Optimisation of Saw Process Parameters for Bead Geometry of Bead on Plate Welds Deposited on Structural Steel IS-2062 Using Taguchi Method

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Abstract: ***This paper deals with the investigation of optimal submerged arc welding (SAW) process parameters that affect weld bead geometry and quality of welds using TAGUCHI method. A planned experimental investigation has been carried out on a semiautomatic SAW machine. The effects of process parameters and signal to noise ratios have been computed and the contribution of the each factor has been validated by ANOVA. The results indicate the welding voltage to be the most significant contributor to weld penetration. The contribution of voltage, current, welding speed and nozzle to plate distance have been found to be respectively 60.8 %, 9.9%, 3.5% and 13.8%. Optimum parameters have been found to be 26V, 475A, at welding speed of a 15 m/s and NTP distance of 16 mm .The main interaction effects of control factors on bead geometry have also been presented in graphical form.***

Keywords: Submerged arc welding, Weld bead geometry Taguchi method, ANOVA, IS-2062 steel, Signal to noise ratio, Welding parameters optimization.

1.Introduction

Submerged arc weld (SAW) bead geometrical parameters such as weld width, depth of penetration and reinforcement height determine its mechanical properties. Bead geometric parameters in turn depend upon the SAW process parameters. Some work on weld bead geometric parameters in relation to process parameters and mechanical properties has been carried out earlier by Khan (1-3) and Gupta (4, 5). They studied the effect of welding parameters on bead geometry without any attempt to optimize weld bead parameters. In practice, usually the welding parameters are set by trial and error based on the values available in the welding handbooks or according to manufacturer's recommendations. This procedure may not yield optimal performance of weld deposits and also leads to waste of time, energy and materials. A scientific approach in this regard has been attempted by many investigators. Purohit [6] has optimized bead geometric parameters for metal inert gas (MIG) underwater welded bead-on-plates welds using 2-level factorial design of experiments.

Gunaraj and Murugan [7] have used 5-level factorial experiments to determine the main and interaction effects of process control variables on important bead geometric parameters including bead volume quantitatively and optimal bead volume with maximum penetration, minimum reinforcement height and bead width have been obtained successfully. More recently Taguchi method is being used extensively for solving optimization problems in the field of production engineering [8].It is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. Taguchi method can be efficiently used for designing a system that operates consistently and optimally over a variety of conditions. To determine the best design it requires the use of strategically designed experiments. Taguchi approach to design of experiments is easy to adopt and apply for users with limited knowledge of statistics [8-9] hence it has gained wide popularity in the engineering and scientific community.

The present work utilizes a well-planned experimental design consisting of a limited number of experimental runs, called orthogonal array (OA) and signal-to-noise ratio (S/N) which serve as the objective function to be optimized within the experimental limits. Further, to determine the significance of factors on the responses analysis of variance (ANOVA) has been used. Experiments in this investigation have been carried out on IS-2062 steel using SAW process to yield desired quality of bead as influenced by voltage (V), current(A), Trolley speed (Tr) and nozzle-to-plate distance (NPD) which are varied at five different levels. Grey-based Taguchi approach has been used to solve this multi-response optimization problem.

2.Literature Review

Raveendra and Parmar [10] have built mathematical models using the fractional factorial technique to predict the weld bead geometry (penetration, width, and reinforcement height), shape relations (width to penetration ratio) and percentage dilution. The base metal used was low carbon structural steel plate. The parameters of the flux cored arc welding process considered in this work were: arc voltage, welding current, welding speed, gun angle and nozzle-to-plate distance. They have developed models which can be used either to predict the bead geometry or to determine a combination of a range of parameters to obtain the desired bead geometry dimensions within the factors domain. Furthermore, these models can also be used in a production system for automatic control of welding conditions.

Yang et al. [11] have used linear regression equations for computing the weld features (melting rates, total fusion area, penetration, deposit area, bead height and bead width) for

SAW process variables (electrode extension, welding voltage, welding current, welding speed and electrode diameter) using both positive and negative electrode polarities. The base material was a 19 mm thick ASTM A36 steel plate. They managed to develop regression equations for each weld feature in both the polarity conditions. Their results indicated that the linear regression equations developed were useful for computing the various features of the SAW process.

Dhas and Kumanan[12] used NNPSO (Neural network model trained with Particle swarm optimization) to predict the weld quality of submerged arc welding with traditional algorithms which increased productivity, flexibility, safety and developed robots for attending risky jobs. They also suggested a hardware control setup for online weld quality monitoring. Taguchi method has been used by Khan and Pandey [13] to investigate the effect of current on tensile strength and nugget diameter of spot welds made on AISI-1008 steel sheets.

Survey of current literature indicates that no systematic work has been reported on the optimization of weld bead geometrical parameters for bead-on-plate SAW deposited on IS-2062 steel using Taguchi method. This steel is used in the fabrication of structures in Indian Railways. This work, therefore, becomes important.

3. Experimental Procedure

The experiments were conducted at RDSO Lucknow with the following experimental set up:

a. **The equipment used:** The submerged arc welding equipment.
Welding rod used: W-1, 3.2 mm diameter.
Work Piece: IS: 2062 Steel plates of 300*150*20 mm size
Type of joint: Bead on plate
Flux: Type F-1
Electrode to work angle: 90^o

b. Chemical composition of IS: 2062
C 0.23%; Mn: 1.50 5; S: .050%; P: 0.050%; Si: 0.40%; C.E: 0.42% (Remaining iron)

c. Chemical composition of bare wire:
IRS class: 1
Grade of wire: W-1
C: 0.10%; Mn: 0.4-0.6%; Si: 0.03%; S: 0.03%; P: 0.03%; Cu; 0.4 %(includes weight of copper coating on feed wire)

Analysis of S/N Ratio Based on Taguchi Method

Taguchi recommends analyzing data using the S/N ratio that will offer two advantages; it provides guidance for selection of the optimum level based on least variation around the average value, which is closest to the target, and it also offers objective comparison of two sets of experimental data with respect to deviation of the average from the target. The experimental results have been analyzed to investigate the main effects.

According to Taguchi method, S/N ratio is the ratio of "Signal" representing the desirable value, i.e. mean of output characteristics and the "noise" representing the undesirable value i.e., squared deviation of the output characteristics. It is denoted by η and the unit is dB. The S/N ratio is used to measure quality characteristic and is also used to measure significant welding parameters. According to quality engineering, the characteristics are classified as Higher the best (HB) and lower the best (LB). HB includes penetration which deserves higher values. Similarly LB includes Heat Affected Zone (HAZ) for which lower value is preferred. The summary statistics:

The S/N ratio η is given by:

$$\eta = -10 \log \frac{1}{N} \sum_{i=1}^{n} \frac{1}{y^2}$$

Larger the best performance

$$\eta = -10 \log \frac{1}{N} \sum_{i=1}^{n} y^2$$

Lower the best performance

Table 1: Process parameters with their values at five levels

Parameter	*Level 1*	*Level 2*	*Level 3*	*Level 4*	*Level 5*
Arc voltage (volts)	24	26	28	30	32
Welding current (Amp)	375	425	475	525	575
Trolley speed (m/min.)	0.25	0.30	0.35	0.40	0.45
Nozzle to plate distance(mm)	15	16	17	18	19

The Experimental design matrix is obtained by Taguchi Methodology by using MINITAB 16 software is shown in table 2. The parameters are set by studying the existing setup and quality requirements of components.

Table 2: Design matrix showing levels of factors

SL No	V	I	Tr	NPD
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	1	5	5	5
6	2	1	2	3
7	2	2	3	4
8	2	3	4	5
9	2	4	5	1
10	2	5	1	2
11	3	1	3	5
12	3	2	4	1
13	3	3	5	2
14	3	4	1	3
15	3	5	2	4
16	4	1	4	2
17	4	2	5	3
18	4	3	1	4
19	4	4	2	5
20	4	5	3	1
21	5	1	5	4
22	5	2	1	5
23	5	3	2	1
24	5	4	3	2
25	5	5	4	3

4.Result and Discussion

The Penetration depth is important quality parameter which affects the strength of the weld and thereby the durability of the weld. S/N ratios for quality characteristic (higher the best for weld bead penetration) in each experimental run is calculated. The results are shown in table 3. The effect of different control factors on bead penetration is shown in fig. 1.

Table 3: Experimental data and S/N ratios

Voltage	Current	Trolley Speed	npd	Penetration	S/N ratio
24	375	0.25	15	2.8	8.9432
24	425	0.30	16	2.9	9.2480
24	475	0.35	17	3.1	9.8272
24	525	0.40	18	2.6	8.2995
24	575	0.45	19	3.0	9.5424
26	375	0.30	17	3.1	9.8272
26	425	0.35	18	3.2	10.1030
26	475	0.40	19	3.4	10.6296
26	525	0.45	15	3.2	10.1030
26	575	0.25	16	3.4	10.6296
28	375	0.35	19	2.7	8.6273
28	425	0.40	15	2.9	9.2480
28	475	0.45	16	2.8	8.9432
28	525	0.25	17	2.6	8.2995
28	575	0.30	18	2.7	8.6273
30	375	0.40	16	3.0	9.5424
30	425	0.45	17	2.6	8.2995
30	475	0.25	18	2.7	8.6273
30	525	0.30	19	2.9	9.2480
30	575	0.35	15	2.8	8.9432
32	375	0.45	18	2.3	7.2346
32	425	0.25	19	3.0	9.5424
32	475	0.30	15	2.7	8.6273
32	525	0.35	16	2.4	7.6042
32	575	0.40	17	2.7	8.6273

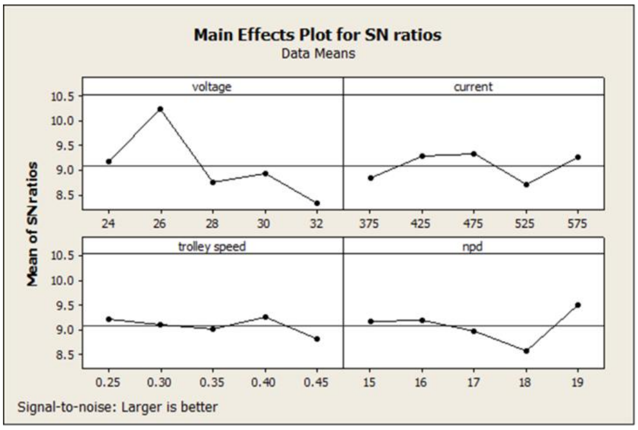

Figure 1: Main Effect Plot for S/N Ratios

Table 4: Response table for S/N ratios

Level	*Voltage*	*Current*	*Trolley Speed*	*npd*
1	9.172	8.835	9.208	9.173
2	10.258	9.288	9.116	9.193
3	8.749	9.331	9.021	8.976
4	8.932	8.711	9.269	8.578
5	8.327	9.274	8.825	9.518
DELTA	**1.931**	**0.620**	**0.445**	**0.940**
RANK	**1**	**3**	**4**	**2**

The response table includes ranks based on Delta statistics, which compare the relative magnitude of the effects. The delta is the highest average value minus the lowest average value for each factor. MINITAB assigns ranks on delta values; rank 1to the highest Delta value. From response table it is clear that the most significant factor is voltage (V) followed by nozzle to plate distance (NPD), current (A) and trolley speed (Tr).

5.Analysis of Variance (ANOVA)

The results have been analysed using ANOVA. 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. Table 5 shows the result of the ANOVA with the penetration .The second last column of the table indicates P-value for the individual control factors. It is known that smaller the P-value, greater the significance of the factor. The ANOVA table for S/N ratio (Table 5) indicate that, the voltage (P = 0.003) is the most significant control factor affecting penetration.

Table 5: Analysis of Variance for S/N ratios (Penetration)

Source	*DF*	*SS*	*MS*	*F-ratio*	*P-value*	*C %*
V (Volts)	4	10.4760	2.6190	10.14	0.003	60.8 %
Wf (Cm/s)	4	1.6997	0.4249	1.65	0.254	9.86%
Tr (Cm/s)	4	0.6102	0.1526	0.59	0.679	3.54%
NPD (Cm)	4	2.3773	0.5943	2.30	0.147	13.8%
Residual Error	8	2.0658	0.2582			
Total	24	17.2290				

R-Sq = 95.3% R-Sq (adj) = 81.1%; Significant at 95% confidence

6.Conclusion

The following conclusions could be drawn from the above investigation:

a. The response of S/N ratio with respect to Penetration indicates the welding voltage to be the most significant parameter that controls the weld penetration whereas the other parameters are comparatively less significant in this regard.

b. The contribution of voltage current trolley speed and nozzle to plate distance are 60.8%, 9.86%, 3.54% and 13.8% respectively (fig-2).

c. Optimum results have been obtained by Taguchi method using voltage 26, current 475, trolley speed 0.25, NPD 16.

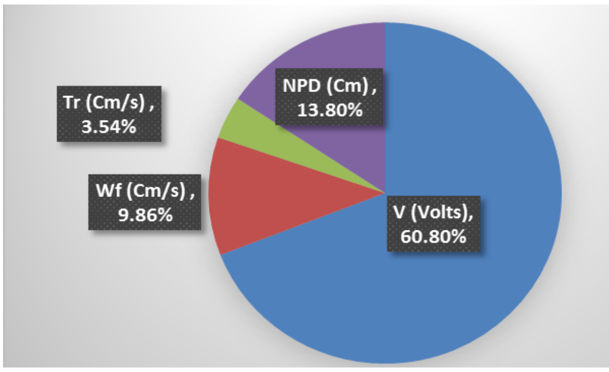

Figure 2: Contribution of parameters in submerged arc welding as determined by the ANOVA method.

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