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Optimization of thermal effects on weld bead geometry and developing mathematical model for GTAW

Mr. A. D. Sarolkar1, Dr. K. P. Kolhe2.

[1]Department of mechanical engineering, savitribai phule pune university, wagholi, Pune, Maharashtra, India.
[2] Department of mechanical engineering, savitribai phule pune university, wagholi, Pune, Maharashtra, India.

Abstract

Gas tungsten arc welding is one of the widely used techniques for joining ferrous and non-ferrous metals. In this project we optimize the thermal effects on weld bead geometry and mathematical model is to be developed for bead geometry of GTAW correlating current, voltage, gas flow rate, welding speed and rate of heat input by using the regression analysis. The input process parameters such as current, welding speed, gas flow rate and rate of heat input controlled using the control panel of the welding set up for welding Aluminium, and we optimize the effects of these parameters on weld bead geometry such as bead penetration, bead width & bead height or reinforcement, hardness of weld joint is to be studied. 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. The project focuses on review from the published literature on the thermal effects in GTAW for different temperature also the mathematical models are collected from literature.

Keywords: *Bead geometry, mathematical model, gas tungsten arc welding, process parameter, etc.*

1. Introduction

TIG uses the heat produced by the arc between the non-consumable tungsten electrode and the base metal. An inert shielding gas supplied through the torch shields the molten weld metal, heated weld zone, and non-consumable electrode from the atmosphere. The gas protects the electrode and molten material from oxidation, and provides a conducting path for the arc current. An electric current passing through an ionized gas produces an electric arc. In this process, the inert gas atoms are ionized by losing electrons and leaving a positive charge. Then the positive gas ions flow to the negative pole and the negative electrons flow to the positive pole of the arc. The intense heat developed by the arc melts the base metal and filler metal (if used) to make the weld. As the molten metal cools, coalescence occurs and the parts join. There is little or no spatter or smoke. There sulting weld is smooth and uniform, and requires minimum finishing (*Figure 1*). While there is no need to add filler metal when welding thinner materials, edge joints, or flange joints. This is known as autogenously welding. For thicker materials, an externally fed or "cold" filler rod is generally used. The filler metal in gas tungsten arc welding does not transfer across the arc, but is melted by it. Strike the arc in one of three ways:

1. By briefly touching the electrode to the work and quickly withdrawing it a short distance.
2. By using an apparatus that will cause the arc to jump from the electrode to the work.
3. By using an apparatus that starts and maintains a small pilot arc. This pilot arc provides an ionized path from the main arc. The torch then progresses along the weld joint manually or mechanically after remaining in one place until a weld puddle forms. Once the welder obtains adequate fusion, the torch moves along the joint so the adjacent edges join and the weld metal

solidifies along the joint behind the arc, thus completing the welding process.

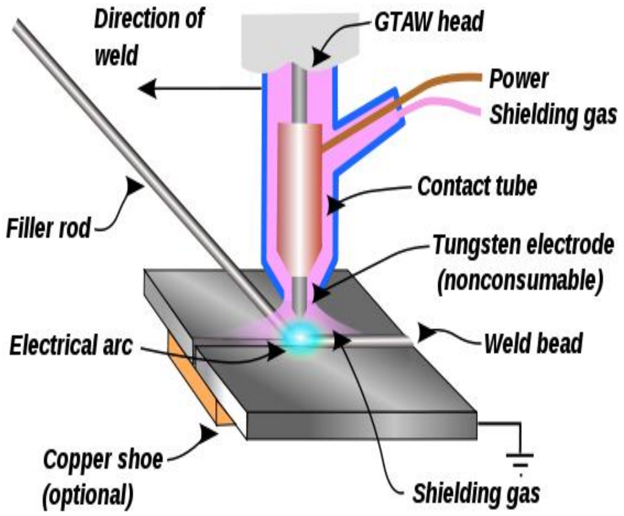

Fig.1 GTAW Process

Advantages of TIG welding are concentrated arc, no slag, no splatter, little smoke or fumes, good weld penetration, preferred for stainless steel alloys. Disadvantages are slow process, good skill requirement for manual operation.

Problem Statement

Basically, TIG weld quality is strongly characterized by the weld bead geometry. This is because the weld bead geometry plays an important role in determining the mechanical properties of the weld. Therefore, it is very important to select the welding process parameters for obtaining optimal weld bead geometry. Usually, the desired welding process parameters are determined based on experience or from a handbook. However, this does not ensure that the selected welding process parameters can produce the optimal or near optimal weld bead geometry for that particular welding machine and environment. The aim of this dissertation work is to optimize effect of process parameters on weld bead geometry and microstructure, heat affected zone etc. for welding aluminum TIG (Tungsten Inert Gas) Welding process.

Weld bead geometry

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 **Figure.2**.

As shown in figure of weld bead geometry where

w=weld bead

h=height of weld

p=depth of penetration of weld

Ap= penetration area

Ar=reinforcement area

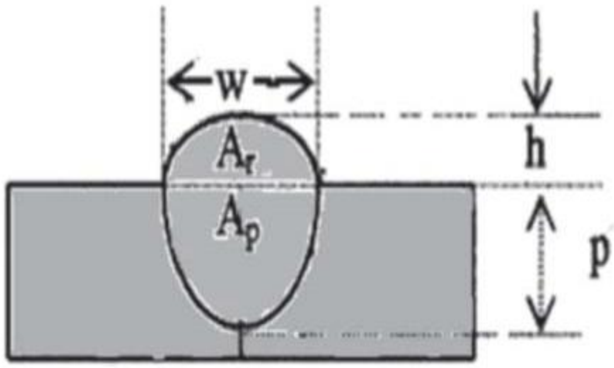

Fig 2 weld bead geometry

2) Selection of material and welding parameters

Aluminium plate in TIG welding, has thickness 7mm.Welded specimen dimension is 140 mm in length and 30 mm in width. All specimens are welded by butt-joint. Aluminium is difficult to be welded, because of its low melting. Aluminium has low melting point-1200 degree Fahrenheit compared to 2600 degree Fahrenheit to 2700 degree Fahrenheit for steel. Manual TIG welding is used for experiment. In experiment, welding parameters are welding current, welding speed, welding voltage and gas flow rate, rate of heat input etc.

3) Objective of project

Objective of this experimental project are as follows,

1) Specimen preparation. In this project we used aluminum specimen.

2) Design of experiment. And

3) Development of mathematical model for,

   a) Bead width on both of the material
   b) Bead height
   c) Bead penetration.

4) Optimization of effects of process parameter on weld bead geometry, reinforcement and hardness of weld joint etc.

4) Methodology

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 will be then taken like weld penetration, weld width and weld bead height and ultimate tensile strength of the weld joint. A confirmatory experiment was also carried out based on optimal process parameter, to illustrate and validate the proposed approach. Systematic approach required to develop the mathematical models that predict and control the bead geometry parameters for GTAW process includes the following steps.

(1) Identification of process parameters and their limits

(2) Developing the mathematical models.

(3) Arriving at the final mathematical models.

(4) Record and response

(5) Result and discussion

(6) Conclusion

4.1) Identification of process parameters and their limits

The independently controllable process parameters are identified: they are welding voltage, welding current, feed rate and gas flow rate and their working ranges are 16-36V, 40-300A, 4-8 mm/sec and 7-12lit/min respectively. The coded values for intermediate values are calculated from the following relationship:

$X_i = 2[2X-(X_{max} + X_{min})] / [X_{max} - X_{min}]$

Where X_i is the required coded value of the variable X; X is any value of the variable from X_{min} to X_{max};X_{min} is the lower level of the variable and X_{max} is the upper level of the variable. The process parameters levels with their units and notations are given in Table 1

Parameter	Unit	Notation	Factor levels		
			minimum	Average	Maximum
Welding current	A	I	120	180	240
Welding voltage	V	V	22	26	31
Welding speed	mm/min	S	390	435	480
Gas flow rate	Lpm	G	7	10	12
Heat input rate	Kj/mm	H	0.332	0.643	0.954

Table 1 Welding Process Parameters and their Levels

4.2) Developing of Mathematical Model

Mathematical model developed is given as ,Y= f (V, I, S,G), Where Y is the measured response (bead height, bead width and bead penetration) and V is welding voltage in volts, I is welding current in amps, feed rate in m/min and G gas flow rate in lit/min, heat input rate in kj/mm. And also table is to be prepared. The response Y may be any of the bead parameters i.e. penetration, width height etc. Assuming a linear relationship in the first instance and taking into account all possible two factor interactions, Equation could be written in the form of a following polynomial.

$Y = b0+b1 V+b2S+b3G+b12VS+b13VG+ + b23SG$

Or it can be written as,

Y=b0+b1 V+b2S+b3G+b4VS+b5VG+b6SG where, $b0$ is free term coefficient, $b1$, $b2$, $b3$ and $b4$ are Linear coefficients, $b11$, $b22$, $b33$ and $b44$ are quadratic coefficient sand $b12$, $b13$, $b14$, $b23$, $b24$, $b34$ are interaction coefficients.

Evaluation of Coefficients

The regression coefficients of the selected model were calculated using Equation (4.4). This is based on the method of least squares.

bij=$\frac{Xji\ .Yi}{M}$ where, j = 0,1,2,3------,k

Where,

X ji Value of a parameter or interaction in coded form

Y i Average value of the response parameters

M Number of observations

K Number of coefficients of the model

4.3). Arriving the Final Mathematical Models

In the final mathematical model there is bead height, bead width, bead penetration will be calculated. Formulas for calculating bead height, bead width, and bead penetration.

B.H. = -4.573+0.390V+0.865S–0.093G+0.002I-0.007V2-0.098S2+0.003G2.

B.W=-22.157+1.057V+0.001I+6.946S–0.034G-0.011V2-0.598G2–0.005S2+0.044SG-0.110V.

B.P.=0.149+0.142V+0.003I+0.135S–0.017G-0.001V2+0.067S2+0.001G2-0.024VS–0.003SG+0.001VG.

4.4) calculation of heat input

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. Heat input is typically calculated as follows: H = [60VI]/1000S, Where H = Heat Input (kJ/mm), V = Arc Voltage (Volts), I = Current (Amps) and S = Welding speed (mm/min).

4.5). Record the Responses

Experimental results will be conducted as per the central composite design matrix at random to avoid any symmetric error creeping into the system. The weld bead profiles traced by using an optical microscope and the bead geometry dimensions like bead height, bead width and bead penetration to be measured.

4.6) Result and discussion

To meet the objective, experimental set up was 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, and rate of heat input etc. Following are the results obtained for the experiments carried out as per the Design of experiment mentioned above.

Table 2 Design of experiment table.

Sample no.	Voltage(v)	Current (I)	Welding speed(mm /min)	Gas flow rate (Lit/min)	Heat input (kJ/mm)
1	22.5	120	390	8	0.332
2	24	160	390	8	0.472
3	24	140	450	8	0.492
4	25	140	450	8.5	0.466
5	26	180	450	9	0.624
6	28	190	450	9	0.709
7	29	200	480	9	0.725
8	30	220	480	10	0.825
9	31	240	480	10	0.930
10	31.8	240	480	10	0.954

Table 3 Experimental results for samples

Sample no.	Bead width (mm)	Bead Height or reinforcement (mm)	Bead penetration(mm)
1	7.775	0.68	1.35
2	8.720	0.73	1.41
3	8.976	0.81	1.4
4	8.236	0.63	1.525
5	7.567	0.65	1.599
6	8.647	0.67	1.625
7	8.723	0.58	1.7

8	9.237	0.6	1.83
9	9.986	0.62	1.85
10	10.632	0.59	1.9

4.7) Effect of process parameters on weld bead geometry

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 deposited metal. 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. It increases with the increase in welding wire feed rate irrespective of the welding current. It is indirectly proportional to welding voltage, welding speed. 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 Aluminium. It can be seen that: 1) Bead height decreases with the increase in welding speed. 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. 4) Increase in heat input bead height is increases.

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. 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, arc travel speed. On bead penetration at different parameters like welding speed, current and gas flow rate and temperature in GTAW process of for welding of Aluminium. It can be seen that: 1) Bead penetration decreases with the increase in welding speed. 2) Bead penetration is increases with the increase in current. 3) There is a decrease in bead penetration with the increase in gas flow rate. 4) Increase in heat input the bead penetration increases.

Sample no.	Current (A)	Voltage (V)	Welding speed (mm/min)	Rate of heat input (KJ/mm)	Hardness in BHN
1	300	26	270	1.733	27.12
2	315	26	350	1.51	26.53
3	332	28	390	1.49	38
4	335	28	410	1.32	40

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. It can be seen: 1) Bead width decreases with the increase in welding speed. 2) Bead width decrease with the increase in current. 3) Bead width is almost constant with change in gas flow rate. 4) According to experiment higher heat input causes higher width of weld bead in line with this for high value of 0.725 KJ/mm of heat input, causes width of weld bead is found to be better.

Effect of process parameter on hardness of weld joint

It 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 plastic deformation. Hardness is the one of the most critical factor which indicates the quality of weld. The hardness tests are taken on the Brinell hardness testing machine"75 HB 10/500/30". As welding speed increases hence the rate of heat input decreases causes better hardness of weld joint. Low rate of heat input causes better hardness of weld joint. Table 3 Effect of process parameter on hardness of weld joint.

Optimization

The proposed methods could be effectively used in determining the weld bead geometric descriptors for GTAW process. Mathematical models for bead height, bead width and bead penetration can give direct values without going for long design process, thus study saves designer's time and efforts. Designer can easily predict dimensions bead geometry parameters. Increase temperature or heat input it is affected on welding joint strength and reduce the hardness of welding joint. Weld parameters of weld bead like weld bead width, reinforcement, and bead penetration are greatly affected by heat input within the range of welding experiments done. In all of the cases, weld bead geometry parameters have linear relationships with heat input. Heat input of 0.660 kJ/mm may be recommended for better welding, as this condition gives the maximum reinforcement and wide weld bead width. Higher value of 0.744KJ/mm heat input gives better bead penetration. 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.

Conclusion

In this study, we conclude that the weld quality depends mainly on input parameters, namely the welding speed, current, voltage and the temperature measured. These parameters, if not carefully controlled, might result the damage of welding area. Accordingly, the aim of this research is the effects of this parameter on weld bead and the resulted mathematical models will be then statistically analyzed to determine the significance of these input parameters individually in addition to their interactions with the output parameters. An optimization process for the input parameters will be then achieved for the input parameters and responses to obtain their optimum values for the weld geometry.

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