EFFECT OF PROCESS PARAMETERS ON WELD BEAD GEOMETRY AND MICRO-HARDNESS OF WELDING AA 6082 USING GTAW PROCESS

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Abstract: ***Among all the welding processes, the chief advantages in using Gas Tungsten arc welding (GTAW) for surfacing are high reliability, all position capability, ease of use, low cost and high productivity. Gas tungsten arc welding is one of the widely used techniques for joining aluminum alloy, nickel, nickel alloy, stainless steel, mild steel etc. To automate a welding process it is essential to establish the relationship between weld bead geometry and process parameters to control and predict weld bead quality. The main objective of this paper is to analyze the effect of welding process parameters such as welding current, voltage, welding speed and rate of heat input on weld bead geometry to weld AA 6082 (Parameters of weld bead geometry are weld bead width, bead penetration and bead height) and Microstructures of weld metal under different process parameter inputs are viewed and captured with an optical microscope coupled with an image analyzing software. Optical microscopic analysis has been done on the weld zone to evaluate the effect of welding parameters on welding quality and also Micro-hardness values of the fusion zone, heat affected zone, and base metal are measured for the welded specimens at the cross section to understand the change in mechanical property of the welded zone. AA6082 is an alloy of Al-Mg-Mn-Si which are employed in insulation foils, kitchenware, chemical and food industry, equipment containers, automotive trim, light reflectors, architecture, vessels, piping beer barrels and milk churns etc., due to their medium strength alloy with a very good corrosion resistance and also the grade 6082 aluminium offering the highest strength of all the 6000 series it is widely regarded as a material for structural type applications. Parameters of weld bead geometry are weld bead penetration, bead width, and bead height or reinforcement. It is essential to assess the effect of process parameters on specific bead geometry and shape relationships. The result of this study helps to apply control methods in forecasting the quality of weldments during Gas Tungsten Arc Welding. By using of this experimental study we will improve the productivity, quality of product and also efficiency of GTAW and we will reduce the expenditure money on the waste of material and maintenance.***

Keywords: Process parameters, micro hardness, microstructure, weld bead geometry, Gas Tungsten Arc Welding, AA6082 etc.

1) INTRODUCTION

Welding is a process of joining two similar or dissimilar materials by application of heat and with or without application of pressure and with or without use of filler material. On cooling, molten edges fuse together to form a strong joint. During welding, the workpieces 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.

TIG (Tungsten Inert Gas) welding also known as GTA (Gas Tungsten Arc) in the USA and WIG (Wolfram Inert Gas) in Germany, is a welding process used for high quality welding of a variety of materials, especially, Stainless Steel, Titanium and Aluminum, Aluminum alloy, mild steel, copper, nickel alloy etc. Equipment used in TIG Welding is as follows,

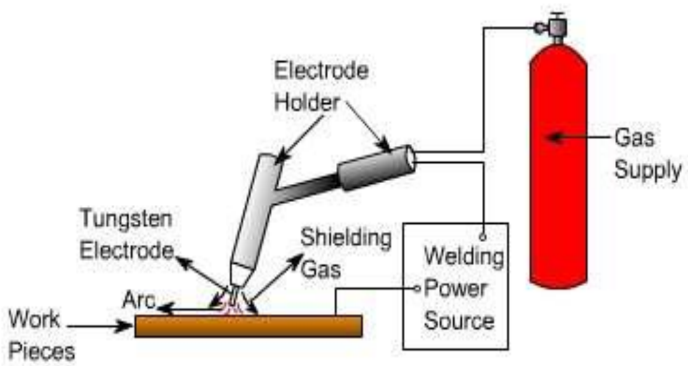


Fig 1.1 Schematic Diagram of TIG Welding System or set up

- **a)** DC or AC power source
- **b)** TIG torch
- **c)** Work return welding lead
- **d)** Foot control unit

The Gas Tungsten arc welding system is illustrated in figure 1.1 here. The process uses a non-consumable tungsten (or tungsten alloy) electrode held in a torch. Shielding gas is fed through the torch to protect the electrode, molten weld pool, and solidifying weld metal from contamination by the atmosphere. The gas tungsten arc welding (GTAW) process uses a non-consumable tungsten electrode to produce the weld. A shielding gas (usually an inert gas such as argon), protects the weld area from atmospheric contamination, and the process normally uses a filler metal, though some welds, known as *autogenesis* welds, do not require a filler metal. A constant-current welding power supply produces energy that is conducted across the arc through a column of highly ionized gas and metal vapors known as plasma. Welders most commonly use TIG to weld thin sections of stainless steel and non-ferrous metals such as aluminum, magnesium, and copper alloys. TIG provides the welder with greater control over the weld than competing procedures such as shielded metal arc welding (SMAW) and gas metal arc welding (GMAW), thus allowing for stronger, higher quality welds. However, GTAW/TIG is comparatively more complex and difficult to master closer tolerance requirements and filler metal usually added by other hand, and is significantly slower than most other welding techniques as well. It will also cover core competencies such as setting up equipment, preparing materials, fitting up, starting an arc, welding pipes and plates, and repairing welds.

Gas tungsten arc welding is widely used because of its versatility. When weld purity is important, this process welds stainless steel, low alloy steel, steel, nickel, cobalt, titanium, aluminum, copper, magnesium, and most other metals in all positions and produces clean weld deposits. The clean weld deposits TIG produces usually avoids the need of grinding and finishing, and all methods are usable: manual, semiautomatic, mechanized, and fully automatic. Welding pipe or nuclear power components are typical examples of the wide variety of TIG applications. This process can also weld thin metals and small objects such as transistor cases, instrument diaphragms, and other delicate parts.

The main objective of this paper is effect of process parameters (process parameters are current, speed voltage and rate of heat input) on weld bead geometry. Also effect of process parameter on micro hardness and microstructure is to be studied. In this research aluminium alloy 6082 is used as a base metal.

2) LITERATURE SURVEY

The effects of these parameters on weld bead geometry such as penetration, width & height have been studied [1]. The effect of pulse currents, secondary currents, pulse frequencies and pulse duty cycles on the bead geometry of GTA Welded AA7039 [2]. Welding process aims at obtaining a welded joint with the desired weld bead parameters, excellent mechanical properties with minimum distortion. Quality of weld joint depends upon welding input parameters [3]. Effect of process parameters of pulsed current tungsten inert gas welding on aluminum alloy 6061 using sinusoidal AC wave with argon and helium gas mixture. From the study they have found that pulse current pulse duty cycle, frequency, percentage of helium in argon plays an important role on microstructure, and hardness of weld, Pulsed current plays major role in all of them [4]. Effect of shielding gas parameter on mechanical properties and microstructures of heat-affected zone and fusion zone on gas tungsten arc welding (GTAW) in aluminium alloy 5083 [5]. It is essential to control shape of weld bead geometry which plays an important role in determining mechanical properties as it is affected by weld bead geometry shape. Therefore, proper selection of process parameter is necessary. It is not easy task to developed mathematical models which gives relationship between input and output process parameters of GMAW process because there were some unknown nonlinear process parameters [6].

3) OBJECTIVES OF PROJECT

Objective of this experimental project are as follows,

1) Identification of process parameters and their limits.
2) Welding of samples using GTAW process.
3) Design of experiment.
4) Specimen micro hardness test using Vickers hardness test.
5) Specimen microstructure test.
6) To study the effect of various process parameters on weld bead geometry, micro hardness and microstructure of weld plate.

4) METHODOLOGY AND MATERIAL

4.1) Methodology

Commercial AA6082 plate of thickness 4 mm was selected as work piece material for the present experiment. AA 6082 plates are cut with dimension of 100 mm x 40 mm (as shown in fig 1.2) 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. The composition of the base plate and filler wire (2.4mm diameter) are shown in Table 1. The AA6082 plates were cleaned chemically and mechanically to remove the oxide layer and any other source of hydrogen. Bead on plate welds are laid on the plates of 100×40×4mm size. The ranges of the parameters and their level have in following beat. The experiments were performed in random manner to avoid any systematic error. After welding, transverse sections of the weld beads were cut from the middle portions of the plates as specimens for each of the bead-on-plate specimens, the important dimensions of the weld bead geometry were measured.

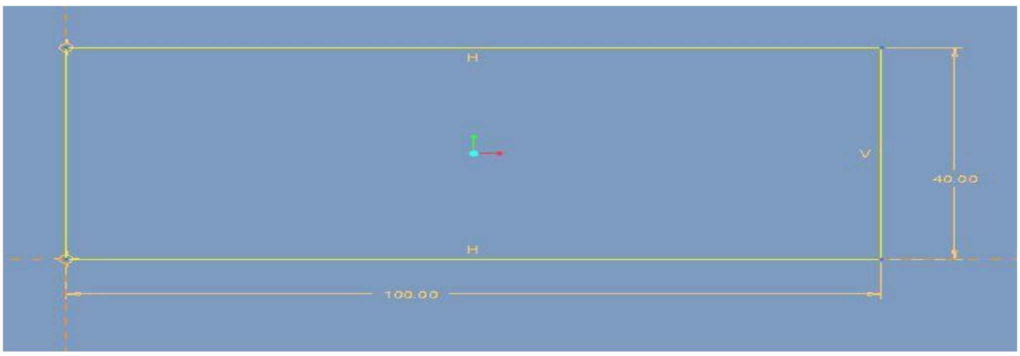


Fig 1.2 Design of AA 6082 plate specimen

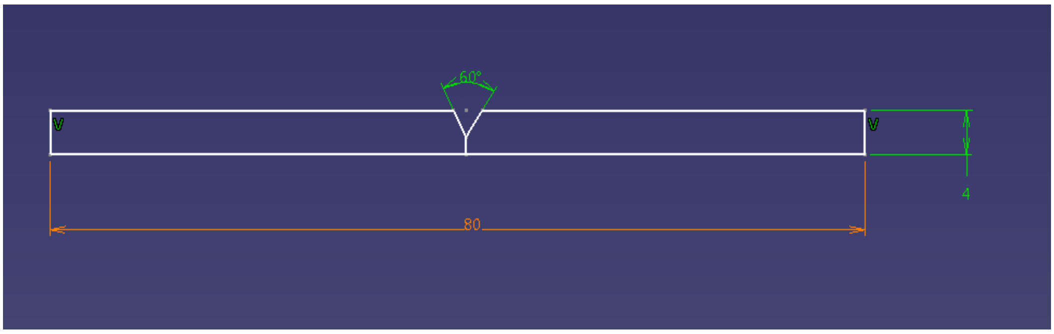


Fig 1.3 Edges of welding sample

To meet the objective, experimental set up searched first of all. The experimental setup consists of semi-automatic welding machine with control over welding parameters such as welding current, welding speed, shielding gas flow rate, voltage & rate of heat input etc. The experiment done by establishing the range of process parameters based on trial experiments and theoretical background of process parameter range selection from AWS (American Welding Society) Handbook titled "Weldability of metals and alloys" The experimental readings is to be then taken like weld penetration, weld width and weld bead height of the weld bead and also the effect of these process parameter on micro-hardness and microstructure of weld plate is to be studied. Optical microscopic analysis has been done on the weld zone to evaluate the effect of welding parameters on welding quality and Micro-hardness is the one of the most critical factor which indicates the quality of weld bead and plate. Micro-hardness of FZ (fusion zone), HAZ (heat affected zone) side and base metal has been observed and found out. Micro-hardness test is done on Vickers micro-hardness Testing Machine which is as shown in the image. On test machine 25 gram load applied for a period of 10 to 15 seconds. Micro-hardness is taken per mm from Centre of weld fusion zone towards the base metal on each sample. 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.

4.2) Material

Aluminium alloy 6082 is used as a base metal for TIG welding, has thickness 4 mm. Welded specimen dimension is 100 mm in length and 40 mm in width, and cleaned the surface of the plates and all the four edges of rectangular shaped metal plates are properly finished. All specimens are welded by butt-joint. Manual TIG welding is used for experiment and all the joint are welded using argon gas. The chemical analysis of AA 6082 is given below,

Table 1 Chemical composition of AA 6082 as per the test report

Element	Al	Mn	Si	Cr	Cu	Ti	Fe	Zn	Mg
% Weight	96.8	0.43	0.78	0.20	0.045	0.033	0.13	0.11	0.67

Filler wire used for Experiment

The choice of filler rod is extremely important as the rod must correctly match the material and alloy you will be welding. The thickness of the material to be welded determines the diameter of the filler rod. In this project we are use the ER 4043 filler wire which is mostly used for welding AA 6082. The diameter of this filler wire is 2.4 mm. ER 4043 give the highest degree of ease of welding. Chemical composition of ER4043 is as shown in table 2.

Table 2 Chemical composition of ER4043

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti
% weight	4.6-6	0.8	0.3	0.05	0.05	0.1	0.2

Image of AA 6082 welded samples using GTA Welding

5) IDENTIFICATION OF PROCESS PARAMETERS AND THEIR LIMITS

5.1) Identification of Process Parameters

Control of the operating variables or process parameters in Gas Tungsten arc welding is essential if high production rates and the welds of good quality are to be obtained. The following are the important variables: (A) Welding current and arc voltage (B) Welding speed and rate of heat input.

A. Welding Current and Arc voltage

It controls the melting rate of the electrode and thereby the weld deposition rate. It also controls the depth of penetration and thereby the extent of dilution of the weld metal by the base metal. Arc voltage, also called welding voltage, means the electrical potential difference between the electrode wire tip and the surface of the molten weld puddle. It hardly affects the electrode melting rate.

B. Welding Speed and Heat input

Welding speed is the linear rate at which the arc moves with respect to plate along the weld joint. Welding speed generally conforms to a given combination of welding current and are voltage. If welding speed is more than required heat input to the joint decreases, less filler metal is deposited than required, Reinforcement height decreases'. If welding speed is slow, heat input rate increases, Weld width increases and reinforcement height also increases more convexity. the following formula is used for calculate the rate of heat input,

Heat input rate= $\frac{60VI}{1000S}$ KJ/mm.

V=arc voltage in volts,

I=welding current in ampere,

s =speed of welding in mm/min [6].

5.2) Process parameters limit

The independently controllable process parameters are identified and they are welding voltage, welding current, welding speed, rate of heat input and gas flow rate and their working ranges are 12-22V, 130-165A, 10-15 mm/sec, 0.20-0.42 KJ/mm, 20-25 lit/min respectively.

6) DESIGN OF EXPERIMENT

In design of experiment taken the reading of all of the process parameters, the following table consists design of experiment.

Sample no.	Voltage(v)	Current (I)	Welding speed(mm/min)	Gas flow rate (Lit/min)	Heat input (kJ/mm)
1	15.6	130	600	20	0.2028
2	15.6	135	588	20	0.2148
3	15.8	140	570	20	0.2328
4	16.7	145	480	23	0.3026
5	16.7	150	462	23	0.3253
6	16.7	155	450	25	0.3451
7	17.7	160	432	25	0.3933
8	17.7	165	420	25	0.4172

Table 3 Design of experiment

Sample no.	Bead width (mm)	Bead Height or reinforcement (mm)	Bead penetration(mm)
1	6.12	1.12	1.77
2	6.84	1.4	2.00
3	7.12	1.83	2.41
4	7.41	2.3	2.40
5	7.51	1.33	2.68
6	8.34	2.38	2.36
7	8.53	1.7	2.96
8	11.50	1.8	2.98

Table 4 Experimental results for samples

7) RESULT AND DISCUSSION

1) Effect of process parameter on weld bead geometry

7.1.1) about weld bead geometry

The weld bead shape is an indication of bead geometry which affects the load carrying capacity of the weldments and number of passes needed to fill the groove of a joint. The bead geometry is specified by bead width, reinforcement or bead height, penetration etc. Bead geometry in the arc welding process is an important factor in determining the mechanical characteristics of the weld. Bead geometry variables, such as bead width, and penetration depth are greatly influenced by welding process parameters, such as welding current, welding voltage, welding speed, heat input, temperature and shielding gas. The selection of the appropriate welding process parameters is required in order to obtain the desired weld bead geometry, which greatly influences weld quality, leading to costly and time-consuming experiments to determine the optimum welding process parameters due to the complex and nonlinear nature of the welding process. Therefore, a more efficient method is needed to determine the optimum welding parameters. The typical main features of geometry of the weld bead are shown in Figure1.4 and explanation is as follows,

As shown in figure of weld bead geometry where,

w=weld bead width

h=height of weld

p=depth of penetration of weld

Ap= penetration area

Ar=reinforcement area

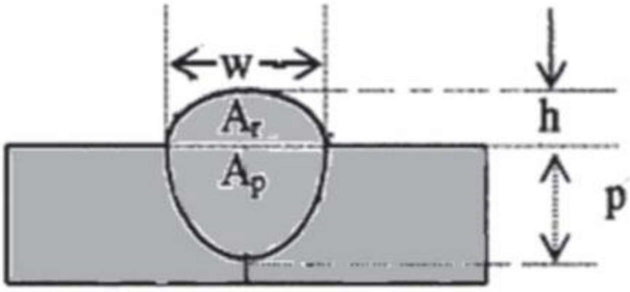


Fig 1.4 weld bead geometry

7.1.2) Effect of process parameters on Bead Height or reinforcement

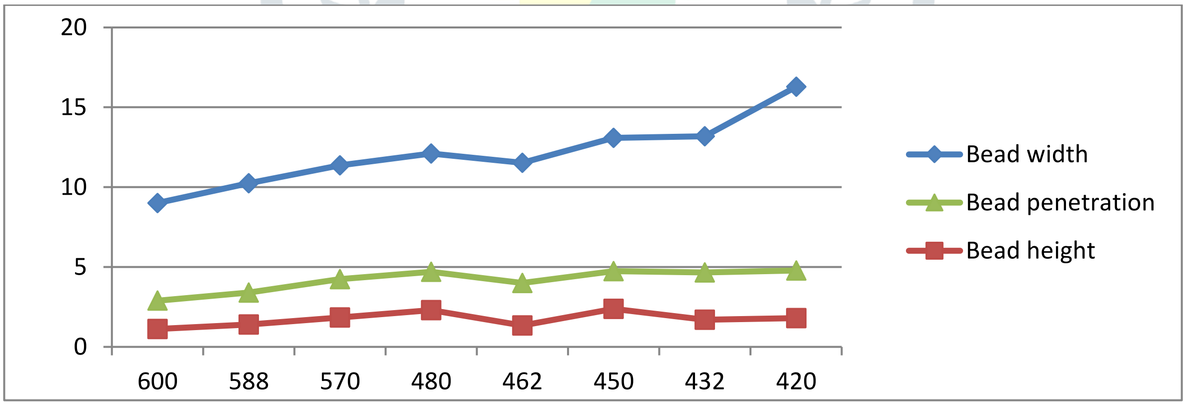
Reinforcement or bead height is the maximum distance between the base metal level and the top point of the weld bead. Reinforcement is the crown height of the weld bead from the base plate. It affects the strength of the weld joint and welding wire consumption rate. As shown in the graph 1 bead heights is an increase with the welding current but at the current 160 A bead height slightly decreases. In graph 1, X axis consists of current in ampere and Y axis consists of bead height, bead width, and bead penetration in mm. Bead height indirectly proportional to welding voltage the decrease of reinforcement with the increase in voltage is due to increase in weld bead width. On bead height at different parameters like welding speed, current and gas flow rate and rate of heat input in GTAW process for welding of AA 6082. It can be seen that: 1) Bead height decreases with the increase in welding speed(as shown in graph 2). 2) Bead height increases with the increase in current 3) there is a slight decrease in bead height with the increase in gas flow rate.

7.1.3) *Effect of process parameters on Bead Penetration*

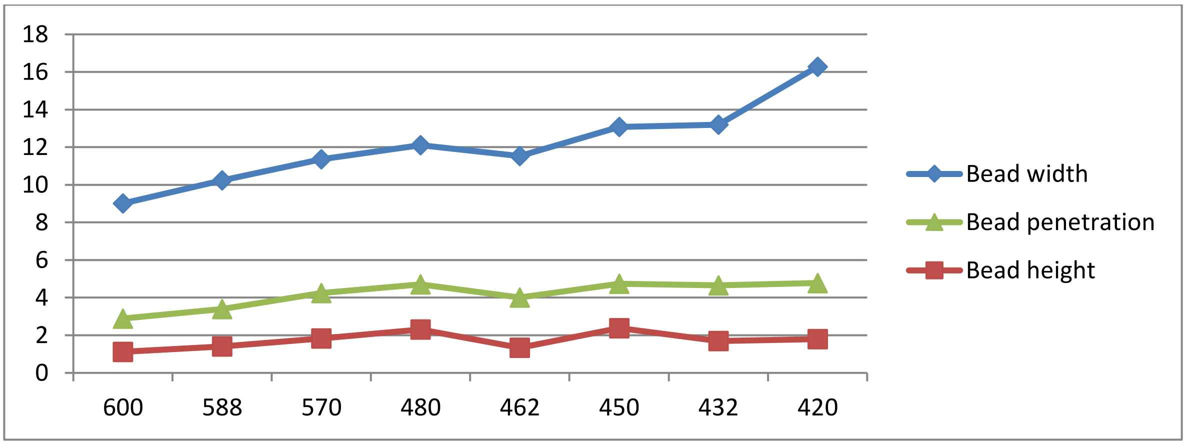
Weld bead penetration is the maximum distance between the base plate top surface and depth to which the fusion has taken place. Depth of penetration measured from sectional cross cutting of weld beads through measuring instrument after cutting all the welded specimens perpendicular to the direction of welding and variations in the penetration are analyzed. The more the penetration, the less is the number of welding passes required to fill the weld joint which consequently results in higher production rate. It is observed that the penetration is influenced by welding current, welding speed. On bead penetration at different parameters like welding speed, current and gas flow rate and temperature in GTAW process of for welding of AA 6082. It can be seen that: 1) Bead penetration decreases with the decrease in welding speed. 2) Bead penetration is increases with the increase in current. As shown in graph 1.

7.1.4) Effect of process parameters on Bead Width

The weld bead width is the maximum width of the weld metal deposited. Width is directly proportional to arc current, welding voltage and indirectly proportional to the welding speed. On bead width at different parameters like welding speed, current and gas flow rate and temperature in GTAW process of for welding of Aluminum alloy 6082. It can be seen: 1) Bead width decreases with the increase in welding speed (as shown in graph 2). 2) Bead width increases with the increase in current (As shown in the graph 1). 3) Bead width is almost constant with change in gas flow rate.



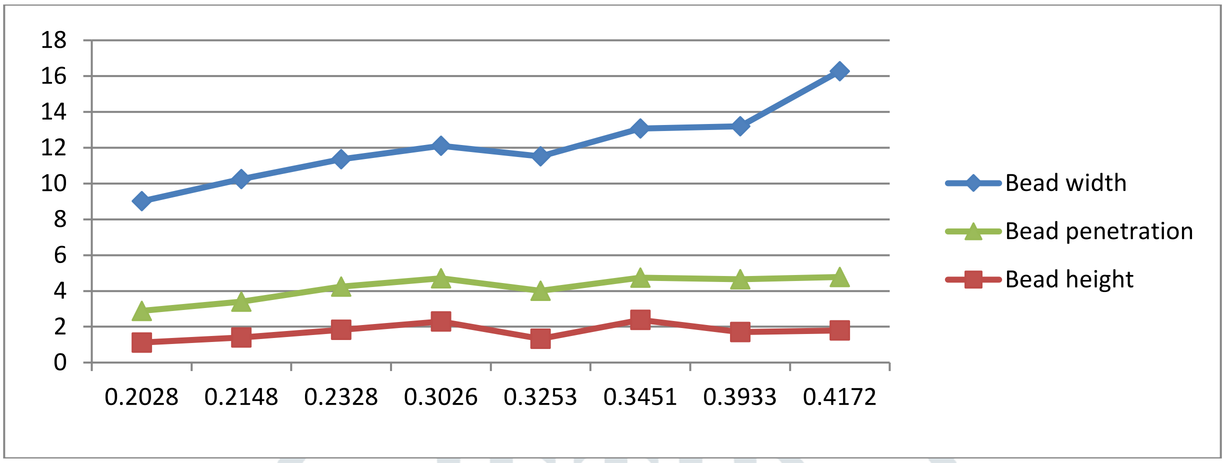
Graph 1 Effect of Current (A) on bead width (mm), Bead height, Bead penetration(mm).



Graph 2 Effect of Welding speed (mm/min) on Bead width, Bead height, and bead penetration (mm).

7.1.5) Effect of heat input on weld bead geometry

Heat input serves a significant role in welding. The rate of heat input is directly proportional to the voltage and current and inversely proportional to the welding speed. The graph 3 shows relation between rate of heat input and depth of penetration, bead width and bead height. Graph shows that as increasing heat input, the depth of penetration increases until an optimum value which gives maximum depth of penetration as shown in graph 3. After that optimum value, depth of penetration begins to decrease linearly. Graph 3 consists of X-axis is heat input rate in Kj/mm and Y- axis consists bead penetration, bead height and bead width in mm. According to experiment higher heat input causes higher width of weld bead in line with this for high value of 0.425 KJ/mm of heat input. Increase in heat input bead height is also increases.



Graph 3 Effect of heat input (KJ/mm) on bead Height, width and penetration(mm).

2) Micro hardness test

Hardness is property of a metal, which gives it the ability to resist being permanently deformed (bent, broken, or have its shape changed), when a load is applied. The metal with greater hardness it has greater resistance to deformation. In metallurgy hardness is defined as the ability of a material to resist deformation. Micro hardness is the one of the most critical factor which indicates the quality of weld bead and plate. Micro hardness of FZ (fusion zone), HAZ (heat affected zone) side and base metal has been observed and found out. Micro hardness test is done on Vickers micro hardness Testing Machine. On test machine 25 gram load applied for a period of 10 to 15 seconds. Micro hardness is taken per mm from Centre of weld fusion zone towards the base metal on each sample. 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.

7.2.1) Specimen preparation for testing Micro- hardness.

First of all, the required size was cut from the welded pieces after this these were made smooth by filing followed by smoothen with help of emery papers. Then to get more smoothness, polishing machine was used. The alumina powder and then diamond powder were used for polishing the surface.

7.2.2) Basic Metallurgy of Fusion Zone, HAZ and base metal

A typical fusion welded joint varies in metallurgical structure from the fusion zone to the base material with consequential variations in mechanical properties. This is because of the fact that fusion welding processes result in melting and solidification with very high temperature gradient within a small zone with the peak temperature at the center of the fusion zone. In general, a weld can be divided in four different zones as shown schematically in figure 1.5.

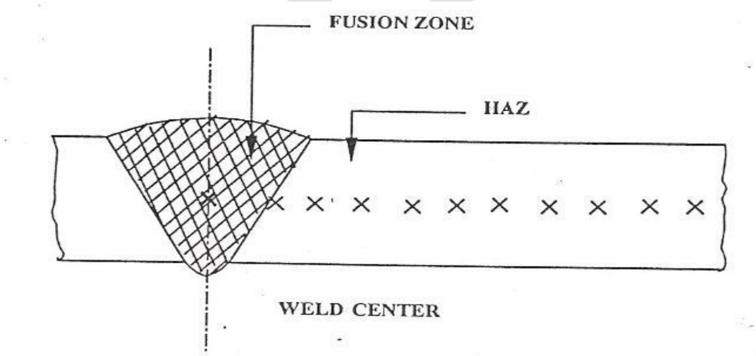
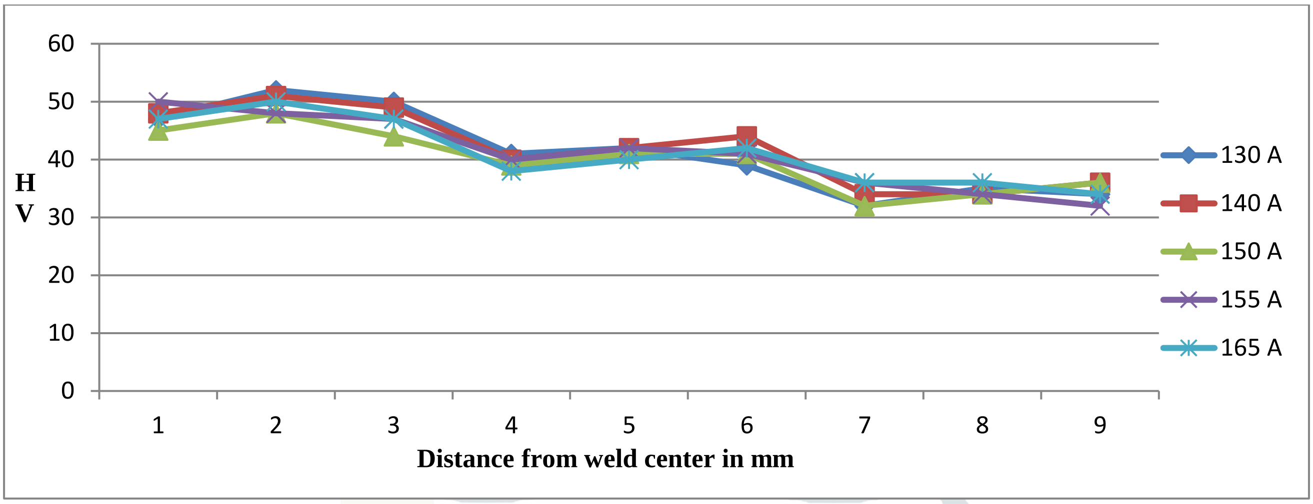


Fig 1.5 Schematic presentations of several zones in a fusion welded joint

7.2.3) Micro hardness test result

Micro hardness (Vickers) was measured from the weld Centre line to the unaffected base metal with a load of 25 gram. Micro hardness testing is an indentation method for measuring the hardness of a material on a microscopic scale. A precision diamond indenter is impressed into the material at load. The impression length, measured microscopically and the test load are used to calculate a hardness value. The variations of micro hardness from the weld Centre were given in graph 4. In graph 4, x axis consists of distance from Centre line of weld bead and y axis consists of Micro hardness in VHN of various samples which are welded by using various current in ampere. The Micro hardness testing is conducted and the hardness of the various portion such as base metal, fusion zone and heat affected zone (HAZ) are found out for samples. The results of the hardness test are used to compare the samples for microstructure study and macrostructure study. From the graph it is found that for almost all the sample micro hardness value increases in the fusion zone than the base metal and these values are in the range of 45 to 52 HV in the welded zone. The individual effect of current, voltage, speed on hardness of fusion zone and HAZ is higher. It is observed that the hardness is higher in the HAZ than the base metal. It is found that hardness value in HV almost decreasing with the distance from the center of fusion zone. High heat input generates wider weld zone and HAZ, which reduces the joint strength and weld hardness. When welding current is increased the micro hardness of the plate is reduced.



Graph 4 Micro hardness of Samples from the Weld Centre.

7.2.4) Microstructure test results

Microstructures of weld metal under different inputs of process parameters are viewed and captured with an optical microscope coupled with an image analyzing software. Optical micrographs showing the microstructures of weld zone for different inputs of process parameters are presented from fig. 1.6. It is observed from these optical micrographs that as heat input increases the dendrite size and inter dendritic spacing in the weld metal is increase.

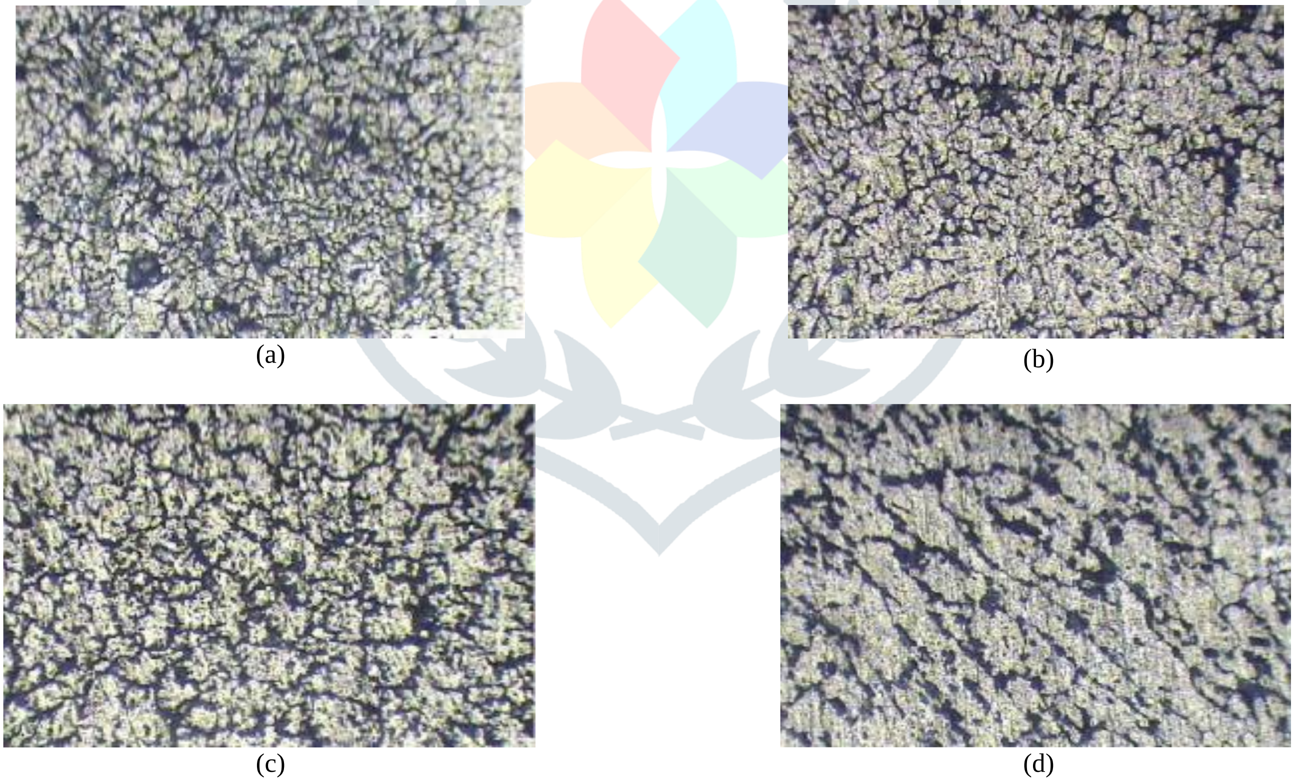


Fig 1.6 Microstructure of weld metal at current (a) 130A. (b) 140A. (c) 155A. (d) 165A.

8) CONCLUSION

From the experiment of GTA welding of AA 6082 plate following conclusion can be made. In this study, we conclude that the weld bead geometry and micro hardness depends mainly on input parameters, namely the welding speed, current, voltage and the rate of heat input is measured. These parameters, if not carefully controlled, might result the damage of welding area. Rate of heat input decreases then hardness of weld joint is increases, hence the heat input rate is inversely proportional to the hardness. Because of Higher heat input causes tempering of weld metal which lower down micro hardness of the weld metal. A low heat input results increase in hardness.

- With the increase in current, micro hardness of the weld joint increases. And decrease in welding speed then increase in hardness of weld joint.
- Welding current has larger influence on bead width than on bead penetration and bead height.

- Increasing in heat input increases bead width, penetration, and bead height.
- The individual effect of current, voltage, speed on hardness of fusion zone and HAZ is higher. It is observed that the hardness is higher in the HAZ than the base metal. When welding current is increased the micro hardness of the plate is reduced.
- Distortion is the major problems in welding of thin sections, when current increased the plates are distorted due to the pressure of electric arc.
- In all the sample micro hardness value increases in the fusion zone than the base metal and these values are in the range of 45 to 52 HV in the welded zone, This is due to the fast cooling rate.

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