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Process Parameters Optimization of TIG Welded Joints of SS 304 using Taguchi's Experimental Design Method

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ABSTRACT

Tungsten inert gas (TIG) welding is a fusion welding process having side range of applications in current industry. The TIG welding process parameters plays a very significant role in estimating the quality of a welded joint. So appropriate selection of welding process parameters is very much necessary to attain weld joint with increased tensile strength value. In the work, experiments were carried out on Austenitic Stainless Steel (AISI 304L) using Tungsten inert gas (TIG) welding process. In this study Butt welded joints have been made by using three levels of current, gas flow rate and nozzle to work piece distance. The quality of the weld has been estimated in terms of ultimate tensile strength of the welded specimens L9 orthogonal array of Taguchi`s experimental design method was utilized for optimization of welding current, gas flow rate and nozzle to work piece distance on welded joints.

Keywords : AISI 304L Austenitic Stainless Steel, Tungsten Inert Gas (TIG) Welding , Taguchi`S Experimental Design Method , ANOVA.

I. INTRODUCTION

1.1. AISI 304L Austenitic stainless steel

Austenitic stainless steels have been invented in the beginning of the 20th century. They were been developed in Germany, who now characterize more than 3/4 of the total production of Stainless Steel in world. These austenitic stainless steels are widely used in almost all types of important in industries. Stainless Steel are used in typical areas such as piping systems, heat exchangers, tanks and process/Pressure vessels for the food, chemical, pharmaceutical, pulp and paper and other process industries [1,2] . The most important characteristics of AISI 304L corrosion resistance, good weldability, formability, toughness, ductility and strength, which is an austenitic Chromium-Nickel stainless steel. The process of TIG welding (also called the gas tungsten arc welding (GTAW)) being used in austenitic stainless steel is one of the most important area where an extensive number of researches have been carried out, in order to control the process of welding in a precise manner to improve the acceptance and quality of weld in an efficient way.

1.2. TIG welding of AISI 304L Austenitic stainless steel

The mechanical properties have found to be increased in Stainless Steel by using Tungsten Inert Gas (TIG) welding process[3]. TIG welding process can be widely used in any industry for joining either similar or dissimilar metals comparatively providing better quality, accurate weld, low heat affected zone, absence of slag, less defects than that of Submerged Metal Arc Welding (SMAW) as well as Metal Inert Gas (MIG) weld process in wide range of alloys. And hence, the process of TIG welding is mostly used to join stainless steel and other type of metals. Gas tungsten arc welding uses a non- consumable tungsten electrode to create the weld and the weld zone is protected by an inert gas to prevent from atmospheric effects [5].

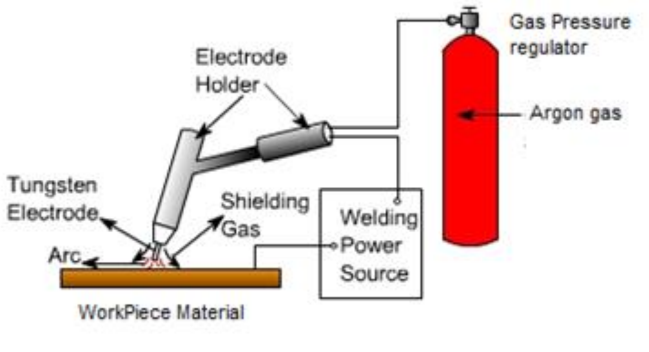

Fig.1. Principle components of TIG welding process

The preparation of a satisfactory quality weld is supposed to be a difficult job. There are several reasons which mainly depend upon the input parameters such as voltage, current, pressure level, electrode flow, speed of weld, work piece preparation. Moreover it is the process parameters which determine the strength of the weld. The researches were always been in search for the better quality of weld. Therefore, the process of TIG welding being utilised in austenitic stainless steel is to be considered as one of the areas where more extensive research may contribute, in a significant way, to the precise control of welding procedure for better and acceptable quality of weld. The Fig.1. Shows the principle components of TIG welding process.

1.3. Experimental motivation

Researchers had done investigations on joining the 304L austenitic stainless steel materials with use of TIG welding technique, those are discussed below

Harkare M. G. [7] has done an experiment by joining two pieces of AISI 304 Stainless Steel using the process of TIG welding, in which he has found that the process parameters plays an important role. The process parameters that has been considered were weld current, gas flow and work piece thickness of the welded joint. It is found that there was an increase in Heat input when the welding current was increased, which is utilised to melt the base metal. In case of increase in the thickness of work piece material, the rate of gas flow has to be increased so that the heat is diffused at a proper rate to the base metal. The increase of gas flow avoids the vaporisation of molten metal and also increases the penetration. The increase in gas flow along with the weld current which improves the weld characteristics by changing the Bead geometry. G. Magudeeswaran [8] has concentrated only on the depth of penetration of the weld and reduction in the width of the weld has not been paid much attention.The term aspect ratio is thye width-to-depth ratio of a weld, which has a marked influence on its solidification cracking tendency.

The major influencing TIG welding parameters, that controls the aspect ratio of DSS joints, must be optimized to obtain desirable aspect ratio for DSS joints. Thus The Taguchi method along with Analysis Of Variance (ANOVA) and Pooled ANOVA techniques has been used, which has lead to the results. The optimum process parameters are found to be 1 mm electrode gap, 130 mm/min travel speed, 140 A current and 12 V voltage. The aspect ratio for the DSS joints fabricated using the optimized ATIG parameters are found to be well within the acceptable range. Ugur Esme[9] utilized the process of TIG welding in AISI 304L stainless steel plates of two different thickness. They are of 8mm and 10mm being widely used in the fabrication of pressure vessels. During welding of these plates, the method of multipass has to be done in order to get a proper weld. The result of temperature distribution at the time of multipass which affects the material microstructure, hardness, mechanical properties, and the residual stresses that will be present in the welded material. From these plots, the maximum temperature rise expected in the base plate region during any pass of welding operation can be estimated. Juang, S.C.
[11] has investigated the selection of process parameters for obtaining optimal weld pool geometry in the process of welding of stainless steel using TIG process. The Taguchi method had been employed to analyze the effect of each process parameter on the weld pool geometry, in order to determine which process parameter has the optimal weld pool geometry. Experimental results are provided to illustrate in their approach.

N. Ghosh [6] utilised the Taguchi method to establish the optimal set of control parameters for the welding. The preparation of a satisfactory quality weld is supposed to be a difficult job. There are several reasons which mainly depends upon the input parameters such as voltage, current, pressure level, electrode flow, speed of weld, work piece preparation. Moreover it is the process parameter which determines the strength of the weld. The researches were always been in search for the better quality of weld.

Saurav Datta [12] has experimentally investigated a multi-response optimization problem has been developed in search of an optimal parametric combination to yield favourable bead geometry of submerged arc bead- on-plate weldment. Taguchi's optimization method using L25 orthogonal array (OA) design concept of signal-to- noise ratio (S/N ratio) have been used to derive objective functions to be optimized within experimental domain. The objective functions have been selected in relation to parameters of bead geometry viz. bead width, bead reinforcement, depth of penetration and depth of HAZ. The Taguchi approach followed by Grey relational analysis has been applied to solve this multi-response optimization problem. The significance of the factors on overall output feature of the weldment has also been evaluated quantitatively by analysis of variance method (ANOVA). Optimal result has been verified through additional experiment. This indicates application feasibility of the Grey-based Taguchi technique for continuous improvement in product quality in manufacturing industry.

In the present work, stainless steel of grade 304 was welded by Tungsten Inert Gas (TIG) welding processes and the process parameters were investigated by Taguchi`s experimental design method. The interaction effects of these input parameters have not been considered in this present work.

2. Experimental Plan, Set Up and Procedure

In this study the base material is AISI 304L Austenitic stainless steel is to be considered. Butt welding of AISI 304L austenitic stainless steel: 70mm x 140mm x 3mm thick, have been done using the TIG welding machine make: TOSHON TIG/ARC 250S (Current range: 10-200 A ,Frequency 50/60 Hz, Input power 6 KV, input voltage Ac 230 V 15% power factor 0.73 and the shielding gas Argon) . Taguchi optimisation design has been implemented in order to identify optimal process parameter combination for preferred quality of TIG weld. Total of 9 butt welded specimens have been utilised using 3 levels of current , 3 levels of gas pressure and 3 level of nozzle to plate distance based on L9 Taguchi's Orthogonal Array in Design of experiment method .The interaction effects of these input parameters have not been considered in this present work. The Fig.2. shows the welded specimen of AISI 304L with specified input parameters.

Fig. 2. TIG welded AISI 304L Specimen (Input parameters: C= 110 Amps, GF= 12, D= 15 mm)

The filler rod used has been 308L Grade Stainless Steel 1.6mm TIG rods. Chemical Composition of Base Plate material and Filler metal is shown in Table 1. Welding process parameters and their levels, and Taguchi design matrix and experimental input and output parameters are shown in Table 2 and Table 3 respectively.

Table 1. The chemical Composition of AISI 304L Austenitic stainless steel.

	Base plate material: AISI 304L Austenitic stainless steel (SAE no. 30304)								
	C	Mn	Si	P	Cr	Ni	Mo	Cu	Al
304 L	0.07	0.87	0.58	0.035	18.33	7.83	0.3	0.23	0.02
Filler Metal 316L	0.04	1.78	0.68	0.012	18.45	9.24	0.016	0.072	0.02

Table 2. Working range of process parameters

Factor	**Process Parameter**	**Unit**	**Symbol**	**Level**		
				1	**2**	**3**
A	Welding current	(Amps)	(C)	100	115	120
B	Gas flow Rate	(*l* /min)	(GF)	10	12	15
C	Nozzle to plate Distance	(mm)	(D)	8	10	15

After Butt welded joints being done using TIG welding method under three levels of three different input parameters, tensile test specimens have been prepared from the TIG welded joints, by wire cut EDM process. The tensile test specimens have been tested on universal tensile testing machine as per the ASTM standard. Tensile Test specimen diagram is shown in Fig.3.a and Fig.3.b.

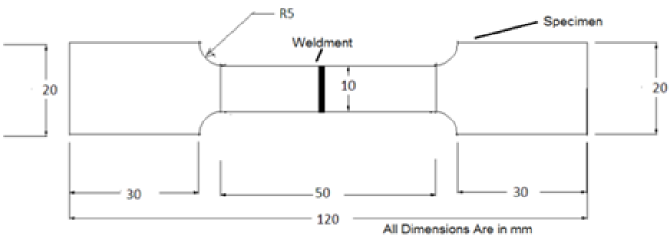

Fig.3. (a). Dimensions of Tensile Test Specimen

Fig.3. (b). Sample Tensile Test Specimen (Input parameters: C= 110 Amps, GF= 12, D= 15 mm)

Table 3. Experimental design matrix and results

Exp. No	Inputs Parameters			Output Parameter
	C (Amps)	GF (l/min)	D (mm)	Ultimate Tensile strength (Mpa)
1	110	10	8	425.14
2	110	12	10	385.23
3	110	15	15	375.21
4	115	10	15	454.23
5	115	12	8	289.25
6	115	15	10	295.23
7	120	10	10	324.25
8	120	12	15	415.23
9	120	15	8	435.78

II. Results and Discussions from tensile test of TIG welded specimens

The tensile test specimens as per ASTM standard were prepared corresponding to L9 Taguchi Orthogonal Array experiments, have been conducted and the specimens were tested for tensile strengths and the results were obtained are given in Table 3. From the Table 3 concluded that for many of the TIG welded of AISI 304 L samples test results are good and satisfactory. The best result was obtained for the experimental no.4 (current 110 A, Gas flow rate 10 l/min and nozzle to plate distance 15 mm). For this test sample the results were obtained as the values of ultimate tensile strength = 454.23 MPa .The lowest value of output parameter from the tensile testing has been obtained for the sample no. 5 (current 115 A, gas flow rate 12 l/min and nozzle to plate distance 08mm). For this test sample the results were obtained as the value of ultimate tensile strength = 454.23 MPa.

III. Optimization of Ultimate Tensile Strength (UTS) by Taguchi method

Genchi Taguchi, a Japanese scientist developed a technique based on the orthogonal array. This technique is used to improve the quality of manufacturing goods. This method is widely used for the Optimization of the process parameters in design in order to reduce the cost for the process of manufacturing of goods and to improve its quality in a schematic and a valuable way, employing the DOE (Design Of Experiment) in order to reduce the variability and to provide a robust design for the process performance for production. The process of analyses of the process parameter is a difficult process as well as time consuming, since the number of experiments to be carried out increases with the number of process parameters. In order to solve this problem, Taguchi method can be used as it implies an orthogonal array way to analyse any number of process parameter with comparatively less number of experiments. Thus, this method reduces the effort to be put by the designer in the process of studying the effects of multiple factors. The main advantages of Taguchi method is that it gives important to the mean performance characteristics value which close to the target value rather than a value within certain limits.

Taguchi method of optimization of process parameter uses a statistical measure of performance called signal to noise (S/N) ratio of corresponding values of ultimate tensile strength. The S/N ratio is defined as the ratio of the mean (Signal) to the standard deviation (Noise). It depends on the quality of the product or process. The three types of the standard S/N ratio used is i. Nominal the better (NB) ,ii. Larger the better (LB) and iii. Lower the better (LB). Maximization of the ultimate tensile strength (output response) is the requirement in this present work so larger the better (equ.1.) has been used.

$$S/N \text{ ratio} = -10 * \log10 [(1/n) * S(1/y_i^2)]$$

S/N ratios have been determined by using the eq.1. Larger S/N ratio indicates that better signal is obtained and lesser noise is occurred. For each factorial experimental run, corresponding S/N ratio is determined and listed in Table 4. Table 5 shows the corresponding values of mean response for ultimate tensile strength. Fig. 4. Shows the main effect plot of ultimate tensile strength.

Table 4. S/N ratio of Ultimate tensile strength

Exp. No	Inputs Parameters			Output Parameter	
	C (Amps)	GF (l/min)	D (mm)	Ultimate Tensile strength (Mpa)	S/N Ratio
1	110	10	8	425.14	52.5706
2	110	12	10	385.23	51.7144
3	110	15	15	375.21	51.4855
4	115	10	15	454.23	53.1455
5	115	12	8	289.25	49.2255
6	115	15	10	295.23	49.4032
7	120	10	10	324.25	50.2176
8	120	12	15	415.23	51.3534
9	120	15	8	435.78	52.7853

Table 5. Mean response table for ultimate tensile strength

Level	Current (Amps)	Gas Flow rate (l/ min)	Nozzle to plate distance(mm)
1	395.2	**401.2**	383.4
2	346.2	379.9	334.9
3	**408.3**	368.7	**431.6**
Delta	62.2	32.5	96.7
Rank	2	3	1

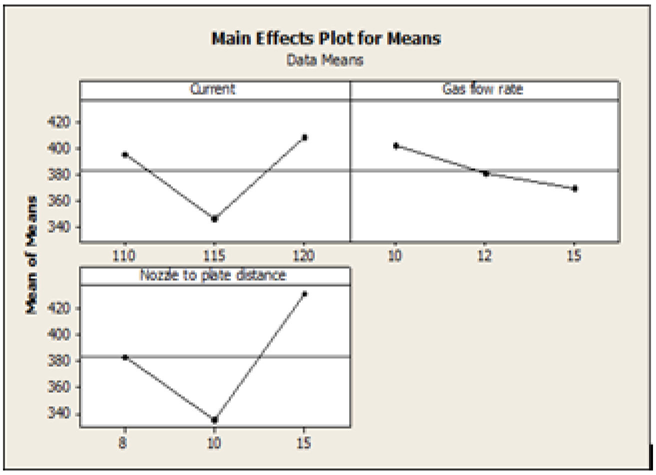

Fig. 4. Main effect plot of ultimate tensile strength

From the Table 5 the following results were obtained,

- Level 3 (120 Amps) for current resulting 408.3 MPa is shown as the optimum condition in terms of ultimate tensile strength while variation of current is only considered; • Level 1(10l/min), for gas flow rate resulting 401.2 MPa is shown as the optimum condition in terms of ultimate tensile strength while varying gas flow rate only;
- Level 3(15 mm) for nozzle to plate distance resulting in 431.6 MPa is shown as the optimum condition in terms of ultimate tensile strength while varying nozzle to plate distance only. Above observations can also be verified through S/N ratio plots where maximum S/N ratio is desired. Table 6 shows the mean S/N ratio of UTS. The Main effect plots for S/N ratio of ultimate tensile strength are given in Fig.4.

Table 6. The mean S/N ratio of Ultimate tensile strength

Level	Current (Amps)	Gas Flow rate (l/ min)	Nozzle to plate distance(mm)
1	51.92	**51.98**	51.53
2	50.59	51.43	50.45
3	**52.12**	51.22	**52.66**
Delta	1.53	0.75	2.22
Rank	2	3	1

Higher the S/N ratio, smaller is the variance of the UTS towards the desired target it is simply referred by higher is the better. From Fig.5, it is found that current at level 3, gas flow rate at level 1 and nozzle to plate distance at level 3 [C3GF1S3] (i.e. current 120 A, gas flow rate 10 l/min and nozzle to plate distance 15 mm) is the optimal process parametric condition which gave the higher values of ultimate tensile strength (UTS) of welded specimen. Analysis of variance (ANOVA) using MINITAB 17 software has been achieved to determine the contribution of input process parameters of TIG welding on ultimate tensile strength for Taguchi design optimization method. From the Table 7 it is found that nozzle to plate distance is the most significant factor followed by current. Gas flow rate is not a very significant input process parameter which influences the output UTS.

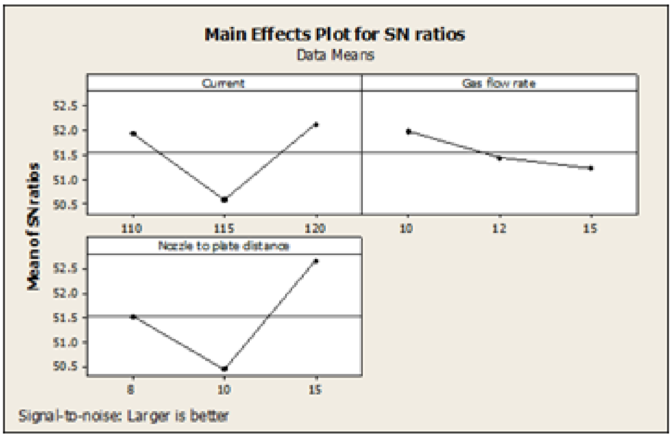

Fig.5. Main effect plot of S/N ration ultimate tensile strength

Table 7. The ANOVA for Ultimate tensile strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Current	2	18338	18338	9169	5.41	0.156
Gas flow Rate	2	664	664	332	0.20	0.436
NozzleDistance	2	14013	14013	7006	8.13	0.195
Error	2	3391	391	1695		
Total	8	36406				

S = 41.1743 R-Sq = 90.69% R-Sq(adj) = 92.75%

Confirmation Test

The Confirmatory tests have been carried out to validate the above discussed optimized condition. That is level 3 (120 Amps) for current, level 1(10l/min), for gas flow rate, and level 3(15 mm) for nozzle to plate distance then the corresponding result were obtained are: UTS at optimized condition = 466.35 MPa. From the results of confirmatory test, it is found that optimum parameters of welding parametric condition produced maximum UTS, this value shows the validation of the proposed Taguchi method of optimization.

IV.CONCLUSION

Following conclusions are drawn in respect of TIG welding of AISI 304L austenitic stainless steel

- The best result was obtained for the experiment no.4 (current 110 A, Gas flow rate 10 l/min and nozzle to plate distance 15 mm). For this test sample the results were obtained as the values of ultimate tensile strength = 454.23 MPa .The lowest value of output parameter from the tensile testing has been obtained for the sample no. 5 (current 115 A, gas flow rate 12 l/min and nozzle to plate distance 08mm). For this test sample the results were obtained as the value of ultimate tensile strength = 454.23 MPa .
- In a optimization by Taguchi, the objective is to maximize i) ultimate tensile strength (UTS) .Taguchi's S/N ratio concept is utilized and it is found that current at level 3, gas flow rate at

level 1 and nozzle to plate distance at level 3 [C3GF1S3] (i.e. current 120 A, gas flow rate 10 l/min and nozzle to plate distance 15 mm) is the optimal process parametric condition which gave the higher values of ultimate tensile strength (UTS) of welded specimen.

- The optimum conditions determined by single-objective optimization techniques (Taguchi) have been validated through attained optimal process parameters in confirmatory tests.

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