Advanced Materials
Manufacturing & Characterization

journal home page: www.ijammc-griet.com

Optimization of Process Parameter of TIG Welding of Stainless Steel Plate Using Taguchi method

Srishti Mishra[a],Ajay Kumar[a], Shashank Mishra[a],Avinash Panday[a],Samrat Raj[a],Rajeev Kumar[b]

[a]*School of Engineering, Gautam Buddha University, Greater Noida -201312, Uttar Pradesh, India*
[b] *Asst.Prof. IIMT group of institutions, Greater Noida-201306, India*

Abstract

This work deals with the effects of various process parameters such as peak welding current ,gas flow rate, root face and welding time on metal deposition rate (MDR) of stainless steel plate of SS304 grade by TIG welding. In order to obtain, high welding strength, process parameter optimization plays an important role in welding process by identifying optimum process parameters.The effect of process parameters of TIG welding like weld current, gas flow rate, work piece thickness on the bead geometry of SS304.It is found that the process parameters considered affected the mechanical properties with great extent. Taguchi methodology is used to analyse the effect of each welding process parameters and optimal process parameters which obtained in order to get maximum deposition rate of TIG welded AISI 304 stainless steel Mainly Four input parameter- current, gas flow rate, face and welding time are select to analyse their effect on the metal deposition rate by changing or varying them.L9 Orthogonal Array technique is used to formulate the experiment layout and various processes. Conclude that the optimal input parameter setting for current, gas flow rate, root face and welding time are 90 amp, 2.0 litre/min, 2mm and 95 second.

*Keywords:*Type your keywords here, separated by semicolons ;

1. Introduction

Stainless steels constitute a group of high-alloy steels based on Fe-Cr, Fe-Cr-C, and Fe-Cr-Ni systems. To be stainless, these steels must contains a minimum of 10.5wt% Cr and this level of Cr allows formation of a passive surface oxide that prevents oxidation and corrosion of the underline ambient, non-corrosive conditions. These steels have good resistance to oxidation, even at high temperature, and they are often referred as to heat-resisting alloys. Mainly the steel are classified as Martensite, Ferrite,Austenitic,Duplex (Austenitic and ferrite) and precipitation hardened(ph).The martensitic types are typically welded in annealed condition for thin sections and the over aged condition for thick section, which inherently have high strength. Semi-austenitic types are typically welded in the solution-treated or annealed condition. The austenitic types are the most difficult types to weld because of solidification, liquation and ductility-deep cracking problem. They are normally welded in a solution-annealed condition, to minimize intrinsic restrength.

Gas Tungsten Arc Welding, often called TIG welding, is an arc welding process in which the heat is produced between a non-consumable electrode and the work metal as shown in Fig 1(b). The heat of the arc produced melts the base metal and produces a weld pool. In contrast to normal stick welding, in GTAW, an inert gas shields the weld area in order to prevent air from contaminating the weld. This shielding gas prevents oxidation of the tungsten electrode, the molten weld puddle and the heat-affected zone adjacent to the weld bead.

Nomenclature

GTAW	gas tungsten arc welding
TIG	tungsten inert gas
MDR	metal deposition rate
R	number of repetition
NB	nominal the better
LB	larger the better
HB	higher the better
MSD	mean square deviation

- Corresponing author: Srishti Mishra E-mail address: srishtimishra3020@gmail.co
- Doi: http://dx.doi.org/10.11127/ijammc.2016.04.14

2. Methodology

2.1 Design of Experiment(DOE)

It is highly essential to design an experiment to determine the effects of variable and welding parameter on the various welding responses on a sound basis rather than a commonly employed trial and error basis in conjunction with a small number of repeat experiments for confirmation of results. Apart from the trial and error method of investigation the following techniques and approaches are commonly employed by researches are Theoretical approach,Qualitative approach,Qualitative cum dimensional analysis method and General quantitative approach.

2.2. Plan of investigation

In order to achieve the desired aim, the investigations were planned to be carried out in the following steps and these are identifying the welding variables,selection of the useful limits of the welding parameters, namely, peak current, background current, pulse frequency and peak current time,developing the design matrix,Conducting the experiment as per design matrix.and analysis of results and conclusions.

2.2.1. Identifying the welding variables

The welding variables were identified to develop mathematical models to predict individual and combined effects of the parameters. The various parameters selected were Peak Welding Current (A),Gas flow rate (B),Root Face (C),Welding Time (D).

2.2.2. Selection of process parameters and their limits

The limits of the welding parameters were selected on the basis of excessive trial runs. The basis of selection of the given range for various welding parameters was that the resultant weld should have good bead appearance, configurations and be free from the visual defects. The three levels selected for each of the four variables are shown in Table 1

Table1. Levels for various control factors

Control factors	Levels			Unit
	1(low)	2(medium)	3(high)	
Welding current (A)	90	100	110	Ampere
Gas flow rate (B)	1	1.5	2.0	Litre per minute (LPM)
Root face (C)	1	1.5	2.0	mm.
Welding time (D)	95	140	195	Seconds

2.2.3 Developing the design matrix

Factorial design can be represented in the form of design matrix where column and row correspond to levels of factors and the different experimental runs respectively as shown in Table 2.

Salient features of Design Matrix table are trials indicate the sequence number of run under consideration and the 1, 2 and 3 as already indicated refer to the low, medium and high level of that parameter under which they are recorded.

2.2.3 Conducting Experiments as per the design matrix given below

Table2.Design matrix with actual values of parameters

Exp.Run	Welding Current(A)	Gas Flow Rate (B)	Root Face (C)	Welding Time
1	1(90)	1(1.0)	1(1.0)	1(95)
2	1(90)	2(1.5)	2(1.5)	1(140)
3	(90)	3(2.0)	3(2.0)	3 (195)
4	2(100)	1(1.0)	2(1.5)	1 (95)
5	2(100)	2(1.5)	3(2.0)	1 (95)
6	2(100)	3(2.0)	2 (1.0)	2 (140)
7	3(110)	1(1.0)	3 (2.0)	2 (140)
8	3(110)	2(1.5)	1 (1.0)	3 (195)
9	3(110)	3(2.0)	2 (1.5)	1 (95)

2.3 Taguchi Method

Taguchi proposed several approaches to experimental designs that are sometimes called "Taguchi Methods." These methods utilize two-level, three-level, four-level, five-level, and mixed-level fractional factorial designs. Taguchi refers to experimental design as "off-line quality control" because it is a method of ensuring good performance in the design stage of products or processes.Taguchi introduces his approach, using experimental design for Designing products/processes so as to be robust to environmental conditions, robust to component variation and Minimizing variation around a target value.

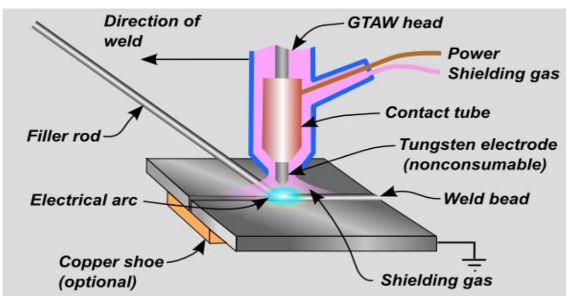
2.3.1 Steps in Taguchi Technique

When the problem involves data that are subjected to experimental error, statistical methodology is the only objective approach to analysis. Thus, there are two aspects of an experimental problem: the design of the experiments and the statistical analysis of the data.Parameter design is an investigation conducted to identify the settings of design parameters that optimize the performance characteristic and reduce the sensitivity of engineering designs to the source of variation (noise).In this method to optimize a process with multiple performance characteristics includes the steps such as identify the performance characteristics and select process parameters to be evaluated, determine the number of levels for the process parameters and possible interactions between the process parameters ,select the appropriate orthogonal array and assignment of process parameters to the orthogonal array, conduct the experiments based on the arrangement of the orthogonal array, calculate the total loss function and the S/N ratio, analyze the experimental results using the S/N ratio, select the optimal levels of process parameters, and verify the optimal process parameters through the confirmation experiment.This methods of design optimization developed by Taguchi are referred to as Robust Design. The

Robust Design method provides a systematic and efficient approach for finding the near-optimum combination of design parameters so that the product is functional, exhibits a high level of performance, and is robust to noise factors. Noise factors are those parameters that are uncontrollable or are too expensive to control.

Number of Levels	Number of Parameters (P)																													
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16	L16	L16	L16	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32
3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27	L27	L36	L36	L36	L36	L36	L36	L36	L36	L36	L36								
4	L'16	L'16	L'16	L'16	L'32	L'32	L'32	L'32	L'32																					
5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50																			

Fig.1 (a) Array selector



(b) Process diagram- TIG Welding

For design the experiments, certain elements such as number of run, randomization must be taken into consideration .The standard two level arrays L4, L8, L12, L16,L32and three level arrays areL9, L18, L27 are choosen from the Fig.1(a)By knowing the parameters and their corresponding levels we can chose a standard OA. Three levels for each parameter considered, if we have taken three levels of each parameter than focus on three level arrays only which is L9, L18 and L27. Now we can choose a standard OA, based on the Degrees of freedom.

The number of D.O.F. for a factor = Number of levels – 1

The number of D.O.F. for Current = 3 – 1 = 2, the number of D.O.F. for Ton = 3 – 1 = 2

The number of D.O.F. for T_{off} = 3 – 1 = 2, the number of D.O.F. for Feed = 3 – 1 = 2

Since there is no interaction between parameters, then total degree of freedom is 2+2+2+ 2=8

A three-level L_9 OA is selected for conducting the experiment, because in our consideration we have each 3 level for all parameter. Hence we should pick a OA from a three-level OA and in thatL_9 OA is selected because the total D.O.F is 8 which is equal to the D.O.F. of the selected L_9 OA (which is - No .of trials – 1= 8).

3.Experimentation

Taguchi suggests two different routes to carry out the complete analysis .First, the standard approach, where the results of a single run or the average of repetitive runs are processed through main effect and ANOVA analysis (Raw data analysis).

The second approach which Taguchi strongly recommends for multiple runs is to use signal- to-noise ratio(S/N) for the same steps in the analysis. Taguchi method uses a statistical measure of performance called signal-to-noise ratio. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise).

By maximizing the S/N ratio, the loss associated can be minimized. The standard S/N ratios generally used are as follows Higher the better (HB) as in eq (1), Lower the better (LB) as in eq (2) and Nominal is best (NB) as in eq (3).The mean squared deviation (MSD) is a statistical quantity that reflects the deviation from the target value.

$$(S/N)_{HB} = -10\log(MSD)_{HB}$$

Where

$$MSD_{HB} = \frac{1}{R}\sum_{j=1}^{R}\left(1 \big/ Y_j^2 \right)$$

$$(S/N)_{LB} = -10\log(MSD)_{LB}$$

Where

$$MSD_{LB} = \frac{1}{R}\sum_{j=1}^{R}\left(y_j^2\right)$$

3.1. Taguchi design experiments in MINITAB

MINITAB calculates response tables and generates main effects for Signal-to-noise ratios (S/N ratios) vs. the control factor and Means (static design) vs. the control factors. In the Taguchi Method the term 'signal' represents the desirable value (Mean) for the output characteristic and the term 'noise' represents the undesirable value (Standard Deviation) for the output characteristic. S/N ratio used to measure the quality characteristic deviating from the desired value. In S/N ratio, S is de-fined as S= -10 log (M.S.D.) where, M.S.D. is the Mean Square Deviation for the output characteristic. To obtain optimal welding performance, higher-the better quality characteristic for metal deposition rate (MDR) must be taken. As shown in Table 3 the response values for metal deposition rate. The M.S.D. for higher-the -better quality characteristic can be expressed as,

M.S.D = Σ 1/Pi2, Where, Pi is the value of MDR

MDR= (Weight of plate after welding- weight of plate before welding/welding time)

Table 3. Response values for MDR

Exp. Run	Welding Current (A)	Gas Flow Rate (B)	Root Face (C)	Welding Time (Sec)	MetalDeposition Rate (gm/sec)
1	90	1.0	1.0	95	0.08420
2	90	1.5	1.5	140	0.15714
3	90	2.0	2.0	195	0.06153
4	100	1.0	1.5	195	0.05641
5	100	1.5	2.0	95	0.09447
6	100	2.0	1.0	140	0.04285
7	110	1.0	2.0	140	0.07857
8	110	1.5	1.0	195	0.03589
9	110	2.0	1.5	95	0.07368

This normal probability plot was drawn using MINITAB 17 software and is that set of values of response variables lies very close to the median of set of values; The Normal Probability Plot for Response Variables is shown in Fig.2 (a) and percentage contribution of factors influencing MDR is shown in Fig.2(b)

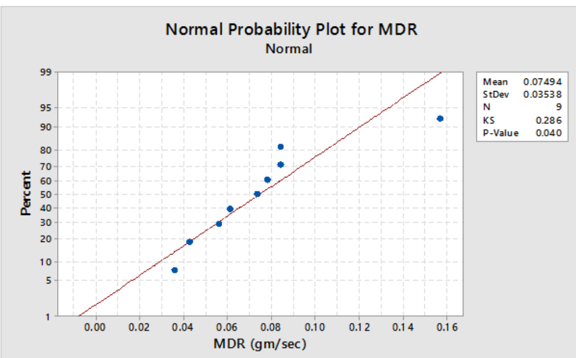
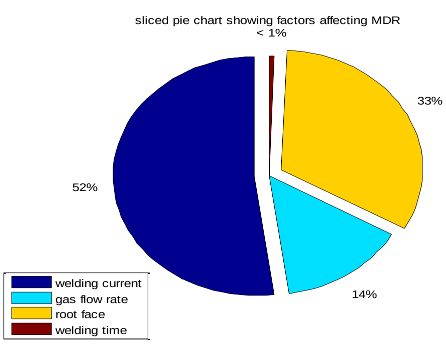


Fig 2(a) Normal Probability plot (MDR)



(b) Percentage Contribution of factors influencing MDR

Conversion of S/N ratio and mean for MDR is shown in Table 4 Regardless of the category of the quality characteristic; a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio. The S/N response table for MDR is shown in Table 5 as below.

Table 4. Conversion of S/N ratio and Mean for MDR

A (Amp.)	B (LPM)	C (mm)	D (sec)	MDR (gm/sec)	SNR (db)	MEAN (gm/sec)
90	1.0	1.0	95	0.08420	-21.4938	0.08420
90	1.5	1.5	140	0.08420	-21.4938	0.08420
90	2.0	2.0	195	0.15710	-16.0765	0.15710
100	1.0	1.5	195	0.06153	-24.2183	0.06153
100	1.5	2.0	95	0.05641	-24.9729	0.05641
100	2.0	1.0	140	0.04285	-24.9729	0.04285
110	1.0	2.0	140	0.07857	-22.0949	0.07857
110	1.5	1.0	195	0.03589	-28.9005	0.03589
110	2.0	1.5	95	0.073684	-22.6530	0.073684

Table5. Response table for S/N ratio

Level	Welding Current (Amp)	Gas Flow Rate (LPM)	Root Face (mm)	Welding Time (Sec)
1	-19.69	-22.60	-25.92	-23.04
2	-25.52	-25.12	-22.79	-23.65
3	-24.55	-22.03	-21.05	-23.07
Delta	5.83	3.09	4.87	0.61
Rank	1	3	2	4

From Table 6 it is clear that welding current and root face have maximum effect on MDR. The welding timeplaysaleast effect on MDR on TIG welded stainless steel plate. The above table shows that the values of control factors at each level and bold values are the highest values of control factors at different levels. The response table for Means is shown in Table 6

Table 6. Response table for Means

Level	Welding Current (Ampere)	Gas Flow Rate(LPM)	Root Face(mm)	Welding Time(Sec)
1	0.10850	0.07477	0.05431	0.07143
2	0.05360	0.05883	0.07314	0.06854
3	0.06271	0.09121	0.09736	0.08484
Delta	0.05490	0.03238	0.04305	0.01630
Rank	1	3	2	4

Figure shows the S/N ratio response and mean response plots demonstrating the effects of each parameter on the metal deposition rate.

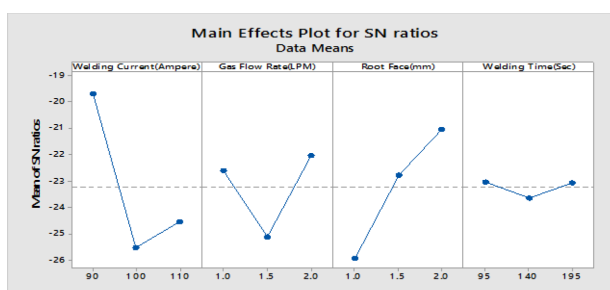
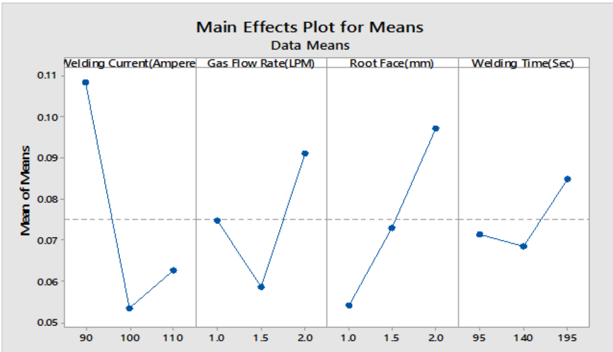


Fig 3(a)Main effects plot of S/N ratios for MDR



(b)Main effects plot of Means for MDR

Analysis of variance (ANOVA) and figure shows that the percentage contribution (%P) for each process parameters for maximum MDR. The ANOVA for the factors is shown in table 7 which clearly indicates that the welding current (A) is the most influencing factor of MDR and root face (C), gas flow rate (B), and welding time (D) are influencing factors in decreasing order.
Percentage contribution indicates the contribution of each factor to the total variation. By controlling the factors with high contribution, the total variation can be reduced leading to improvement of the welding process performance. The rank order based on contribution is same a the rank order obtained by the response graph method.

Table7. Results of ANOVE for MDR

SourceDF		Seq SS	Adj SS	Adj MS	%P
Welding Current (Amp)	2	58.55258.552429.276252.254			
Gas Flow Rate	2	16.240	16.2401	8.1201	14.493
Root Face2		36.546	36.5463	18.2731	32.615
Welding Time	2	0.715	0.7147	0.3573	0.631
Total	8	112.053			100.00

3.3 Optimal value of metal deposition rate

Optimal setting of process parameters for maximum MDR is A1B3C3D1. The average value of nine results of MDR is $T_{avg.=}$0.076114. The optimal value of MDR can be calculated as follows.

$Y_{optimal}=T_{avg}+(A1_{avg.}-T_{avg})+(B3_{avg.}-T_{avg})+(C3_{avg.}-T_{avg})+(D1_{avg.}-T_{avg})$

Here, from the mean table

$A1_{avg}=0.086890$

$B3_{avg}=0.059357$

$C3_{avg}=0.262869$

$D1_{avg}=0.084206$

Predicted or optimal value

$Y_{optimal}$=0.076114+(0.086890-0.076114)+(0.059357-0.076114)+(0.262869-0.076114)+(0.084206-0.076114)

=0.26498

$Y_{optimal}$=0.26498 gm/sec

4.Results

A Taguchi orthogonal array, the signal-to-noise (S/N) ratio and analysis of variance were used for the optimization of welding parameters. A conformation experiment was also conducted and verified for the effectiveness of the Taguchi optimization method. The experiment value that is observed from optimal welding parameters, the metal deposition rate is 0.26498gm/sec.

5. Conclusion

The effects of welding process parameters on metal deposition rate using pulsed GTAW process have been studied and the conclusions may be drawn from this analysis as follows Taguchi optimization method was applied to find the optimal process parameters for MDR.In this study, selected parameters were welding current, gas flow rate, root face and welding time. Effects of selected parameters on micro-hardness and microstructure can be studied.

6.References

E. Taban, E. Deleu, A. Dhooge, E. Kaluc, “Gas metal arc welding of modified X2CrNi12 ferritic stainless steel” Published in Kovove Mater. 2007, p.67-74.

Olson D.L., Siewert T.A., Liu S. & Edwards G.R, “ASM Hand-Book Vol.6, Welding, Brazing and Soldering, Fourth Edition, (1997), The Materials Information Society, U.S.A.
Montgomery, Design and Analysis of Experiments, New York: John Wiley & Sons, 1991.

www.weldreality.com.,

Manual for Gas tungsten arc welding of Miller Electric Mfg. Co. USA.