MULTI- RESPONSE OPTIMIZATIONOF FLUX CORED ARC WELDING PROCESS PARAMETERS USING TOPSIS APPROACH

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Abstract— **This paper presents a multi response optimization approach to determine the optimal process parameters in Flux cored arc welding (FCAW) process in order to obtain optimum weld bead geometry in mild steel plates IS 2062. Experiments have been conducted using four parameters such as welding current, voltage, stick out and wire speed at four levels for obtaining the responses like penetration, bead width, reinforcement and percentage of dilution. Taguchi's L_{16} orthogonal array is used to gather information regarding the process with less number of experimental runs. The traditional Taguchi method cannot solve multi optimization problems. In order to overcome this difficulty, a multi criteria optimization technique for order preference by similarity to ideal solution (TOPSIS) is applied in this study. The significant contributions of parameters are estimated using analysis of variance (ANOVA) test. Confirmation test is conducted and reported. It is found that wire speed is the most significant factor. Results indicate feasibility of TOPSIS analysis in continuous improvement of welding industry.**

Index Terms— **FCAW, ANOVA, Taguchi method, TOPSIS.**

1. INTRODUCTION

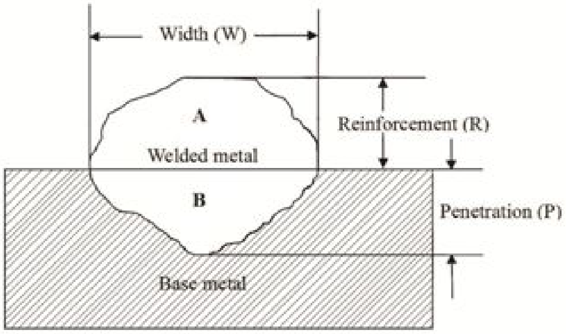
Optimization techniques are widely used in today's manufacturing environment in order to effectively respond to severe competition and to meet increasing demand of quality product in the market. Taguchi's method is one of the most effective systems of off-line quality control where the quality is in built at the product design stage instead of controlling at the manufacturing stage through effective inspection method. Actually a customer considers several correlated factors while considering a product. Accordingly, variability of a product's response has to be reduced and customers preferences brought to be close to the target.

Flux cored arc welding is a multi-factor, multi-objective manufacturing process. Because of easy control of process variables, high quality, deep penetration and smooth finish, it is widely preferred in fabrication industry [1]. In the present work, the effect of voltage, current, welding speed and stick out on bead geometry has been studied. Mechanical and chemical properties of good weld depend on bead geometry. Bead geometry has a direct effect on process parameters. So it is necessary to study the relationship between process parameters and weld bead geometry.

Fig 1 shows the weld bead geometry. Mechanical strength of weld metal is highly influenced by the composition of metal but also by weld bead shape. This is an indication of bead geometry. It mainly depends on voltage, welding current, wire speed etc [2]. Therefore it is necessary to study the relationship between in process parameters and bead parameters to study weld bead geometry. This paper highlights the study carried out to develop mathematical models to optimize weld bead geometry on bead on plate welding by FCAW.

The Taguchi method is a powerful tool for the design of high quality welding operations. It provides a systematic approach for optimization problems. The methodology is valuable when the process parameters are qualitative and discrete. Taguchi method uses a special type of design of orthogonal arrays (OA) to study the entire parameter space with smaller number of experiments. The experimental results are then transferred to signal- to- noise (S/N) ratio. This ratio can be used to measure the quality characteristics deviating from desired values. Usually there are three categories of in the analysis of the signal-to-noise ratio, that is the lower- the-better, higher- the- better and nominal- the- better. Regardless of category of quality characteristics larger signal –to-noise ratio corresponds to the better quality characteristics. The optimal process parameters are the levels with highest signal–to-noise ratio [3].

In the present study, the Taguchi method with TOPSIS is used as an efficient approach to determine the optimal welding parameters for flux cored welded parts for optimization of bead width, penetration, reinforcement and dilution.



Percentage dilution (D) = [B/ (A+B)] X 100
Figure 1: weld bead geometry

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2. EXPERIMENTATION

Test plates of size 300 x 200 x 6 mm were cut from mild steel plate of grade IS – 2062 and one of the surfaces is cleaned to remove oxide and dirt before welding. E7 IT-1C wire of 1.2 mm diameter was used for depositing bead on plate welding. The properties of base metal and filler wire are shown in Table 1.

The selection of the welding electrode wire based on the matching the mechanical properties and physical characteristics of the base metal, weld size and existing electrode inventory. A candidate material for welding which has excellent corrosion resistance and weld ability is stainless steel [4]. These have chloride stress corrosion cracking resistance and strength significantly greater than other materials. These have good surface appearance, good radiographic standard quality and minimum electrode wastage.

Table 1: Chemical Composition of Base Metal and Filler Wire

Elements, Weight %									
Materials	C	SI	Mn	P	S	Al	Cr	Mo	Ni
IS 2062	0.150	0.160	0.870	0.015	0.016	0.031	-	-	-
E7 IT-1C	0.12	0.90	1.75	0.030	0.030	-		0.30	0.50

3. PLAN OF INVESTIGATION

The research work is carried out in the following steps.

- Identifying the quality characteristics and process parameters to be evaluated.
- Select appropriate orthogonal array and assign process parameters.
- Determine the number of levels for the process parameters and possible
- Orthogonal array.
- Conduct experiment as per arrangement of orthogonal array.
- Use of TOPSIS method
- Main response for each level of parameters is calculated and response graph is plotted.
- Select optimum level of parameters.
- Analysis of TOPSIS with ANOVA.
- Conduction of confirmation experiment.

3.1 Identification of factors and responses

The percentage of dilution has got a very dominating effect in welding. The properties of the welding is the significantly influenced by dilution obtained. Hence control of dilution is important in welding where a high dilution is highly desirable [6]. When dilution is quite low, the final deposit composition will be closer to that of filler material and hence corrosion resistant properties of welding will be greatly improved. The chosen factors have been selected on the basis to get optimal dilution and optimal weld bead geometry [1]. These are wire speed (T), welding voltage (V), welding current (I) and stick out (N). The responses chosen were clad bead width (W), height of reinforcement (R), Depth of Penetration (P) and percentage of dilution (D). The responses were chosen based on the impact of parameters on final composite model.

3.2 Finding the limits of process variables

Working ranges of all selected factors are fixed by conducting trial run. This was carried out by varying one of factors while keeping the rest of them as constant values [5]. Working range of each process parameters was decided upon by inspecting the bead for smooth appearance without any visible defects. The chosen level of the parameters with their units and notation are given in Table 2.

Table 2: Welding Parameters and their Levels

Parameters	Factor Levels					
	Unit	Notation	1	2	3	4
Welding Voltage	V	V	20	22	24	25
Welding Current	A	I	87	123	138	155
Stick out	mm	N	15	20	25	30
Wire speed	mm/min	T	25	40	50	53

3.3 Development of Orthogonal array.

Design matrix chosen to conduct the experiments was Taguchi’s robust design. The design matrix comprises of $L_{16}(4^4)$ designs. This is shown in Table 3.

Table 3: Design Matrix

Trial Number	Design Matrix			
	V	I	N	T

1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

V - Welding voltage; I - Welding current; N –Stick out; T – Wire speed.

3.4 Conducting experiments as per orthogonal array

In this work sixteen experimental run were allowed for the estimation of each treatment combination of parameters on bead geometry as shown Table 3 at random. At each run settings for all parameters were disturbed and reset for next deposit. This is very essential to introduce variability caused by errors in experimental set up. The experiments were conducted at Younus College of Engineering and technology, Kollam, 649010, India.

3.5 Recording of Responses

For measuring the weld bead geometry, the transverse section of each weld overlays was cut using band saw from mid length. Position of the weld and end faces were machined and grinded. The specimen and faces were polished and etched using a 5% nital solution to display bead dimensions. The clad bead profiles were traced using a reflective type optical profile projector at a magnification of X10, in YCET Kollam [6]. Then the bead dimension such as depth of penetration height of reinforcement and clad bead width were measured [7]. The profiles traced using AUTO CAD software. This represents profile of the specimen (front side). The measured weld bead dimensions and percentage of dilution is shown in Table 4.Fig 2.shows flux cored arc welding procedure. Fig 3. Shows scanned specimen.

Figure 2: Bead on plate welding specimen

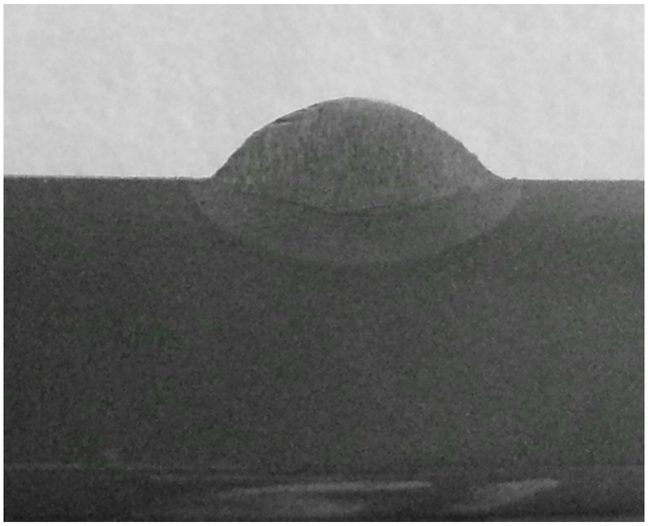

Figure 3: Scanned specimen

Table 4: Design Matrix and Observed Values of weld Bead Geometry

Trial No.	Design Matrix				Bead Parameters			
	V	I	N	T	W (mm)	P (mm)	R (mm)	D (%)
1	1	1	1	1	8.306	1.235	2.815	17.623
2	1	2	2	2	8.243	1.347	2.543	17.462
3	1	3	3	3	8.731	1.388	2.675	17.842
4	1	4	4	4	8.925	1.425	2.931	17.442
5	2	1	2	3	9.792	1.657	2.449	18.332
6	2	2	1	4	10.415	1.586	2.779	16.692
7	2	3	4	1	8.869	1.456	2.863	17.823
8	2	4	3	2	8.614	1.738	2.597	20.424
9	3	1	3	4	8.908	1.416	2.538	17.912
10	3	2	4	3	9.371	1.537	2.397	18.182
11	3	3	1	2	9.087	1.465	2.432	18.218
12	3	4	2	1	8.853	1.368	2.672	17.512
13	4	1	4	2	9.125	1.487	2.423	18.221
14	4	2	3	1	8.753	1.398	2.567	17.943
15	4	3	2	4	8.971	1.457	2.697	17.841
16	4	4	1	3	9.807	1.868	2.243	21.512

W-Width; R – Reinforcement; P - Penetration; D - Dilution %

4. OPTIMIZATION OF FLUX CORED ARC WELDING PARAMETERS USING TOPSIS APPROACH

In this section, the use of the Taguchi’s method coupled with TOPSIS is used to determine the welding parameters with optimal welding performance in the flux cored arc welding process. The TOPSIS method was developed by Hwang and Yoon [8]. The method is based on the concept of that the chosen alternative should have shorter Euclidean distance from the ideal solution, and farthest from the negative ideal solution. The ideal solution is a hypothetical solution for which all attributes values correspond to the maximum attribute hypothetical solution for which all attribute values correspond to the minimum attribute values in the database. TOPSIS thus gives a solution that not only closest to the hypothetically best, that is also the farthest from hypothetically worst [9].

Let X_{ij} score of option i with respect to criterion j we have a matrix X= (x_{ij}); m×n matrix.

Let J be the set of benefit attributes or criteria (More is better).

Let $J^!$ be the set of negative attributes or criteria (Less is better).

Step: 1

Normalize the data using the following equation:

$R_{ij} = {}^{X_{ij}}\!/\!\left(\sum_i X^2{}_{ij}\right)$ For i=1..... , m; j=1,....,n ....(1)

Step: 2

Construct the weighted normalized matrix using equation:

$V_{ij} = W_j r_{ij}$.. (2)

Step: 3

Determine ideal and negative ideal solution.

Ideal solution.

$A^* = \{ V_1{}^*, \dots\dots\dots V^*{}_n \}$, where

$V_j^* = \{\max\limits_i (V_{ij})$ if j € J; min (V_{ij}) if j € $J^!\}$.. (3)

Negative ideal solution.

$A^! = \{ V_1{}^!, \dots\dots\dots V^!{}_n \}$, where

$V_j^* = \{\min\limits_i (V_{ij})$ if j € J; max (V_{ij}) if j € $J^!\}$..(4)

Step: 4.
Calculate separation measures.
The separation from ideal alternative is :

$S_i^* = \left[\sum_j \left(\left(V_j^* - V_{ij}\right)^2\right)\right]^{1/2}$ i=1,......, m.. (5)

The separation from negative ideal alternative.

$S_i^* = \left[\sum_j \left(\left(V_j^{\text{¦}} - V_{ij}\right)^2\right)\right]^{1/2}$ i=1,...., m...(6)

Step: 5.
Calculate relative closeness to ideal solution.

$C_i^* = S_i^{\text{¦}} \big/ \left(S_i^* + S_i^{\text{¦}}\right)$...(7)

4.1 Optimization by TOPSIS

TOPSIS method has been applied to covert the multi objective optimization problem in to a single response. First normalised decision matrix shown in Table 5, Constructed using equation (1). The weighed normalised decision matrix constructed assigning weights 0.25 to each factors and applying equation (2) which is shown in Table 6. Then positive ideal solution and negative ideal solution calculated. The separations of each alternatives calculated using equations (5) and (6),this is shown in Table 7.The relative closeness of particular alternative to ideal solution is computed using equation (7),shown in Table 8.

Table: 5. Normalized matrix $R_{16\times4}$

0.229076	0.206246	0.269869	0.241808
0.227339	0.22495	0.243793	0.239599
0.240798	0.231797	0.256447	0.244813
0.246148	0.237976	0.280989	0.239325
0.270059	0.27672	0.234781	0.251537
0.287242	0.264863	0.266417	0.229034
0.244603	0.243153	0.27447	0.244553
0.237571	0.290247	0.248969	0.280241
0.245679	0.236473	0.243313	0.245774
0.258448	0.25668	0.229796	0.249479
0.250616	0.244656	0.233151	0.249973
0.244162	0.228457	0.25616	0.240285
0.251664	0.24833	0.232288	0.250014
0.241404	0.233467	0.246093	0.246199
0.247417	0.24332	0.258556	0.2448
0.270473	0.311957	0.215032	0.29517

Table: 6.The weighted normalized matrix $V_{16\times4}$

0.057269	0.051561	0.067467	0.060452
0.056835	0.056237	0.060948	0.0599
0.060199	0.057949	0.064112	0.061203
0.061537	0.059494	0.070247	0.059831
0.067515	0.06918	0.058695	0.062884
0.07181	0.066216	0.066604	0.057259
0.061151	0.060788	0.068618	0.061138
0.059393	0.072562	0.062242	0.07006
0.06142	0.059118	0.060828	0.061443
0.064612	0.06417	0.057449	0.06237
0.062654	0.061164	0.058288	0.062493
0.061041	0.057114	0.06404	0.060071

$$\left| \begin{matrix} 0.062916 & 0.062082 & 0.058072 & 0.062503 \\ 0.060351 & 0.058367 & 0.061523 & 0.06155 \\ 0.061854 & 0.06083 & 0.064639 & 0.0612 \\ 0.067618 & 0.077989 & 0.053758 & 0.073793 \end{matrix} \right|$$

Ideal solution A^{*} = {0.05681, 0.077989, 0.053758, 0.073793}
Negative ideal solution $A^{!}$= {0.067618, 0.051561, 0.070247, 0.05725}

Table 7. Separation measures

Trial No.	Design Matrix				Separation measures	
	V	I	N	T	S^{-}	S^{+}
1	1	1	1	1	0.011587	0.033692
2	1	2	2	2	0.013054	0.027511
3	1	3	3	3	0.011448	0.026733
4	1	4	4	4	0.008343	0.029662
5	2	1	2	3	0.022208	0.018654
6	2	2	1	4	0.016427	0.029122
7	2	3	4	1	0.01306	0.027072
8	2	4	3	2	0.026601	0.011169
9	3	1	3	4	0.013132	0.02466
10	3	2	4	3	0.01933	0.020294
11	3	3	1	2	0.017492	0.02204
12	3	4	2	1	0.009971	0.028091
13	4	1	4	2	0.018421	0.021326
14	4	2	3	1	0.013196	0.02526
15	4	3	2	4	0.011531	0.025027
16	4	4	1	3	0.076264	0.010925

Table 8.Closeness coefficient values.

Experiment No	CC_1	S/N ratios
1	0.255902	-11.8385
2	0.255902	-9.8481
3	0.255902	-10.4624
4	0.255902	-13.1704
5	0.255902	-5.2962
6	0.255902	-8.8584
7	0.255902	-9.7510
8	0.255902	-3.0450
9	0.255902	-9.1814
10	0.255902	-6.2345
11	0.255902	-7.0822
12	0.255902	-11.6351
13	0.255902	-6.6798
14	0.255902	-9.2904
15	0.255902	-10.0223
16	0.255902	-1.1628

5. ANALYSIS OF VARIENCE

The ANOVA investigates those process parameters which is significantly affecting the performance characteristics. This is accomplished be separating the total variability of multi response performance indexes, which is measured by sum of squared deviations from the total mean of CC_1, into contributions by each of the process parameter and error. First the total sum of the squared deviations SS_T from the total mean of the μ_m can be calculated as:

$$SS_T = \sum_{i=1}^{n} (\mu_m - \mu_m)^2 \ldots\ldots\ldots\ldots (8)$$

where n is the number of experiments in orthogonal array and μ is the mean of the CC_1 for the *ith* experiment.
The total sum of the squared deviations SS_T is decomposed in to two sources: the sum of the squared deviations ss_d due to each process parameter and the sum of the squared error ss_e. The percentage of contribution by each of the process parameter in the total sum of the squared deviations SS_T can be used to evaluate the importance of the process parameter change on performance characteristics. F test is used to determine which process parameter has a significant effect on performance characteristics. When F value is large the change of in process parameter has significant effect on performance characteristic.

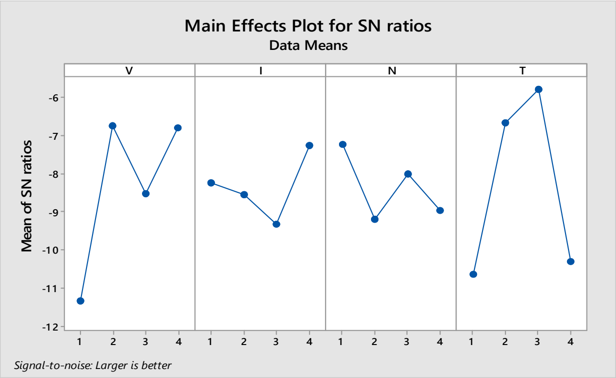

Figure: 4. Main effects of S/N ratios

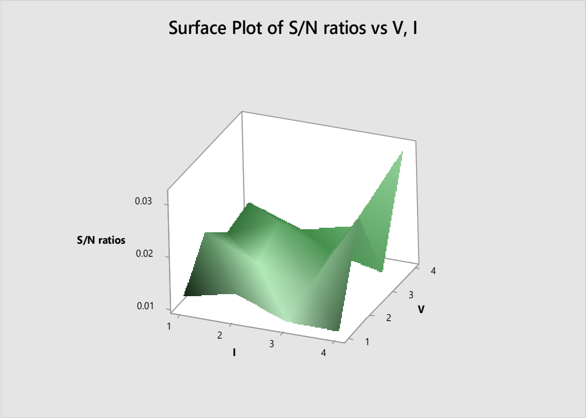

Figure: 5. Surface plot of S/N ratios Vs. Voltage and current

Table 9: Analysis of Variance for SN ratios

Source	DF	Adj SS	Adj MS	F	P
Regression	4	0.101531	0.025383	0.78	0.561
V	1	0.066405	0.066405	2.04	0.181
I	1	0.018610	0.018610	0.57	0.465
N	1	0.014055	0.014055	0.43	0.524
T	1	0.002461	0.002461	0.08	0.788
Error	11	0.357574	0.032507		

6. CONFIRMATION EXPERIMENT

After obtaining optimum level of process parameters, a verification test needs to be conducted. The S/N ratio at the optimum level has been determined by the following formula.

$$\hat{\gamma}=\gamma_m+\sum_{i-1}^{p}(\hat{\gamma}_i-\gamma_m)$$

Where γ_m is the average value of the S/N ratio in all experimental runs $\hat{\gamma}_i$ is the value of S/N ratio corresponding to optimum level and p is the number of factors. The optimum conditions are set for the process parameters and selected test is done under that specified condition. Table 10. Show the comparison of predicted and actual S/N ratios obtained in the experiment using optimum conditions. It shows that quality has been considerably improved.

Table 10: Results of conformity experiment

Parameters	Initial factor setting	Prediction	Experiment
Level of factors	V_1 I_1 N_1 T_1	V_2 I_4 N_1 T_3	V_2 I_4 N_1 T_3
Bead width	8.306		8.325
Reinforcement	1.235		1.247
Penetration	2.815		2.985
Dilution (%)	17.235		16.957
S/N ratio	-11.8335	-12.4009	- 10 .2908

RESULTS AND DISCUSSIONS

The optimal welding parameter has been obtained from response graph as shown in Fig .4.

It is proved that V_2 I_4 N_1 T_3 is the optimal setting. Then analysis of variance (ANOVA) is done which is a particular form of statistical hypothesis testing heavily used in the analysis of experimental data. ANOVA is used to determine which welding parameter significantly affects the performance characteristic shown in Table 9. It is proved that significant factor is wire speed. Fig 5 shows surface plot between S/N ratio, welding voltage and current.

CONCLUSION

This paper presents the selection of optimum process parameters in flux cored arc welding process by considering experimental results for obtaining optimum weld bead geometry using TOPSIS method. The suggested multi response approach using TOPSIS method in combination with Taguchi's robust design methodology is quite capable for any type of optimization problem involving any number of responses.

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