Optimization of TIG Welding Parameters For Improvement of Strength and Hardness

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Abstract- The purpose of this study is to propose a method to decide optimal settings of the welding process parameters in TIG welding. The properties of the welded joints perform by a large number of welding parameters. Properties consist of Tensile strength, Impact force, Hardness etc. In an attempt to model the welding operation for predicting the parameters of welded joints, modeling and optimization of parameters in tungsten inert gas (TIG) welding process has been tried in the present work. TIG welding process considering the effects of main variables on weld strength. By using the experimental data, an attempt has been made to expect the strength. In this study which parameter is mostly effect the weld strength, Weld strength varies under a variety of conditions. By using Taguchi and ANNOVA technique an optimal solution is find out, which gives us an optimal results of the varying condition.

Keywords- SS 304, TIG welding, Tensile Strength, Hardness, Taguchi, ANOVA

I. INTRODUCTION

TIG welding is an electric arc welding process, in which the fusion energy is produced by an electric arc between the work piece and the tungsten electrode. During the welding process the electrode, the arc and the weld pool are protected against the damaging effects of the atmospheric air by an inert shielding gas. By means of a gas nozzle the shielding gas is lead to the welding zone where it replaces the atmospheric air. TIG welding differs from the other arc welding processes by the fact that the electrode is not consumed like the electrodes in other processes such as MIG/MAG and MMAW. Welding often requires sufficient heat to generate high temperature for melting and joining raw materials. With the development of technology, the demand for the welding of new raw materials and larger thickness has been increased This increment led to their placement of old gas flame welding by metal inert gas welding, tungsten inert gas welding, laser and electron beam welding. The equipment involves in TIG welding are a DCEN power source, tungsten electrode, welding torch, filler wire, shielding inert gas and personal safety equipment. SS 304 is the most common austenitic grade containing approximately 18.29% chromium and 8.09% nickel as the main component. The filler rod used was stainless steel of ER316 grade containing approximately 18.46% chromium and 11.39% nickel. SS304 finds its application in the field of food, dairy, chemical processing equipment, beverage industries, heat exchangers and milder chemicals. Austenitic steel has been chosen from the various classification of SS304 because of its easy availability and low cost. For the better quality of weld, there is a need to maintain the gap between electrode and work piece. The interaction of the process parameters on the weld bead geometry, mechanical and metallurgical properties of the weldments occur directly or indirectly. The quality of weld joint has an essential dependence on the input process parameters. We also know that the properties of the welded samples are affected by a greater number of welding parameter. Properties are Tensile strength, Hardness, Impact force, etc. Now, in order to overcome from this problem, there are various optimization methods are there to get desired output.

Nowadays application of evolutionary computational network algorithm and DOE are used to establish the relationship between input process parameters and output variables to obtained desired weld quality

II. LITERATURE REVIEW

TIG welding is widely used for different types of metal & alloy and still lots of research work is going for better performance by TIG welding process.

Krishnan et al. [5] done experiment to analyze the microstructure and oxidization resistance at completely different regions within the steel weld by TIG welding. during welding method, a sharp modification within the microstructure due to complex thermal cycle and rapid solidification was observed. This micro-structure modification also affects the mechanical properties and oxidation resistance of the steel weld. autogenous TIG welding was performed on 12-millimeter-thick mild steel with 200 A current, 19 V voltage and 100 mm/min welding speed. Finer grain size was obtained at weld metal and warmth affected zone.

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Raj and Varghese [10] predict the distortion developed throughout TIG attachment of low steel. In their study, have developed 3 dimensional finite element model like longitudinal, angular or cross distortion. Distortion in welding created because of non-uniform heating and cooling. To validate the model welding was performed with welding current 150 A, electrode gap three millimeter, gas rate of flow 25 l/min, electrode diameter 0.8 millimeter and atomic number 18 as shielding gas. They all over that, most distortion happens at surface opposite to the weld and on X direction of weld compare to alternative 2 directions.

Mishra et al. [7] have done comparison of mechanical properties between TIG and MIG welded dissimilar joints. steel and stainless-steel dissimilar material joints are quite common structural application. These dissimilar joints give good combination of mechanical properties like corrosive resistance and tensile strength with lower cost. welding parameters thought-about for MIG welding were welding current 80-400 A and Vage 26-56 volt. TIG welding was performed with 50 to 76 A current & 10 to 14-volt voltage. TIG welded dissimilar joint give better tensile strength because of less porousness. each dissimilar joint has best ductility & yield strength for TIG and MIG welding

Abhulimen and Achebe et al. [1] performed experiments to spot the economical welding parameters using Response surface methodology (RSM) throughout TIG welding of mild steel pipe. welding Parameters thought-about were gas rate of flow 25 to 30 l/min, welding current 130 to 180 A, arc voltage ten.5 to 13.5 V and noble gas as shielding gas. Results showed that, by using TIG welding of mild-steel maximum tensile strength and yield strength of 542 MPa and 547 MPa was achieved respectively.

Kuok et al. [6] investigate effect of oxide fluxes throughout TIG welding of 6 mm thick dissimilar joint between mild steel and stainless steel. The Cao, Fe2O3, Cr2O3 and SiO2 fluxes were utilized in powder kind. These powders were mixed with acetone to provide paint. Before welding a thin layer of flux was brushed onto the surface of the joint to be welded. TIG welding was performed with welding speed 150 mm/min, welding current 200 A and gas flow of 12 l/min. The result indicates that surface look of

Fuji et al. [3] developed an advanced activated TIG welding method for deep penetration of weld joint. Marangoni convection induced on the melted pool by surface tension gradient. so as to manage Marangoni convection bit of oxidizing gas was used. welding process done with welding current 160 A, attachment speed 0.75 mm/s, electrode gap of 1mm and Ar-O2 shielding gas. They determined that Marangoni convection changes from inward to outward and weld shape become wide and shallow.

TIG welds created with oxide flux fashioned residual slag. TIG welding with SiO2 flux powder can increase joint penetration and weld to depth quantitative relation.

Vices et al. [14] studied the effect of activated flux on TIG welding method. They centered on the result of penetration in steel by TIG welding method. Compare to alternative arc welding method it having small depth of penetration. an activating flux powder is used to avoid this problem. Taguchi optimization is used to optimize welding method parameters using activating TIG welding method on steel. They observe from experimental result that improves in depth of penetration at weld zone with increase weld current. Depth of penetration is inversely proportional to the travel speed.

Pal and Kumar et al. [9] studied the effect of activated TIG welding on wear properties and dilution proportion in medium steel welds of 12 mm thick plate. TiO2 and Cr2O3 fluxes were utilized in powder form. Flux powder was uniformly mixed with acetone and brushed onto the surface of joint to be welded. DC current & straight polarity was used with constant welding speed. a single pass TIG welding was performed with 180A welding current. The result indicated that TiO2 flux coated weld increased the dilution on base metal as compare to Cr2O3 flux coated weld.

Nay et al. [8] studied the effect of oxide primarily based fluxes on metallurgical and mechanical properties of weld joint. tungsten inert gas welding process is used to provide welds between 6mm thick mild steel and stainless-steel plate with activating flux. during this investigation No, TiO2 and MnO2 powder were used. welding process performed with welding current 200 A, arc voltage 12.5 V and welding speed of 5 mm/min. Highest width to depth ratio get under TiO2and No fluxes compare to conventional TIG welding method. Among all three fluxes TiO2 shows lowest angular deformation.

Rucker et al. [11] show that in TIG welding method application of activated fluxes improve weld penetration and process competitiveness. They summaries the investigations on TIG welding of plain carbon steel, stainless steel, aluminum and titanium using activating flux. welding method performed with 150 A current and 15 cm/min welding speed. it was revealed that fluxes based on fluorides contribute to increased weld penetrations of titanium and SiO2 flux for stainless-steel, plain carbon steel and aluminum. The importance of flux composition, flux homogeneity and profile are shown to be primordial in determining width to depth ratio of weld.

Dhandha et al. [3] done experiment to point out the effect of activated fluxes on mild steel welds. maximum 2 to 3-millimeter-thick plates of stainless-steel and carbon steel may be weld with TIG welding under autogenous mode.

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The activating flux welding method is considered as feasible alternative to increase process productivity. Grade 91 steel is used as a piece material. A TIG welding was applied on P91 steel during which oxide powders Cano, No, Fe2O3, TiO2, MnO2 & CrO3 were used as flux material to provide a bead on plate weld. This methodology is responsible for increase in depth of penetration and additionally reduction in weld width. Heat input was increased with use of activated fluxes.

III. EXPERIMENTAL PROCEDURE

SS304 plates of dimension 130 mm length 60mm width, and 3mm thickness was butt welded by using TIG machine with polarity Direct Current Electrode Negative [DCEN]. The chemical composition of the base material and filler rod is given in table 1 and table 2 respectively. The input process parameters used for welding were welding current[A], voltage[V], and flow rate of gas[L/min]. Taguchi method was used to generate Taguchi Design to set up a Taguchi orthogonal array design in the worksheet. Each row of the design specifies a combination of factor, levels to be used for a run of the experiment.

Some more parameters:

Pressure used	0.15 MPa or 22 psi
Welding speed	12 inches/min
Filler metal diameter	1.5 mm
Electrode diameter	1.5 mm
Gap between plates	1.5 mm

Work material and filler rod

The work material selected was austenitic stainless steel 304 with dimension 130 mm length,60 mm width and 3 mm thick in which argon at 0.15 MPa was used as shielding gas. The filler rod used was stainless steel ER316 grade. The specimen was welded by TIG as per the standard of ASTM240.

Table 1: Composition of base metal SS304

%	C %	Si %	MN %	P %	S %	Cr %	Ni %
COMP	0.0570	0.4300	1.2800	0.0370	0.0120	18.2900	8.09
REQD	- 0.0800	- 1.0000	- 2.0000	- 0.0450	- 0.0300	18.0000 20.000	8.00 11.00

Table 2: Composition of filler rod

%	C %	Si %	MN %	P %	Cr %	Mo %	Ni %	S %	Cu %
COMP	0.047	0.39	1.12	0.028	18.46	2.12	11.39	0.01	0.28
REQD	- 0.08	0.30.65	1.00 2.50	- 0.03	18.00 20.00	2.0 3.00	11.00 14.00	- 0.03	- 0.75

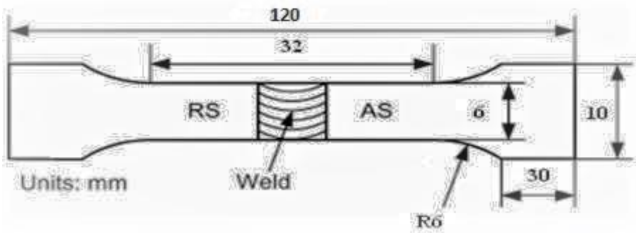

Fig.1: Test specimen size prepared according to ASTM-E8 [courtesy: reference 15]

Fig: 2 Welded plates

Fig.3: Specimen for tensile test

TIG welding equipment

Fig.4: TIG welding setup

IV. TESTING MACHINE

In this experimental work, tests such as Ultimate tensile strength and Hardness has been carried out on the following machine by varying various process parameters like current voltage and flow rate of the gas. The tensile test is crucial in evaluating the behaviour of engineering materials as well as in assessing the amount of material for use in design. Tensile test measures the YS, which is the stress at which welded specimen begins to deform plastically and cannot return to its original position. The tensile testing specimen

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was prepared transverse to the weld bead having three tensile testing specimens in one weld run. Hardness is generally defined as resistance to permanent indentation. In this experiment, hardness testing machine is shown in Fig. 3

$$BHN = \frac{2P}{\pi D\left[D-\sqrt{DD^2-d^2}\right]}$$

Where,
P= load kg
D= diameter of steel ball
D= diameter of indentation
BHN= Brinell hardness number

Fig 5: Hardness Testing Machine

Fig. 6: Universal Testing Machine

Table 3: Control factors and levels:

	unit	Level 1	Level 2	Level 3
Current	A	95	120	140
Voltage	V	12	14	16
Gas flow rate	L/min	15	20	25

Table 4: Experimental layout using L9 orthogonal array and performance results

Exp. No.	Welding current (A)	Voltage (V)	Flow rate of gas (L/min)	Hardness(BHN)	UTS (mpa)
1	95	12	15	190	675
2	95	14	20	193	679
3	95	16	25	195	700
4	120	12	20	199	529
5	120	14	25	186	705
6	120	16	15	202	708
7	140	12	25	200	695
8	140	14	15	201	701
9	140	16	20	203	685

V. EXPERIMENTAL ANALYSIS

Analysis of variance

Analysis of variance (ANOVA) is a method of calculation that significantly evaluates the contribution of each parameter variation made by overall response variation. It is used to determine the significance of input parameters. The statistical software Minitab 18.0 is employed to examine the implication of welding parameters namely welding current, voltage and flow rate of the gas.

A.1 Analysis of Variance for tensile strength:

Table: 5(A) ANOVA for tensile strength

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
current	2	450.1	5.84%	450.1	225.1	1.34	0.427
Voltage	2	2884.4	37.43%	2884.4	1442.2	8.59	0.104
Gas flow rate	2	4035.9	52.37%	4035.9	2018.0	12.02	0.077
Error	2	335.7	4.36%	335.7	167.8		
Total	8	7706.1	100.00%				

From the above table, it is clear that percentage contribution of welding current is 5.84%, voltage 37.43% and gas flow rate 52.37%. It can be observed that gas flow rate is the most significant factor.

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A.2 Analysis of variance for Hardness

Table: 5(B) ANOVA for Hardness

Source	DF	Esq. SS	Contribution	Ad SS	Adj MS	F-Value	P-Value
current	2	256.970	54.69%	256.970	128.485	44.75	0.022
voltage	2	137.062	29.17%	137.062	68.531	23.87	0.040
flow rate of gas	2	70.063	14.91%	70.063	35.031	12.20	0.076
Error	2	5.742	1.22%	5.742	2.871		
Total	8	469.838	100.00%				

From above table, it is clear that percentage contribution of welding current is 54.69%, voltage 29.17% and flow rate of gas 14.91%. It can be found that current is the most significant factor.

ANALYSIS OF SIGNAL-TO-NOISE RATIO

Main Effects plots for S/N ratios for larger is the better was analyzed for each response variable. The S/N Ratios is termed as signal to noise ratios. The change in the quality characteristics of the product under investigation in response to a factor introduced in the experimental design is the 'signal' of the desired effect. However, when an experiment is conducted, there are numerous external factors not designed into the experiment but influence the outcome, these external factors are called noise factors and them on the outcome of quality characteristics is known as 'the noise.'

The signal to noise ratios measures the sensitivity of the quality characteristics under control to those noise factors not under control.

B.1 Analysis of S/N Ratio for hardness

Table: 6 Response Table for Signal to Noise Ratios for Hardness versus current, voltage and gas flow rate; Larger is better

Level	current	voltage	flow rate of gas
1	45.70	45.86	45.92
2	45.82	45.72	45.95
3	46.08	46.02	45.74
Delta	0.38	0.30	0.21
Rank	1	2	3

From the above table, it is clear that current has the greatest effects on signal to noise ratios when the graph is plotted for hardness versus current, voltage, and gas flow rate. From the figure 7 it is clear that current at 95 A has low s/n ratios and current at 140 A has more s/n ratios. Main effects plot for hardness from which it was observed that optimum parameter setting for hardness is obtained at a current of 140 A, voltage of 16 V and gas flow rate of 20 L/min.

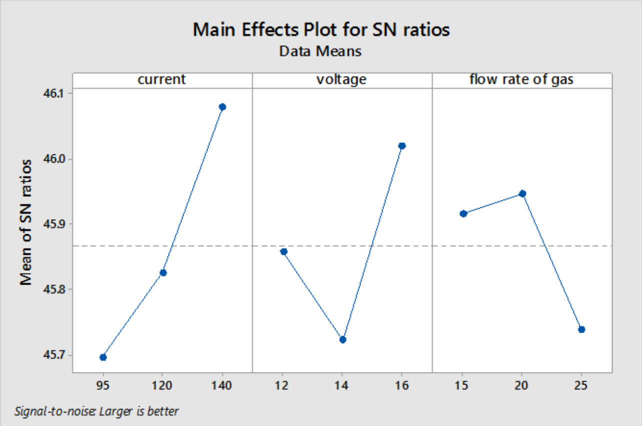

Fig.7: Main effects plot for S/N ratio (a) hardness vs current, (b) hardness vs voltage and (c) hardness vs gas flow rate

B.2 Analysis of S/N Ratio for Ultimate Tensile Strength

Table: 7 Response Table for Signal to Noise Ratios for UTS versus current, voltage and gas flow rate: *Larger is better*

Level	Welding current (A)	Voltage (V)	Flow rate of gas (L/min)
1	56.71	55.96	56.83
2	56.14	56.84	55.94
3	56.82	56.87	56.90
Delta	0.68	0.91	0.96
Rank	3	2	1

From the above table, it is clear that gas flow rate has the greatest effects on S/N to noise ratios when the graph is plotted for UTS versus current, voltage and gas flow rate. From Fig.8 it is clear that gas flow rate at 20 L/min has low S/N ratios and at 25 L/min has more S/N ratios.

Main effects plot for tensile strength from which it was observed that optimum parameter setting for hardness is obtained at a current of 140 A, voltage of 16 V and gas flow rate of 25L/min.

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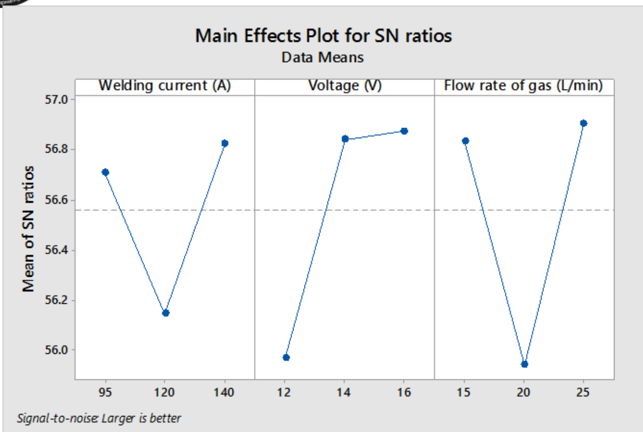

Fig. 8: Main effects plot for S/N ratio (a) UTS vs current, (b) UTS vs voltage and (c) UTS vs gas flow rate Conformation test

Confirmatory test was conducted at optimum combination of process parameters to check the

Validity of optimal parameters of welding. The conformation experiment done to validates the Initial experiment results obtained and the conclusion of experiment. In this case the

Improvement of the performance characteristics of the welding process parameter are

Predicted and verified. The predicted S/N ratio using the optimal levels of the welding

C.1 Conformation test for Hardness

For parameter optimization following formula based upon Taguchi design has been used for hardness:

Ƞopt = m+ (mA1–m) + (mB2–m) + (mC3–m)

Where "m" is the overall mean of S/N data,

mA3 is the mean of S/N data for welding current at level 2

mB3 is the mean of S/N data for welding voltage at level 2 and

mC3 is the mean of S/N data for electrode flow rate of gas at level 3.

Calculation, overall mean of SN ratio (m) was taken from Minitab software.

m= 45.8677

Therefore,

ηopt = 45.86+(46.08-45.86) +(46.02-45.86) +(45.95-45.86) =46.31

Yopt) ^2= (10) ^ (ηopt / 10) for properties, higher is better

(Yopt)^2= (10) ^ (46.31/10) = 42756.28862

Yopt= 206.77

Table 8: Confirmation Experimental Test Results for Hardness

Responses	Optimal process parameters		Improvement in S/N ratio	%Error
	Prediction value	Experiment Value		
LEVEL	A3B3C2	A3B3C2		
Hardness(BHN)	206.77	203		
S/N(db)	46.31	46.19	0.12	0.259

C.2 Conformation test for Tensile strength

For parameter optimization following formula based upon Taguchi design has been used for Tensile strength:

Ƞopt = m+ (mA1–m) + (mB2–m) + (mC3–m)

Where "m" is the overall mean of S/N data,

mA3 is the mean of S/N data for welding current at level 3

mB3 is the mean of S/N data for welding voltage at level 3 and

mC3 is the mean of S/N data for electrode flow rate of gas at level 3.

Calculation, overall mean of SN ratio (m) was taken from Minitab software. m= 56.55

Therefore,

ηopt = 56.55+(56.82-56.55) +(56.87-56.55) +(56.90-56.55) =57.48

Yopt) ^2= (10) ^ (ηopt / 10) for properties, higher is better

(Yopt)^2= (10) ^ (57.48/10) = 55975.6015

Yopt= 748.16

Table 9: Confirmation Experimental Test Results for Tensile strength

Responses	Optimal process parameters		Improvement in S/N ratio	%Error
	Prediction value	Experiment Value		
LEVEL	A3B3C3	A3B3C3		
Hardness(BHN)	748.16	745		
S/N(db)	57.48	56.90	0.58	1.0193

VI. CONCLUSION

In this project a Taguchi orthogonal (L_9) array, the signal to noise (S/N) ratio and analysis of variance (ANOVA) were used to optimize the TIG Welding process parameters of joints of stainless-steel plates.

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The following conclusion can be drawn based on the experimental results of this project work.

1. Optimum parameter setting for tensile strength was obtain data current of 140 amps, 16 volts, and 25-litre/min gas flow rate. It was clear that percentage contribution of welding current is 5.84%, voltage 37.43% and flow rate of gas 52.37%, so flow rate of gas is the most significant factor.
2. Optimum parameter setting for hardness is obtained at a current of 140amps, 16volts, and 20-litre/min gas flow. It was clear that percentage contribution of welding current is 54.69%, voltage 37.43% and gas flow rate 52.37%, so current is the most significant factor.
3. The experiment design by Taguchi method full fills the desire objective. ANOVA has been used to find contribution of process parameters on welded joint.

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