Table 8: Maximum load at tensile strength and tensile strength value of different welded samples (Both side welding)

Sample No	Load at tensile strength(N)	Tensile strength (MPa) UTS
1	6711.35578	111.8559
2	5538.17376	92.3029
3	4835.23384	80.58724
4	4517.39766	75.28996
5	5962.58473	99.37641
6	5752.48897	95.87498
7	6289.73264	104.8289
8	5994.42478	99.90709

In fig. 17 tensile strength value of the welded specimen plotted against welding speed for applied welding current of 150 A. Form the figure it is clear that tensile strength value of the welded joint decreases from approximately 110 MPa to 75 MPa for increasing welding speed form 3.5 mm/s to 5 mm/s. However, welding done with current setting 180 A (Fig. 18) it is found that tensile strength value of the welded joint are in the range of 95-105 MPa and no specific trend in change of tensile strength for the change of welding speed has observed.

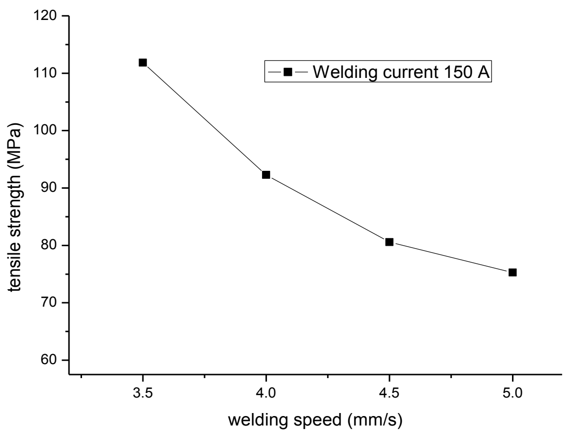

Fig. 17: Tensile strength of the welded joint against different welding speed for applied current of 150 A

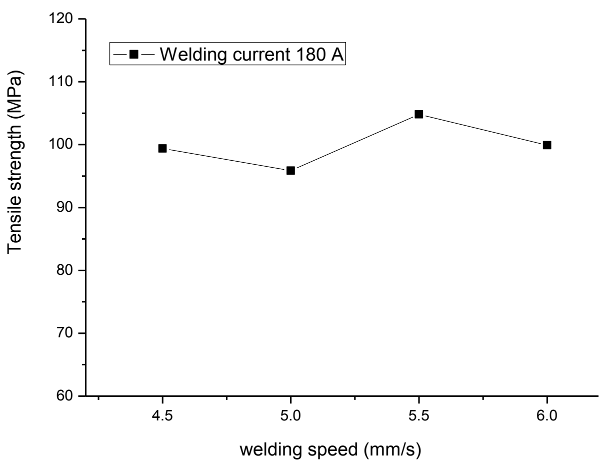

Fig. 18: Tensile strength of the welded joint against different welding speed for applied current of 180 A

In fig. 17 tensile strength value of the welded specimen plotted against welding speed for applied welding current of 150 A. Form the figure it is clear that tensile strength value of the welded joint decreases from approximately 110 MPa to 75 MPa for increasing welding speed form 3.5 mm/s to 5 mm/s. However, welding done with current setting 180 A (Fig. 18) it is found that tensile strength value of the welded joint are in the range of 95-105 MPa and no specific trend in change of tensile strength for the change of welding speed has observed.

At relatively lower current setting i.e. 150 A when welding speed increase overall heat input for the welding decreases and corresponding welding penetration from both side also decreases and therefore tensile strength of the welded joint decreases. However, when welding perform with 180 A and different welding speed value heat input decreases with increase value of welding speed but with the minimum heat input maximum welding penetration obtained for the use of higher amount of current (180 A). Therefore for changing the welding speed no specific variation in the welding speed has been observed.

4.4.2: Micro hardness value for both side welding:

Fig. 19 shows the micro hardness profile from the centre of the weld zone towards the base material for welding done with welding speed (3.5 mm/s and 4mm/s) and welding current(150 A) when welding done from the both side. From the figure it is found that hardness value almost decreasing with the distance from the centre.

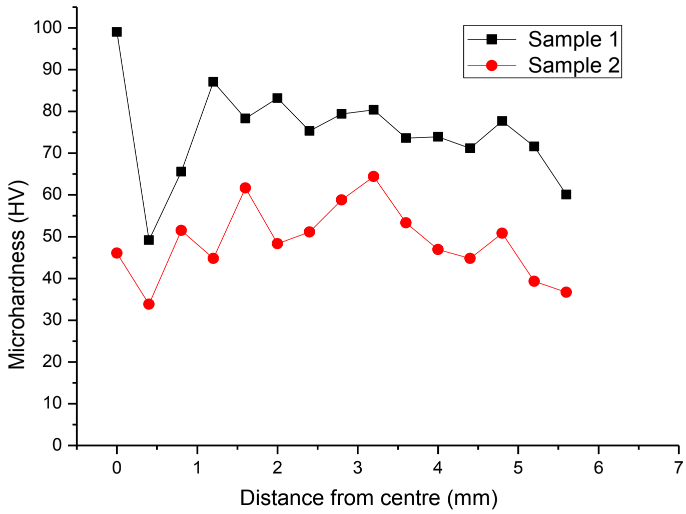

Fig. 19: : Micro-hardness value from the centre of the weld zone towards the base material for welding done with welding speed (3.5 mm/s and 4mm/s) and welding current(150 A)

Chapter 5

Conclusion

From the experiment of TIG welding of Aluminium plate following conclusion can be made

- With the automated welding system uniform welding of Aluminium plate can be possible.
- Welding strength or tensile strength of the weld joint depends on the welding parameters like welding speed and welding current.
- With the increase in current, tensile strength of the weld joint increases.
- Hardness value of the weld zone change with the distance from weld centre due to change of microstructure.
- At lower welding speeds strength is more due to more intensity of current.
- For both side welding tensile strength is found almost equivalent to the strength of base material.
- For both sided welding performed with high current (180 A), welding speed have no specific effect on tensile strength of the weld joint.

Future scope

In present work welding is performed without any filler material. A filler rod/wire feeding system can be included in the system so that by using filler rod/wire thicker plate can be welded. Welding setup can also be use for welding of some other materials.

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