Optimization of Welding Parameters Using Taguchi Method for Submerged Arc Welding On Spiral Pipes

Pradeep Deshmukh, M. B. Sorte

Abstract**:** ***Welding input parameters play a very significant role in determining the quality of a weld joint. The joint quality can be defined in terms of properties such as weld-bead geometry, mechanical properties, and distortion. Generally, all welding processes are used with the aim of obtaining a welded joint with the desired weld-bead parameters, excellent mechanical properties with minimum distortion. The Submerged Arc Welding (SAW) process finds wide industrial application due to its easy applicability, high current density and ability to deposit a large amount of weld metal using more than one wire at the same time. It is highly emphasized in manufacturing especially because of its ability to restore worn parts. In order to obtain an efficient joint, several process parameters of SAW need to be studied and precisely selected to improve weld quality. SAW is characterized by a large number of process parameters influencing the performance outputs such as deposition rate, dilution and hardness, which subsequently affect weld quality. An exhaustive literature survey indicates that five control factors, viz., arc current, arc voltage, welding speed, electrode stick-out and preheat temperature, predominantly influence weld quality. In relation to this, an attempt has been made in this study to analyses the effect of process parameters on outputs of welding using the Taguchi method.***

Index Terms**:** ***Regression Analysis, Welding Parameters, Submerged Arc Welding, Taguchi Method.***

I. INTRODUCTION

In today's global competition and economic liberalization, quality has become one of the important factors for achieving competitive advantage. A good quality product or service enables an organization to add and retain customers. Poor quality leads to discontented customers, so the costs of poor quality are not just those of immediate waste or rectification but also the loss of future sales. Technological innovations have diffused geographical boundaries resulting in more informed customers. The business environment has become increasingly complex and the marketplace has changed from local to global. Constant pressure is applied on the management to improve competitiveness by lowering operating cost and improving logistic. Customers are becoming increasingly aware of rising standards, having access to wide range of products and services to choose from. Submerged Arc Welding is one of the major welding processes in industry because of its inherent advantages, including deep penetration and a smooth bead.

Lots of critical sets of input parameters are involved in Submerged Arc Welding Process which needs to be controlled to get the required weld bead quality. Detailed information on effects of input parameters on weld bead quality parameters and finding out the relationship between them are very essential for decreasing trial run of SAW process.

K. srinivasulu reddy [1], in his paper presented optimization & prediction of welding parameters and bead geometry in submerged arc welding. He collected data as per Taguchi's Design of Experiments and analysis of variance (ANOVA) and experiment was carried to establish input–output relationships of the process. By this relationship, an attempt was made to minimize weld bead width, a good indicator of bead geometry, using optimization procedures based on the ANN models to determine optimal weld parameters. The optimized values obtained from these techniques were compared with experimental results and presented. Vukojevic, N., Oruc, M., Vukojevic, D. et al.[2,3], done performance analysis of substitution of applied materials using fracture mechanics parameters. Younise, B., Rakin, M., Medjo, B., et al. performed numerical analysis of constraint effect on ductile tearing in strength mismatched welded CCT specimens using micromechanical approach. Sharma, A., Chaudhary, A. K., Arora, N., et al.[4],done estimation of heat source model parameters for twin- wire submerged Arc welding[4].

Pillia, K. R., Ghosh [5,6] have presented some investigations on the Interactions of the Process Parameters of Submerged Arc Welding. Reducing of trial run is essential to reduce the cost of welding procedure. Ghosh, A., Chattopadhyaya [7], presented prediction of weld bead penetration, transient temperature distribution & haz width of submerged arc welded structural steel plates for the submerged arc welding plates, engineers often face the problem of selecting appropriate combination of input process control variables for achieving the required weld bead quality or predicting the weld bead quality for the proposed process control values.

Juang and Tarng [8] have adopted a modified Taguchi method to analyze the effect of each welding process parameter (arc gap, flow rate, welding current and speed) on the weld pool geometry (front and back height, front and back width) and then to determine the TIG welding process parameters combination associated with the optimal weld pool geometry.

Revised Manuscript Received on 30 November 2013.
* Correspondence Author
Mr. Pradeep Deshmukh, Department of Mechanical Engineering, Mumbai University/ Saraswati College of Engineering/ Mumbai, India.
Prof. M. B. Sorte, Department of Mechanical Engineering, Mumbai University/ Saraswati College of Engineering/ Mumba, India.

It was experimentally reported that, the four smaller-the-better quality characteristics, 'four responses' of the weld pool in the TIG welding of S304 stainless steel of 1.5 mm in thickness are greatly improved by using this approach.

Lee et al. [9] have used the Taguchi method and regression analysis in order to optimize Nd-YAG laser welding parameters (nozzle type, rotating speed, title angle, focal position, pumping voltage, pulse frequency and pulse width) to seal an iodine-125 radioisotope seed into a titanium capsule. The accurate control of the melted length of the tube end was the most important to obtain a sound sealed state. It was demonstrated that the laser pulse width and focal position were the laser welding parameters that had the greatest effects on the S/N ratios of the melted length. The optimal welding conditions were obtained at a pulse width of 0.86 ms and a focal position of 3.18 to 3.35 mm. Furthermore, confirmation experiments were conducted at the optimal welding conditions, it can be said that the titanium tube ends were sealed perfectly.

Laser butt-welding of a thin plate of magnesium alloy using the Taguchi method has been optimized by Pan et al. [10]. They studied the effect of Nd-YAG laser welding parameters (shielding gas type, laser energy, conveying speed, laser focus, pulse frequency and pulse shape) on the ultimate tensile stress. Their result indicated that the pulse shape and energy of the laser contributed most to thin plate butt-welding. It was found that the optimal combination of welding parameters for laser welding were argon as a shielding gas, a 360 W laser energy, a work piece speed of 25 mm/s, a focus distance of 0 mm, a pulse frequency of 160 Hz and type III pulse shape. It was also found that the superior ultimate tension stress was 169 MPa at an overlap of the welding zone of approximately 75%. Anawa et al. [11] have applied the Taguchi approach to optimize the laser welding process of dissimilar materials, namely: plain carbon steel and AISI316 with the same thickness of 1.5 mm. The process parameters were laser power, welding speed and focus position against one response NTS. The experimental results indicated that the process could be optimized using the Taguchi method in order to obtain superior welded joints.

Anawa et al. [12] have continued their investigation and studied the effect of the laser welding parameters mentioned above on the impact strength of the same joint at room temperature using the same optimizing technique. The results indicated that the laser power has the most significant effect on the impact strength. Also, it was mentioned that the optimal settings to obtain excellent impact strength were the highest laser power, a welding speed of 750 mm/min and a focus position of -0.5 mm.

II. SUBMERGED ARC WELDING

Submerged arc welding (SAW) is widely used welding process in most fabrication industries. It requires a no continuously fed consumable solid or tubular (flux cored) electrode. The molten weld and the arc zone are protected from atmospheric contamination by being ―submerged‖ under a blanket of granular fusible flux consisting of lime, silica, manganese oxide, calcium fluoride, and other compounds. When molten, the flux becomes conductive, and provides a current path between the electrode and the work. This thick layer of flux completely covers the molten metal thus preventing spatter and sparks as well as suppressing the intense ultraviolet radiation and fumes that are part of the shielded metal arc welding (SMAW) process as shown in figure 1. SAW is normally operated in the automatic or mechanized mode, however, semi-automatic (hand-held) SAW guns with pressurized or gravity flux feed delivery are available. Semi-automatic with gravity flux feed SAW machine is used in the present work.

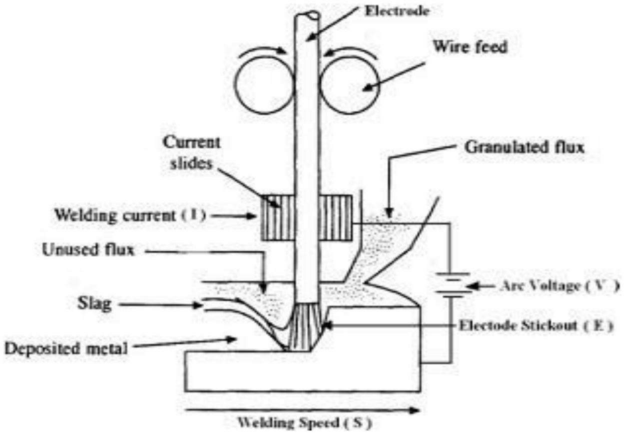

Figure 1: Submerged Arc Welding Process (Figure adopted from reference [1])

A. *Taguchi Method*

The Taguchi method is a standardized approach for determining the best combination of inputs to produce a product. The Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. The greatest advantage of this method is the saving of effort in conducting experiments; saving experimental time, reducing the cost, and discovering significant factors quickly. The Taguchi method provides:

1. A basis for determining the functional relationship between controllable product design factors and the outcomes of a process.
2. A method for adjusting the mean of a process by optimizing controllable variables.
3. A procedure for examining the relationship between random noise in the process and product variability.

Essentially, traditional experimental design procedures are very complicated and not easy to use. A large number of experimental works have to be carried out when the number of process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. The utmost advantage of this method is the saving of effort in conducting experiments; saving experimental time, reducing the cost, and determining significant factors quickly.

Step 1: Identification of important process variables.
Step 2: Development of process plan.
Step 3: Conducting experiments as per the plan.
Step 4: Recording the responses.
Step 5: Testing the welded job.
Step 6: Finding out the optimized values of the parameters
Step 7: Presenting the main and substantial effects of process parameters.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

III. EXPERIMENTATION: TAGUCHI Method

The Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. The greatest advantage of this method is the saving of effort in conducting experiments; saving experimental time, reducing the cost, and discovering significant factors quickly. Important process variables identified are shown in table 1. Levels of process parameters identified are shown in table 2.

The experiment was conducted at the Welding Centre of “TOPWORTH PIPES & TUBES LTD”, Mumbai with the following set up. MODEL-LINCON1000,automatic SAW equipment with a constant voltage, rectifier type power source with a 1000A capacity was used to join the two mild steel pipes of size12000mm (length)X1500mm (width)X 12mm (thickness)with a V angle of 30° to 45° ,4mm root height and 0.75 mm gap between the two plates. Copper coated Electrode Auto melt EH-14 wire size: 3.20mm diameter, of coil form and basic fluoride type granular flux were used.

Table 1 Welding parameters with different levels

Symbol	Welding Parameters	Level 1	Level 2
A	Welding current(amp)	650	750
B	Arc voltage(volts)	33	34
C	Welding speed (mm/min)	500	600
D	Electrode stick out(mm)	30	33

A. *Taguchi Method*

The quality engineering method of Taguchi, employing design of experiment (DOE), is one of the most important statistical tools for designing the high quality systems at reduced cost .The Taguchi methods provide an efficient and systematic way to optimized designs for performance, quality and cost. Optimization of process parameters is the key step in the Taguchi’s method to achieve high quality without increasing cost. This is because, optimization of process parameters can be improve quality characteristic and optimal process parameters obtained from Taguchi method are insensitive to the variation of environment conditions and other noise factors. Classical process parameter design is complex and not an easy task. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with a small number of experiments only. Taguchi has created a transformation of repetition data to another value, which is a measure of the variation present. The transformation is known as signal to noise(S/N) ratio. The S/N ratio consolidates several repetitions (at two data points are required) into one value, which reflects the amount of variation present. There are several S/N ratio depending on the characteristic;(i)Lower is better(LB),(ii)Nominal is better(NB),(iii)Higher is better(HB).The control factors that may contribute to reduce variation (improved quality) can be quickly identified by looking at the amount of variation present as a response. The bead width, weld reinforcement, depth of penetration of the weld bead geometries and weld bead hardness belong to higher the better quality characteristic. The loss function of the higher the better quality characteristic can be expressed as:

Higher the better

$$MSD = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, y_i are the observed data (or quality characteristics) at the i^{th} trial, and n is the number of trials at the same level. As a result, four quality characteristic corresponding to the bead width, reinforcement, penetration of the weld bead geometry and hardness are obtained using equation (1) repetition data to another value, which is a measure of the variation present. The overall loss function is further transformed into the signal to noise ratio. In the Taguchi method, the S/N ratio is used to determine the deviation of the quality characteristic from the desired value. The S/N ratio (η) can be express as

$$\eta = -10\log_{10}(MSD), \quad \text{for higher is better characteristic.} \quad \ldots\ldots (2)$$

Regardless of the quality of the quality characteristic, a large S/N ratio corresponds to a better quality characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio as shown in table 3.

Table 2: Experimental layout using L_8 orthogonal array

Trial No.	Welding Current	Arc Voltage	Welding Speed	Electrode Stick Out
1	1	1	1	1
2	1	1	1	2
3	1	2	2	1
4	1	1	2	1
5	2	1	2	1
6	2	1	2	2

B. *Multiple regression analysis*

Multiple regression analysis technique is used to ascertain the relationships among variables. The most frequently used method among social scientists is that of linear equations. The multiple linear regression take the following form:

$$Y=a+b1X1+b2X2+b3X3+\ldots\ldots+bkXk \quad \ldots\ldots\ldots\ldots(3).$$

Where Y is the dependent variable, which is to be predicted;$X_1,X_2,X_3 \ldots\ldots\ldots X_k$ are the known variables on which the predictions are to be made and a, b_1, b_2, b_3,..........b_k are the co- efficient, the values of which are determined by the method of least squares.

Multiple regression analysis is used to determine the relationship between the dependent variables of bead width and weld bead hardness with welding current, arc voltage, welding speed, and electrode stick out. The regression analysis was done by Minitab 15 version.

After completion of the welding process the welded specimen has been kept properly on a table and the weld bead width has measured with the help of a measuring scale. Similarly S/N ratio for weld bead width has been found separately. The largest signal to noise ratio (mean) is considered to be the optimum level, as a high value of signal to noise ratio indicates that the signal is much higher than the random effects of the noise factors.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

Table 3 shows the mean S/N ratios for the welding current, arc voltage, welding speed and electrode stick out. From the Table 3, it is evident that largest signal to noise ratio (average) is the optimum level, because a high value of signal to noise ratio indicates the signal is much higher than the random effects of the noise factors. The largest S/N_{avg} for parameter is indicated by Optimum in the Table 3. Results shown in table 4, it can be stated that contribution of current is maximum and contribution of speed and electrode stick out are minimum in optimum bead width.

IV. RESULT AND DISCUSSION

This paper has presented the application of Taguchi technique to determine the optimal process parameters for SAW process. Experimentation was done according to the Taguchi's design of experiments. Using the signal-to-noise ratio technique the influence of each welding parameters are studied and the prediction of the bead geometry is done. Then it is used to predict the SAW process parameters for any given welding conditions.
From the available 6 data sets, 6 data sets are used to train the network as given in table 3.

Table 3 (A) Training data sets

Trial No.	Welding Current (Amps)	Arc Voltage (Volts)	Welding Speed mm/min	Electrode Stick Out (mm)
1	650	33	500	30
2	650	33	500	33
3	650	34	600	30
4	650	33	600	30
5	750	33	600	30
6	750	33	600	33

Table 3 (B) Training data sets

Trial No.	Bead Width (mm)	Weld Reinforcement (mm)	Depth of Penetratio n (mm)	Weld Bead Hardn ess (BHN)
1	12	2.0	2.0	37
2	12	2.0	2.0	40
3	12	2.5	2.0	42
4	12	2.4	1.5	34
5	12	2.0	1.5	42
6	12	2.3	1.5	38

From Table 3 it can be predicted that the optimum level parameters for achieving optimum result of weld bead width if the path A1-B2-C1-D2 is followed: [Welding current (A1) 650A, Arc voltage (B2) 34V, Welding speed (C1) 500mm/min, electrode stick out (D2) 33 mm]. Multiple regression analysis has been used to determine the relationship between the dependent variables of bead width with welding current, arc voltage, welding speed, and electrode stick out. The regression analysis has been performed by Minitab 15 software. The regression analysis of the input parameters is expressed in linear equation as follows:
Predicted Weld bead width

13.7-0.125A+1.13B-0.375C+0.375D ………… (4)
=13.7-0.125 x welding current + 1.13 x Arc voltage -0.375 x welding speed + 0.375 x Electrode stick out. From the above equations, predicted values of weld bead width has been found out and tabulated with the measured value at Table 4.

Table 4: Predicted Data

Trial No.	Welding Current (Amps)	Arc Voltage (Volts)	Welding Speed mm/min	Electrode Stick Out (mm)	Predicted Bead Width
1	650	33	500	30	13
2	650	34	600	33	11
3	650	33	500	30	12.5
4	750	34	600	33	12.9
5	750	34	600	30	12.2
6	750	33	500	33	12.58

Table 5: Comparison of actual and predicted values

Trial No	Measured Weld bead width	Predicted Weld bead width	Mean square deviati on	S/N ratio (dB)
1	12	13	169	22.28
2	12	11	121	20.82
3	12	12.5	156.25	21.93
4	12	12.9	166.41	22.21
5	12	12.2	148.84	21.72
6	12	12.58	158.25	21.99

Table 6: Final MSEs

All Runs	Training Standard Deviation
Average of Final MSEs	0.00660476

V. CONCLUSION

An experiments was carried out to establish the relationship between process variables and optimization tools are used to find an optimal solution. It is observed that the developed of model is a powerful tool in experimental welding optimization, even when experimenter does not have to model the process. Modular network model predicts accurately and corresponding sensitivity analysis revels that bead width is highly sensitive to welding current, weld reinforcement and bead hardness are sensitive to electrode stick out and depth of penetration is sensitive to welding speed.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

A. Confirmation test for weld bead width

A test sample, having same size and dimension as per earlier specification has been taken and performed welding at the optimum predicted process parameters at path, welding current, 650A, Arc voltage 34V, Welding speed 500mm/min and Electrode stick out 33 mm.Then, measured the weld bead width and found 15.0mm.It is within 95% confidence level.

REFERENCES

1. K. srinivasulu reddy, "Optimization & Prediction of Welding Parameters and Bead Geometry in Submerged Arc Welding", International Journal of Applied Engineering Research and development (IJAERD) ISSN 2250-1584 Vol. 3, Issue 3, Aug 2013.
2. Vukojevic, N., Oruc, M., Vukojevic, D. et al., "Performance analysis of substitution of applied materials using fracturemechanics parameters", Tehnicki vjesnik-Technical Gazette, 17, 3 (2011), pp. 333-340.
3. Younise, B., Rakin, M., Medjo, B., et al.,"Numerical analysis of constraint effect on ductile tearing in strength mismatched welded CCT specimens using micromechanical approach", Tehnicki vjesnik-Technical Gazette, 17, 4(2010), pp. 411- 418.
4. Sharma, A., Chaudhary, A. K., Arora, N., et al.,"Estimation of heat source model parameters for twin- wire submerged Arc welding", International Journal of Advanced Manufacturing Technology, 45, 11-12(2009), pp. 1096-1103.
5. Pillia, K. R., Ghosh, A., Chattopadhyaya, S., Sarkar, P. K., Mukherjee, K.,"Some investigations on the Interactions of the Process Parameters of Submerged Arc Welding", Manufacturing Technology & Research (an International Journal), 3, 1(2007), pp. 57-67.
6. Ghosh, A., Chattopadhyaya, S., Sarkar, P. K.,"Output Response Prediction of SAW Process", Manufacturing Technology & Research (an International Journal), 4, 3(2008), pp. 97-104.
7. Ghosh, A., Chattopadhyaya, S.,"Prediction of Weld Bead Penetration, Transient Temperature Distribution & HAZ width of Submerged Arc Welded Structural Steel Plates", Defect and Diffusion Forum, 316-317(2011), pp. 135-152.
8. S. C. Juang and Y. S. Tarng, Process parameters selection for optimizing the weld pool geometry in the tungsten inert gas welding of stainless steel, J. of Materials Processing Technology, Vol. 122, 2002, 33-37.
9. H. K. Lee, H. S. Han, K. J. Son and S. B. Hong, Optimization of Nd-YAG laser welding parameters for sealing small titanium tube ends, J. of Materials Science and Engineering, Vol. A415, 2006, pp. 149-155.
10. L. K. Pan, C. C. Wang, Y. C. Hsiso and K. C. Ho, Optimization of Nd-YAG laser welding onto magnesium alloy via Taguchi analysis, J. of Optics & Laser Technology, Vol. 37, 2004, pp. 33-42.
11. E. M. Anawa, A. G. Olabi and M. S. J. Hashmi, Optimization of ferritic/Austenitic laser welded components, presented at AMPT2006 Inter. Conf. July 30 – Aug. 3, 2006, Las Vegas, Nevada, USA, 2006.
12. E. M. Anawa and A. G. Olabi, Effect of laser welding conditions on toughness of dissimilar welded components, J. of Applied Mechanics and Materials, Vol. 5-6, 2006, 375-380.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)