Optimization of Flux Cored Arc Welding Process Parameters by Grey-Based Taguchi Approach

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Abstract - For controlling weld bead geometry in Flux cored arc welding (FCAW) process, selection of appropriate values for process variable is necessary. In this study Grey based Taguchi method is used for optimizing the weld bead geometry developed by flux cored arc welding process. Mathematical models were developed to optimize the process parameters such as voltage, current, stick out and wire speed on various bead parameters such as penetration, reinforcement, bead width and percentage of dilution. The study involved sixteen experiments based on Taguchi's L_{16} orthogonal array (OA) design and result indicates that optimal process parameters are 20V for voltage, 155A for current, 15 mm for stick out and 25mm/min for wire speed from selected range. Adequacy and significance of the developed models have been checked by analysis of varience (ANOVA) test. Accuracy of optimization was confirmed by conducting confirmation tests. From the experimental results it is proved that optimal process parameters can be effectively determined using grey based Taguchi method.

Keywords - *FCAW, weld bead geometry, Taguchi's concept, Grey-based Taguchi method, ANOVA.*

I. INTRODUCTION

Flux cored arc welding (FCAW) is a multi-factor, multi-objective manufacturing process. It is widely preferred in fabrication industry because of easy control of process variables, high quality, deep penetration and smooth surface finish [1].In FCAW process which is a fully automated process, the welding electrode is in tubular wire form which is continuously fed into the weld area. The flux materials are in the core of the tube and the outer shell of the tube conducts the electricity that forms the arc and then becomes the filler material as it is consumed. FCAW is a repair weld techniques that provides better control over the current and heat input to carry out to repair. Quality of FCAW weld influenced by welding parameters such as current, voltage, speed of welding, wire diameter and stick out. These parameters have to be selected carefully in order to get a good weld. In the present work, the effect of voltage, current, wire speed and stick out on bead geometry has been studied. Mechanical and chemical properties of good weld depend on bead geometry and have direct effect on process parameters. Study of the relationship between process parameters and weld bead geometry is necessary to get a good weld.

How to control the input process parameters to obtain a good welded joint with required bead geometry is the main problem faced in industries. Usually these parameters are selected by trial and error which is time consuming and there are chances of error. In order to overcome this problem various optimization techniques have been used to get the desired result.

The weld bead geometry is shown in figure 1. 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 wire speed, welding current, stick out and voltage 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.

Multi objective optimisation problems cannot be solved effectively by traditional Taguchi method. Commonly used approach is to solve these type problems by assigning weights for every response. To overcome this type of situations Taguchi method based grey relational analysis approach was developed. The purpose of the grey relational analysis is to aggregate multiple responses (objective functions) in to an equivalent quality index (single objective function) which can be easily optimized by Taguchi method. But these method is based on the assumption that response features i.e. quality indices are uncorrelated i.e., independent.

Tarng *et al* used grey based Taguchi method for optimizing submerged arc welding process parameters in hard facing by considering multiple weld qualities and determined optimal process parameters based on grey relational grade proposed by Taguchi method [3].

Norasiah Mohammed *et al* used multi objective Taguchi method to optimize process parameters of resistance spot welding towards weld zone development. This optimization attempts to consider simultaneously the multiple characteristics namely weld nugget and heat affected zone using multi objective Taguchi method [4].

The review of literatures reveals that the researchers are mainly focussed in optimizing multi response characteristics. Grey based Taguchi method is employed by many characteristics in optimizing conventional and non-conventional welding process. Very rarely a complete optimization of weld bead geometry of flux cored arc welding process is observed in the contemporary literature. In this study Taguchi method coupled with grey relational analysis is used for solving the optimization problem. This method utilizes a well-balanced experimental design with limited number of experimental runs called orthogonal array (OA) and signal to noise ratio (S/N ratio) which serve the objective function to be optimized, within experimental domain. Multi-objective optimization problems cannot be solved effectively by traditional Taguchi method. In order to overcome this difficulty, the Taguchi method coupled with grey relational analysis is used to solve the optimization problem in this study. In grey based Taguchi method a multi response process optimization problem can be converted to a single response optimization problem where overall grey relational grade serves as a single objective function to be optimized (maximized).

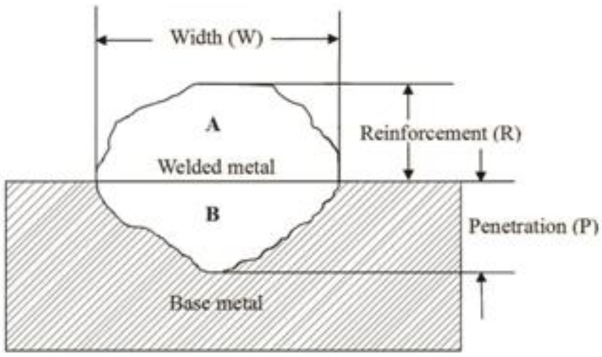

Fig.1: Weld bead geometry

II. TAGUCHI METHOD

Taguchi method uses a special type of design called 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 which can be used to measure the quality characteristics deviating from desired values [3]. 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 considered with levels that have highest signal-to-noise ratio.

In general signal to noise ratio (η, dB) represents quality characteristics for the observed data in Taguchi design of experiments (DoE) and mathematically represented as:

η = -10log [MSD]........... (1)

In this, MSD is the mean square deviation from the desired value and commonly known as quality loss function. In this case smaller –the- better characteristic is used for reinforcement and bead width.

Nominal the best =-10 log10σ2............. (2)

Smaller- the- better =η=-10log$\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right]$........ (3)

Where, y_i is represented as the mean. From the S/N ration the effective parameters having influence on process results can be obtained and optimal sets of process parameters can be obtained. The Taguchi method also provides a better feel for the relative effect of the different parameters that it can be analyzed by analysis of variance (ANOVA). If p- value is less than the significance level (α), the factor is then regarded as statistically considered as significant. The relative significance of factors is represented in terms of F-ratio or percentage of contribution. The greater F- ratio indicates that the variation of the process parameters makes big changes on performance, or p- ratio is less than .05 the more significant will be the factor.

III. GREY RELATIONAL ANALYSIS

First experimental data are normalized from zero to one which is known as Grey relational generation. Based on the normalized data, Grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. After that overall Grey relational grade is determined by averaging the Grey relational coefficient corresponding to selected responses [5]. The overall performance characteristics of the multiple responses process depends on the calculated Grey relational grade. This process converts a multiple response process optimization problem with objective function as Grey relational grade. The optimal parametric combination is then evaluated which would result highest grey relational grade.

In Grey relational generation, Normalized bead width and reinforcement corresponding to lower-the-better (LB) criterion can be termed as:

x_i (k) = $\frac{\max yi(k) - yi(k)}{\max yi(k) - \min yi(k}$……………………(4)

Bead penetration and percentage of dilution should be the larger the better and is expressed as:

$$x_i\,(k) = \frac{y_i\,(k) - \min y_i\,(k)}{\max y_i(k) - \min y_i(k)} \;\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where $x_i(k)$ is the value after the grey relation generation, min $y_i(k)$ is the smallest value of $y_i(k)$ for kth response, and max $y_i(k)$ is the largest value of $y_i(k)$ for kth response. The normalized data after Grey relational generation are tabulated in Table 7.An ideal sequence is $x_0(k)$ where k=1, 2, 3....16, for the responses. The definition of Grey relational grade in the course of grey relational analysis is to reveal the degree of relation between the 16 sequences [$x_0(k)$ and $x_i(k)$,i=1,2,3....16] . The grey relational coefficient shown in Eq (3)

$$\epsilon_i\,(k) = \frac{\Delta\min + \psi\Delta\max}{\Delta 0i(k) + \psi\Delta\max} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

where $\Delta_{0i}= \|x_0(k) - x_i\,(k)\|$ is the difference of the absolute value $x_0(k)$ and $x_i(k)$;ψ is the diminishing coefficient $0\leq \psi \leq$i;$\nabla_{min}=\forall j^{min}\ \epsilon i \forall k^{min}\|x_0(k) - x_i\,(k)\|$ is the smallest value of Δ_{0i}; and $\Delta_{max}=\forall j^{max}\ \epsilon i\ \forall k^{max}\|x_0(k) - x_i\,(k)\|$ = largest value of Δ_{0i}. After averaging the Grey relational coefficients, the grey relational grade γ_i can be calculated by Eq (4):

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i\,(k) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where n is the number of process responses. The higher value of grey relational grade corresponds to intense relational degree between sequence $x_0(k)$ and the given sequence $x_i(k)$. The reference sequence $x_0(k)$ represents the best process sequence. This means that higher grey relational grade it is closer to the optimal point.

IV. EXPERIMENTATION

300 x 200 x 6 mm plates 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. Table 1 shows the properties of base metal and filler wire.

The selection of the welding electrode wire is based on the mechanical properties and physical characteristics of the base metal, weld size and existing electrode inventory available. [6].These should 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

V. PLAN OF INVESTIGATION

The research work is carried out in the following steps.

- Identifying the quality characteristics and process parameters to be evaluated.
- Selection of appropriate orthogonal array and assign process parameters.
- Determination the number of levels for the process parameters and possible
- Preparation of orthogonal array.
- Conducting experiment as per arrangement of orthogonal array.
- Analyze the experiments through Grey –based Taguchi approach.
- Conduction of confirmation experiment.
- Selection the optimum level of process parameters.

A. Identification of factors and responses

The percentage of dilution has got a very dominating effect in welding. The properties of the welding are significantly influenced by dilution obtained. Hence control of dilution is important in welding where a high dilution is desirable. The chosen factors have been selected on the basis to get maximum 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 weld 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.

B. 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 [7].

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.

C. Development of Orthogonal array.

Design matrix chosen for conducting the experiments was Taguchi's robust design. The design matrix comprises of $L_{16}(4^4)$ designs which is shown in Table 3.

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

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

D. Conducting experiments as per orthogonal array

In this work sixteen experimental run were conducted as per the combination of parameters on bead geometry as shown Table 3. 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.

E. Recording of Responses

To mesure 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 to get a smoother appearance. The specimen and faces were polished and etched using a 5% nital solution to display bead dimensions. The weld bead profiles were traced using a reflective type optical profile projector at a magnification of X10, in YCET Kollam [8]. Then the bead dimensions such as depth of penetration height of reinforcement and weld bead width were measured using vernier calliper. The area of reinforcement and area of penetration were measured by using a digital planimeter. The percentage of dilution is obtained by Eq (8).

Percentage dilution (D) = [B/ (A+B)] X 100..... (8)

Where A is the reinforcement area and B is the area of penetration. Bead on plate welding and scanned specimen is shown in Figure 2. The weld bead dimensions and percentage of dilution is shown in Table 4.

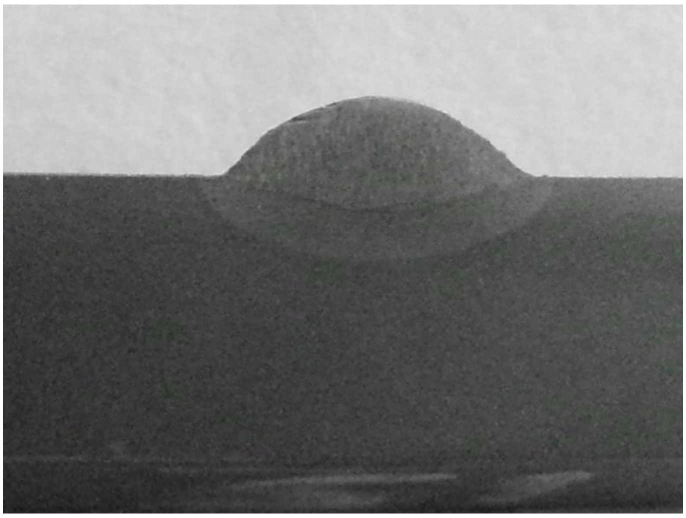

Fig.2: Scanned specimen

TABLE 4. DESIGN MATRIX AND OBSERVED VALUES OF CLAD BEAD GEOMETRY

Trial No.	Design Matrix				Bead Parameters			
	I	S	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 %

VI. OPTIMIZATION OF FCAW PROCESS

Experimental data have been normalized first; this is known as Grey relational generation. Experimental data is shown in Table 5. For bead width and reinforcement lower-the-better (LB) and for depth of penetration and percentage of dilution higher-the better (HB) criterion has been selected. Grey relational coefficients for each performance characteristics have been calculated using Eq (5) and Eq (6) and shown in Table 6.These Grey relational coefficients for each response has been accumulated to evaluate Grey relational grade by Eq (7) which is the overall representative of all features of weld quality, shown in Table 7.Table 8 shows grey relational coefficient of each performance characteristics done by using Eq (7). Using a combination of Taguchi approach and grey relational analysis, multi criteria optimization problem has been transformed in to a single equivalent objective function using Eq (8). Higher the value of Grey relational grade, the corresponding factor combination is said to be closer to optimal solution [8]. Table 9 shows the mean response table for the overall Grey relational grade and is represented graphically in Figure 3.The overall Grey relational grade is calculated using larger-the-better criterion using Eq (9).

$$SN\ (\text{Larger-the-better}) = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y2}\right] \quad \text{.......... (9)}$$

Where n is the number of measurements and y_i is the measured characteristic value. From orthogonal experimental design, it is possible to separate out the effect of each welding parameter at different levels. Total mean Grey relational grade is the average of all entries which is shown in Table 9.With the help of Fig 3, the optimal parametric combination has been determined as $V_1I_4N_1T_1$. Response table for means for grey relational grade is shown in Table 10.

TABLE 5. EXPERIMENTAL DATA

W (mm)	P (mm)	R (mm)	D (%)
8.306	1.235	2.815	17.623
8.243	1.347	2.543	17.462
8.731	1.388	2.675	17.842
8.925	1.425	2.931	17.442
9.792	1.657	2.449	18.332
10.415	1.586	2.779	16.692
8.869	1.456	2.863	17.823
8.614	1.738	2.597	20.424
8.908	1.416	2.538	17.912
9.371	1.537	2.397	18.182
9.087	1.465	2.432	18.218
8.853	1.368	2.672	17.512
9.125	1.487	2.423	18.221
8.753	1.398	2.567	17.943
8.971	1.457	2.697	17.841
9.807	1.868	2.243	21.512

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

TABLE 6. GREY RELATIONAL GENERATIONS

Bead Parameters			
W	R	P	D
1(Ideal)	1(Ideal)	1(Ideal)	1(Ideal)
1	0	1	
0.9129	0.176935	0.8230	0.193154
0.7078	0.241706	0.7582	0.159751
0.6263	0.300158	0.6999	0.238589
0.2618	0.666667	0.3333	0.155602
0	0.554502	0.4454	0.340249
0.6498	0.349131	0.6508	0
0.7570	0.794629	0.2053	0.234647
0.6326	0.28594	0.7140	0.774274
0.2875	0.477093	0.5229	0.253112
0.5582	0.363349	0.6287	0.309129
0.6565	0.210111	0.7898	0.316598
0.5422	0.398104	0.6018	0.170124
0.6986	0.257504	0.7429	0.31722
0.6069	0.350711	0.6429	0.259544
0.2543	1	0	0.238382

TABLE 7. EVALUATION OF Δ_{0I} FOR EACH RESPONSE

Bead Parameters			
W	P	R	D
1	1	1	1
0	1	0	0.806846
0.0871	0.823065	0.177	0.840249
0.2922	0.758294	0.2418	0.761411
0.3737	0.699842	0.3001	0.844398
0.7382	0.333333	0.6667	0.659751
1	0.445498	0.5546	1
0.3502	0.650869	0.3492	0.765353
0.243	0.205371	0.7947	0.225726
0.3674	0.71406	0.286	0.746888

0.7125	0.522907	0.4771	0.690871
0.4418	0.636651	0.3713	0.683402
0.3435	0.789889	0.2102	0.829876
0.4578	0.601896	0.3982	0.68278
0.3014	0.742496	0.2571	0.740456
0.3931	0.649289	0.3571	0.761618
0.7457	0	1	0

TABLE 8. GREY RELATIONAL COEFFICIENT OF EACH PERFORMANCE CHARACTERISTICS (WITH Ψ=.5)

Bead Parameters			
W	P	R	D
1	1	1	1
1	0.333333	1	0.34352
0.851644	0.37791	0.738552	0.334431
0.631154	0.397363	0.674036	0.356707
0.572279	0.416722	0.624922	0.333336
0.403812	0.6	0.428559	0.390224
0.333333	0.528822	0.474113	0.296865
0.588097	0.434454	0.588789	0.355523
0.672948	0.708847	0.38619	0.651626
0.576435	0.411841	0.636132	0.361138
0.412371	0.488803	0.511718	0.379313
0.530898	0.439889	0.573855	0.381876
0.592768	0.38763	0.704027	0.337202
0.52203	0.453763	0.556669	0.382091
0.623908	0.402416	0.660415	0.363136
0.559848	0.435052	0.583363	0.356645
0.41666	1	0.3333	1

TABLE 9. OVERALL GREY RELATIONAL GRADES.

Experiment No	Grey relational grade	S/N ratio
1	0.669213	-3.48871
2	0.575634	-4.79707
3	0.514815	-5.76698
4	0.486815	-6.25273

5	0.455649	-6.8274
6	0.408283	-7.78077
7	0.491716	-6.16572
8	0.604903	-4.36629
9	0.496387	-6.0836
10	0.448051	-6.97345
11	0.48163	-6.34574
12	0.505407	-5.92718
13	0.478638	-6.39985
14	0.512469	-5.80665
15	0.483727	-6.30799
16	0.687495	-3.25461

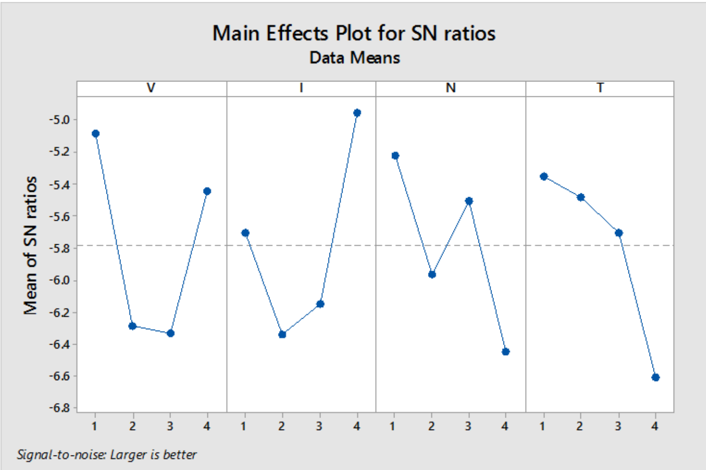

Fig.3: Main effects plot for S/N ratios

TABLE 10. RESPONSE TABLE (MEAN) FOR OVERALL GREY RELATIONAL GRADE

Level	V	I	N	T
1	-5.076	-5.700	-5.217	-5.347
2	-6.285	-6.339	-5.965	-5.477
3	-6.332	-6.147	-5.506	-5.706
4	-5.442	-4.950	-6.448	-6.606
Delta	1.256	1.389	1.230	1.259
Rank	3	1	4	2

VII. ANALYSIS OF VARIANCE (ANOVA)

To test the adequacy of the model analysis of variance (ANOVA) technique was used. This method is very useful to reveal the level of significance of influence of factors or interaction factors on particular response which is accomplished by separating the total variability of the grey relational grades. This is measured by the sum of the squared deviations from the total mean of the grey relational grade separating the total variability of responses into contributions rendered by each of parameter and error.

$SS_T=SS_F+SS_e$ ………(10)

Where

$SS_T= \sum_{j=1}^{p} (\gamma_j-\gamma_m)^2$

SS_T =Total sum of squared deviations about the mean
SS_F = Sum of squared deviations due to each other
SS_e =Sum of squared deviations due to error
γ_j =Mean response for *jth* experiment
γ_m = Grand mean of responses

In ANOVA table mean square deviation is defined as:

$MS=\frac{Ss\ (sum\ of\ squared\ deviation)}{DF\ (Degree\ of\ freedom)}$……(11)

F-value of Fishers F ratio (variance ratio) is defined as:

$F=\frac{MS\ for\ a\ term}{MS\ for\ the\ error\ term}$……… (12)

Depending on F-value, P- value (probability of significance) is calculated. If P value of a term is less than .05 (95% confidence level), it can be concluded that effect of factors is significant. ANOVA for overall Grey relational grade is shown in Table 11. It can be shown that P value for welding current is 0.685.It can be evident that welding current is the most significant factor in this study. Most insignificant factor is wire speed.

TABLE 11. ANALYSIS OF VARIANCE (ANOVA)

Source	DF	Adj SS	Adj MS	F	P
Regression	4	0.026885	0.006721	1.18	0.373
V	1	0.000991	0.000991	0.17	0.685
I	1	0.004229	0.004229	0.74	0.408
N	1	0.010489	0.010489	1.84	0.202
T	1	0.011176	0.011176	1.96	0.189
Error	11	0.062767	0.005706		
Total	15	0.089653			

VIII. VALIDATION OF MODELS

The estimated Grey relational grade $\hat{\gamma}$ using the optimal level of design parameters can be calculated as:

$\hat{\gamma}=\gamma_m+\sum_{i-1}^{0}(\hat{\gamma}_i-\gamma_m)$…… (13)

Where γ_m is the total mean Grey relational grade, $\hat{\gamma}_i$ is the mean Grey relational grade at the optimal level and o is the number of the main design parameters that affect the quality characteristics. This means that the predicted Grey relational grade is equal to the mean grey relational grade plus the summation of the difference between overall mean Grey relational grades for each of the factors at optimum level.

Table 12 represents the comparison of the predicted bead geometry parameters with that of actual by using optimal welding conditions obtained from this study. Good agreement between the predicted and experimental results has been observed and improvement of overall Grey relational grade is the result obtained. This proves the utility of the proposed approach in relation to process optimization, where more than one objective has to be fulfilled simultaneously.

TABLE 12. RESULTS OF CONFORMITY EXPERIMENT

Parameters	Initial factor setting	Prediction	Experiment
Level of factors	$V_1 I_1 N_1 T_1$	$V_1 I_4 N_1 T_1$	$V_1 I_4 N_1 T_1$
Bead width	8.306		8.425
Reinforcement	1.235		1.347
Penetration	2.815		2.985

Dilution (%)	17.235	16.657
Overall Grey relational grade	0.66923	0 .76473
Improvement in grey relational grade = 0.1		

IX. RESULTS AND DISCUSSIONS

In this work a detailed methodology of Taguchi optimization technique coupled with Grey relational analysis has been adapted and applied for evaluating the optimal parameters that is deeper penetration maximum dilution, minimum bead width and minimum reinforcement produced by flux cored arc welding. This study has intended to prove the application feasibility and merit of Grey relational Taguchi method for solving multi objective optimization technique in the field of flux cored arc welding process. Figure 4 and Figure 5 shows microstructure of HAZ in flux cored arc welding. In the weld zone grains becomes finer than het affected zone. In fusion zone there is increased dendritic growth.

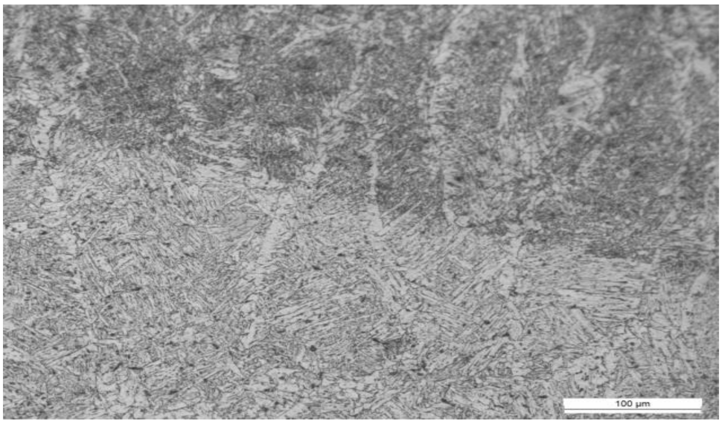

Fig.4. Fusion line of weld zone

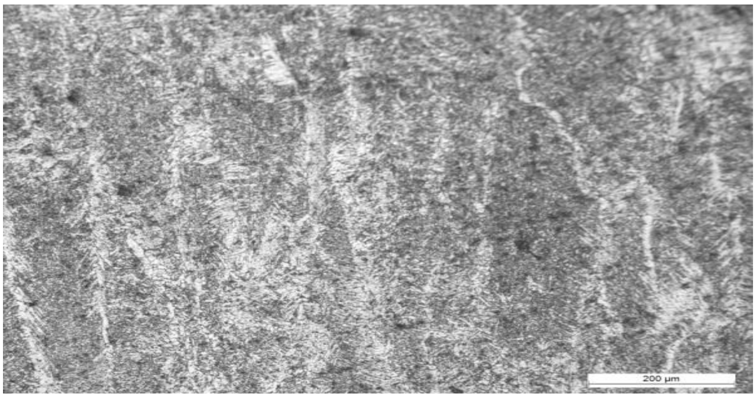

Fig.5. Microstructure of weld zone

X. CONCLUSIONS

In grey relational analysis the composite quality indicator is overall grey relational grade, which is based on quality loss function .It minimizes the quality loss i.e., in contrary it maximizes the inverse quality loss. Grey relational coefficient is determined by taking inverse function of quality loss. Therefore overall grey relational grade is inversely proportional to cumulative quality loss due to multiple responses. Based on the above study it can be observed that the developed model can be used to optimize weld bead geometry within the applied limits of process parameters. This method of optimization process parameters can be used to get maximum percentage of dilution and penetration, minimum reinforcement and bead width. Grey relational theory can combine individual components into a single component i.e., grey relational grade to be taken under consideration for optimization. This is very helpful when large number of responses have to be optimized simultaneously. In this study Grey relational Taguchi method was used for achieving optimal weld bead dimensions in flux cored arc welding process. The above approach can be recommended and can be used for continuous improvement in welding area.

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