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Flux Cored Arc Welding Parameter Optimization of AISI 316L (N) Austenitic Stainless Steel

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Abstract**—**Bead-on-plate welds were carried out on AISI 316L (N) austenitic stainless steel (ASS) using flux cored arc welding (FCAW) process. The bead on plates weld was conducted as per L25 orthogonal array. In this paper, the weld bead geometry such as depth of penetration (DOP), bead width (BW) and weld reinforcement (R) of AISI 316L (N) ASS are investigated. Taguchi approach is used as statistical design of experiment (DOE) technique for optimizing the selected welding input parameters. Grey relational analysis and desirability approach are applied to optimize the input parameters considering multiple output variables simultaneously. Confirmation experiment has also been conducted to validate the optimized parameters.

Keywords**—**bead-on-plate welding, bead profiles, desirability approach, grey relational analysis

I. INTRODUCTION

THE 316L (N) is a low carbon, nitrogen-enhanced, molybdenum-bearing austenitic stainless steel, as a structural material ,is widespread among several industrial sectors including nuclear, cryogenic, shipbuilding, and defense sectors.

Flux-cored arc welding is an attractive welding process having high productivity with all-positional welding capability compared with other flux-shielded welding processes (basic flux system) such as shielded metal arc welding (SMAW) and submerged arc welding (SAW) processes. FCAW weld metals are generally about 5–10% stronger at room temperature than weld metals from SMAW and SAW processes and are similar to those of gas tungsten arc welding (GTAW) deposit after similar post weld heat treatment (PWHT) [1].

Murugan et al. [2] developed mathematical models using a five-level factorial technique to predict the weld bead geometry for depositing 316L stainless steel onto structural steel IS2062. The responses namely, penetration, reinforcement, width and dilution as affected by open circuit voltage, wire feed rate, welding speed and nozzle to plate distances have been investigated. The models were developed and checked for their adequacy and significance. The main and interaction effects of the control factors on dilution and bead geometry have been presented in graphical form, which is more useful in selection of process parameters to achieve the desired quality of the overlay.

Murugan et al. [3] determined the main and interaction effects of process control variables on important bead geometry parameters including bead volume quantitatively and represented the results graphically. Optimal parameter setting has been derived in their work to yield optimal bead volume with maximum penetration, minimum reinforcement and bead width.

The common approaches to tackle optimization problem in welding include multiple regression analysis, response surface methodology (RSM), artificial neural network (ANN) modeling and Taguchi method [4–7]. In most of the cases the optimization has been performed using single objective function. For a multi-response process, while applying the optimal setting of control factors, it can be observed that an increase/improvement of one response may cause change in another response, beyond the acceptable limit. Thus for solving multi-criteria optimization problems, it is convenient to convert all the objectives into an equivalent single objective function. This equivalent objective function, which is the representative of all the quality characteristics of the product, is to be optimized (maximized). The Taguchi method is very popular for solving optimization problems in the field of production engineering [8] and [5]. The method utilizes a well-balanced experimental design (allows a limited number of experimental runs) called orthogonal array design, and signal-to-noise ratio (S/N ratio), which serve the objective function to be optimized (maximized) within experimental domain. However, traditional Taguchi method cannot solve multi-objective optimization problem.

To overcome this, the Taguchi method coupled with Grey relational analysis has a wide area of application [9 -11]. This approach can solve multi- response optimization problem simultaneously. It is appropriate to apply this technique to a complex system like welding process.

Apart from process optimization, it is necessary to determine the degree of significance of the factors on the output features of the final product. This statistical significance of the factors can be evaluated through analysis of variance (ANOVA).

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Though several studies made on weld quality by considering response variables separately and also literature on simultaneous consideration of response variables is scarce in FCAW process of 316 L (N) material. In the present paper, an attempt has been made to carry out the experiments based an L25 orthogonal array. This study introduced to determine the near optimal welding process parameters using grey relational analysis and desirability approach by simultaneously considering multiple output parameters. Through this technique, the welding parameters were evaluated and compared with the experimental results.

II. EXPERIMENTAL DESIGNS AND PROCEDURE

Taguchi approach was used for designing the experiment, L25 orthogonal array was used which composed of five levels and 25 rows, which means that 25 experiments were carried out. Design of experiments was selected based on a four welding parameters with five levels each. The selected welding input parameters for this study are wire feed rate (WFR), voltage (V), travel speed (TS) and torch angle (TA). The welding input parameters and their levels are presented in Table I.

TABLE I
WELDING PARAMETERS AND THEIR LEVELS

Parameters	Units	Levels				
		1	2	3	4	5
Wire Feed Rate (WFR)	m/min	7	8	9	10	11
Voltage (V)	volts	19	21	23	25	27
Travel Speed (TS)	cm/min	0.3	0.36	0.42	0.48	0.54
Torch Angle (TA)	°	50	60	70	80	90

Bead-on-plate welding trials were conducted using an ABB MIG Robot 500 with IRC 5 controller welding system is presented in Fig.1(a and b).

(a) Welding machine (b) welding in operations

Fig. 1 (a) and (b) Experimental set up of ABB MIG Robot 500 Welding system

The materials employed in this investigation were plates of AISI 316 L (N) austenitic stainless steel in dimensions of 100 X 50 X 8 mm each were used as base material and E 316LT (diameter of 1.2 mm) was used as filler wire. The typical chemical compositions of the base material and filler wire are shown in Table II.

The welding trails were conducted based on the L25 orthogonal array as shown in Table III. Argon as a shielding gas at a constant flow rate of 18 lpm and stick out distance is 15 mm as maintained. Weld profiles were obtained by sectioning and polishing with suitable abrasive and diamond paste. Weld samples were etched with 10% oxalic acid, an etchant to state and increase the contrast of the fusion zone with the base metal. The weld bead profiles were measured using optical microscope. The measured bead profiles are depth of penetration (DOP), bead width (BW) and reinforcement(R) were presented in Table III.

TABLE III
EXPERIMENTAL RESULTS USING L25 ORTHOGONAL ARRAY

Sl.No	WFR	V	TS	TA	DOP mm	BW mm	R mm
1	1	1	1	1	2.814	8.034	2.356
2	1	2	2	2	3.843	8.623	2.485
3	1	3	3	3	3.876	8.931	2.674
4	1	4	4	4	3.334	8.527	2.745
5	1	5	5	5	3.487	8.234	2.789
6	2	1	2	3	4.315	8.723	2.945
7	2	2	3	4	3.893	8.965	2.864
8	2	3	4	5	3.756	9.167	2.654
9	2	4	5	1	3.032	9.583	2.479
10	2	5	1	2	4.067	8.869	2.987
11	3	1	3	5	3.912	8.783	2.843
12	3	2	4	1	2.889	9.267	2.489
13	3	3	5	2	3.445	8.935	2.681
14	3	4	1	3	4.889	8.347	2.712
15	3	5	2	4	4.553	8.587	2.567
16	4	1	4	2	3.564	8.743	2.145
17	4	2	5	3	4.078	8.845	2.647
18	4	3	1	4	4.378	8.384	2.741
19	4	4	2	5	4.583	8.457	2.856
20	4	5	3	1	2.932	9.987	2.146
21	5	1	5	4	3.348	9.267	2.216
22	5	2	1	5	4.392	8.932	2.347
23	5	3	2	1	3.641	9.124	2.045
24	5	4	3	2	3.994	9.256	2.249
25	5	5	4	3	3.826	9.016	2.198

TABLE II
CHEMICAL COMPOSITION OF BASE MATERIAL AND FILLER WIRE (WEIGHT IN %)

Material	C	Cr	Ni	Mo	N	Mn	Si	P	S	Cu	Ti	Nb	Fe
AISI 316L(N)	0.024	16.89	10.07	2.16	0.0597	1.51	0.42	0.026	0.0016	0.35	0.02	0.02	Bal
316LT	0.033	18.94	11.82	2.34	-	1.18	0.62	0.022	0.008	0.10	-	-	Bal

III. METHODOLOGIES

A. Grey Relational Analysis

Deng first proposed grey relational analysis in 1982[12] to fulfill the crucial mathematical criteria for dealing with poor, incomplete, and uncertain systems [13]. This grey-based Taguchi technique has been widely used in different fields of engineering to solve multi-response optimization problems. In order to apply the grey-based Taguchi method for multi-response optimization, the following seven steps are followed:

Step 1: Calculate S/N ratio for the corresponding responses, using the following formula:

(i)Larger-the–better:

$$\text{S / N ratio } (\eta) = -10 \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_{ij}^{2}}\right) \tag{1}$$

Where n=number of replications y_{ij}=observed response value where i=1, 2,…n; j=1, 2...k

This is applied for problem where maximization of the quality characteristic of interest is sought. This is referred as the larger-the-better type problem.

(ii)Smaller-the–better:

$$\text{S / N ratio } (\eta) = -10 \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_{ij}^{2}\right) \tag{2}$$

This is termed as the smaller-the-better type problem where minimization of the characteristic is intended.

Step 2: Step 2: y_{ij} is normalized as Z_{ij} ($0 \le Z_{ij} \le 1$) by the following formula to avoid the effect of adopting different units and to reduce the variability. It is necessary to normalize the original data before analyzing them with the grey relation theory or any other methodologies. An appropriate value is deducted from the values in the same array to make the value of this array approximate to 1. Since the process of normalization affects the rank, we also analyzed the sensitivity of the normalization process on the sequencing results. Thus, we recommend that the S/N ratio value be adopted when normalizing data in grey relation analysis.

$$Z_{ij} = \frac{y_{ij} - \min(y_{ij}, i = 1, 2, ..., n)}{\max(y_{ij}, i = 1, 2, ..., n) - \min(y_{ij}, i = 1, 2, ..., n)} \tag{3}$$

(To be used for S/N ratio with larger the better manner)

$$Z_{ij} = \frac{\max(y_{ij}, i = 1, 2, ..., n) - y_{ij}}{\max(y_{ij}, i = 1, 2, ..., n) - \min(y_{ij}, i = 1, 2, ..., n)} \tag{4}$$

(To be used for S/N ratio with smaller the better manner)

Step 3: The grey relational coefficient is calculated as

$$\gamma(y_o(k), y_i(k)) = \frac{\Delta_{\min} + \xi\Delta_{\max}}{\Delta_{oj}(k) + \xi\Delta_{\max}} \tag{5}$$

where

1. j=1, 2…n; k=1, 2…m, n is the number of experimental data items and m is the number of responses.
2. $y_o(k)$ is the reference sequence ($y_o(k)$=1, k=1,2…m); $y_i(k)$ is the specific comparison sequence.
3. $\Delta_{ij} = \| y_o(k) - y_j(k) \| ==$ The absolute value of the difference between $y_o(k)$ and $y_i(k)$
4. $\Delta\min = \min\limits_{\forall j\varepsilon i} \min\limits_{\forall k} \| y_o(k) - y_j(k) \|$ is the smallest value of $y_i(k)$
5. $\Delta\max = \max\limits_{\forall j\varepsilon i} \max\limits_{\forall k} \| y_o(k) - y_j(k) \|$ is the largest value of $y_i(k)$
6. ξ is the distinguishing coefficient, which is defined in the range $0 \le \xi \le 1$(the value may adjusted based on the practical needs of the system).

Step 4: The grey relational grade $\left(\bar{\gamma}_j\right)$ is calculated by averaging the grey relational coefficients corresponding to each experiment.

$$\bar{\gamma}_j = \frac{1}{k}\sum_{i=1}^{m}\gamma_{ij} \tag{6}$$

Where $\bar{\gamma}_j$ the grey relational grade for the jth experiment and 'k' is the number of performance characteristics.

Step5: Determine the optimal factor and its level combination. The higher grey relational grade implies the better product quality; therefore, on the basis of grey relational grade, the factor effect can be estimated and the optimal level for each controllable factor can also be determined. For example, to estimate the effect of factor 'i', we calculate the average of grey grade values (AGV) for each level 'j', denoted as AGV_{ij}, then the effect, E_i is defined as:

$$Ei = \max(AGVij) - \min(AGVij) \tag{7}$$

If the factor i is controllable, the best level j*, is determined by

$$j *= \max(AGVij) \tag{8}$$

Step 6: Perform ANOVA for identifying the significant parameters. ANOVA establishes the relative significance of parameters. The calculated total sum of square values is used to measure the relative influence of the parameters.

B. Desirability Approach

The desirability function approach to optimize multiple equations simultaneously was originally proposed Derringer and Suich [14]. Their procedure introduces the concept of desirability functions. The method makes use of an objective function, D(X), called the desirability function and transforms an estimated response into a scale free value (d_i) called desirability. The desirable ranges are from zero to one (least to most desirable, respectively). The factor settings with maximum total desirability are considered to be the optimal parameter conditions. Essentially, the approach is to translate the functions to a common scale (0, 1), combine them using the geometric mean and optimize the overall metric. There are many statistical techniques for solving multiple response problems like overlaying the contours plot for each response, constrained optimization problems and desirability approach. The desirability method is recommended due to its simplicity, availability in the software, flexibility in weighting and giving importance for individual response. Solving such multiple response optimization problems using this technique involves using a technique for combining multiple responses into a dimensionless measure of performance called the overall desirability function. The desirability approach involves transforming each estimated response, Yi, into a unit less utility bounded by $0<d_i<1$, where a higher 'd_i' value indicates that response value Y_i is more desirable, if $d_i = 0$ this means a completely undesired response [15].

Step 1: Calculate the individual desirability index (d_i). There are three forms of the desirability functions according to the response characteristics.

i. Nominal - the – best

$$d_i = \begin{cases} \left(\dfrac{y_j - y_{\min}}{T - y_{\min}}\right)^s, & y_{\min} \le y_j \le T, s \ge 0 \\ \left(\dfrac{y_j - y_{\min}}{y_{\max} - y_{\min}}\right)^r, & y_{\min} \le y_j \le y_{\max}, r \ge 0 \\ 0 & \end{cases} \tag{9}$$

The value of y_j is required to achieve a particular target T. When the 'y' equals to T, the desirability value equals to 1; if the departure of 'y' exceeds a particular range from the target, the desirability value equals to 0, and such situation represents the worst case.

ii. Larger-the better

$$d_i = \begin{cases} 0, y_j \le y_{\min} \\ \left(\dfrac{y_j - y_{\min}}{y_{\max} - y_{\min}}\right)^r, y_{\min} \le y_j \le y_{\max}, r \ge 0 \\ 1, y_j \ge y_{\min} \end{cases} \tag{10}$$

The value of 'y_j' is expected to be the larger the better. When the 'y' exceeds a particular criteria value, which can be viewed as the requirement, the desirability value equals to 1; if the 'y' is less than a particular criteria value, which is unacceptable, the desirability value equals to 0.

iii. smaller-the better

$$d_i = \begin{cases} 1, y_j \le y_{\min} \\ \left(\dfrac{y_j - y_{\max}}{y_{\min} - y_{\max}}\right)^r, y_{\min} \le y_j \le y_{\max}, r \ge 0 \\ 0, y_j \ge y_{\min} \end{cases} \tag{11}$$

The value of 'y_j' is expected to be the smaller the better. When the 'y' is less than a particular criteria value, the desirability value equals to 1; if the 'y' exceeds a particular criteria value, the desirability value equals to 0.

Step 2: Compute the composite desirability (d_G). The individual desirability index of all the responses can be combined to form a single value called composite desirability (d_G) by the following Equation (12).

$$d_G = \left(d_1^{w1} \times d_2^{w2} ....d_i^{wi}\right)^{\frac{1}{w}} \tag{12}$$

Step 3: Determine the optimal parameter and its level combination. The higher composite desirability value implies better product quality. Therefore, on the basis of the composite desirability (d_G), the parameter effect and the optimum level for each controllable parameter are estimated. For examples, to estimate the effect of factor 'i', we calculate the composite desirability values (CDV) for each level 'j', denoted as CDV_{ij}, and then the effect, E_i is defined as:

$$E_i = \max(CDV_{ij}) - \min(CDV_{ij}) \tag{13}$$

If the factor i is controllable, the best level j*, is determined by

$$j^* = \max j\,(CDV_{ij}) \tag{14}$$

Step 4: Perform ANOVA for identifying the significant parameters. ANOVA establishes the relative significance of parameters. The calculated total sum of square values is used to measure the relative influence of the parameters.

IV. IMPLEMENTATION OF THE SOLUTION METHODOLOGY

A. Grey Relational Analysis

Step 1: The S/N ratios are calculated for all the responses depending upon the type of quality characteristics. The main objective of this work is maximization of depth of penetration and minimization of bead width, reinforcement. According to this objective the responses are considered in this study larger the better type and smaller the better types are selected. The values of computed S/N ratios for each quality characteristic from Table III using one of the (1) and (2) are presented in Table IV.

Step 2: Normalize the S/N ratio values using one of the (3) and (4). The results are given in the Table IV.

TABLE IV
S/N RATIOS AND NORMALIZED VALUES

Sl.No	S/N Ratios			Normalized values		
	DOP	BW	R	DOP	BW	R
1	8.9865	-18.0986	-7.4435	0.0000	0.0000	0.3737
2	11.6934	-18.7132	-7.9065	0.5642	0.3251	0.5144
3	11.7677	-19.0180	-8.5432	0.5797	0.4864	0.7078
4	10.4593	-18.6159	-8.7708	0.3070	0.2737	0.7770
5	10.8490	-18.3122	-8.9090	0.3882	0.1130	0.8190
6	12.6996	-18.8133	-9.3817	0.7739	0.3781	0.9626
7	11.8057	-19.0510	-9.1395	0.5876	0.5039	0.8890
8	11.4945	-19.2445	-8.4780	0.5227	0.6063	0.6880
9	9.6346	-19.6300	-7.8855	0.1351	0.8102	0.5080
10	12.1855	-18.9575	-9.5047	0.6667	0.4544	1.0000
11	11.8480	-18.8729	-9.0755	0.5964	0.4096	0.8696
12	9.2150	-19.3388	-7.9205	0.0476	0.6561	0.5186
13	10.7438	-19.0219	-8.5659	0.3663	0.4885	0.7147
14	13.7844	-18.4306	-8.6658	1.0000	0.1756	0.7451
15	13.1660	-18.6768	-8.1885	0.8711	0.3059	0.6000
16	11.0388	-18.8332	-6.6285	0.4277	0.3886	0.1260
17	12.2089	-18.9340	-8.4551	0.6716	0.4420	0.6810
18	12.8255	-18.4690	-8.7582	0.8001	0.1960	0.7732
19	13.2230	-18.5443	-9.1152	0.4714	0.2358	0.8816
20	9.3433	-19.9887	-6.6326	0.0744	1.0000	0.1272
21	10.4957	-19.3388	-6.9114	0.3146	0.6561	0.2120
22	12.8532	-19.0190	-7.4103	0.8059	0.4869	0.3636
23	11.2244	-19.2037	-6.2139	0.4664	0.5847	0.0000
24	12.0282	-19.3285	-7.0398	0.6340	0.6507	0.2510
25	11.6549	-19.1003	-6.8406	0.5562	0.5300	0.1904

Step 3: Perform the grey relational analysis. From the data in Table 4, calculate the grey relational co-efficient for the normalized S/N ratio values by using (5). The values for ξ is taken as for depth of penetration (0.5), bead width (0.25) and reinforcement (0.25) and were considered in (4). The results are given in Table V.

Step 4: Next, the grey relational grade can be computed by using (6). Finally, the grades are considered for optimizing the multi response parameter design problem. The results are given in the Table V.

TABLE V
GREY RELATIONAL CO-EFFICIENT AND GREY GRADE VALUES

Sl.No	Grey relational co efficient			Grey grade
	DOP	BW	R	
1	0.3333	0.3333	0.4439	0.3610
2	0.5343	0.4256	0.5073	0.5004
3	0.5433	0.4933	0.6312	0.5528
4	0.4191	0.4077	0.6916	0.4844
5	0.4497	0.3605	0.7342	0.4985
6	0.6886	0.4457	0.9304	0.6883
7	0.5480	0.5019	0.8183	0.6041
8	0.5116	0.5595	0.6158	0.5496
9	0.3663	0.7249	0.5040	0.4904
10	0.6001	0.4782	1.0000	0.6696
11	0.5533	0.4586	0.7931	0.5896
12	0.3443	0.5925	0.5095	0.4476
13	0.4410	0.4943	0.6367	0.5033
14	1.0000	0.3775	0.6623	0.7600
15	0.7950	0.4187	0.5556	0.6411
16	0.4663	0.4499	0.3639	0.4366
17	0.6036	0.4726	0.6105	0.5726
18	0.7144	0.3834	0.6879	0.6250
19	0.4861	0.3955	0.8086	0.5441
20	0.3507	1.0000	0.3642	0.5164
21	0.4218	0.5925	0.3882	0.4561
22	0.7204	0.4936	0.4400	0.5936
23	0.4838	0.5463	0.3333	0.4618
24	0.5773	0.5887	0.4003	0.5359
25	0.5298	0.5154	0.3818	0.4892

Step 5: From the value of grey relational grade in Table V, using (7), the main effects are tabulated in Table VI and the factor effects are plotted in Fig.2.

TABLE VI
MAIN EFFECTS ON GREY GRADES

Factor / Levels	1	2	3	4	5	Difference	Rank
WFR	0.4794	**0.6004**	0.5883	0.5389	0.5073	0.121	2
V	0.5063	0.5436	0.5385	0.5629	**0.5629**	0.056	4
TS	**0.6018**	0.5671	0.5597	0.4814	0.5041	0.120	3
TA	0.4554	0.5291	**0.6125**	0.5621	0.5550	0.157	1

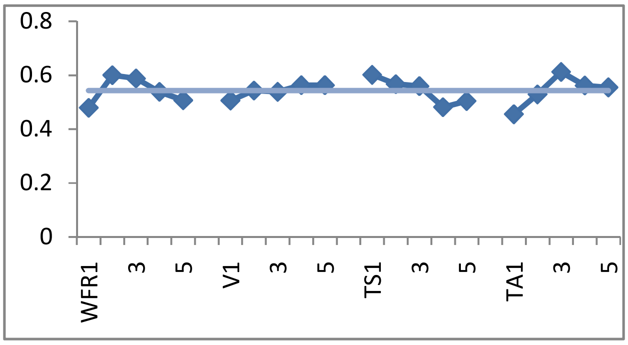

Fig. 2 Factor effects on grey grade values

Considering maximization of grade values (Table VI and Fig. 2), we can obtain the optimal parameter condition WFR2 V5 TS1 TA3.

Step 6: Using the grey grade value, ANOVA is formulated for identifying the significant factors. The results of ANOVA are given in Table VII. From ANOVA, it is clear that Torch angle (34.2267%) influences more on welding followed by wire feed rate (27.6792%), travel speed (23.3601%) and voltage (9.7974%).

TABLE VII
RESULTS OF ANOVA ON GREY GRADE

Factor	Sum of Squares	Degree of freedom	Mean squares	F-Cal	F-table	% Contribution
Wire feed rate	0.0534	4	0.0134	11.2136	3.8379	27.6792
Voltage	0.0189	4	0.0047	3.9692	3.8379	9.7974
Travel speed	0.0451	4	0.0113	9.4638	3.8379	23.3601
Torch angle	0.0661	4	0.0165	13.8662	3.8379	34.2267
Error	0.0095	8	0.0012			4.9367
Total	0.1930	24				

B. Desirability Approach

Step 1: The individual desirability (d_i) is calculated for all the responses depending upon the type of quality characteristics. The main objective of this work is minimization of bead width and maximization of tensile strength and depth of penetration. According to this objective the responses are considered in this study and larger the better type and smaller the better type are selected. The values of computed individual desirability for each quality characteristic using one of the (10) and (11) are presented in Table VIII. The desirability value varies from 0 to 1. The higher value shows that it has higher influence than others.

Step 2: The composite desirability values (d_G) are calculated using (12). The weightage for depth of penetration (0.5), bead width (0.25) and reinforcement (0.25) and were considered and the calculated results are given in the Table VIII.

TABLE VIII
DESIRABILITY VALUES AND COMPOSITE DESIRABILITY VALUES

Sl.No	Desirability			Composite desirability
	DOP	BW	R	
1	0.0000	1.0000	0.6699	0.0000
2	0.4959	0.6984	0.5329	0.5500
3	0.5118	0.5407	0.3323	0.4658
4	0.2506	0.7476	0.2569	0.3314
5	0.3243	0.8976	0.2102	0.3753
6	0.7234	0.6472	0.0446	0.3505
7	0.5200	0.5233	0.1306	0.3687
8	0.4540	0.4199	0.3535	0.4182
9	0.1051	0.2069	0.5393	0.1873
10	0.6039	0.5725	0.0000	0.0000
11	0.5292	0.6165	0.1529	0.4030
12	0.0361	0.3687	0.5287	0.1263
13	0.3041	0.5387	0.3248	0.3567
14	1.0000	0.8397	0.2919	0.7036
15	0.8381	0.7168	0.4459	0.6883
16	0.3614	0.6370	0.8938	0.5222
17	0.6092	0.5847	0.3609	0.5290
18	0.7537	0.8208	0.2611	0.5907
19	0.8525	0.7834	0.1391	0.5305
20	0.0569	0.0000	0.8928	0.0000
21	0.2573	0.3687	0.8185	0.3760
22	0.7605	0.5402	0.6794	0.6788
23	0.3986	0.4419	1.0000	0.5147
24	0.5687	0.3743	0.7834	0.5549
25	0.4877	0.4972	0.8376	0.5610

Step 3: From the value of composite desirability in Table VIII, by using (13) and (14), the main parameter effects are tabulated in Table IX and the factor effects are plotted in Fig.3

TABLE IX
MAIN EFFECTS ON COMPOSITE DESIRABILITY VALUES

Factor / Levels	1	2	3	4	5	Difference	Rank
WFR	0.4556	**0.5370**	0.2649	0.4344	0.3445	0.1906	2
V	0.3303	0.4505	0.3249	0.4615	**0.4692**	0.1442	4
TS	**0.5268**	0.3946	0.3584	0.3918	0.3648	0.1683	3
TA	0.1656	0.3967	**0.5219**	0.47102	0.48116	0.35632	1

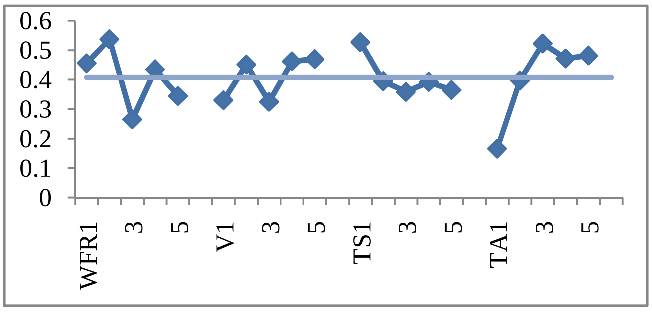

Fig. 3 Factor effects on composite desirability values

From Table IX and Figure 3, we obtain the optimal parameter condition WFR2 V5 TS1 TA3.

Step 5: Using the composite desirability value, ANOVA is formulated for identifying the significant factors. The results of ANOVA are given in Table X. From ANOVA, it is clear that Torch angle (34.9895%) influences more on welding followed by wire feed rate (22.8593%), travel speed (21.0985%) and voltage (14.0232%).

TABLE X
RESULTS OF ANOVA ON COMPOSITE DESIRABILITY

Factor	Sum of Squares	Degree of freedom	Mean squares	F-Cal	F-table	% Contribution
Wire feed rate	0.2373	4	0.0593	6.5039	3.8379	22.8593
Voltage	0.1456	4	0.0364	3.9899	3.8379	14.0232
Travel speed	0.2191	4	0.0548	6.0029	3.8379	21.0985
Torch angle	0.3633	4	0.0908	9.9551	3.8379	34.9895
Error	0.0730	8	0.0091			7.0294
Total	1.0383	24				

V. RESULTS AND DISCUSSIONS

A. Confirmation Tests

Based on the preliminary trails, the initial parameters were chosen and the bead on plate welding trail was made and subsequently the bead profiles were measured. A confirmation experiment trail was carried out to validate the results and it has been compared with the initial condition. Table XI reflects the satisfactory results of confirmatory experiment. From the Table XI the predicted bead profiles have the better depth of penetration, lesser bead width and reinforcement.

TABLE XI
RESULTS OF CONFIRMATORY EXPERIMENT

	Wire feed rate	**Voltage volts**	**Travel speed m/min**	**Torch angle °**	**Depth of penetration**	**Bead width (mm)**	**Reinforcement (mm)**
Initial parameter	9	25	0.3	70	4.889	8.347	2.712
Predicted parameter	8	27	0.3	70	4.901	8.252	2.684

VI. CONCLUSIONS

Based on the Flux cored arc welding parameters (AISI 316L (N) ASS) considered in this study, *the following points are deduced:*

1. The optimization of flux cored arc welding by calculating the grey relational and desirability analysis and using the recommendation of design for determining welding parameters was successful and the optimal parameter condition is WFR2 V5 TS1 TA3.
2. Based on ANOVA results, grey relational analysis (error 4%) is more accurate than desirability approach (error 7%) to optimize the flux cored arc welding process in order to obtain the good bead profile.
3. In both the analyses, torch angle has the most significant parameter followed by wire feed rate, travel speed and voltage.
4. Predicted results confirmed higher depth of penetration less bead width and reinforcement.

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