Effect of Tig Welding Process Parameters on The Quality of Joint

GURAVTAR SINGH MANN[1], SATNAM SINGH[2]
[1]School of Mechanical Engineering, Lovely Professional University, Phagwara, India
[2]School of Polytecnic, Lovely Professional University, Phagwara, India
*Corresponding author email:guravtar.14443@lpu.co.in

Abstract

Welding of parts, assemblies or complete machines is an important process throughout the construction organizations, industries and manufacturing units. Welding of inert tungsten gas (TIG) is among the most widely used and effective welding techniques used in welding process..Essentially, TIG weld performance is highly defined by weld pool geometry that has several value responds such as bead height (BH), bead width (BW), penetration or depth of penetration (DOP), heat-affected zone (HAZ), upper width (UW), upper height (UH), tensile load (TL) and much more.Because Weld pool geometry plays a major role in deciding the weld's mechanical properties, choosing the correct welding process specifications is very important in order to achieve optimum weld pool geometry.This study investigated, studied and examined the consequence of TIG welding process parameters (welding voltage, welding current, gas flow rate and electrode diameter) on the shape of the weld pool and the quality responses such as bead height bead width and penetration depth.

Keywords: Tungsten Inert Gas Welding (TIG), Weld Pool Geometry, Design of expert (DOE), Response Analysis of variance (ANNOVA)

1. Introduction

The process of mating or joining same or different materials is called welding. The primary requirement is heat for joining two or more pieces of metal. In some processes, pressure is also applied apart from heat[1]. Welding joins various metals and alloys by number of processes where in heat is provided electrically or by the means of torch containing gas. Items used in our everyday life such as automobiles, aircrafts, machinery, household appliances, electronic equipments and much more are the result of welding for their economical construction automobiles, building structures, and nuclear vessels etc. one of the welding process is the TIG welding is also recognized as Heliarc tungsten inert gas welding process as during the Second World War it was invented for joining magnesium and aluminium as a need of American aircraft industry. A non-consumable tungsten electrode is used in TIG welding shielded by an inert gas. Mainly the electrode is of pure tungsten or it is mixed with small amounts of oxides thorium or zirconium which upgrades the stability of the arc and makes it convenient to strike on work metal. The range of temperature is between 11700 ^{0}C and 14700 ^{0}C above the pool and 1427 ^{0}C to 2500 ^{0}C of the melted portion, depending upon the type of material being weld [2].Hot wire or Cold wire can be used in automatic TIG welding depending upon the thickness of the work piece and the type of joint needed to be welded. Cold wire or the cold rod is fed manually at theleading

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edge in the front of the melted pool[3].Hot wire as shown is fed from the back and develops a heated filler metal which increases the rate of deposition for the procedure.The wire is heated to the temperature of the fusion and provided at the trailing edge of the weldingbath[4].
Welding process variables have effects on the metallurgical changes of the weld metal and the adjoining base plate. Energy input from the welding arc, preheats and underpass temperatures, cooling rate, chemical properties and thermal compositions and properties of the plate and filler material, the mechanical, micro structural properties and pool geometry of the steels are influenced by the joint design for base metal[5]. The TIG welding process, which is the most flexible of all fusion welding processes, is limited by the characteristics of the particular metal and joint efficiency requirements. Three main parameters group are defined in TIG welding[6] .The basic variables that mostly influence the weld pool geometry and are controlled from the start to the finish with an automatic TIG process are Weld current,Weldingspeed,Weldvoltage,Gas flow rate,Arc Length,Polarity. optimization of pulsed gas tungsten arc welding process parameters were carried by them to achieve the optimal geometry of the weld pool for full penetration at 3mm thick stainless steel and designed the mathematical model for the process parameters as weld area, aspect ratio, bead width for correlating controllable process parameters of pulsed GTAW[7]. Robotic arc welding process with multi pass weld was employed for the optimization of bead width by them. They developed new algorithms for regression method and neural network to establish mathematical models for optimizing bead width. They concluded that the proposed model performed better then the empirical methods with reasonable accuracy[8]. Optimized and created the mathematical model for the prediction of the weld bead geometry and dimensions of stainless steel cladding by fluxed cored arc welding. Maximum reinforcement, minimum penetration, maximum dilution and maximum bead width was achieved using the excel solver for the optimization of process parameters[9].They experimentally showed the increase and decrease in the penetration on nickel based metal with increase in welding current and decrease in travel speed after optimizing the weld bead parameters by plasma transferred arc surfacing[10].

Research Methodology

Design of experiment (D.O.E).It is a technique that is used toexamine the process and product variables that influence the product quality, manufacturability, and reliability, quality and field performance in a systematic way. As the resources are limited, the appropriate and maximum information must be obtained from the experiment done. The effects that are considered to be of great value and importance are ensured by the designed experiment. If two variables have interaction between them then both variables must be considered and included. Interaction occurs when one input variable's effect the level of another input variable.The design of experiment is carried in four stages: planning, screening, optimization and verification. In general the goal of D.O.E is to exploit the effect of each input variables, to determine the effect of interactions and experimental error and gain as much information for given data.The welding was done manually on the mild steel plate of constant size of 200mm X 100 mm sheet of thickness 5 mm checked by the Vernier Calliper. In all 16 experiments were achieved and the responses were measured for each runs.A sample where in total of 16 mild steel plates were used during the overall research.which was obtained after conducting the test at the centre at Central Institute of hand tools where the major components like Carbon and silicon were obtained as they have more impact on the metallurgical and mechanical properties of the mild steel.In total of 16 Experiments were conducted using these parameters and there interaction and their effect were studied on the bead geometry consisting of Bead height Bead width and Depth of diffusion.

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2. Problem formulation

Investigation was done on the Mild steel plate having size 200mm X 100mm.The various variable Parameters of Tungsten inert gas welding were observed and analysed as Welding current, Welding voltage, Gas flow rate and Electrode diameter to obtain the responses and their effect on the geometrical parameters such as Bead height, bead width and the Depth of penetration or simply Dispersion. The interaction between the variables and the responses were analysed by using the Design of experiment and response surface methodology through which the feasibility and the significance of the model and the results were observed. It was seen previously that not much emphasis has been put on to the manual working condition during TIG Welding and also due to the vast scope for research onto this topic the 2 factor factorial design was not much considered. Keeping in view the limitations during manual working and the working conditions the research was done on limited factors and on 2^4 factorial design method and thus was the objective for the present research. In the current research work the effect of TIG welding has been studied on the Mild steel plate to obtain the results and values which were seen as the gaps in the previous studies.To analyse the effect and influence of Welding current on the geometry of the welded portion.Figure. 1 shows the equipment.

3.1 Experimental Setup

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Figure.1 Mega Master 600

As the welding current increases there is an increase in the heat input thus the increase of welding current from minimum to maximum increases the bead height. This is due to the corrosion effect from the electrode due to current. Also the increase in voltage increases the bead height as there is increase in the heat due to increase in resistance. As observed there is little decrease in the bead height when the gas flow rate is increased this is due to the fact that increase in gas flow rate results in the fast cooling of the molten pool compensating for the shrinkage of the molten metal pool which results in the decrease of bead width. Now, when the diameter of the electrode is increased the area of contact and the arc length increases which then increases the weld area. Thus, there is increase in the bead height due to more accumulation of molten pool.As the welding current increases there is an upsurge in the heat input thus the increase of welding current from minimum to maximum increases the bead height. This is due to the corrosion effect from the electrode due to current. Also the increase in voltage increases the bead height as there is increase in the heat due to increase in resistance. As detected there is little decrease in the bead height when the gas flow rate is improved this is due to the fact that increase in gas flow rate results in the fast cooling of the molten pool compensating for the shrinkage of the molten metal pool which results in the decrease of bead width.when the diameter of the electrode is increased the area of contact and the arc length increases which then increases the weld area. Thus, there is increase in the bead height due to more accumulation of molten pool.need to be kept in mind when handling the manual welding techniques. It has been concluded that for obtaining the feasible desirability of the weld the welding current and the voltage are to be kept as confined as possible so that minimum bead height and width can be achieved with maximum penetration as per the thickness of the material.Table 1 and Table 2 shows Mean and standard deviation for Responses.Figure 2 shows the microstructure after welding.

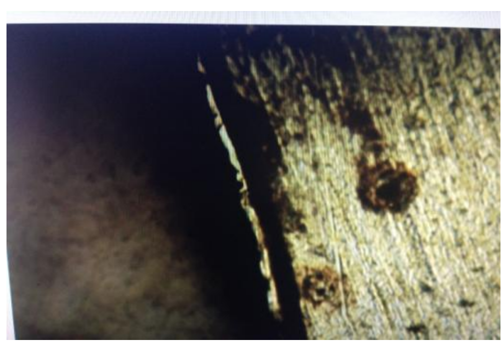

Figure2. Microstructure

3. Results and Observations

Table 1. Mean and standard deviation for Responses

Response	Name	Units	Obs	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Trans	Model
R1	Bead height	Mm	16	Factorial	0.35	0.78	0.51625	0.109962	2.22857	None	Mean

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R2	bead width	Mm	16	Factorial	3.85	4.52	4.07437	0.187473	1.17403	None	Mean
R3	Penetration	Mm	16	Factorial	1.95	2.5	2.12188	0.158165	1.28205	None	Mean

Table 2. Mean and standard deviation for factors

Factor	Name	Units	Type	Subtype	Minimum	Maximum	Coded	Values	Mean	Std. Dev.
A	current	Amp	Numeric	Continuous	80	120	-1.000=80	1.000=120	100	20.6559
B	voltage	V	Numeric	Continuous	10	20	-1.000=10	1.000=20	15	5.16398
C	gas flow rate	lt/min	Numeric	Continuous	12	15	-1.000=12	1.000=15	13.5	1.54919
D	electrode Dia	mm	Numeric	Continuous	6	8	-1.000=6	1.000=8	7	1.0328

4.1 Optimization of TIG Welding Process Parameters

The BH, BW and DOP were the objective functions chosen for optimization. As the number of constraints increases, the field in which the function solution lies decreases. The drawbacks with the upper limits will be less than or equal to the corresponding value of optimization.Additionally, it typically minimizes or maximizes the function as well as the constraint functions. It is always beneficial to have maximum penetrating depth with minimum bead height and bead width without compromising certain bead qualities in order to obtain a solid weld in any application.Thevalues obtained from runs as per their standard deviation and mean value for factors and responses are depicted in table1 and 2 indicating the nominal range or the value which is desirable to get the optimal results and solutions for the experiment conducted. Figure .3Effect of welding parameters on bead height

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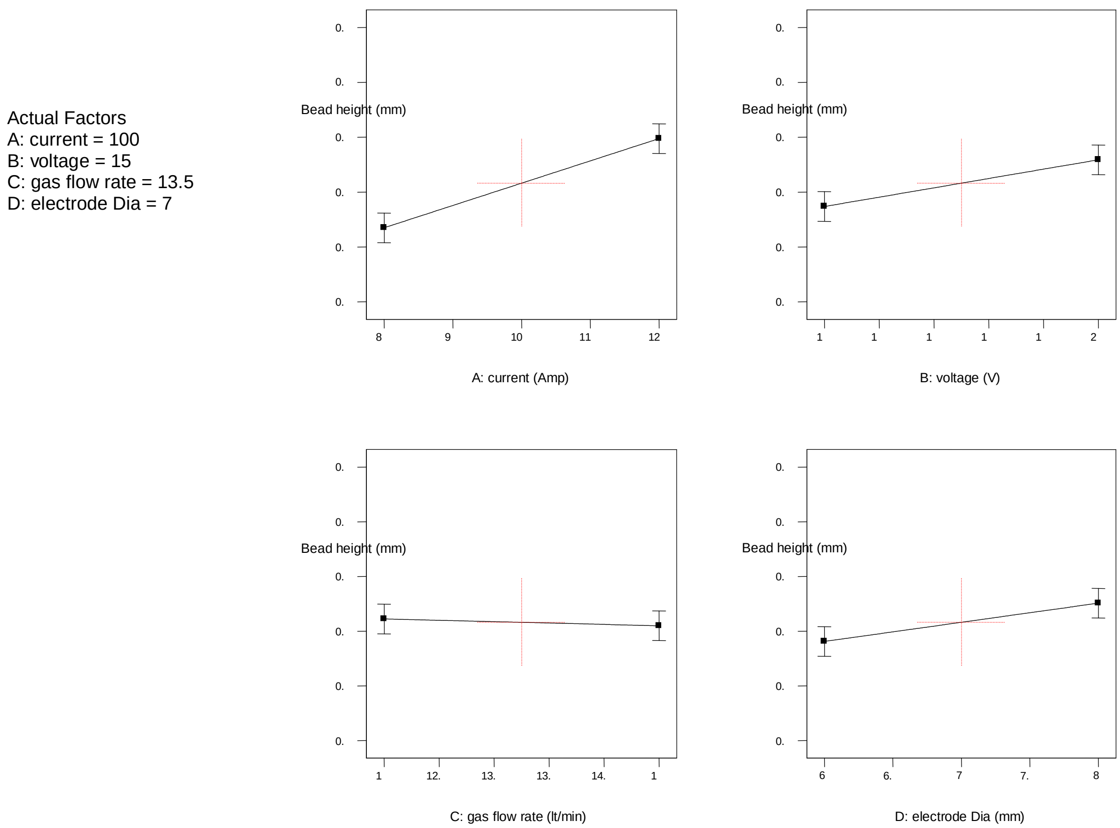

Figure .3 Effect of welding parameters on bead height

As the welding current increases there is ansurge in the heat input thus the increase of welding current from minimum to maximum increases the bead height. This is due to the corrosion effect from the electrode due to current. Also the increase in voltage increases the bead height as there is increase in the heat due to increase in resistance. As observed there is little decrease in the bead height when the gas flow rate is improved this is due to the fact that increase in gas flow rate results in the fast cooling of the molten pool compensating for the shrinkage of the molten metal pool which results in the decrease of bead width. Now, when the diameter of the electrode is increased the area of contact and the arc length increases which then increases the weld area. Thus, there is increase in the bead height due to more accumulation of molten pool. Table3.Shows analysis of bead height for variable parameters.

Table3.Analysis of bead height for variable parameters

Analysis of Variance for selected factorial model						
ANNOVA table [Partial sum of squares - Type III]						
	Sum of		**Mean**	**F**	**p-value**	

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Source	Squares	df	Square	Value	Prob> F	
Model	0.16	10	0.016	4.78	0.0491	Significant
A-current	*0.11*	*1*	*0.11*	*30.75*	*0.0026*	
B-voltage	*0.029*	*1*	*0.029*	*8.41*	*0.0338*	
C-gas flow rate	*6.250E-004*	*1*	*6.250E-004*	*0.18*	*0.6874*	
D-electrode Dia	*0.020*	*1*	*0.020*	*5.71*	*0.0625*	
AB	*1.000E-004*	*1*	*1.000E-004*	*0.029*	*0.8712*	
AC	*6.250E-004*	*1*	*6.250E-004*	*0.18*	*0.6874*	
AD	*2.500E-003*	*1*	*2.500E-003*	*0.73*	*0.4326*	
BC	*4.900E-003*	*1*	*4.900E-003*	*1.43*	*0.2859*	
BD	*1.225E-003*	*1*	*1.225E-003*	*0.36*	*0.5764*	
CD	*1.000E-004*	*1*	*1.000E-004*	*0.029*	*0.8712*	
Residual	0.017	5	3.435E-003			
Cor Total	0.18	15				

The value 4.78 for F model implies the model is major. F-value of 4.91% signifies that this can be due to noise. The model terms are significant as Values of "Prob> F" less than 0.0500. A, B are significant model terms in this case. Predictions are made about the response for the given levels of each factor by the equation in term of the actual factors. The levels must be the original units as specified for each factor.
The bead width has almost same results as that of bead height. As the current increases it increases the rate of heat and thus the area of heat affected zone increases which increase the bead width. The ANNOVA test conducted also suggested that the model is significant and has a feasible solution. The equation here obtained was for the major interactions required for the optimal results. The calculations are depicted in the form of tables and were confirmed on the matlab tool.

4.2 Analysis of bead width for variable parameters

The F model value of 26.31 means that the system is important. There is only a 0.11 percent chance that such a large F-value may occur because of noise. Model terms are less than 0.0500 as "Prob> F" values. A, B, C, D, AB, AC, BD are important terms of model here. A reasonable agreement exists between 0.8090 "Pred R-Squared" and 0.9441 "Adj R-Squared;"i.e. the difference is less than 0.2."Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. the ratio obtained is 18.359 representing an adequate signal. As can be seen from the graphs that welding current, welding voltage plays a significant role in the depth of penetration. More will be the heat input more will be the depth of penetration. Penetration directly related to the welding current and the amount of welding speed. The effect of gas flow rate is not much affect the penetration depth. Its effect can be seen by adding other inert gases and can be increased by changing the gas type. Changing the gas flow parameters from minimum to maximum does not really affect the penetration. The electrode diameter increases the depth of penetration but when combined with high input of voltage and current. The interaction among the variables in context to the responses clarifies the increase or decrease in the graphs and values.Table 4 showsanalysis of depth of penetration for variable parameters

Table 4. Analysis of depth of penetration for variable parameters

ANOVA for selected factorial model						
Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Model	0.32	8	0.040	4.83	0.0260	Significant
A-current	*0.15*	*1*	*0.15*	*18.25*	*0.0037*	
B-voltage	*0.074*	*1*	*0.074*	*9.03*	*0.0198*	
C-gas flow rate	*1.563E-004*	*1*	*1.563E-004*	*0.019*	*0.8943*	
D-electrode Dia	*0.022*	*1*	*0.022*	*2.64*	*0.1480*	
AB	*0.011*	*1*	*0.011*	*1.28*	*0.2957*	
AD	*6.006E-003*	*1*	*6.006E-003*	*0.73*	*0.4212*	
BC	*7.563E-004*	*1*	*7.563E-004*	*0.092*	*0.7706*	
BD	*0.054*	*1*	*0.054*	*6.57*	*0.0374*	
Residual	0.058	7	8.228E-003			
Cor Total	0.38	15				

F-value off 4.83 the model implies the model is significant. There exists only 2.60% chance that an F-value could be large due to noise. Model terms are substantial as Values of "Prob> F" less than 0.0500. In this case A, B and BD are the major model terms."Adeq Precision" measures the signal to noise ratio. Here ratio of 7.331 indicates an adequate signal. This model can be used to navigate the design space.Table 5.optimized responses and Table.6 Confirmation report for responses.

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4.3 Optimization of responses

Table 5.optimized responses

Welding Current	80.029	80.045	80
Welding voltage	10.571	10.514	10.496
Gas flow rate	15	15	14.838
Electrode Dia	6	6.032	6
Bead height	0.35	0.35	0.352
Bead width	3.959	3.96	3.951
Penetration	2.018	2.017	2.018
Desirability	**0.915**	**0.914**	**0.912**

Table.6 Confirmation report for responses

	Predicted	**Predicted**				**CI for**	**Mean**	**99% of**	**Population**
Response	**Mean**	**Median 1**	**Observed**	**StdDev**	**SE Mean**	**95% CI low**	**95% CI high**	**95% TI low**	**95% TI high**
Bead height	0.350001	0.350001	-	0.0586089	0.0466285	0.230138	0.469863	-0.0593658	0.759367
bead width	3.95949	3.95949	-	0.0443424	0.0352783	3.8688	4.05017	3.64977	4.26921
Penetration	2.01845	2.01845	-	0.0907066	0.0646597	1.86556	2.17135	1.47606	2.56085

Conclusion

It was thus concluded that out of the four variable factors welding current had the most noteworthy influence on the Bead height, Bead width and depth of penetration. Almost same influence was also observed by welding voltage. So it could be said that current and voltage were the most significant factors. Electrode diameter also had a certain amount of impact on the

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response variable but it was mostly with the interaction of diameter with current and voltage.Gas flow rate had the least significance on the responses with the fact that it reduced bead width a bit when supplied on the higher range and having low value of current for the same. As the (TIG) welding is a high speed process, all welding parameters should be controlled and used in a proper combination to obtain feasible weld pool geometry in the manufacturing stations, industries and other sites. To determine the mechanical properties of the welding, weld geometry is a very important consideration. There are so many limitations and constraints which need to be kept in mind when handling the manual welding techniques. It has been concluded that for obtaining the feasible desirability of the weld the welding current and the voltage are to be kept as confined as possible so that minimum bead height and width can be achieved with maximum penetration as per the thickness of the material.

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