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Optimization of Various Parameters of SMAW by Using Taguchi Method

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Abstract: *The SMAW is the most widely used welding process in the small scale industries, because of its low cost, flexibility, portability and versatility. The SMAW welding parameter are the most important factor affecting the quality, productivity and cost of welding. In this, the optimization of SMAW process parameters namely; welding current, welding speed and electrode angle considered for experimentation which is based on design of experiment (DOE) using Taguchi Method. An orthogonal array of L9 experimental design was adopted and ultimate tensile strength is to be find out for each experimental run. The tensile test will be carry out on extracted welded specimens using UTM. In addition the analysis of variance (ANOVA) will also apply to identify the most significant factor. For optimization of this parameter we will consider Mild Steel as a work material.*

***Index Terms**: Electrode, Ultimate Tensile Strength, DOE, Orthogonal Array, ANOVA*

I. Introduction

Welding is a fabrication or sculptural process that joins materials usually metals or thermoplastics, by using high heat to melt the parts together and allowing them to cool causing fusion. Welding is distinct from lower temperature metal-joining techniques such as brazing and soldering, which do not melt the base metal. In addition to melting the base metal, a filler material is typically added to the joint to form a pool of molten material (the weld pool) that cools to form a joint that, based on weld configuration (butt, full penetration, fillet, etc.), can be stronger than the base material (parent metal). Pressure may also be used in conjunction with heat, or by itself, to produce a weld. Welding also requires a form of shield to protect the filler metals or melted metals from being contaminated or oxidized. Many different energy sources can be used for welding, including a gas flame (chemical), an electric arc (electrical), a laser, an electron beam, friction, and ultrasound. While often an industrial process, welding may be performed in many different environments, including in open air, under water, and in outer space. Welding is a hazardous undertaking and precautions are required to avoid burns, electric shock, vision damage, inhalation of poisonous gases and fumes, and exposure to intense ultraviolet radiation. In this method, welding parameters are the most important factors affecting thE quality, productivity and cost of welding joint. Accordingly these parameters affecting the arc and welding bath should be estimated and their changing conditions during process must be known before in order to obtain optimum results. In an effort to obtain high quality welds in shielded metal arc welding method, selection of ideal parameters should be performed according to engineering facts. Commonly, welding parameters are determined by trial and error, based on handbook values, and manufacturers' recommendations. On the other hand, this option may not yield optimal or in the vicinity of optimal welding performance.

In shielded metal arc welding method, the electrodes are coated with a shielding flux of a suitable composition. The flux melts together with the electrode metallic core, forming a gas and a slag, shielding the arc and the weld pool. The flux cleans the metal surface, supplies some alloying elements to the weld, protects the molten metal from oxidation and stabilizes the arc. The slag is removed after Solidification. Figure shows a schematic image of shielded metal arc welding. As seen in this figure, process consists of electrode and its coating, arc formation, protecting gas, weld pool and solidified weld.

To determine the welding parameters, the national and international welding standards and also welding experience in application are taken into consideration for shielded metal arc welding method.

Equipment's used in SMAW are-

a) Power Supply or Power Source (AC or DC)
b) Electrodes
c) Electrode Holder
d) Cables
e) Clamps

1.1 OBJECTIVES

1. To optimize the welding parameters of Shielded Metal Arc Welding.
2 .To obtain maximum tensile strength of welded joint.
3. To determine the effect of following parameters on tensile strength of welded joint.
a. Welding Current
b. Groove Angle
c. Electrode Angle
4. To determine the fundamentals of Shielded Metal Arc Welding (SMAW).

II. Determination Of Shielded Metal Arc Welding Parameters

Experiments have been conducted for various welding process parameters like welding current, electrode angle and groove angle to obtain bead-on-plate welding SMAW process. Three values are taken for each parameter.

1. Welding Current

During the welding, that is, while arc occurs in welding period, current against working voltage is called as welding current. Welding machine is plugged into the alternative current and poles are determined. Welding current is set by welders prior to welding application. During the welding application, the value of welding current is not changed. However, arc is cut or current can be increased depending on welding application. For conducting experiment we have selected current range as 150,160,170 amp.

2. Groove Angle

Groove angle play an important role in improving tensile strength while keeping ductility at relatively high level. The right choice of groove angle help to obtain a weld with tough structure. For conducting experiment we have selected the groove angle as 50,60,70 deg.

3. Electrode Angle

The molten metal can be transferred by arc along the welding process and the welder should orientate the arc to form melting on joining surfaces. The angle between electrode and advance direction is generally 45 to 70°, however this value can also be changed between 45to 90°. The parameter of oscillation angle directly affects the surface width of weld seam. If oscillation angle rises, the width of seam increases, when it decreases seam width lowers. Width changes depending on electrode core diameter (Welding seam width = d × 2.5 tolerance 20%).For our experiments we have selected as 40,50,60 de

2.1 MATERIAL

The base material used for this study is Mild Steel. Mild steels are generally those steels that have low carbon contents and are the most readily weldable. In mild steel there are two types as low carbon steels and the high strength structural steels.

We have used Mild Steel rod of dimension (16mm diameter and 250mm length). The chemical compositions of the mild steel rod IS 2062 and the welding consumable used for SMAW is E6013, size of the electrode of 3.5 mm is used.

2.2 METHOD USED FOR OPTIMIZATION

A.Taguchi Method

Taguchi methods are statistical methods developed by Genichi Taguchi to improve the quality of manufactured goods and more recently also applied to engineering. Taguchi's techniques have been used widely in engineering design. The Taguchi method contains system design, parameter design, and tolerance design procedures to achieve a robust process and result for the best product quality. The main trust of Taguchi's techniques is the use of parameter design, which is an engineering method for product or process design that focuses on determining the parameter (factor) settings producing the best levels of a quality characteristic (performance measure) with minimum variation. Taguchi designs provide a powerful and efficient method for designing processes that operate consistently and optimally over a variety of conditions. To determine the best design, it requires the use of a strategically designed experiment, which exposes the process to various levels of design parameters. Experimental design methods were developed in the early years of 20th century and have been extensively studied by statisticians since then, but they were not easy to use by practitioners.

Taguchi specified three situations-

1. Larger the better (for example, agricultural yield)
2. Smaller the better (for example, carbon dioxide emissions)
3. On-target, minimum-variation (for example, a mating part in an assembly)

III. Experimental Procedure

The project work has been completed by several activities in a sequential way. First of all information about material, electrodes, welding parameters and details about SMAW process has been gathered. This information has been gathered from the several books, previous year thesis paper and also from various sites in internet. After gathering information about SMAW process, appropriate data is selected and welding has been performed.

In this study, the SMAW process is done on (16mm diameter and 250mm length) mild steel rod. The experimental setup of the work piece for SMAW process is shown in Fig.2. The chemical compositions of the mild steel rod IS 2062 and the welding consumable used for SMAW is E6013, size of the electrode of 3.5 mm is used. In this section, the use of grey based Taguchi method to determine the welding process parameters are reported. Optimal welding process parameters with considerations of the multiple performance characteristics are obtained and verified.

A.L9 Orthogonal array experiment

In the present study, the interaction between the welding process parameters is neglected. The degrees of freedom required for the study is six and Taguchi's L9 orthogonal array is used to define the nine trial conditions. The Experimental layout for the welding process parameters using L9 orthogonal array is shown in Table 1.

Trial No.	Welding Current(I)	Groove Angle (φ)	Electrode Angle(θ)
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

Table 1. L9 Orthogonal Array

3.1 SAMPLE PREPARATION

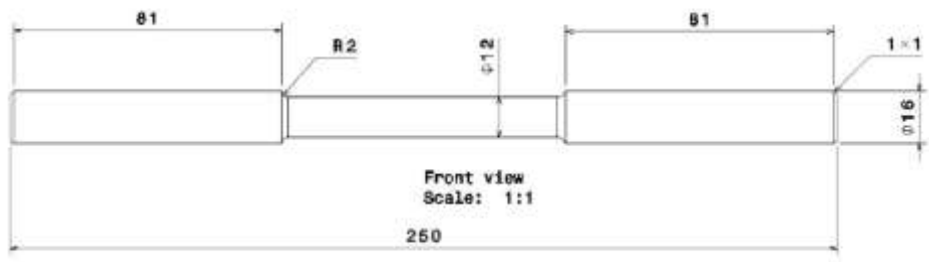

Fig.1

Nine Mild Steel Rod have been selected (250mm length &16mm dia.) for the experiment as shown in Fig.1. Fillets are provided at the central portion to reduce stress concentration which can be induced during Tensile Test. Knurling is also provided at the ends of the rod for proper grip, while performing UTM operation. The mild steel specimens were taken as the base metal upon which the hard facing material has been deposited by SMAW welding.

Experiments have been conducted for various welding process parameters like welding current, electrode angle and groove angle to obtain bead-on-plate welding SMAW process. Three values are taken for each parameter. The welding current is varied as 150,160 and 170 amps respectively. Similarly electrode angle is varied as 40, 50 and 60 and the groove angle is varied as 50, 60 and 70 respectively. The process parameters and levels are listed in Table.2.

Sr. No	Parameters	Notation	Unit	Level 1	Level 2	Level 3
1	Welding current	I	Amp	150	160	170
2	Groove Angle	Φ	Deg.	50	60	70
3	Electrode Angle	θ	Deg.	40	50	60

Table No. 2 Welding Parameters

Taguchi's parameter design is an important tool for robust design. Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The methodology of Taguchi for three factors at three levels is used for the implementation of the plan of experiments. Nine experiments are carried out based on the L9 orthogonal array. Only the main effects are of interest and factor interactions are not studied. The Experiments are conducted as per the setting discuss in Orthogonal array. Each experiment are conducted thrice to nullify the effect of error. The experiment is done like the welding current is set at 150 amp, groove angle is at 50 deg. And electrode angle is at 40 deg. By setting this parameters welding has been done on each specimen. All prepared samples are shown in Img.1

Img.1 Prepared Sample

3.2 TESTING

The tensile strength of specimens is calculated after testing it on servo hydraulic UTM machine having 40 Tones of capacity. The Taguchi method is used to measure the quality characteristics deviating from desired values. All the calculations are obtain from Minitab 18 software differs for different quality characteristics.

Img.2

After conducting experiment on each specimen it is observed that all the specimens are fails at weld section because it is weaker than base metal. All the tested specimens are shown in Img.3.

Img.3 Tested Specimens

IV. Results

4. RESULT

4.1 Taguchi Design

Design summary

Taguchi Array: L9(3^3)

Factors: 3

Runs: 9

Columns of L9 (3^4) array: 1 2 3

- **Taguchi Analysis for Ultimate Tensile Strength**

Readings obtained from tensile test carried on servo hydraulic UTM machine for Ultimate Tensile Strength are given in table:

Sample No.	Current (Amp) (I)	Groove Angle (□)	Electrode Angle (□)	Experimental Tensile strength (MPa)
1	150	50	40	343.4
2	150	60	50	334.3
3	150	70	60	330.9
4	160	50	50	346.5
5	160	60	60	322.5
6	160	70	40	319.3
7	170	50	60	315
8	170	60	40	312.4
9	170	70	50	304.5

Table No.3 Taguchi Analysis for Ultimate Tensile Strength

Ultimate Tensile Strength versus Current

From experimental data it is noticed that at low current such as at 150 A current the strength of joints are relatively low. By increase of current the strength of joints improves but again it starts to fall if the current is further increased. This is because, at low current supply the fusion doesn't occur properly. In complete fusion fails to produce sufficient heat to melt the filler metal properly thus the joints remains weak. During high current supply excessive heat is produced. This excessive heat causes void, crack formation and partially spurt out molten metal. Thus the strength of the joint decreases. From above graph it is seen that as current increases from 150 A to 160 A, tensile strength increases. But when current is increased from 160 A to 170 A, tensile strength decreases.

Ultimate Tensile strength versus Groove Angle

Groove angle play an important role in improving tensile strength while keeping ductility at relatively high level. The right choice of groove angle help to obtain a weld with tough structure. From above graph it is seen that as groove angle increases from 50^o to 60^o and from 60^o to 70^o tensile strength goes on decreasing.

Ultimate Tensile Strength versus Electrode Angle

The molten metal can be transferred by arc along the welding process and the welder should orientate the arc to form melting on joining surfaces. If oscillation angle rises, the width of seam increases, when it decreases seam width lowers. A plain welding seam is obtained if electrode moves in horizontal position, but if we move the electrode in various shapes, welding seam displays changeability. The important point here is keeping the hand movements of electrode as much as same of each other. This can be obtained as a result of developing the hand experience after for a while welding practice. While performing welding of samples electrode is moved steadily without doing any action to right or left. From above graph it is seen that as electrode angle increases from 40^o to 50^o, tensile strength increases. But when electrode angle is increased from 50^o to 60^o, tensile strength decreases.

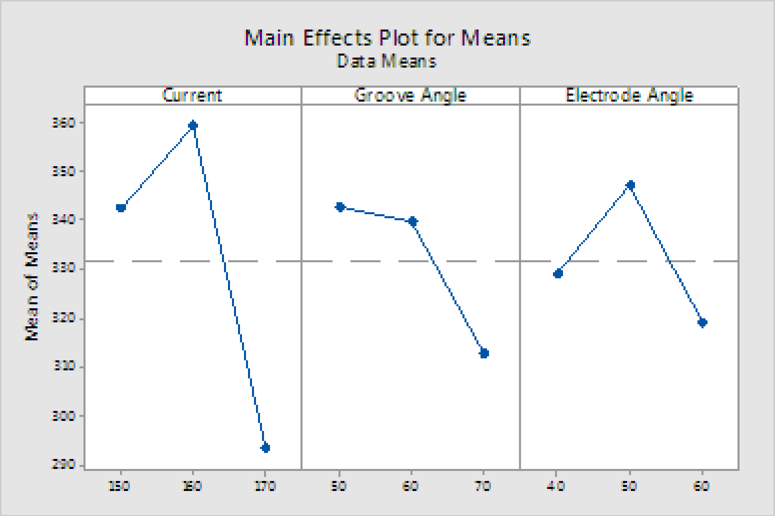

Fig. Graph For Ultimate Tensile Strength

REGRESSION ANALYSIS:

For Ultimate Tensile Strength versus Current, Groove Angle, Electrode Angle.

Regression Equation:-

Ultimate Tensile Strength = 840 – 2.45 X – 1.50 Y - 0.50 Z

Coefficients:-
X = Current
Y = Groove Angle
Z = Electrode Angle

Sample No.	Current (Amp) (I)	Groove Angle (□)	Electrode Angle (□)	Experimental Ultimate Tensile Strength (MPa)	Predicted Ultimate Tensile Strength (Mpa)
1	150	50	40	343.4	377.5
2	150	60	50	334.3	357.5
3	150	70	60	330.9	337.5
4	160	50	50	346.5	348
5	160	60	60	322.5	328
6	160	70	40	319.3	323
7	170	50	60	315	318.5
8	170	60	40	312.4	313.5
9	170	70	50	304.5	293.5

Table No.4 Regression Analysis for Ultimate Tensile Strengt

- **Taguchi Analysis for Elongation**

Readings obtained from tensile test carried on servo hydraulic UTM machine for elongation of test specimen are given in table:

Sample No.	Current (Amp) (I)	Groove Angle (□)	Electrode Angle (□)	Elongation (□) (mm)
1	150	50	40	2.5
2	150	60	50	2.9

3	150	70	60	1.6
4	160	50	50	2.8
5	160	60	60	2.6
6	160	70	40	2.1
7	170	50	60	1.64
8	170	60	40	1.2
9	170	70	50	1.4

Table No.4.3 Taguchi Analysis for Elongation

Elongation versus Current

From above graph it is seen that as current increases from 150 A to 160 A, elongation increases. But when current is increased from 160 A to 170 A, elongation decreases

Elongation VS Grove Angle

Groove angle play an important role in keeping ductility at relatively high level.
From above graph it is seen that as groove angle increases from 50o to 60o and from 60o to 70o elongation goes on decreasing.

Elongation versus Electrode Angle

From above graph it is seen that as electrode angle increases from 40o to 50o, elongation increases. But when electrode angle is increased from 50o to 60o, elongation decreases.

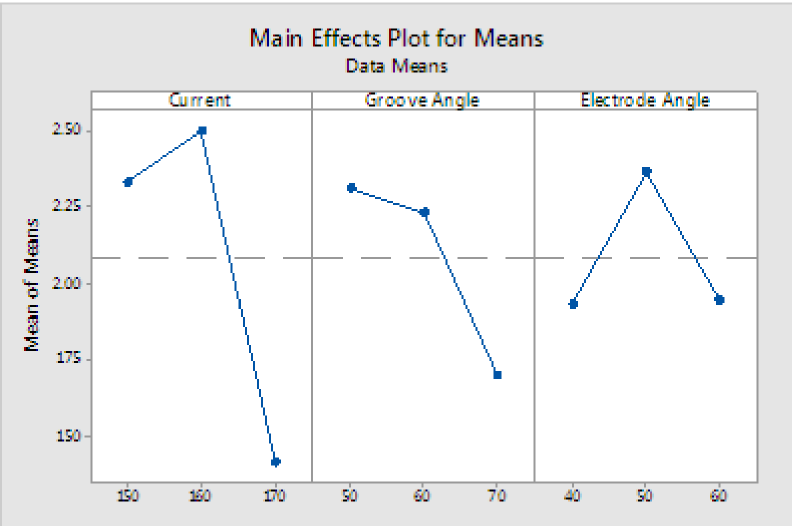

Fig. Graph For Elongation

- **Regression Analysis:**

  For Elongation versus Current, Groove Angle, Electrode Angle

Regression Equation

$$\text{Elongation} = 11.25 - 0.0460\,X - 0.0307\,Y + 0.0007\,Z$$

Coefficients
X = Current
Y = Groove Angle
Z = Electrode Angle

Sample No.	Current (Amp) (I)	Groove Angle (□)	Electrode Angle (□)	Experimental Elongation (□) (mm)	Predicted Elongation (□) (mm)
1	150	50	40	2.69	2.84
2	150	60	50	2.45	2.54
3	150	70	60	2.20	2.24
4	160	50	50	2.32	2.39

5	160	60	60	2.1	2.09
6	160	70	40	1.50	1.76
7	170	50	60	1.80	1.93
8	170	60	40	1.59	1.61
9	170	70	50	1.29	1.31

Table No. 4.4 Regression Analysis for Elongation

VALIDATION

Once the optimal level of the process parameters are selected, the final step is to predict and verify the improvement of the performance characteristics using the optimal level of the input parameters. Below tables shows the % error of experimental validation of the developed models for the responses with parametric setting.

Welding parameters for Experimental Validation			
Sr. No.	Welding Current	Groove Angle	Electrode Angle
1	155	50	45

Table No.5.1 Welding parameters for Experimental Validation

For Ultimate Tensile Strength			
Sr. No.	Predicted	Experimental	% Error
1	362.75	351.06	3.22

Table No.5.2 Validation of Ultimate Tensile Strength

For Elongation			
Sr. No.	Predicted	Experimental	% Error
1	2.61	2.47	5.40

Table No.5.3 Validation of Elongation

From the analysis of this table, it can be observed that the calculated error is small. The small percentage error between experimental and predicted values for Ultimate Tensile Strength and Elongation is 3.22 and 5.40 respectively.

V. Conclusion

In this study, the effects of experimental parameters namely Welding Current, Groove Angle and Electrode Angle on Ultimate Tensile Strength and Elongation are investigated experimentally and statistically by using Taguchi Technique. By using Taguchi method, optimization of welding process parameters for Shielded Metal Arc Welding is achieved. Taguchi method also help in reducing the number of samples and experiments to be performed.The regression models for quality of SMAW were developed to evaluate the relationship of welding process parameters to ultimate tensile strength and elongation. Through these models, any experimental results of the measured response data with any combination of SMAW process parameters can be estimated. By this project work it has been observed that without changing the machineries, only optimizing the welding current it is possible to get good quality of welding.

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