Process Parameter Optimization for Tensile Strength for Plasma Arc Welding of SS304

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***Abstract*— The Joining of the Austenitic Stainless Steels is often used in the pressure vessels, chemicals and processing industries. The mechanical properties at the weld bead should also fulfill requirement of applicable code. Several process parameters interact in the complex manner resulting in direct or indirect influence on the mechanical properties. It is necessary to find out the optimum process conditions which are capable of producing desired weld quality. Therefore to achieve the typical tensile strength in Plasma Arc Welding (PAW) is the primary objective of this study. The parameters Current (I), Voltage (V), Wire feed (W_f) were optimized using Taguchi Orthogonal Array and Analysis of Variance (ANOVA) is used for the analysis. The optimum parameters observed are Current: 230A; Voltage: 28V; Wire feed: 740mm/min resulting UTS of 687.35 MPa for SS304 of 6mm thickness**

Keywords*— *Taguchi, ANOVA, PAW

I. INTRODUCTION

An arc welding process employing a constricted arc between a non-consumable electrode and the work piece (transferred arc) or between the electrode and the constricting nozzle (non-transferred arc).

Plasma arc welding (PAW) is an arc welding process similar to gas tungsten arc welding. The electric arc is formed between an electrode (which is usually but not always made of sintered tungsten) and the work piece. The key difference from GTAW is that in PAW, by positioning the electrode within the body of the torch, the plasma arc can be separated from the shielding gas envelope. The plasma is then forced through a fine-bore copper nozzle which constricts the arc and the plasma exits the orifice at high velocities (approaching the speed of sound) and a temperature approaching 28,000 °C (50,000 °F) or higher.

II. LITERATURE SURVEY

The Optimization of process parameters in ATIG welding for aspect ratio of UNS S32205 duplex stainless steel welds was studied by G. MAGUDEESWARAN et al. The optimum welding parameters are found to be electrode gap of 1mm, travel speed of 130mm/min, current 140A and voltage 12V. The optimization techniques used were Taguchi, ANOVA, pulled ANOVA. [1]

Studied Optimization of 316 Stainless Steel Weld Joint Characteristics using Taguchi Technique was studied by P Bharat et al. He studied parameters as welding speed (50-65-80), current(60-80-100), electrode(316-309L-347), root gap(1-1.5-2.0), operator(1,2,3). In the same work optimization of tensile strength and bending strength was performed. The result shows that current is most influencing factor to have highest bend strength and Speed that is to be used while welding is the most influencing factor to get higher tensile strength. [2]

The effects of shielding gas compositions on arc plasma and metal transfer in gas metal arc welding was studied by Z.H.Rao and concluded that it is easier for Ar to establish a plasma arc due to lower ionization potential as compared to helium. The addition of helium produces a larger hot arc core because of higher thermal conductivity but the further increase in helium may decrease the degree of ionization. [3]

Ugur Esme had worked on Optimization of weld bead geometry in TIG welding process using grey relation analysis and taguchi method. The following weld parameters were taken welding speed (1.06-1.99-2.31-3.55), Current (40-55-70-85), Gas flow rate (8-10-12-14 lit/min), Gap distance (1.5-2-2.5-3). It was also mentioned that TIG welding is a multi input and multi response process. He performed the optimization on bead width, bead height, Penetration, area of penetration as well as width of heat affected zone and tensile load and found that welding speed (52.41 % contribution) is the most effective parameter on the responses under the multi criteria optimization. The percent contributions of other parameters are gap distance (20.12 %), current (15.40 %) and shielding gas flow rate (9.09 %). He also identified that the Taguchi based grey relational analysis can be used for optimization of the TIG welding bead geometry parameters successfully. [4]

S.M.Ahir et. al. observed Experimental Investigation of welding distortion of Austenitic Stainless Steel 316 in TIG Welding. The process parameters were as follows Current (125- 150,-175) , Speed (60-70-80), Grove angle (60- 70- 80). Distortion was observed. Angle has major effect of weld distortion followed by current. [5]

Vedprakash Singh et. al. In Experimental investigation of GTAW Process for austenitic stainless steel using DOE Studied with the process parameters as Current (150-175-200), grove angle (45-60-75), speed (2-2.5-3). Distortion was observed and found that Current has maximum effect on distortion followed by welding speed, grove angle. [6]

Vijay Gohel et.al. in Optimization of process parameter for tensile strength and hardness of S.S 304 by TIG welding observed that welding current is most significant parameter for Tensile strength which contributes 58.49% and Gas flow rate is most significant parameter for Hardness which contributes 73.92%.[7]

Prashant S Lugade in Optimization of Process Parameters of Activated Tungsten Inert Gas (A-TIG) Welding for Stainless Steel 304L using Taguchi Method studied the Tensile Strength

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of SS 304 150×50×6 mm using Electrode gap (1-2-3), Speed(100-150-200) , Current(140-170-200) , Gas flow rate(7-10-13) as the process parameters and found that travel speed has maximum effect followed by current, electrode gap, gas flow rate. 8]

J. Pasupathy et al. 8] performed experimentation for Parametric optimization of TIG welding using taguchi method for dissimilar joint of low carbon steel with AA1050 having 1 mm & 2 mm thickness respectively. He observed that, The Welding speed has maximam effect on tensile strength followed by welding current.

A. Sivasankaran et al. studied Taguchi optimization of TIG Welding for Maximizing Weld Strength of Aluminum 8011 plate of thickness 6 mm. The experimental value of ultimate tensile strength that is observed from optimal level of welding parameters is 155.682 N/mm^2 .Pulse current has maximum effect on tensile strength followed by base current. 9]

Mallikarjun Kallimatha et.al observed TIG Welding Al6061 using Taguchi and Regression analysis methods. He studied using the parameters as current(50-60) ,Voltage (80-100) ,Gas flow rate (8,10). Tensile strength, bead width ,bead height. were the mechanical properties observed. The following conclusions were drawn - The Gas flow rate is found to be a major contributing factor. The interactions of current and gas flow rate are the most influencing factor with respect to bead length. The interactions of voltage and gas flow rate and the gas flow rate alone influence the bead width. 10]

J. Pasupathy et al. studied, The parametric optimization of TIG welding of galvanized Steel with AA1050 of 2 mm thickness using Taguchi Method. The parameter selected were as Current (78-80-82), Speed(2.5-3-3.5), Frequency(4-6-8). The experiment value that he observed from optimal welding parameters, the strength is 99.01MPa. The parameter most contributed for optimum strength was frequency followed by welding speed. 11]

Nirmalendhu Choudhury et al. Studied Design optimization of Process Parameters for TIG Welding based on Taguchi Method where parameters selected were current (90-100-110-120), gas flow rate(12-14-16-18), filler rod diameter (1.6-2-2.5-3) & improved the ultimate tensile strength by optimizing the parameter. 12]

Arun Kumar et al. had done the performance analysis in Multi-response optimization of process parameters for TIG welding of Incoloy 800HT by Taguchi grey relational analysis & optimize ultimate tensile strength, yield strength (at room temperature and 750^0C),impact toughness. The parameters Current (90-110-130), voltage (10-12-14), Speed (1.2-1.5-1.8) was chosen. He observed that, The welding current (58%) exerted a significant influence on multiple responses followed by welding speed (30%) and voltage (12%). 13]

Plasma Arc welding is commonly used to weld nonferrous materials, such as titanium and it's alloys, repairing of tools and dies, tube mill welding. It is widely used in Stainless steel applications manufacturing industry. However the key hole effect can be problematic for some of the applications.

Plasma Arc Welding (PAW) Welding of SS 304 is used to weld the Pressure Vessels. Parametric Optimization Could be successfully be used in order to optimize the weld Characteristics as seen from the literature.

In the literature survey it was found that the optimization is done with 3 parameters mainly Current, Voltage, Gas flow rate. In case of long seam welding is to be done for manufacturing of boilers or shells it is difficult to maintain the desired Gas flow by manually setting parameters at once. However the Effect of wore feed for welding without edge preparation is not found.

Hence it is decided to determine the optimum levels for parameters Current, Voltage and Wire feed for welding 6mm SS304 material for Ultimate Tensile strength.

III. MATERIAL

Flat plates of SS 304 with dimension 300x150x6 mm are taken. The chemical composition is verified with the Material Test Certificate received with the material. Additionally PMI testing is done.

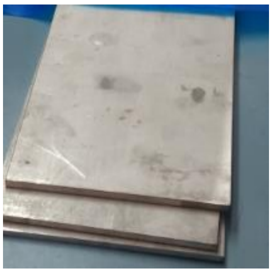

Figure 1: Raw material

BASE METAL	Chemical Composition								
	%C	%Mn	%Cr	%Ni	%Mo	%S	%P	%Si	%Fe
	0.061	0.83	18.14	8.02	-	0.002	0.041	0.43	Remaining

Table 1: Chemical composition of SS 304

IV. EXPERIMENTAL DESIGN

In order to optimize the tensile strength levels of parameter Current, Voltage and Gas flow are decided after pre experimentation done for various levels of these process parameters.

Parameter	Level 1	Level 2	Level 3
Current (A)	210	220	230
Voltage (V)	24	26	28
Wire feed (mm/min)	700	740	780

Table 2: Level of Process parameters

The experimentation was conducted for L_9 orthogonal array. The plates were tacked first and then the sample number identification was done by itching sample number on the plate. The process parameters were written on the plate by means a permanent marker.

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Sr. No.	Current (A)	Voltage (V)	Wire feed rate (mm/min)
1	210	24	700
2	210	26	740
3	210	28	780
4	220	24	740
5	220	26	780
6	220	28	740
7	230	24	780
8	230	26	700
9	230	28	740

Table 3: Layout of L9 array

The experimentation was done referring above Taguchi Design L_9 array.
The experimentation set up was as follows

Table 4: Experimental Set up

V. TESTING AND ANALYSIS OF RESULTS

The samples were tested for non-destructive testing such as Visual Inspection, Dye Penetration Testing and Radiographic Testing> The reports are examined certified Level-II inspector and all the results are found satisfactory.
The tensile test was conducted with reference to standard ASTM A370-2017. Following are the obtained results.

Sample no	Ultimate Tensile Strength in MPa
1	650.14
2	616.16
3	684.09
4	645.11
5	653.08
6	642.19
7	654.44
8	640.35
9	667.53

Table 5: Results of Tensile Test

A. Analysis of Results

Taguchi method uses a statistical measure of performance, called as signal-to-noise (S/N) ratio. The S/N ratio is a logarithmic function of desired output serves as objective functions for optimization. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). This ratio is a measure of robustness used to identify control factors that reduce variability in a product or process by minimizing the effects of uncontrollable factors. The standard S/N ratios generally used are categorized as Nominal the best (NB), Lower the better (LB) and Higher the better (HB). The S/N ratio for each quality characteristic can be computed independently and regardless of the category of the performance characteristics, a larger S/N ratio corresponds to better quality characteristics.

The analysis of the result was done by using Minitab17 software.

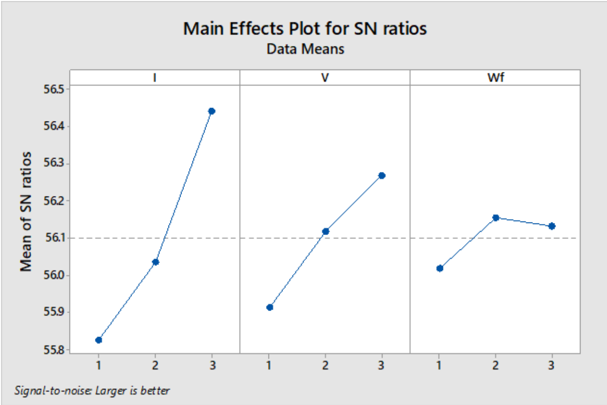

Figure 2: Means Plot for Tensile Test from MINITAB 17

Shows the variation of a particular factor away from the mean value. The more the deviation the greater is the effect of the factor on the response. Here current at level 3,Voltage at level 3,wire feed at level 2 observed to be most effective with the response Ultimate Tensile Strength.

B. ANOVA Calculation for Ultimate Tensile Strength

The analysis of variants was done using Minitab 17 software. Following results are obtained.

Source	DF	SS	Mean of Squares	F	% Contribution
Current	2	3247.4	1623.72	10.35	67.825
Voltage	2	1049.7	524.83	3.35	21.92
Wire feed	2	177	88.49	0.56	3.69
Error	2	313.8	156.89		
Total	8	4787.9			

Table 6: ANOVA results

From the above results It can be seen that the Current being most dominant factor with percentage contribution of 67.825%, followed by Voltage with 21.92% and Wire feed with 3.69% contribution on ultimate tensile strength.

C. Regression Analysis

The regression model for the tensile strength is calculated from software MINITAB 17.
$UTS = -109 + 2.282\ I + 6.59\ V + 0.100\ W_f$
The calculations are done for Predicted values of Ultimate Tensile stress are done and observed against the actual values of UTS. We could get following graphical relation

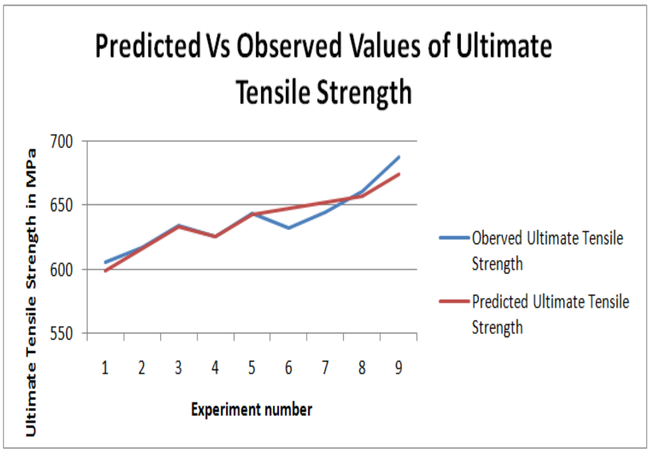

Figure 3: Predicted Vs Observed values of UTS

D. CONFIRMATION TEST

The confirmation of experiment is done with the process parameters Current: 230A, Voltage 28V and wire feed 740 mm/min.

Three samples were welded on the same parameter setting and the samples were tested.

The testing results were as follows.

	Sample 1	Sample 2	Sample 3
Observed Value of UTS(MPa)	686.14	680.33	682.68
Predicted Value UTS(MPa)		674.38	

Table 7: Confirmation Test Results

VI. CONCLUSION

The present work is concerned determining the optimum parameters for tensile strength for Plasma Arc Welding.

After the experimentation it was observed that the maximum tensile strength is achieved 687.53 MPa for the current as 230A, voltage as 28V and wire feed as 740 mm/min.

These results are confirmed by confirmation test taken on three samples for which tensile strength was found to be 686.14, 680.33, 682.68 MPa.

The ANOVA analysis gives result that the current is the most dominant factor for tensile strength with 67.825% contribution followed by voltage with 21.92% contribution.

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