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# Determination of the Optimal Process Parameters for Submerged Arc Welding

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**ABSTRACT**

**In this study, influences of the welding process parameters on the Submerged Arc welding were investigated. The Welding Arc Voltage, Welding Current and Welding Speed are chosen as welding process parameters. With the help of above welding process parameter we analyzed the effective welding time for SAW. This paper has analyzed in Minitab 17 software and application of Taguchi technique is used for determining the optimal process parameters for SAW process. This paper includes a analysis and study of various process control variables and important weld bead quality parameters in SAW of structural steel (IS:2062). Mathematical models were developed for the submerged arc welding of structural steel plate's thickness of 6 mm using steel electrodes which diameter is 3.15 mm. In this analysis three factors namely welding current, welding voltage and welding speed, were considered. Accordingly, a suitable orthogonal array was selected and experiments were conducted in Minitab 17 software. After conducting the experiments the welding time measured and Signal to Noise ratio was calculated. With the help of graph and table, optimum parameter values were obtained.**

***Keywords—*** Submerged Arc Welding, Taguchi method, orthogonal array, Design of experiment, Minitab 17

## I. INTRODUCTION

Welding is a process of joining two or more different materials. Submerged Arc Welding is one of the oldest automatic welding processes which introduced in 1930s for providing high quality of weld. SAW is more economical and is a much faster process compared to both casting and riveting. The quality of weld in Submerge Arc Welding is majorly influenced by various factors such as welding current, welding speed, welding arc voltage, electrode extension etc.

The schematic diagram of Submerge Arc Welding is shown in figure 1. Submerged arc welding having formation of arc between a continuously fed wire electrode and the given work piece. The submerged arc welding process generate protective gas and slag by using flux, and also helps to control the composition of the deposited metal by providing alloying elements to the weld bead. Since the arc fully submerged in the flux that's why arc moves along joint line. Since the arc is completely covered by the flux layer, the heat loss is minimum. This process also provides thermal efficiency of as high as 90–95%.

**Figure 1: Setup of SAW**

## II. PROBLEM IDENTIFICATION

***2.1 Effects of Welding Process Parameters***

***i. Effect of welding current***

If current is too high at a given welding speed

- Excessive depth of penetration resulting into melt through the metal being joined.
- Excessive reinforcement leading to wastage of electrode.
- Increased heat affected zone.
- Increased weld induced distortion.

If current is too low

- Inadequate penetration or incomplete fusion
- Unstable arc

***ii. Effect of welding arc voltage***

if arc voltage is increased

- A flatter and wider bead obtained.
- Increased flux consumption
- Reduction of porosity caused due to rust or scale on base metal
- Helps to bridge an exessive root opening
- Increase in pickup of alloying elements from flux.

If arc voltage is low

- Resist arc blow
- Excessive reduction in arc voltage will produce a high and narrow bead and slag removal along the bead edges becomes difficult.

***iii. Effect of welding speed***

If welding speed is increased

- Heat input per unit length decreases.
- Less filler metal is applied per unit length of weld leading to less weld reinforcement.
- Weld bead becomes smaller.

If if welding speed is decreased

- Heat input per unit length of weld is increased.
- More filler metal is consumed.
- Leads to more weld reinforcement.
- Increased penetration.

## III. MATERIAL AND PROCESS PARAMETERS

***3.1 Material used for SAW***

This paper includes a analysis and study of various process control variables and important weld bead quality parameters in SAW of structural steel (IS: 2062). Mathematical models were developed for the submerged arc welding of structural steel plate's thickness of 6 mm using steel electrodes which diameter is 3.15 mm.

***3.2 Selection of welding process parameters for SAW***

The selection of welding process parameters for Submerged Arc Welding process is based on the literature review of various research papers. There are multiple process parameters which effects the submerged arc welding, which are-

***(a) Welding Current and Arc voltage***

It controls the melting rate of the electrode and thereby the weld deposition rate. It also controls the depth of penetration and thereby the extent of dilution of the weld metal by the base metal. Arc voltage, also called welding voltage, means the electrical potential difference between the electrode wire tip and the surface of the molten weld puddle. It hardly affects the electrode melting rate.

***(b) Welding Speed and Heat input***

Welding speed is the linear rate at which the arc moves with respect to plate along the weld joint. Welding speed generally conforms to a given combination of welding current and are voltage.

***If welding speed is more than required***

1. Heat input to the joint decreases.
2. Less filler metal is deposited than requires, less weld reinforcement

***If welding speed is slow***

1. Heat input rate increases.
2. Weld width increases and reinforcement height also increases more convexity.

$$\textit{Heat Input Rate} = \frac{V \times I \times 60}{v} \ \text{J/mm}$$

V=arc voltage in volts
I=welding current in ampere,
*v* =speed of welding in mm/min.

From the Above welding process parameters of Submerged Arc Welding, we are selecting 4 parameters for our analysis. All other welding parameters considered as constant. The selected process parameters are-

- Welding Current
- Welding Voltage
- Welding Speed
- Welding Time

## IV. METHODOLOGY

For research work submerged arc welding machine in the welding department of Bhilai Engineering Corporation, Bhilai (Chhattisgarh) was selected. For optimize the welding time in SAW process following methodology followed-

- Select the SAW welding department in industry.
- Collection of data regarding the various factors affecting the SAW process.
- Finding out the parameter responsible for the welding time.
- Apply the Taguchi's method.
- Predict the process parameters which are optimized.

***4.1 Taguchi Method***

The statistical concept for quality improvement has developed by Dr. Genichi Taguchi. Taguchi's method based upon an approach which is totally different from the conventional methods of quality engineering. Taguchi optimization for any process begins with the following procedure:

- Firstly Identify the factors.
- After that Identify the levels.
- Select the proper orthogonal array.
- Assign level and factors to orthogonal array.
- Conduct experiment.
- Interpret and analyze the result using obtained data for SNR, ANOVA and response plot.

- Optimized process parameters obtained.

The flow chart for implementing the Taguchi optimization method is shown in figure 2.

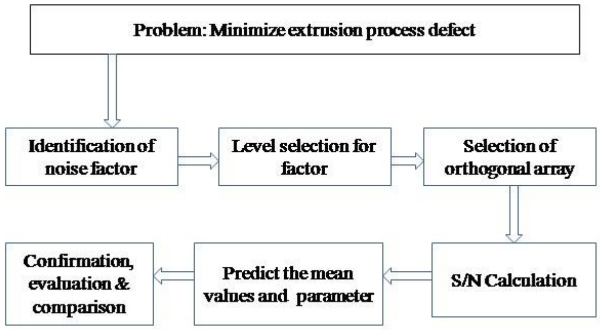



**Figure 2: Flow chart for Taguchi Methodology**

***4.2 Selection of levels and orthogonal array for process parameters***

The range of process parameters are collected from industry. For designing experiment and to visualize the effect of process parameters such as welding current, welding voltage and welding speed, on the welding time of SAW process, three levels are selected.

**Table 1: Selected values of process parameters**

| Submerged Arc Welding | | | | |
|---|---|---|---|---|
| Factors and Levels | | | | |
| Code | Factors | Levels | | |
| | | 1 | 2 | 3 |
| A | Welding Voltage, (V) | 18 | 20 | 22 |
| B | Welding Current,(A) | 250 | 300 | 350 |
| C | Welding speed,(mm/ min) | 98.18 | 101.71 | 102.22 |

For selecting an appropriate Orthogonal Array (OA) for conducting the experiments, the degrees of freedom are to be computed. Hence, the total DOF required for three parameters, each at three levels is [3x(3-1)], i.e. 6. Thus L9 orthogonal array was selected to make the present analysis with the help of Minitab17 software. This design requires nine experiments with three parameters, each at three levels. The assignment of the process parameters is given in Table 2 [12].

**Table 2: Orthogonal Array (OA9)**

| Experiment Numbers | Controlling Factors | | |
|---|---|---|---|
| | A | B | C |
| 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 |
| 3 | 1 | 3 | 3 |
| 4 | 2 | 1 | 2 |
| 5 | 2 | 2 | 3 |
| 6 | 2 | 3 | 1 |
| 7 | 3 | 1 | 3 |
| 8 | 3 | 2 | 1 |
| 9 | 3 | 3 | 2 |

***4.3 Design of Experiment (DOE)***

In accordance with the above OA, experiments were conducted with their factors and their levels as mentioned in table 1.The welding process parameters were selected by experiment. Each of the above 9 experiments were conducted 3 times (total 27 experiments) to account for the variations that may occur due to the noise factors [13].

**Table 3: Experimental result for pipe diameter**

| EXP | PROCESS PARAMETERS | | | WELDING TIME TRIAL 1 (SEC) | WELDING TIME TRIAL 2 (SEC)) | WELDING TIME TRIAL 3 (SEC) | MEAN TIME (SEC |
|---|---|---|---|---|---|---|---|
| | A | B | C | | | | |
| 1 | 18 | 250 | 98.18 | 45.83 | 45.26 | 45.86 | 45.6500 |
| 2 | 18 | 300 | 102.22 | 42.34 | 42.63 | 42.12 | 42.3633 |
| 3 | 18 | 350 | 101.71 | 43.45 | 43.25 | 43.27 | 43.3233 |
| 4 | 20 | 250 | 102.22 | 42.37 | 42.71 | 42.36 | 42.4800 |
| 5 | 20 | 300 | 101.71 | 43.05 | 43.28 | 43.45 | 43.2600 |
| 6 | 20 | 350 | 98.18 | 45.83 | 45.25 | 45.27 | 45.4500 |
| 7 | 22 | 250 | 101.71 | 43.25 | 43.27 | 43.81 | 43.4433 |
| 8 | 22 | 300 | 98.18 | 45.52 | 45.35 | 45.04 | 45.3033 |
| 9 | 22 | 350 | 102.22 | 42.09 | 42.43 | 42.20 | 42.2400 |

***4.4 Calculation***

S/N ratios are calculated based on the objective chosen “Nominal the best” in Minitab 17.

$$S/N_{N} = 10 \log \left(\frac{\bar{y}^2}{s^2}\right)$$

Where, $\bar{y}$ is mean, $s^2$ is variance.

Since the objective function (Nominal Diameter), nominal the best type of control function was used in calculating the S/N ratio. The S/N ratios of all the experiments were calculated with the help of Minitab17 software as shown in table 4.

**Table 4 Calculated Values**

| Experiment No. | Mean Time (sec) | Standard Deviation | S/N ratio (db) |
|---|---|---|---|
| 1 | 45.6500 | 0.338083 | 42.6084 |
| 2 | 42.3633 | 0.255799 | 44.3818 |
| 3 | 43.3233 | 0.110151 | 51.8946 |
| 4 | 42.4800 | 0.199249 | 46.5758 |
| 5 | 43.2600 | 0.200749 | 46.6687 |
| 6 | 45.4500 | 0.329242 | 42.8004 |
| 7 | 43.4433 | 0.317700 | 42.7181 |
| 8 | 45.3033 | 0.243379 | 45.3969 |
| 9 | 42.2400 | 0.173494 | 47.7288 |

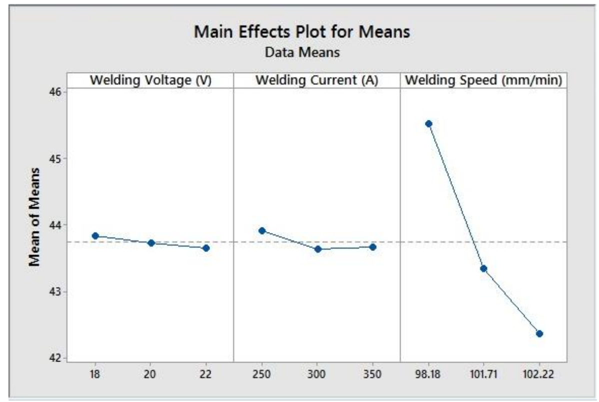
## V. RESULTS

### *5.1 Response Table for Signal to Noise Ratios*

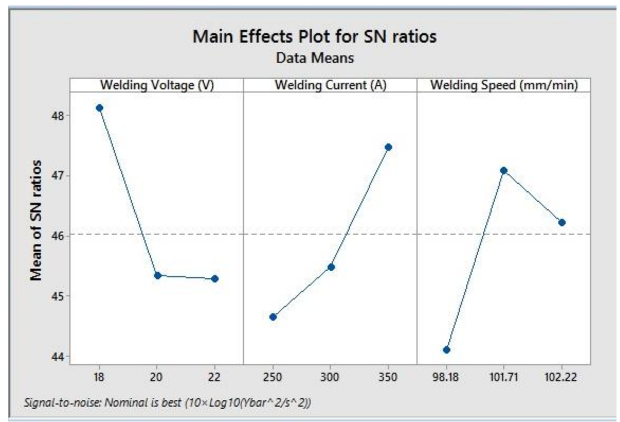
**Table 5 Response Table for S/N Ratio**

| Level | Welding Voltage(V) | Welding Current (A) | Welding Speed(mm/min) |
|---|---|---|---|
| | (A) | (B) | (C) |
| 1 | 48.14 | 44.65 | 44.10 |
| 2 | 45.35 | 45.48 | 47.09 |
| 3 | 45.28 | 47.47 | 46.23 |
| Delta | 2.86 | 2.83 | 3.00 |
| Rank | 2 | 3 | 1 |

In the Table 3 nine set of experiment has been performed for selected welding process parameters as per the Taguchi L9 orthogonal array design system, for optimization of welding time for SAW. Since welding time is considered as a result parameter so it is measured and signal to noise ratio has been calculated for all the nine experiments and Main effects plot for S/N Ratios are drawn with the help of Minitab 17 software.




**Graph 1: Main Effect Plot for Mean**




**Graph 2: Main Effect Plot for S/N ratio**

The response table of the S/N ratio is given in table 5, and the best set of optimum parameter can be determined by selecting the level with highest S/N ratio value for each factor i.e. A1B1C1.

**Table 6: Optimum value of factors**

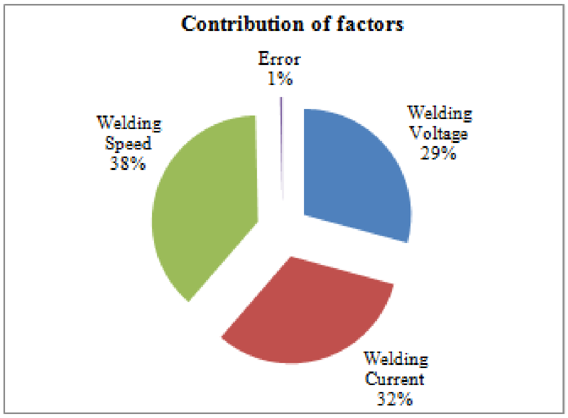
| Parameter | Optimum Value |
|---|---|
| Welding voltage (V) | 18 |
| Welding current (A) | 350 |
| Welding speed (mm/min) | 101.71 |

### *5.3 Analysis of Variance (ANOVA) and its Significance*

Table 7: Analysis of Variance (ANOVA) for S/N ratio

| Source | DF | Adj SS | Adj MS | F-Value | P-Value | Percentage Contribution (%) |
|---|---|---|---|---|---|---|
| Welding Voltage | 2 | 25.2605 | 12.6302 | 0.76 | 0.567 | 29.190 |
| Welding Current. | 2 | 27.8454 | 13.9227 | 0.84 | 0.543 | 32.177 |
| Welding Speed | 2 | 33.1297 | 16.5648 | 0.01 | 0.991 | 38.283 |
| Error | 2 | 0.3020 | 0.1510 | | | 0.3489 |
| Total | 8 | 86.5375 | | | | 100 |

It can be seen from this table that for the nominal welding time, the contribution of Welding speed (38.283%) is more significant followed by welding current (32.177%) and welding voltage (29.190%). It is clear that the effect of error (0.3489%) on welding time is negligible as compared to the control factors.




## IV. CONCLUSION

This study illustrate the application of the parameter deign using Taguchi method in the optimization of submerged Arc Welding. With this experiments the influencing of the different process parameter on the welding time of submerged arc welding is analyzed and so as to contribution for the improving the welding reliability. The level of importance of the process parameters is determined by using ANOVA analysis. The following conclusion can be drawn based on the above experimental results of the study.

- For carrying out the successful welding operation, The Welding Current, Welding Arc Voltage, Welding Speed, should be optimized.
- Taguchi's Method of parameter design can be performed with lesser number of experimentations as compared to that of full factorial analysis.
- It is found that the parameter design of the Taguchi method provides a simple, systematic and efficient methodology for optimizing the process parameters.
- S/N ratio is calculated with objective nominal the best. The optimum parameter is selected with highest S/N ratio value.
- The optimum process parameter obtained by the response table of S/N ratio is welding speed at 101.71mm/min, welding voltage at 18V, and welding current at 350A.
- Result analysis is done by Analysis of Variance (ANOVA). It gives the significant of the factor.
- From ANOVA table it is found that welding speed (38.283%) is the most significant process parameter.
- The submerged arc welding is benefited from this project work as it is related to customer satisfaction which is one of the objectives of a company.

***Scope for future work***

Taguchi method is successfully implemented in this project work. It gives the effect of process parameter on production of pipe industry.

- Future work is possible by study of interaction effect of the process parameters in other welding process.
- The analysis of influence of other unaccounted parameters with the combined interaction effect can be done.

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