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Parametric Optimization of TIG Welding on Stainless Steel (202) & Mild Steel by using Taguchi Method

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Abstract: The main objective of industries reveal with manufacturing better quality product at low cost and increase productivity. TIG welding is most vital and common operation use for joining of two similar or dissimilar parts with heating the material or applying the pressure by using the filler material for increasing productivity with less time and cost constrain. The TIG welding parameters are the most important factors affecting the quality, productivity and cost of welding. The purpose of this study is to propose a method to decide near optimal settings of the welding process parameters in TIG welding. The paper presents the influence of welding current, arc voltage, and gas flow rate on strength of SS-202 and mild steel material during welding. A Taguchi Orthogonal array, signal to noise (S/N) ratio and analysis of variance (ANOVA) are employed to investigate the welding characteristics of dissimilar joint and optimize the welding parameters.

Keywords: TIG welding, Taguchi's Technique, S/N Ratio, ANOVA

1. Introduction

Welding is a process in which we join two similar or dissimilar metals or non metals by applying pressure or non pressure. Gas tungsten arc welding, GTAW, also known as tungsten inert gas welding, is an arc welding process that uses a non-consumable tungsten electrode for establishing an electric arc. Weld area is protected by shielding gases like argon or helium. It is generally used for welding hard-to-weld metals such as Stainless Steels, Magnesium, Aluminium, and Titanium. TIG welding is most commonly used to weld thin sections. For welding stainless steel we use direct current with negative electrode. Direct current with positive electrode is very less common and used rarely.

Prashant Kumar Singh et al [1].This paper gives us a review on TIG welding for optimizing process parameters on dissimilar metals. Tungsten Inert Gas Welding of dissimilar material such as stainless steel and mild steel has the potential to hold good mechanical and metallurgical properties. I. U. Abhulimen et al. [2]. This paper gives a prediction on weld quality using TIG welding. The technique we used here is Response Surface Methodology. Response surface methodology, based on the central composite face centered design was generated for the purpose of optimization of the weld quality. K. M. Eazhil et at. [3]. In this paper, the Taguchi method is used for the Optimization of Tungsten Inert Gas Welding on 6063 Aluminum Alloy. The Taguchi method L27 is used to optimize the pulsed TIG welding process parameters of 6063 aluminum alloy weld ments for maximizing the mechanical properties. D. Devakumar et al. [4]. An attempt is made to review and unite the important research works done on TIG welding of stainless steel in past years, by various researchers.

It has been discovered, that most of the works done, is on austenite steel, which is the most widely used type of stainless steel in the world. Main aim of this paper is to give a brief idea about the research works done in the past, on TIG welding of stainless steel by various researchers. M. Zuber et al. [5]. Purpose of present work is to investigate the effect of oxide flux on welding of austenitic stainless steel 304L plates having thickness 8 mm its effect on welding distortion, ferrite number, hardness value and depth of penetration. SiO2 is used as a flux in the form of powder mixed with the acetone and applied on bead plate without making a joint preparation and without addition of filler wire. The result showed that this technique can increase depth of penetration and weld aspect ratio resulting in lower angular distortion. R. D. Kumar et al.

[6]. In this paper, an attempt is made to reduce the effect of heat affected zone on strength by using Pulsed TIG welding process. This paper describes the optimization of process parameters like current, voltage, stand-off distance, pulse on time and off time & gas flow to improve weld quality. In this work Taguchi method is used to get the optimal parameters.

2. SELECTION OF MATERIAL

Stainless Steel

Most stainless steels are considered to have good weld ability and may be welded by several welding processes including the arc welding processes, resistance welding, electron and laser beam welding, friction welding and brazing. For any of these processes, joint surfaces and any filler metal must be clean. The coefficient of thermal expansion for the austenitic types is 50% greater than that of carbon steel and this must be considered to minimize distortion. The low thermal and electrical conductivity of austenitic stainless steel is generally helpful in welding. Stainless steels are defined as iron base alloys which contains chromium not less than 10.5%. The thin layer of chromium oxide film which forms on the surface of a stainless steel provides corrosion resistance & prevents further oxidation. Most stainless steels are considered to have good weldability and may be welded by several welding processes including the arc welding processes, resistance welding, electron and laser beam welding, friction welding and brazing. For any of these processes, joint surfaces and any filler metal must be clean.

Elements	C	Mn	Si	Cr	Ni	P	S	N
% wt	0.15	7.5-10	1	16-18	4-6	0.06	0.03	0.25

Mild steel

Elements	C	Mn	Si	Ni	P	S
%wt	0.16	0.7-0.9	0.4	0.0	0.044	0.04

3. METHODOLOGY

- Selection of base metals.
- Selection of process parameters.
- Preparation of samples for welding.
- Welding of samples.
- Specimen for tensile test & hardness test.
- Analyzing the result.

Base Metals
Stainless Steel
Mild Steel

Process Parameters
The selection of parameters of interest was base on study some research papers and experiment preliminary. The identified process parameters are given below:

1. Welding Current
2. Arc Voltage
3. Gas Flow Rate

4. Arc Travel Speed
5. Electrode Size
6. Electrode Extension
7. Electrode Position
8. Welding Position

The following process parameters are selected for the present work:

a) Welding Current (amp)
b) Arc Voltage (volt)
c) Gas Flow Rate (lt/min)

4. TAGUCHI'S EXPERIMENTAL DESIGN METHOD

The main motive behind Taguchi method is to reduce variation in a process through robust design of experiment. The overall motive of the method is to give high quality product at low cost to the manufacturer. The experimental design given by Taguchi involves implying orthogonal arrays to organize the parameters affecting the process and the levels at which they give different values. In the place of having to test all possible combinations like the factorial design, the Taguchi technique tests pairs of combinations. This allows for the collection of the important data to find out which factors most affect product quality with a less amount of experimentation, thus saving time and resources. Study of ANOVA table for a given analysis helps to determine which of the parameters need control.

Signal To Noise (S/N) Ratio
Taguchi method stresses the necessity of studying the response variation using the signal-to-noise ratio, resulting to decrease the effect of quality characteristic variation due to uncontrollable parameter. The S/N ratio can be used in three types:

1. Larger the better:

$$SN_L = -10\log\left[\frac{1}{n}\sum_{i=0}^{n} {}^{1}/_{yi}\,2\right]$$

2. Smaller the better:

$$SN_L = -10\log\left[\frac{1}{n}\sum_{i=0}^{n} y_i\,2\right]$$

3. Nominal the best:

$$SN_N = 10\log\left[\frac{\overline{\overline{Y^2}}}{S^2}\right]$$

Where,
n = Number of trials or measurement
y_i = measured value
ȳ = mean of measured value
s = standard deviation

ANOVA (Analysis Of Variance)
The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This is accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error. First, the total sum of squared deviations SST from the total mean S/N ratio nm can be calculated as,

$$SST = \Sigma\,(n_i - n_m)\,2$$

Where,
n_i = S/N ratio of ith run or experiment.
n_m = total mean of S/N ratio

Selection of Orthogonal Array

In this research work, we have taken three parameters and three levels of each parameter. So, L9 orthogonal array has been selected. The array shown below:

NO. of RUNS	CONTROL FACTORS		
	A	B	C
1	L1	L1	L1
2	L1	L2	L2
3	L1	L3	L3
4	L2	L1	L2
5	L2	L2	L3
6	L2	L3	L1
7	L3	L1	L3
8	L3	L2	L1
9	L3	L3	L2

Where A, B, C are process parameters & L1, L2, L3 are levels of each parameter.

5. EXPERIMENTAL WORK

Prepare of welding specimen

To prepare the specimen of SS-202 & MS with dimension 100×50×2 mm were used. Experiments were designed by the Taguchi method using an L9 orthogonal array that was composed of three columns and 3 rows. This design was selected based on three welding parameters with three levels each. The selected welding parameters for this study were: Current, Wire feed rate and Gas flow rate. The S/N ratio for each level of process parameters is computed based on the S/N analysis. There are three categories of quality characteristic in the analysis of the signal-to-noise (S/N) ratio, i.e. the smaller-the-better, the bigger-the-better and the nominal-the-better. In this experiment maximizing the tensile strength so Therefore, the optimal level of the process parameters is the level with the highest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) was also performed to indicate which process parameters are significant; the optimal combination of the process parameters can be predicted.

Parameters	Code	Level 1	Level 2	Level 3
Current(amp)	A	70	80	90
Voltage (volt)	B	20	30	40
GFR (lt/min)	C	6	8	10

TESTING OF WELDED SPECIMEN

Tensile Test

The tensile test was done on UTM 400KN. A tensile test is also known as tension test & it is probably the most common type of mechanical test you can perform on material. Tensile tests are simple, less expensive, and fully standardized. By pulling on something, you will very quickly determine how the material will react to forces being applied in tension. By pulling material, you will find its strength along with how much it will elongate. One of the properties you can determine about a material is its ultimate tensile strength. This is the maximum load the specimen sustains during the test. The ultimate tensile strength may or may not equate to the strength at break. This all depends on what type of material you are testing brittle, ductile or a substance that even carries both properties. The test process involves placing the test specimen in the machine and applying tension to it until it fractures. During the application of tension, the elongation of the gauge section is recorded against the applied force.

Hardness Test

This term may also refer to stiffness or temper or to resistance to scratch, abrasion, or cutting. 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.

Vickers Hardness Test

Vickers hardness is a measure of the hardness of a material, calculated from the size of an impression generates under load by a pyramid shaped diamond indenter. The diamond is pressed on the surface of material at loads ranging up to approximately 120 kilogram force and the size of the impression (not greater than 0.5 mm) is measured with the help of a calibrated microscope. The Vickers hardness number (HV) is calculated using the following formula:

$$HV = 1.854(F/D^2)$$

With F being the applied load (measured in kilogram force) and D^2 the area of the indentation (measured in square millimeters).
The Vickers hardness should be reported like 800 HV/10, which means a Vickers hardness of 800, was obtained using a 10kgf force. Extremely accurate readings can be observed in this test, which is one of the major advantage of the Vickers hardness test and just single type of indenter is used for each and every type of metals or surface treatments.

6. RESULT & DISCUSSION

Tensile testing has been done on the welded specimens. It was done on Universal Testing Machine (UTM). The value of tensile strength has been observed and then S/N ratio has been calculated manually as well as using software called MINITAB. The effect of each parameter on welding has been calculated and with the help of ANOVA, their percentage contribution is also evaluated. A figure shows the specimen of tensile test.

Tensile test specimens before testing

Tensile test specimens after testing

Calculation for S/N Ratio:
We know S/N Ratio for larger is better is:

$$SN_L = -10 \log \left[\frac{1}{n} \sum_{i=0}^{n} {}^{1}/_{yi}\, 2 \right]$$

For 1st run:
n = 1 because we get the result in single trial
y = 266.507 (observed value)
So, S/N = -10 log (1/ 266.507^2) = 48.5142
Similarly we calculate S/N Ratio for every run.

Reading of Tensile Strength & S/N Ratio:

Run	**Arc current (amp)**	**Arc voltage (volt)**	**GFR (lt/min)**	**Tensile strength (mpa)**	**S/n ratio**
1	70	20	6	266.507	48.51
2	70	30	8	296.519	49.44
3	70	40	10	244.898	47.78
4	80	20	8	262.905	48.39
5	80	30	10	315.726	49.99
6	80	40	6	301.321	49.58
7	90	20	10	247.299	47.86
8	90	30	6	277.311	48.86
9	90	40	8	238.896	47.56

Response Table for S/N Ratio

Level	Arc Current	Arc Voltage	Gas Flow Rate
1	48.5782	48.26	**48.98**
2	**49.32**	**49.43**	48.47
3	48.10	48.31	48.54
Delta	1.22	1.17	.52
Rank	1	2	3

Result Discussion of tensile Strength

The response tables show the average of each response characteristic (S/N rations, means) for each level of each factor. The tables include ranks based on Delta statistics, which compare the relative magnitude of effects. The Delta statistic is the highest minus the lowest average for each factor. Minitab assigns ranks based on Delta values: rank 1 to the highest Delta value, rank 2 to the second highest, and so on. Use the levels averages in the response tables to determine which level of each factor provides the best result. In our experimental analysis, the ranks indicate that current has the greatest influence on both the S/N ratio. The arc voltage has the next greatest influence, followed by gas flow rate. Hence, because our goal is to increase the tensile strength, we want factor levels that produce the highest mean. In Taguchi experiments, we always want to Maximize the S/N ratios and the means were maximized when the Current was 80, the Gas Flow Rate was 6 and the arc voltage was 30. Based on these results, we should set the factor at the calculated value.

Response Table for Means:

Welding Current	Level 2	80
Arc Voltage	Level 2	30
Gas Flow Rate	Level 1	6

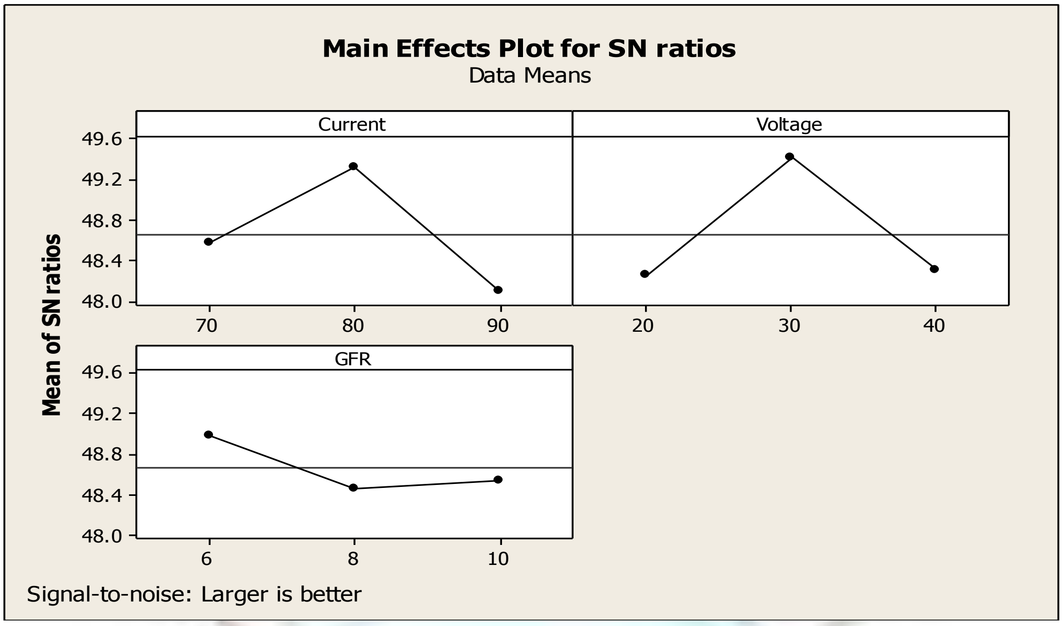
So, on the basis of these results we can say that Tensile Strength of stainless steel and mild steel will be higher when we will use Current at 80 A, Gas Flow Rate of 6 lt/min and Arc Voltage at 30 volt. So these are optimum welding parameters on which we can attain the higher tensile strength of Stainless Steel 202 & Mild Steel welds.

Analysis of Variance for S/N Ratio Tensile Strength

ANOVA is a statistically based, objective decision-making tool for detecting any differences in the average performance of groups of items tested. ANOVA helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors at specific confidence levels.

Source	DOF	Seq. SS	Adj. MS	F	P	%
Current	2	0.04265	0.03622	4.02	0.199	22.46 %
Voltage	2	0.08344	0.04172	4.63	0.178	44.11 %
GFR	2	0.01524	0.00763	0.85	0.542	8.05 %
Residual Error	2	0.01801	0.00902			
Total	8	0.18914				

It can be observed from the table that no parameter is significant for tensile strength up to 95% confidence level and welding current affect the tensile strength maximum 44.11% followed by arc voltage 22.46%. Gas Flow Rate has minimum affect only 8.05% and graph is shown below:



Hardness Test

This test has been done on the samples of welding prepared by TIG welding. Hardness of WZ (welding zone), HAZ (heat affected zone) mild steel side and HAZ (heat affected zone) stainless steel side, has been observed and found out. Hardness test is done on Vickers Hardness Testing Machine. The micro-structure of each zone has also been observed and captured for better understanding. The samples were prepared accordingly and all 9 samples are tested for hardness. The 9 samples for hardness test are prepared on a mould of Bakelite Powder. We use Bakelite because of its high heat resistance ability. The figure of samples is shown below:

Hardness Reading and S/N Ratio

Run	Current	Voltage	GFR	Hardness WZ	Hardness PM	Hardness HAZ	S/N ratio
1	70	20	6	207.9	307.3	194.7	11.69
2	70	30	8	219.6	296.0	196.3	13.16
3	70	40	10	216.0	280.8	187.8	13.59
4	80	20	8	218.4	280.4	178.1	12.82
5	80	30	10	190.3	304.5	183.0	10.41

6	80	40	6	199.8	284.1	164.9	10.95
7	90	20	10	215.9	269.7	210.7	17.03
8	90	30	6	217.0	280.1	201.4	14.94
9	90	40	8	216.8	272.5	212.0	16.84

Response Table for S/N Ratio

Level	Current	Voltage	GFR
1	12.82	**13.85**	12.53
2	11.40	12.84	**14.28**
3	**16.27**	13.80	13.68
Delta	4.88	1.01	1.74
Rank	1.00	3.00	2.00

Result Discussion for Hardness Testing

The response table shows the average of each response characteristic (S/N ratio, means) for each level each factor. The tables include ranks based on Delta statistics, which compare the relative magnitude of effects. The Delta statistic is the highest minus the lowest average for each factor. Minitab assigns rank based on Delta values; ranks 1 to the highest Delta value rank 2 to the second highest, and so on. Use the level averages in the response tables to determine which level of each factor provides the best result. In our experimental analysis for hardness of weld zone, heat affected zone (MS Plate) & heat affected zone (SS Plate), the ranks indicate that Gas Flow Rate has the greatest influence on the S/N ratio. The Current has the next greatest influence, followed by Wire Feed Rate. Here, because our global is to increase the weld ability by keeping the hardness at nominal value, we want factor levels that produce the highest mean. In Taguchi experiments, we always want to maximize the S/N ratio. The level averages in the response tables show that the S/N ratio & Mean is maximized when the value of Current was 350 A, the Wire Feed Rate was 30 mm/min and the Gas Flow Rate was 35 L/min. Based on these results, we should set the hardness at:

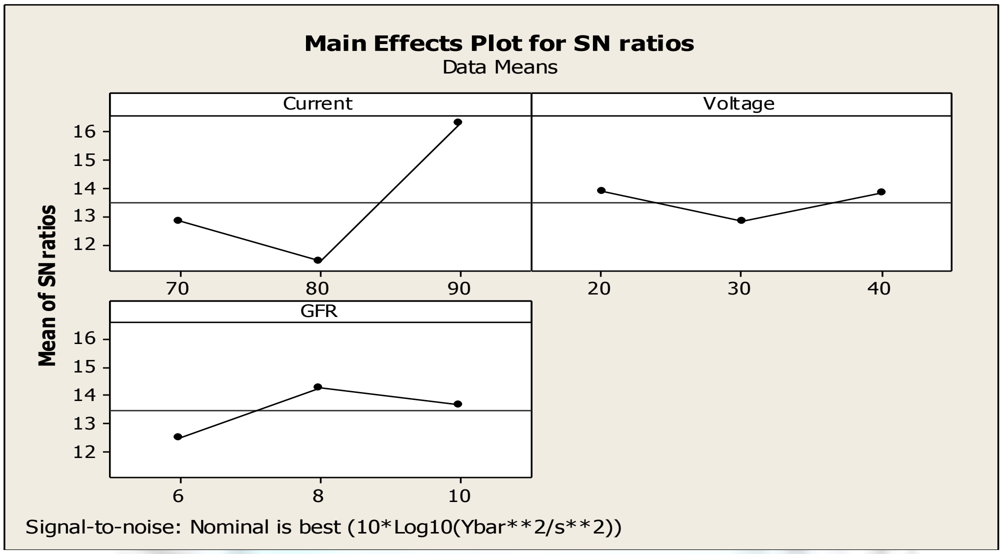
Response Table for Means:

Current	Level 3	90
Voltage	Level 1	20
Gas Flow Rate	Level 2	8

Analysis of Variance for Signal to Noise Ratio:

SOURCE	**DOF**	**Seq. SS**	**Adj. MS**	**F**	**P**	**%**
CURRENT	2	37.71	18.858	31.64	0.03	82.73 %
VOLTAGE	2	1.948	0.973	1.63	0.38	4.27 %
GFR	2	4.720	2.359	3.96	0.20	10.34 %
ERROR	2	1.192	0.596			
TOTAL	8	45.57				

The analysis of variance was carried out at 95% confidence level. The main purpose of analysis of variance is to investigate the influence of deign parameters on Hardness by including that which parameter is significantly affected the quality characteristics. By use of ANOVA analysis the percentage contribution of welding current is 82.73 %, welding voltage of 4.27 % and gas flow rate of 10.34 % and the remaining are of errors. This error is due to human ineffectiveness and machine vibration. The purpose of ANOVA is to investigate which welding process parameters significantly affect the quality characteristics. Graph shows the correlation between different process parameters.



7. CONCLUSION

The purpose of the present research was to optimize the welding process parameters and find out their optimized values with the help of Tensile and Hardness testing of the welding samples. An important finding to emerge in this study is the values of the process parameters for maximum tensile strength and hardness. The use of L9 (3×3) orthogonal array with three control parameters allowed this study to be conducted with a sample of 9 work pieces. The study found that the control factors had varying effects on the tensile strength, arc voltage having the highest effect. Taguchi method has been very successful in designing high quality products and processes of many different fields. The present study can be concluding as follows:

1. Taguchi design of experiment technique can be very efficiently used in the optimization of welding parameters in manufacturing operations.

2. Optimum parameters setting for Tensile Strength is

PARAMETERS	LEVELS	VALUES	% CONTRIBUTION
Current	Level 2	80	22.46%
Arc Voltage	Level 2	30	44.11%
GFR	Level 1	6	8.05%

3. Optimum parameters setting for hardness:

PARAMETERS	LEVELS	VALUES	% CONTRIBUTION
Current	Level 3	90	82.73%
Arc Voltage	Level 1	20	4.27%
GFR	Level 2	8	10.34%

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