Parametric Optimization of Shielded Metal Arc Welding Processes by Using Factorial Design Approach

Rajeev Ranjan

Assistant Professor, Department of Mechanical Engineering, Haldia Institute of Technology, Haldia-721657, India

Abstract- The Shielded Metal Arc Welding (SMAW) process is an arc welding process which produces coalescence of metal by heating them with an arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering. Pressure is not used. Filler metal is obtained from the electrode. The prediction of the optimal weld deposit area is an important aspect in shielded metal arc welding (SMAW) process as it is related to the strength of the weld. The goal of this research work is to optimize various parameters for Shielded Metal Arc Welding process, including welding voltage, welding current and welding speed by developing a mathematical model for sound weld deposit area of a mild steel specimen. Factorial design approach has been applied for finding the relationship between the various process parameters and weld deposit area. The study revealed that the weld deposit area varies directly with welding voltage and welding current and inverse relationship is found between welding speeds with weld deposit area.

Index Terms- Arc Welding; shielding gases; Shielded Metal Arc Welding; Factorial Design Approach; Weld Deposit Area.

I. INTRODUCTION

Welding is a process of joining different materials. It is more economical and is a much faster process compared to both casting and riveting [1]. The weld deposition area is the maximum area of the weld metal deposited. It influences the flux consumption rate and chemistry of the weld metal and hence determines the mechanical properties of the weld [2]. SMAW input process parameters like welding current, welding speed; open circuit voltage and external magnetic field are highly influencing the quality of weld joints. [3]. A precise means of selection of the process variables and control of weld bead shape has become essential because mechanical strength of weld is influenced not only by the composition of the metal, but also by the weld bead shape. The weld bead width is an important factor of the shape of the weld. The weld quality can be achieved by meeting quality requirements such as bead geometry which is highly influenced by various process parameters involved in the process. Inadequate weld bead dimensions will contribute to failure of the welded structure [4]. Among all the welding processes, SMAW is very important. The advantages of this method are that it is the simplest of the all arc welding processes. The equipment is often small in size and can be easily shifted from one place to the other. Cost of the equipment is very less. This process finds a number of applications because of the availability of a wide variety of electrodes which makes it possible to weld a number of metals and their alloys. The welding of the joints may be carried out in any position with highest weld quality and therefore the joints which are difficult to be welded because of their position by automatic welding machines can be easily welded by shielded metal arc welding. Both alternating and direct current power sources could be used effectively. Power sources for this type of welding could be plugged into domestic single phase electric supply, which makes it popular with fabrications of smaller sizes [5]. However, non equilibrium heating and cooling of the weld pool can produce micro-structural changes which may greatly affect mechanical properties of weld metal. To get the desired weld quality in SMAW process, it is essential to know interrelationships between process parameters and bead geometry as a welding quality. Many efforts have been done to develop the analytical and numerical models to study these relationships, but it was not an easy task because there were some unknown, nonlinear process parameters. For this reason, it is good for solving this problem by the experimental models. These results showed that arc current has the greatest influence on bead geometry, and that mathematical models derived from experimental results can be used to predict bead width accurately. Nearly 90% of welding in world is carried out by one or the other arc welding process; therefore it is imperative to discuss the effects of welding parameters on the weldability of the materials during the arc welding. Mild steel was selected for work-pieces to be welded because it is the most common form of steel as its price is relatively low while it provides material properties which are acceptable for many applications.

II. FACTORIAL DESIGN APPROACH AND TERMINOLOGY

Factorial design approach permits to evaluate the combined effect of two or more experimental variables when evaluated simultaneously. Result obtained from factorial design approach is more accurate than those obtained from a series of single factor design approach, in the sense that factorial design method permits the evaluation of interaction effects. An interaction effect is an effect attributable to the combination of all considered variables which can be predicted from the variables considered separately.

For the need of factorial design, the information gathered experimentally could be used to make decisions, which have a broad range of applicability. In addition to information about how the experimental variables operate in relative isolation, it can be predicted, what will happen when two or more variables are used in combination.

In this approach factors may be classified as treatment and classification factors.

- Classification factors group the experimental units into classes which are homogeneous with respect to what is being classified.
- Treatment factors define experimental conditions applied to an experimental unit.

The administration of the treatment factors is under the direct control of the examiner, where as classification factors are not, in sense.

The effects of the treatment factors are of primary interest to the examiner, where as classification methods are included in an experiment to reduce experimental error and clarify interpretation of the effects of the treatment factors.

The design of factorial experiments is concerned with answering the following questions:

- What factors should be included?
- How many levels of each factor should be included?
- How should the levels of the factors be spaced?
- How many experimental units should be selected for each treatment conditions?
- Can the effects of primary interests be estimated adequately from the experimental data that will be obtained?

A factor is a series of related treatments or related classifications. The related treatments making a factor constitute the levels of that factor. The number of levels within a factor is determined largely by the thoroughness with which an experimental desires to investigate the factor.

The dimensions of a factorial experiment are indicated by the number of levels of each factor. For the case of p*q factorial experiment, PQ different treatment combinations are possible. As number of factors increase, or as the number of levels within a factor increases, the number of treatment combinations in a factorial experiment increases quite rapidly. In an experiment, the elements observed under each of the treatment combinations will generally be a random sample from some specified population. This population may contain potentially infinite number of elements. If n elements are to be observed under each of treatment combination in p*q factorial experiment, a random sample of npq elements from population is required. The npq elements are then subdivide at random to the treatment combinations. The P potential levels may be grouped in to P levels (p<q) by either combining adjoining levels or deliberately selecting what are considered to be representative levels. When p = P then the factor is called the fixed factor. When the selection of the p levels from the potential P levels is determined by some systematic, non-random procedure, then also the factor is considered a fixed factor. In this later case, the selection procedure, reduce the potential P levels to p effective levels .Under this type of selection procedure, the effective, potential number of levels of factor in the population may be designated as P effective and P effective = p. In contrast to this systematic selection procedure, if the p levels of factor A included in the experiment represents a random sample from the potential p levels, then the factor is considered to be random factor. In most practical situations in which random factors are encountered, p is quite small to relative to P, and the ratio p/P is quite close to zero. The ratio of the number of levels of a factor in an experiment to the potential number of levels in the population is called the sampling fraction for a factor. In term of this sampling fraction, the definition of fixed and random factors may be summarized as mentioned in Table 1.

Table1. Relationship between Sampling Fraction and Fixed Random Factors

Sampling fraction	Factor
p/P or p/P effective =1	A is a fixed factor
p/P = 0	A is a random factor

Cases in which the sampling fraction assumes a value between 0 and 1 do occur in practice. However, cases in which sampling fraction is either 1 or very close to 0 encountered more frequently. Main effects are defined in terms of parameters. Direct estimates of these parameters will be obtainable for corresponding statistics. The main effect for the level is the difference between the mean of all potential observations on the dependent variable at the level and grand mean of all potential observations. The interaction between different levels is a measure of the extent to which the criterion mean for treatment combination cannot be predicted from the sum of the corresponding main effects. From many points of views, the interaction is a measure of the non-addivity of the main effects. To some extent the existence or non-existence of interaction depends upon the scale of measurement. For example, the interaction may not be present in terms of a logarithmic scale of measurement, whereas in terms of some other scale of measurement an interaction may be present. If alternative choices are present, then that scales which leads to the simplest additive model will generally provide the most complete and adequate summary of the experimental data.

III. METHODOLOGY

For this research work, after conducting the related literature survey we found that the among the most important parameters were welding voltage, welding current ,and welding speed. So these three variables were used as treatment variables for the model.

3.1 Treatment Variables:

- Welding Voltage (V)
- Welding Current (I)
- welding Speed (S)

For conducting trial runs values or levels of these variables were chosen randomly from an infinite potential level i.e. the sampling fraction for these trials runs was equal to zero, however, we got a rough range of these factors from the literature we surveyed. With the help of these trials runs effective, representative's levels were developed for each factor (variables). The numbers of levels to be included in the experiment were chosen for each factor as per the design. These numbers of levels were two for each so as per the definition it is a 2^n (=2*2*2) factorial experiment. Where n is number of factors. If full factorial approach had been practiced, the number treatment combination would have been 8. The levels for each factor were the highest value and the lowest value of the factors in between and at which the outcome was acceptable. These values were outcomes of trials runs. Highest value has been represented by '+' and the lowest value has been represented by '-' as mentioned in Table 2. As per the design matrix the final runs were conducted and the response i.e. the weld deposit area was measured and noted down against each combination. Then the values of different coefficients were calculated as per the modeling. These values of coefficients represent the significance of corresponding factors (variable) on the response.

3.2 Design Matrix:

Table2. Model showing the treatment variables

S. No.	Voltage (V) X_1	Current (I) X_2	Speed (S) X_3
1.	+	+	+
2.	-	+	+
3.	+	-	+
4.	-	-	+
5.	+	+	-
6.	-	+	-
7.	+	-	-
8.	-	-	-

IV. . MATHEMATICAL MODEL DEVELOPED

Assuming the values of responses as y_1, y_2, y_3, y_4, y_5, y_6, y_7, y_8 against the treatment combinations 1, 2, 3, 4, 5, 6, 7, 8 respectively (as per the S. No. in the matrix design) Y as the optimized value of response (i.e. left hand side in the equation used for the showing the relation among the factors and the response). Relation between main effects interactions effects and the response has been shown in the following equation:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}(X_1X_2) + b_{13}(X_1X_3) + b_{23}(X_2X_3)$$

Here Y is the optimized weld deposit area, y_i (i = 1 to 8) is the response of the ith treatment combination, b_0 is the mean of all the responses, b_j (j =1 to 3) is the coefficient of jth main factor (j = 1 for voltage, 2 for current, 3 for speed), and b_{jk} (j, k=1 to 3) is the coefficient for interaction factor. Values of all these coefficients were calculated as followings:

$b_0 = \Sigma y_i / 8 = [(y_1+y_2+y_3+y_4+y_5+y_6+y_7+y_8)]/8$

$b_1 = [(y_1-y_2+y_3-y_4+y_5-y_6+y_7-y_8)]/8 = [(y_1+y_3+y_5+y_7)-(y_2+y_4+y_6+y_8)]/8$

$b_2 = [(y_1+y_2-y_3-y_4+y_5+y_6-y_7-y_8)]/8 = [(y_1+y_2+y_5+y_6) - (y_3+y_4+y_7+y_8)]/8$

$b_3 = [(y_1+y_2+y_3+y_4-y_5-y_6-y_7-y_8)]/8 = [(y_1+y_2+y_3+y_4) - (y_5+y_6+y_7+y_8)]/8$

$b_{12} = [(y_1-y_2+y_3+y_4+y_5+y_6+y_7+y_8)]/8 = [(y_1+y_4+y_5+y_8) - (y_2+y_3+y_6+y_7)]/8$

$b_{13} = [(y_1-y_2+y_3-y_4-y_5+y_6-y_7+y_8)]/8 = [(y_1+y_3+y_6+y_8) - (y_2+y_4+y_5+y_7)]/8$

$b_{23} = [(y_1+y_2-y_3-y_4-y_5 - y_6+y_7+y8)]/8 = [(y_1+y_2+y_7+y_8) - (y_3+y_4+y_5+y_6)]/8$

V. RESULTS

Using the half factorial approach following are the optimized values of treatment variables obtained as mentioned in Table 3.

Table3. Optimized Shielded Metal Arc Welding Parameters

S. NO.	Voltage (V) in volts X_1	Current (I) in amperes X_2	Speed (S) mm/sec. X_3	Response (WDA) in mm^2 Y_i
1.	24	100	60	23.80
2.	20	100	60	21.74
3.	24	90	60	23.38
4.	20	90	60	21.34
5.	24	100	40	24.36
6.	20	100	40	22.28
7.	24	90	40	23.94
8.	20	90	40	21.86

Now as per the equations mentioned earlier the values of different effects can be calculated as below:

$b_0 = 19.793$
$b_1 = 1.0325$
$b_2 = 0.2075$
$b_3 = - 0.2725$
$b_{12} = 0.0025$
$b_{13} = - 0.0075$
$b_{23} = - 0.0025$

So the actual model could be represented by following equation:

$$Y = 19.793 + 1.0325X_1 + 0.2075X2 + (-0.2725)X_3 + (0.0025)(X1X2) + (- 0.0075) (X1X3) + (- 0.0025)(X2X3)$$

The results of present investigation show the influence of treatment variables (Welding Voltage, Welding Current and Welding Speed) on welding deposition area (WDA) as shown in Fig. 1.

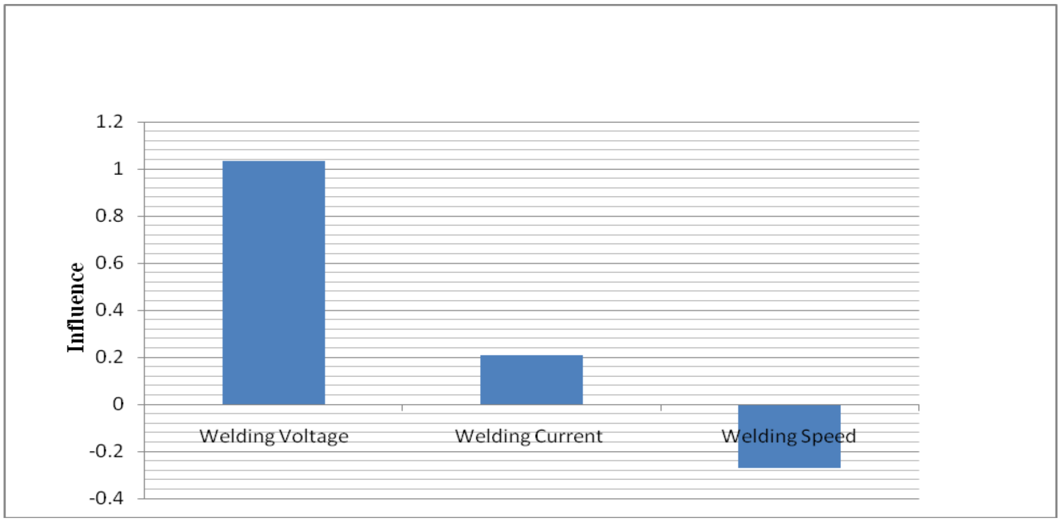

Fig. 1 Influence of Process Parameters on welding deposition area

VI. CONCLUSIONS

Based on the experimental work and the Factorial design approach the following conclusions are drawn:

(1) A strong joint of mild steel is found to be produced in this work by using the SMAW technique.

(2) Results indicate that processes variables influence the weld deposition area to a significant extent.

(3) If amperage is increased, welding deposition area generally increases.

(4) If voltage of the arc is increased, welding deposition area generally increases.

(5) Welding voltage was found to be most influencing variable to WDA.

(6) If travel speed is increased welding deposition area generally decreases.

(7) The two level fractional half area fractional designs is found to be very effective tool for quantifying to main and interaction effects of variable on weld bead area.

REFERENCES

[1] Science and Engineering, An Introduction, John Wiley and Sons, Inc., New York, USA, 1997.

[2] S.V. Nadkarni. Modern Arc Welding Technology, Oxford & IBH Publishing Co. Pvt. Ltd., 1988.

[3] M.I. Khan and A.K. Gupta. A study of Hard Facing under Magnetic Field, ASME Conference, I.I.T. Delhi, 174-176, 1989.

[4] W. Robert Messler. Principles of Welding Processes, Physics, Chemistry and Metallurgy, Wiley, VCH Verlag Gmbh and Co. KgaA Weinheim, 2004.

[5] Chien-Yi Lee. A study of an Automatic Welding System, Dissertation of Ph.D., Institute of Mechanical Engineering at National Central University. Jhongli City, Taoyuan County, Taiwan, Republic of China, 2007.

AUTHORS

First Author – Rajeev Ranjan, Assistant Professor, Department of Mechanical Engineering, Haldia Institute of Technology, Haldia-721657, India, Email: rajeevranjan.br@gmail.com