

Regression and Variance Analysis of Submerged Arc Welding Parameters based on Taguchi L9 Array

Pradeep deshmkh¹, Prof. S. N. Teli²

¹P. G. Student, Saraswati College of Engineering, KhargharNavi Mumbai
India

p_g_deshmkh@ yahoo.co.in

²Prof. Department of Mechanical Engineering
Saraswati College of Engineering, KhargharNavi Mumbai
India

shivananteli@ yahoo.com

Abstract : 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. Submerged arc welding (SAW) process is an important component in many industrial operations. The research on controlling metal transfer modes in SAW process is essential to high quality welding procedures. Quality has now become an important issue in today's manufacturing world. Experiments are conducted using submerged arc process parameters viz. welding current, arc voltage and welding speed (Trolley speed) on mild steel of 12 mm thickness, to study the effect of these parameters on penetration depth. The experiments are designed using Taguchi method (with Taguchi L9 orthogonal array) considering three factors and three levels.

Key words : Analysis, Welding Parameters, Submerged Arc Welding, Taguchi Method.

INTRODUCTION

Submerged arc welding (SAW) is widely used welding process in most fabrication industries. It requires a non-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. In submerged arc welding (SAW), weld quality is greatly affected by the weld parameters such as welding current, welding speed; arc voltage and electrode stickout since they are closely related to the geometry of weld bead, a relationship which is thought to be complicated because of the non-linear characteristics. However, trial-and-error methods to determine optimal conditions incur considerable time and cost. In order to overcome these problems, non-traditional methods have been suggested. Bead-on-plate welds were carried out on mild

steel plates using semi-automatic SAW machine. Data were collected as per Taguchi's Design of Experiments and analysis of variance (ANOVA) was carried to establish input-output relationships of the process.

In this study, the process parameters affecting weld quality in SAW have been identified and their effects on performance measures have been analysed using an inexpensive and easy-to-operate experimental strategy based on Taguchi's parameter design. Further, an attempt has been made to analyse the impact of more than one parameter on welding in the hardfacing process because the resultant performance output is the combined effect of the impacts of several interacting parameters in actual practice. The experimental strategy has been adapted from the methodology outlined for successful parametric appraisal in other applications.

K. srinivasulureddy [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 Tarn [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. 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 SUBMERGED ARC WELDING PROCESS

Submerged Arc Welding (SAW) involves formation of an arc between a continuously-fed bare wire electrode and the workpiece. The process uses a flux to generate protective gases and slag, and to add alloying elements to the weld pool. A shielding gas is not required. Prior to welding, a thin layer of flux powder is placed on the workpiece surface. The arc moves along the joint line and as it does so, excess flux is recycled via a hopper. Remaining fused slag layers can be easily removed after welding. As the arc is completely covered by the flux layer, heat loss is extremely low. This produces a thermal efficiency as high as 60% (compared with 25% for manual metal arc). There is no visible arc light, welding is spatter-free and there is no need for fume extraction.

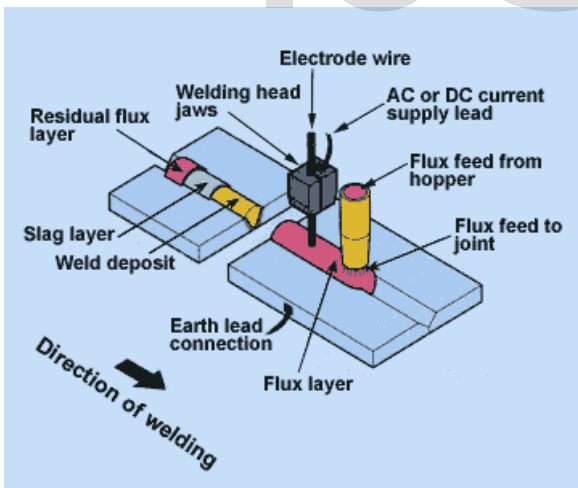


Figure 1: The Submerged Arc Welding Process

Operating Characteristics

SAW is usually operated as a fully-mechanised or automatic process, but it can be semi-automatic. Welding parameters: current, arc voltage and travel speed all affect bead shape, depth of penetration and chemical composition of the deposited weld metal. Because the operator cannot see the weld pool, greater reliance must be placed on parameter settings.



Figure 2: Operating Characteristics

Basic Equipment

Essential equipment components for SAW are:

- power source
- SAW head
- flux handling
- protective equipment

As SAW is a high current welding process, the equipment is designed to produce high deposition rates.



Figure 3 : SAW welding machine used for experimentation

Process Parameters

- Welding current
- Arc Voltage
- Speed of Arc travel
- Electrode Stick Out

Welding Current-

controls the melting rate of the electrode and thereby the weld deposition rate, the depth of penetration and thereby the extent of dilution of the weld metal by the base metal.

- Too high current- cause excessive weld reinforcements, burn through, high narrow bead and undercut

- LOW current cause unstable arc, inadequate penetration and overlapping

Arc 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, but it determines the profiles and surface appearance of the weld bead.

- Increasing voltage produces flatter and wider bead, increases flux consumption , increases resistance to porosity

caused by rust or scale and increases pickup of alloy from flux.

- Excessively high voltage- Produces poor slag removal in groove welds, in multiple-pass welds, increases the normal alloy pickup from flux and produces a hat-shaped bead that is subject to cracking
- Low voltage produces a stiffer arc needed for getting penetration in a deep groove and to resist arc blow on high speed and a high, narrow bead with poor slag removal.

Speed of Arc Travel-

For a given combination of welding current and voltage

- Increase in the welding speed results in lesser penetration, lesser weld reinforcement and lower Heat input
- Excessively high travel speed results in decrease fusion between the weld and base metal, increase tendencies for under cut Arc blow, porosity and slag, and irregular bead shape
- Decrease Travel speed increase penetration and weld reinforcement
- Too slow a speed results in poor penetration, because the weld puddle is directly under the electrode tip and the force of the arc is cushioned by the weld puddle, produce convex bead shape, arc burn and increasing weld size.

Electrode Stick Out

Refers to the length of the electrode between the end of contact tube and the arc.

Longer the stick-out results in greater amount of heating and the higher the deposition rate, it also reduces to some extent the energy supplied to the arc, resulting in lower arc voltage and a different bead shape, and decrease penetration.

Shorter The stick-out results in Arc Burn, Nozzle melts (Cu Entrapped- It cause crack), and Under Cut.

TAGUCHI METHOD

Dr. Genichi Taguchi is regarded as the foremost proponent of robust parameter design, which is an engineering method for product or process design that focuses on minimizing variation and/or sensitivity to noise. When used properly, Taguchi designs provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions. In robust parameter design, the primary goal is to find factor settings that minimize response variation, while adjusting (or keeping) the process on target. When the factors affecting variation have been determined, it could be used to find settings for controllable factors that will either reduce the variation, make the product insensitive to changes in uncontrollable (noise) factors, or both. A process designed with this goal will produce more consistent output.

A product designed with this goal will deliver more consistent performance regardless of the environment in which it is used. Engineering knowledge should guide the selection of factors and responses.

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:

- A basis for determining the functional relationship between controllable product design factors and the outcomes of a process.
- A method for adjusting the mean of a process by optimizing controllable variables.
- 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.

Process flow

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.

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. Levels of process parameters identified are shown in Table 1. 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 size 1200mm (length) X 1250 mm (width) X 12 mm (thickness) with a V angle of 30° to 45°, 4 mm root height and

0.75 mm gap between the two plates. Copper coated Electrode Auto melt EH-14 wire size: 3.20 mm diameter, of coil form and basic fluoride type granular flux were used. Text Font of Entire Document The entire document should be in Times New Roman or Times font. Other font types may be used if needed for special purposes. Recommended font sizes are shown in Table 1.

Table I: Welding parameters with different levels for 6 mm pipe

S.N.	Welding Current (amp)	Arc Voltage (volts)	Welding Speed (mm/min)	Electrode stickout (mm)
Level -1	500	31	900	31
Level -2	525	32	915	32
Level-3	535	33	928	30

The loss function of the higher the better quality characteristic can be expressed as:

Higher the better

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

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. 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 expressed as

$$\eta = -10 \log_{10}(MSD) \dots \dots \dots (2)$$

for higher is better characteristic.

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 5.

A. L9 3 Level Taguchi Orthogonal Array

Taguchi's orthogonal design uses a special set of predefined arrays called orthogonal arrays (OAs) to design the plan of experiment. These standard arrays stipulate the way of full information of all the factors that affects the process performance (process responses). The corresponding OA is selected from the set of predefined OAs according to the number of factors and their levels that will be used in the experiment. Below Table No.2 shows L9 Orthogonal array.

Table II: Experimental layout using L9 orthogonal array

Trial No.	Welding Current	Arc Voltage	Welding Speed	Electrode Stick Out
1	1	1	1	1
2	1	2	2	3
3	1	3	3	2
4	2	1	2	3
5	2	2	3	2
6	2	3	1	1
7	3	1	3	2
8	3	2	2	1

9	3	3	1	3
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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:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + \dots \dots \dots + b_kX_k \dots \dots \dots (3)$$

Where Y is the dependent variable, which is to be predicted; $X_1, X_2, X_3, \dots, X_k$ are the known variables on which the predictions are to be made and $a, b_1, b_2, b_3, \dots, b_k$ 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, flux and Wire has been measured with the help of a measuring scale.

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 9 data sets, 9 data sets are used to train the network as given in Table 3.

Table III: Training data sets

S.N.	Welding Current (amp)	Arc Voltage (volts)	Welding Speed (mm/min)	Electrode stick out (mm)	Bead Width (mm)	Flux kg/m	Wire Kg/m
1	500	31	900	31	8	0.22	0.18
2	500	32	915	32	8	0.22	0.18
3	500	33	928	30	9	0.23	0.19
4	525	31	915	30	8	0.24	0.20
5	525	32	928	31	9	0.24	0.20
6	525	33	900	32	9	0.24	0.22
7	535	31	928	32	10	0.28	0.26
8	535	32	900	30	9	0.26	0.25

9	535	33	915	31	10	0.28	0.26
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Multiple regression analysis has been used to determine the relationship between the dependent variables of bead width , Flux and Wire with welding current, arc voltage, welding speed, and electrode stick out. The regression analysis of the input parameters is expressed in linear equation as follows:

The regression equations are

$$\text{Bead Width (mm)} = - 45.5 + 0.0333 \text{ Welding Current (amp)} + 0.333 \text{ Arc Voltage (volts)} + 0.0232 \text{ Welding Speed (mm/min)} + 0.167 \text{ Electrode stickout (mm)}$$

$$\text{Flux kg/m} = - 0.855 + 0.00128 \text{ Welding Current (amp)} + 0.00167 \text{ Arc Voltage (volts)} + 0.000359 \text{ Welding Speed (mm/min)} + 0.00167 \text{ Electrode stickout (mm)}$$

$$\text{Wire Kg/m} = - 1.02 + 0.00187 \text{ Welding Current (amp)} + 0.00500 \text{ Arc Voltage (volts)} - 0.000006 \text{ Welding Speed (mm/min)} + 0.00333 \text{ Electrode stickout (mm)}$$

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	3.6342	0.9086	2.90	0.164
Residual Error	4	1.2547	0.3137		
Total	8	4.8889			

Source	DF	Seq SS
Welding Current (amp)	1	2.1667
Arc Voltage (volts)	1	0.6667
Welding Speed (mm/min)	1	0.6342
Electrode stickout (mm)	1	0.1667

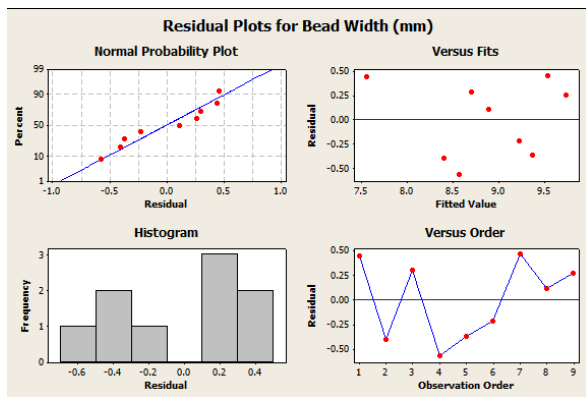


Figure 3:Residual Plots for Bead Width (mm)

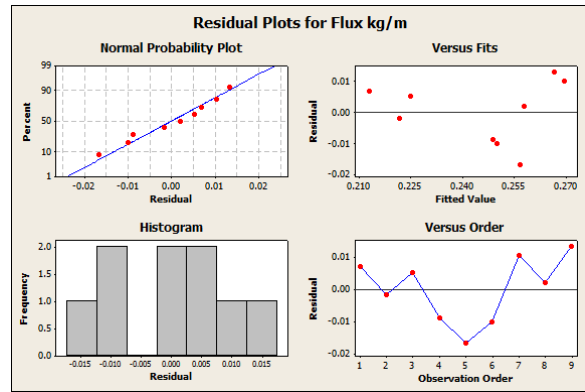


Figure 3:Residual Plots for Flux kg/m

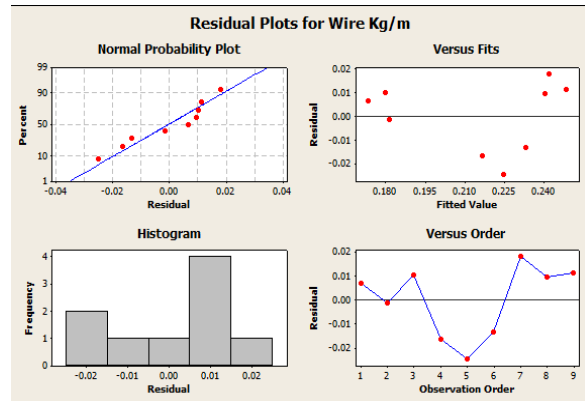


Figure 3:Residual Plots for Wire Kg/m

CONCLUSION

The present study was carried out to study the effect of four input parameters on the weld bead geometry in the submerged arc welding process. These parameters (current, voltage, welding speed and electrode stick out) were varied at different levels in the range available on the machine to optimize the process parameters. The following conclusions have been drawn from the study

- The weld bead geometry is mainly affected by current and voltage.
- It was predicted that for 6 mm thickness pipe, the optimum level parameters for achieving optimum quantity of flux and wire can be achieved if the path A1-B1-C2-D3 is followed: [Welding current (A1) 500A, Arc voltage (B1) 31V, Welding speed (C2) 915 mm/min, electrode stick out (D3) 30 mm].
- The required quantity of flux and wire is mainly affected by welding current.

FUTURE SCOPE

Future investigation is needed to explore more numbers of parameters and operating conditions to develop a general model by using combination of design of experiment techniques and Taguchi method. A combination of both Taguchi and DOE techniques can be used in order to achieve a higher level of verification and to reduce the cost of necessary experimental effort. The basic consumables for submerged arc welding process are welding wires and fluxes. The quantities of consumption needs to be optimized for further reduction in the cost of manufacturing SAW pipes.

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