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OPTIMIZATION FOR HARDNESS OF WELD BEAD IN TIG WELDING USING TAGUCHI METHODS

Puneet Kumar[1], Arun Goyal[2]
[1]Assistant Professor, Department of Mechanical Engineering, LIET, Alwar

ABSTRACT

TIG welding is one of the most widely used welding techniques due to its versatility and ease that can be maintained in almost all kind of working environment. Stainless Steel (SS316) possessing high strength and toughness is usually known to create major challenges during its welding. Stainless Steel (SS316) is suitable for TIG welding with good weld ability and production economy. In this study, Taguchi's DOE approach is used to study the effect of welding process parameters on weld bead hardness. Three input parameters current; gas flow rate and no. of passes were selected to ascertain their effect on the hardness of weld bead. The results show that during the welding of Stainless Steel (SS316) current is the most significant factor followed by no. of passes and gas flow rate in that order.

The experimentation has been carried out by using L_9 OA as standardized by Taguchi and the analysis has been accomplished by following standard procedure on raw data as well as S/N data analysis. It is received that all the three selected parameters- current, no. of passes and gas flow rate –affect both the mean value and variation around the mean value of the selected response i.e. weld bead hardness. The results have been validated by confirmation experiments.

Keywords*:* Welding, Taguchi, Hardness, Stainless Steel.

I. INTRODUCTION

Welding is a joining process that uses heat, pressure, and chemicals to fuse two materials together permanently". Welding covers a temp range of 1500º F - 3000º F (800ºC-1635ºC). Depending upon the combination of temperature and pressure from a high temperature with no pressure to a high pressure with low temperature, a wide range of welding processes has been developed.

TIG Welding

Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by an inert shielding gas (argon or helium), and a filler metal is normally used, though some welds, known as autogenously welds, do not require it. A constant-current welding power supply produces energy which is conducted across the arc through a column of highly ionized gas and metal vapors known as plasma.

GTAW is most commonly used to weld thin sections of stainless steel and non-ferrous metals such as aluminum, magnesium, and copper alloys. The process grants the operator greater control over the weld than competing processes such as shielded metal arc welding and gas metal arc welding, allowing for stronger, higher quality welds. However, GTAW is comparatively more complex and difficult to master, and furthermore, it is significantly slower than most other welding techniques. A related process, plasma arc welding, uses a slightly different welding torch to create a more focused welding arc and as a result is often automated.

II. PROBLEM FORMULATION

The literature review reveals that in the TIG welding operation, the input parameters such as current, no. of passes, gas flow rate affect the physical characteristics of weld bead like hardness to a significant extent. Some research work has been reported in this regard for various work materials such as High-Chromium-High-Carbon die steel, polycarbonate and ABS (acrylonitrile-butadiene styrene) blend, RDE-40 aluminium alloy, aluminium

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alloy A319, SS316 L, stainless steel, carbon steel , Inconel718, AISI1040 steels etc. However there is almost a complete dearth of literature on TIG.

Objectives of the study
To study the effects of input parameters such as current, no. of passes, gas flow rate on the *hardness of weld bead* during welding operation on SS304 as work material using Taguchi's DOE approach and parametric optimization of TIG welding operation for optimizing *hardness of weld bead* using Taguchi Methods.

This work covers the study of complete welding operation on SS304 stainless steel used as work material and more stress is given to the response variable (*hardness of weld bead*) as it is capable to respond fast with the changing input parameters, and these input parameters should be compatible with the new technological changes. A performance measurement frame work has been developed for this study based on extensive review of literature on "Design of Experiment (DOE) approach and Taguchi Method". TIG welding is one of the most prevalent welding techniques in industrial applications. In this study the input parameters which are responsible (significant) for major changes in response variable (*hardness of weld bead*) are identified by using Design of Experiments (DOE) approach.

III. METHODOLOGY IMPLMENTATION

Process Parameters
An Ishikawa Cause-Effect diagram (figure 1) has been drawn in order to identify the process parameters which affect the hardness of weld bead.

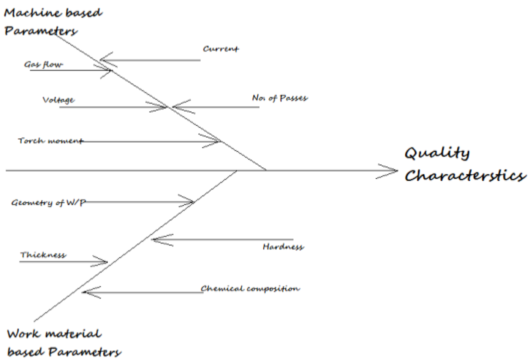

Fig.1. Ishikawa Cause-Effect Diagram

Machine Based Parameters: These parameters include Current, No. of passes, Gas flow rate and automatic movement of torch.
Work Material Based Parameters: These are the geometry of work piece, thickness, weld ability, hardness and chemical composition of work material.

Selection of Input (control) parameters and their Levels
Current, No. of passes, Gas flow rate are selected as control parameters. These three parameters are selected because of their ease of control and due to the limitations of available experimental setup. Parameters used for the actual experiment are given in Table 3.1 along with their levels.

Table 3.1: Control Parameters

Factors	**Symbol**	**Level 1**	**Level 2**	**Level 3**
Current (A)	A	110	130	150
Gas flow rate (L/min)	B	4	8	12
No. of passes	C	1	2	3

Three levels of each parameter have been chosen in order to reveal the presence of non-linear effects. Further, the levels have been taken quite far apart and equally spaced for better visualisation of the graphs.

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Selection of orthogonal array

In this experimental study three process parameters have been selected as already discussed. These three parameters have three levels used in actual experiment. The total degree of freedom of the experiment becomes 6. The following inequality must be satisfied for selecting an OA: DOF of an OA ≥ Total DOF of the experiment. The nearest possible OA satisfying the above inequality is L_9 which has eight DOF.

IV. RESULTS AND DISCUSSION

After conducting the experiment with different setting of input parameters the values of output variable were recorded as given in Table 4.1. The analysis has been performed according to the standard procedure recommended by Taguchi.The S/N data for experimental runs has also been tabulated in Table 4.1.

Main Effects due to Parameters

The main effects can be studied by the level average response analysis of mean data and S/N ratio. The analysis is done by averaging the mean and S/N data at each level of each parameter and plotting the graph. The level average response from the mean data helps in analyzing the trend of performance characteristics with respect to variation of the factors under study. Tables 4.2 and 4.3 reports the factor effect on mean and S/N ratio respectively. The main effects have been plotted as shown in Fig.2.

Table 4.1: Experimental Data for Hardness

Exp. No.	Hardness					Hardness Mean Value	Hardness S/N Ratio
	1st Run	2nd Run	3rd Run	4th Run	5th Run		
1	32	37	33	36	30	33.6	30.4498
2	36	30	32	40	34	34.4	30.6055
3	40	44	50	46	44	44.8	32.9574
4	44.5	37.5	42.5	48	42	42.9	32.5639
5	57.5	60	52.5	48	50	53.6	34.4926
6	48	55.5	52	58.5	50	52.8	34.3873
7	62	56.5	49.5	62	55	57	35.0245
8	48.5	57.5	52.5	60	50	53.7	34.5145
9	63	54	62	52.5	50.5	56.4	34.9215
Average						47.68	33.3241

Table 4.2: Factor Effect on Average Response

FACTOR	LEVELS	HARDNESS
Current	A_1	37.60
	A_2	49.77
	A_3	55.70
Gas Flow Rate	B_1	44.50
	B_2	47.23
	B_3	51.33
No. of Passes	C_1	46.70
	C_2	44.57
	C_3	51.80

Table 4.3: Factor Effect on S/N Ratio

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FACTOR	LEVELS	HARDNESS
Current	A_1	20.73
	A_2	21.15
	A_3	20.46
Gas Flow Rate	B_1	21.01
	B_2	20.11
	B_3	21.22
No. of Passes	C_1	21.35
	C_2	19.97
	C_3	21.02

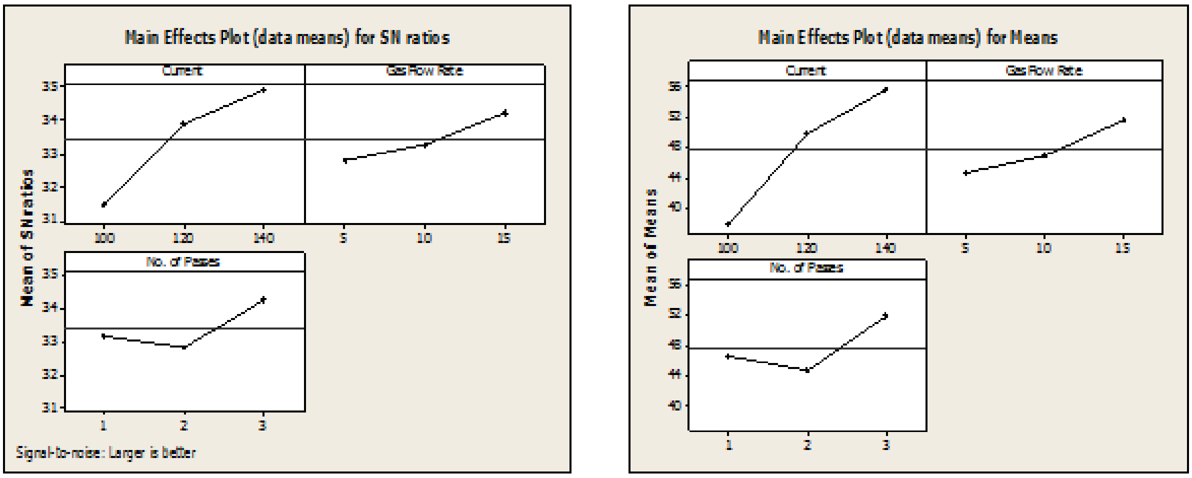

Fig.2 Effect of Process Parameters on Hardness (Raw data and S/N Ratio)

Analysis of Variance (ANOVA)

Analysis of variance is a statistical method used to interpret experimental data and make the necessary decision. ANOVA is statistically based decision tool for detecting any difference in average performance of group of items tested. The ANOVA (general linear model) for mean has been performed to identify the significant parameters to quantify their effect on performance characteristic. The ANOVA for raw data is given below in Table 4.4.

Table 4.4: ANOVA Summary for Hardness (Raw Data)

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage contribution
Current	2	510.84	510.84	252.58	352.58	0.003	76.69
Gas flow rate	2	70.98	70.98	35.49	48.99	0.020	10.66
No. of passes	2	82.88	82.88	41.44	57.20	0.017	12.44
Error	2	1.45	1.45	0.72			
Total	8	666.15					

S = 0851143 R-Sq = 99.78% R-Sq(adj) = 99.13%

Order of significance 1: Current; 2: No. of passes; 3: Gas flow rate;

Table 4.5: S/N ANOVA for Hardness

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Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage contribution
Current	2	19.5753	19.5753	9.6376	3254.86	0.000	76.11
Gas flow rate	2	3.0441	3.0441	1.5220	514.03	0.002	11.84
No. of passes	2	3.3953	3.3953	1.6977	573.34	0.002	13.20
Error	2	0.0059	0.0059	0.0030			
Total	8	25.7206					
S = 0.0544151 R-Sq = 99.98% R-Sq(adj) = 99.91% Order of significance 1: Current; 2: No. of passes; 3: Gas flow rate;							

Discussion

It can be seen from the above order of significance that Current is the most significant factor that is affecting the Hardness. The different input parameters used in experimentation can be ranked in the order of increasing effect as Gas flow rate, No. of passes and Current. From the Figure 4.1 it can be concluded that Gas flow rate is less significant than No. of passes and Current. The analysis of variance test results for Hardness confirms the optimal parameter setting as $\mathbf{A_3B_3C_3}$. In this study we conclude that the optimal input parameters setting for current is 140 amp, gas flow rate 15L/min and no. of passes 3 during the welding of stainless steel (SS304) on TIG welding machine as far as the hardness is concerned. It is revealed from the ANOVAs (raw data & S/N data) that all the three parameters are significant in both ANOVAs, hence these parameters affect both the mean value and variation around the mean of hardness.

Prediction of mean

The estimate of mean is only a point estimate based on average of results obtained from the experiment. It is therefore customary to represent the values of statistical parameter as a range within which it is likely to fall, for a given level of confidence (Ross, 1966). This range is termed as the confidential interval (CI). In other words- The confidential interval is a maximum and minimum value between which the true average should fall at some stated percentage of confidence (Ross, 1966).

The Taguchi approach for predicting the mean performance characteristic and determination of confidence interval for the predicted mean has been applied. The average value of performance characteristic obtained through the confirmation experiments must be within the 95% confidence interval ($\alpha = 0.05$).
For Hardness, overall population mean isμ = 47.68

The predicted optimum value of Hardness is calculated as: Optimum combination for Hardness is A_3 B_3 C_3
Hence, $\mu_{A3B3C3} = (A_3+B_3+C_3) - (2\mu) = 63.47$
$\mu_H = 63.8$

For calculation of CI_{ce},following equation has been used

$$\mathrm{C.I.} = \sqrt{F_{\propto}(1, f_e)V_e\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]} \quad \ldots\ldots (1)$$

Where $F_{\alpha;1,fe}$= the F ratio at a confidence level of α against DOF of mean (always 1) and error DOF
$F_{0.05;1,2} = 18.5$ α = risk

Confidence = 1- risk

$$n_{eff} = \frac{N}{1+[TotalDOFassociatedint\quad heesti\,mateoft\ \ hemean\ ]} \quad \ldots\ldots (2)$$

Where,
N = Total no. of results = 9
R = Sample size for conformation experiment = 3
V_e = Error variance = 0.55

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For Hardness
CI_{ce} (H) = ±3.4
The 95% confidence interval for μ_H is
$60.4 < \mu_H < 67.2$

Confirmation of Experiment
This is the last step in verifying the conclusion of the experiment. Three experiments are conducted at the optimal setting of the predicted parameters and their average value is calculated. This average value should fall within the predicted value of the response at a stated level of confidence. The average of three experiments comes out to be 65 HRC which is well within the 95% confidence interval already predicted.

V. CONCLUSIONS

The following conclusions have been drawn from the study:

1. The percent contribution of current (75.31%) in affecting hardness is maximum followed by no. of passes (12.82%) and gas flow rate (11.70%).
2. The analysis reveals **$A_3B_3C_3$**as the optimal input parameters setting for optimizing the hardness.**A_3=150 amp B_3=12L/min C_3=3**
   A-Current, B-Gas flow rate, C-no. of passes
1. The optimized value of hardness is **63.47 HRC**. The optimized value for hardness has been validated through the confirmation experiments.

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