ON THE PERFORMANCE OF SOLID-WIRE GMAW AND FCAW THROUGH EXPERIMENT AND RELATED EXPERIMENTAL DESIGN

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Abstract In this paper, analysis of the results of experiments carried out with Gas Metal Arc Welding (GMAW) and Flux-Cored Arc Welding (FCAW) are presented. For optimization regression equations were developed with dimensions of the weld zone under various parameter setting of welding. And the influence of different ranges of independent variables on dependent characteristics was found out with a 4^3 factional design. It is shown that FCAW is a better process than GMAW in the range of parameters, used for our experimentation.

Keywords:GMAW,FCAW,ExperimentalDesign

INTRODUCTION

Welding is the most rapid and easiest way of fabrication and assembly of metal parts. Inherent disadvantages of low deposition rates and efficiency gas shielded arc welding process with continuous bare metallic wire electrode. GMAW and FCAW are classified by AWS as two separate process but because of their many similarities in application and equipment, both process are categorized under same group. The use of cheaper active gas like CO_2 (way back in 1953)has made MIG-CO_2 process popular for the welding of structural steel and the use of CO_2 welding increased further with the adaptation of flux-cored filler wires. Carbon-dioxide costs approximately one-tenth as much as argon or helium and is capable of producing a high quality weld when used as a shielding gas.
The deposition efficiencies of both the process are particularly high, approaching 95 to 100% with solid electrodes (depending on shielding gas), 85 to 90% with gas shielded cored electrodes and 80 to 85% with self shielded cored electrodes.

Over the years, the advantages of bare metallic wire CO_2 welding (i.e., MIG-CO_2) has been discussed in many forums. However, the inherent disadvantages of arc spatter because of arc and metal transfer characteristics limited its application at high currents and also often led to higher costs.

Still in the engineering industry, CO_2 welding is advantageously used on account of its capability to automation and its economy.

Hence any further measure to increase productivity and economy by reducing cleaning costs (with better bead geometry) will also favor its increased application.

Following specific problems are investigated in this work. These are:-
1. Comparative effect of current, voltage and speed of travel on bead geometry.
2. Comparative study for fluctuations of arc voltage and current during GMAW & FCAW process.
3. Derivation of regression equations with the dimensions of the weld zone under various parametric setting of welding and to find out the influence of different ranges of independent variables on dependent characteristics with factorial design.

EXPERIMENTAL DETAILS

Plates Used
Different specimens of structural steel flat plates (as per IS 2062) of size $125mm \times 50mm \times 12mm$ were used to form weld bead by varying voltage, current and travel speed.

GMAW
Electrode used =CCMS; E 7015 type with low hydrogen.
Power Source = Rectified AC machine with DC electrode positive.
MIG universal wire feeder
Shielding gas =CO_2
Voltage = 20v, 25v, 30v, 35v
Current = 130, 180, 230, 280 Amp
Beads were formed by varying one parameter at a given time.

FCAW
For FCAW we used Fluxofil-12 as electrodes supplied by Advani Oerlikon Ltd., Calcutta

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ower Source = Rectified Ac machine with DC electrode positive
Shielding gas = CO_2
Voltage = 20v, 25v, 30v, 35v
Current = 130, 180, 230, 280 Amp

Arc and Metal Transfer Characteristics

The Encardio-rite recording system consists of direct writing oscillograph, power supply units, users choice of several Encardio-rite pre-amplifiers, providing a means of recording in permanent form for study and analysis of the amplitude and frequency of any variable that can be converted into an electrical signal.

We took the impulse from the Ammeter input terminals of machine unit and send it to the pre amplifier channel through a six pin Cannon connecter and other knobs are adjusted. We get the pattern of voltage or current variation during welding where from we can predict about the arc stability, mode of metal transfer, arc characteristics etc. in different process like GMAW and FCAW.

DESIGN OF THE EXPERIMENT

In the present investigation we consider three factors viz. voltage (V), Current(I) and Travel speed (T) each at four levels namely 0,1,2,3, i.e., we consider a 4^3 factorial experiment. The levels corresponding to each factor are different. The main effects are intersections with respective degrees of freedom (d.f.) are as follows :

Table 1

Factors	Main effects & Interactions	d.f.
V	V	3
I	I	3
	V×I	9
T	T	3
	V×T	9
	I ×T	9
	V×I×T	27
	Total	63

The process by which unimportant treatment comparisons mixed up with the block comparisons for the purpose of assessing more important comparisons with greater precision is called confounding. In the present case the highest order interaction being *V×I×T* which carries 27 d.f. This interaction has nine components namely VIT, VIT^2, VIT^3, VI^2T, VI^2T^2, VI^2T^3, VI^3T, VI^3T^2, VI^3T^3 each carrying a 3d.f. We consider a (4^3, 4) factorial design containing 4 blocks, each block contains 16 treatment combinations confounding the interacting VIT carrying 3 d.f. Here only one replication of the experiment is considered. Assuming the 3-factor interaction has no significant effect on the response variables under study, the remaining 24 d.f. corresponding to the components of the 3-factor interaction corresponds to error d.f. in the ANOVA table. It is to be noted that each of the main effects and the factor interactions is tested against error whose sum of squares is taken as the sum of squares due to the eight remaining components of the 2nd order interaction *V×I×T*. The layout of the design (4^3, 4) confounding VIT is given below :

Table-2 For factors & levels

V				I				T			
20	25	30	35	13 0	1 8 0	2 3 0	2 8 0	15	25	40	55
0	1	2	3	0	1	2	3	0	1	2	3

Table 3 For blocks

Bl-I	II	III	IV
000	001	002	003
013	010	011	012
022	023	020	021
031	032	033	030
103	100	101	102
112	113	110	111
121	122	123	120
130	131	132	133
202	203	200	201
211	212	213	210
220	221	222	223
233	230	231	232
301	302	303	300
310	311	312	313
323	320	321	322
332	333	330	331

Next we form the ANOVA showing necessary calculations for testing the significance of main effects and interaction.

Table 4

Source	d.f.	S.S.	M.S.	F Calculated
Block	3	SSB	MSB	MSB/MSE
Main effects				
V	3	SSV	MSV	MSV/MSE
I	3	SSI	MSI	MSI/MSE
T	3	SST	MST	MST/MSE
Interactions				
V×I	9	SS (V×I)	MS (V×I)	MS (V×I) / MSE
V×T	9	SS (V×T)	MS (V×I)	MS (V×T) / MSE
I×T	9	SS (I×T)	MS (I×T)	MS (I×T) / MSE
Error	24	SSE	MSE	
Total	63			

This layout and ANOVA is carried out for each of the response variable height, depth of penetration, width.

Table 5

Source	d.f.	S.S.	M.S.	F Calcul-ated	F-Tabulated	
					F-1%	F-5%
Block	3	0.111	0.937	** 2.414	4.72	3.01
Treat-ments Main Effects						
V	3	9.663	3.221	* 209.716	4.72	3.01
I	3	15.141	5.047	* 328.586	4.72	3.01
T	3	32.845	10.948	* 712.782	4.72	3.01
Interac tions						
V×I	9	0.902	0.100	*6.528	3.26	2.30
V×T	9	0.408	0.045	*** 2.957	3.26	2.30
I×T	9	0.576	0.064	*4.167	3.26	2.30
Error	24	0.358	0.015			
Total	63	60.0175				

Now we have to investigate whether the different levels of V have equal effect on height of weld bead. For this we can use Student-Newman-Keuls Range test. Similar procedure is adopted for the factors I and T and also for two different process GMAW & FCAW.

* Significant at both level, ** Not Significant, *** Significant at 5% level but not significant at 1% level.

Table 6

Levels	Means
20(=0)	3.71250(= X_1)
25(=1)	3.46875(= X_2)
30(=0)	3.11250(= X_3)
35(=0)	2.68125(= X_4)

Means arranged form highest to lowest 3.71250(Y_4), 3.46875(Y_3), 3.11250(Y_2), 2.68125(Y_1) where Y_1 is the ith largest among (X_1, X_2 , X_3 , X_4).

$$W_4 = q_{c5,4,24}\sqrt{\frac{S^2}{16}}$$

$$= 3.90 \times \sqrt{\frac{.01536}{16}} = 3.90 \times 0.03098 = 0.12084$$

Now, $Y_4 - Y_1 = 3.71250 - 2.68125 = 1.03125$

Since $Y_4 - Y_1 > W_4$ i.e., the four average are different. Next we divide $Y_4 ,.....Y_1$ into two subgroups as follows.

Table 7

Subgroup	Means in the subgroups
1	Y_4, Y_3, Y_2
2	Y_3, Y_2, Y_1

$W_3 = q_{.05,3,24} \times 0.03098 = 3.53 \times 0.03098 = 0.10935$

Consider the ranges $R_1 = Y_4 - Y_2 = 0.6$

$R_2 = Y_3 - Y_1 = 0.7875$ Since both R_1 and R_2 exceeds W_3, we again divide the K-1 means in the group concerned into two groups of K-2 means each and the ranges of these subgroups are compared with W_{K-2} . It is to be noted that this procedure is continued until a group of 1 means is found whose range does not exceed W_1 .

Table 8

Subgroup	Means in the subgroup	Ranges
S_{11}	$Y_4 \times Y_3$	$R_{11} = 0.24375$
S_{12}	$Y_3 \times Y_2$	$R_{12} = 0.35625$
S_{21}	$Y_2 \times Y_1$	$R_{22} = 0.43125$

$W_3 = q_{.05,3,24} \times 0.03098 = 2.92 \times 0.03098 = 0.09046$

since each of the above ranges exceeds W_2 so we conclude that the levels of the factor V has different effects on the height of the weld bead.

Similar procedure is adopted for current (I) and Travel speed (T).

RESULTS FROM FACTOTORIAL DESIGN

On Depth Of Penetration On GMAW

From the analysis of variance it has been found that the factors voltages, current, travel speed, intersections between current-voltage, voltage-speed have got significant effect on the response variable but current-travel speed interaction has got no significant effect.

On Depth Of Penetration on FCAW

From the ANOVA table it is clear that the effects of the factors voltage, current, travel speed, interaction between voltage-travel speed on this response variable are significant. But the interaction voltage-current and current-travel speed are significant at 5% level but not significant at 1% level.

On Height Of The Weld Bead On GMAW & FCAW

From the ANOVA table it is clear that the effects of the factors voltage, current, travel speed, interaction between voltage-current, current-travel speed have got significant effect but the interaction voltage-travel speed has got significant at only 5% level but at 1% level. On the other hand it has found that no interaction has significant effect on the response variable height and block effect also is not significant in contrary to the GMAW process.

On Width Of The Weld Bead On GMAW & FCAW Process

From the analysis of variance it has been found that expect factors-voltage, current, travel speed, the interaction between none have got significant effect on this character under study, only interaction volt-amps.

Has got significant effect at 5% level but not significant at 1% level. From ANOVA table we find no interactions has got any significant effect, on FCAW.

On HAZ Depth Of Weld Under GMAW & FCAW Process

For GMAW along with the treatments main effect-V.I.T. the interaction between voltage-travel speed, current-travel speed have got significant effect on the character but the interaction between voltage-current has got no significant effect. Whereas for FCAW no interaction has significant effect on the factor HAZ depth of Weld.

If we take the height of the weld bead as character under study, from the means values at different level we can predict the significant levels of voltage current & travel speed, which are pre dominant within the ranges, taken in our experimentation, For GMAW these are 20V.280amps. and 15cm/min travel speed, and for FCAW also those same values give predominant effects.

Taking depth of the penetration has a character under study we get the most effective set of values for voltage current and travel speed which act predominantly are – 35V. 280amps. And 15cm/min travel speed.

If we take the width of the weld bead as character under study, we find the optimum values as 35v. 280 amps and 15cm/min travel speed.

About HAZ depth, for GMAW those values are 35V. 280amps 15 cm/min travel speed. For FCAW also the values are same. The different levels voltage don't have very much distinguishing effect on this character.

From large sample test we find that the H_0 under mean is rejected but same under variance is accepted, due to the evenness of dispersion of studied character values from the mean values through means calculated adopting GMAW & FCAW process are totally different.

Large Sample Test

Case 1: For means of a variable under study under the procedure GMAW and FCAW consider the variable "height of weld bead". We assume that the populations corresponding to this character (variable) under GMAW and FCAW follow Normal distributions. Let the corresponding population means be μ_1 and μ_2 respectively. The two observed samples under height of weld bead are independent. To test

Hypothesis $H_0 : (\mu_1 = \mu_2)$

We use

$$Z = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{S_1^2}{n_1} - \frac{S_2^2}{n_1}}} \sim N(0,1)$$

where S_1^2 and S_2^2 are the respective sample variances

$$S_1^2 = \frac{1}{n}\sum (x - \bar{x})^2 = \frac{1}{n}\left(\sum x^2\right) - (\bar{x})^2$$

If $|Z| > Z_{\alpha/2}$, we reject H_0 the averages under the two process GMAW and FCAW differ.

Similar procedure is adopted for each of the characters under study separately.

$$S_1^2 = \frac{1}{n_1}\left(\sum x\right)^2 - \bar{x}^2$$

$$S_2^2 = \frac{1}{n_2}\left(\sum Y\right)^2 - \bar{Y}^2$$

From table we have $Z = Z_{.025} = 1.96$ and $Z_{.005} = 2.58$

If $|Z|$ (calculated) less than 1.96, accept H_0 otherwise reject H_0.

Prediction Equations

We have developed the following linear regression equations after calculating the different regression coefficients.

Table 9

Dimension	Equations
H_G	: 3.24375-0.5175V+0.6505I-0.059T
H_F	: 2.8125-0.4761V+0.6881I-0.03789
D_G	: 2.56+0.69468V+0.671I-0.0373T
D_F	: 2.285-0.321V+0.496I-0.03959T
W_G	: 10.07+2.099V+1.9386I-0.17466T
W_F	: 12.51+0.7866V+3.5634I-0.1599T
HA_G	: 1.36+0.1828+0.28575I-0.03649T
HA_F	: 1.3+0.3V+0.2517I-0.0154T

From the regression equations we can predict the response/dominance of a welding parameter upon a character under study statistically, with a correct manner. The optimized prediction equations (in table 8) can be used to predict the bead geometry resulting from any combination of welding parameters within the bounds of present investigation. The approach would be useful to determine whether a set of welding parameters would result in the desired weld bead geometry. In this approach the values of the welding parameters should be substituted to coded values into the relevant equation. For a given specific set of requirements for bead geometry we can determine a combination of parameters or range of parameters that will meet the requirements.

Plots from encardio-rite are shown below:

PARAMETERS
25 VOLTS, 230 AMPS, 25CM/MIN TRAVEL SPEED

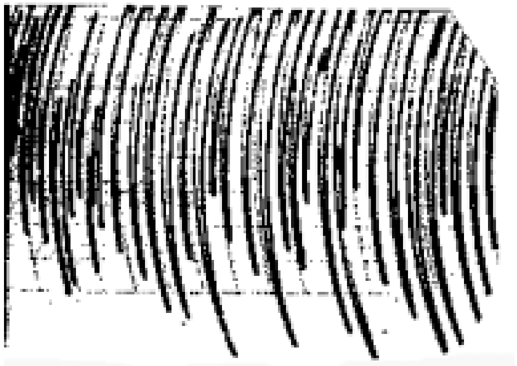

Fig.1 For GMAW

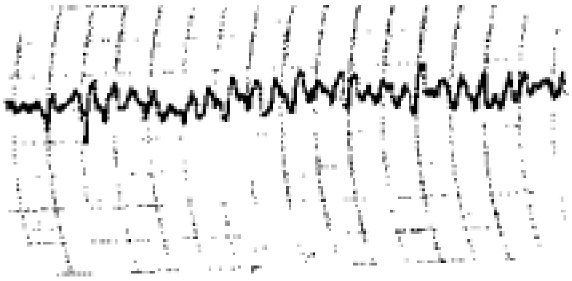

Fig.1 For FCAW

PARAMETERS
25 VOLTS, 230 AMPS, 55CM/MIN TRAVEL SPEED

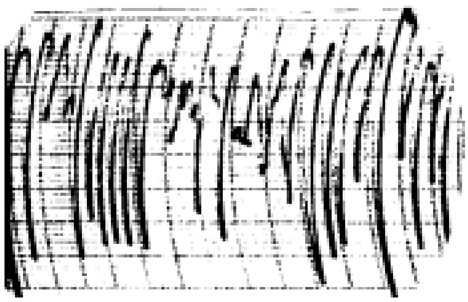

Fig. 2 For GMAW

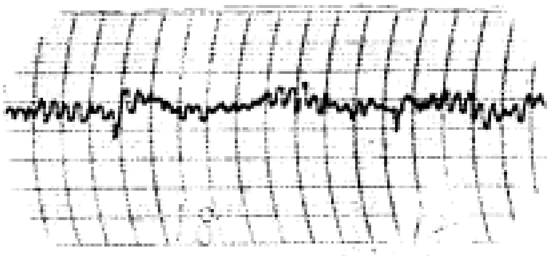

Fig. 2 For FCAW

RESULTS AND DISCUSSIONS

In order to asses the influence of each process variable mentioned earlier, a number of welds have been made by solid wire GMAW & FCAW processes by varying each of the parameters, while keeping the others constant. Samples were cut from the center of the weld across the width of the bead, they were then polished and etched and cross-section was photographed with an average of several times magnification. Different data on width of weld bead, depth of penetration, height of weld bead and HAZ depth was measured from the said photographs and actual specimens. The design of experiments has already revealed the degree of influence of the welding parameters on the above geometrical factors

Figure 1 to figure 2 indicate the Encardiorite plotting through which we compared the behavior of arcs generated during GMAW and FCAW. It is clear that for FCAW we have got smoother curve than that under GMAW process. It is very much easy to stabilize the arc voltage for FCAW. The spattering action at GMAW is more which creates the proneness to weld defects. In FCAW, the slag detachability is excellent, weld bead is smoother and is better in shape & appearances.

CONCLUSION

Based on the experimental investigations and foregoing analysis on the effects of process variables on weld based geometry can draw some vital conclusions regarding the performance of GMAW & FCAW.

Effect Of Process Variables On Weld Bead Geometry

On depth of penetration: i) ANOVA for depth of penetration on GMAW & FCAW (in both cases) established that the effect of voltage, current, travel speed and the interaction between voltage & travel speed, on penetration is highly significant –even at 1% level. ii) From means test we can predict that most suitable values for optimum depth of penetration as 35V., 280 amps. & 15cm/min.

On height of weld bead: i) ANOVA for height of bead established that the effect of voltage, current, travel speed, the interaction voltage-travel speed, on height are highly significant on GMAW process. But no interaction is significant on FCAW process. ii) The most suitable values for optimum height are 20V, 280amps. 15 cm/min.

On width of weld bead: i) ANOVA for width of bead established that the effect of voltage, current, travel speed, excepting interactions are highly significant.

On HAZ depth : ANOVA for HAZ depth on GMAW & FCAW established that the effect of voltage, current, travel speed and all the interactions have significant effect (at least 5% level).

On regression analysis : Regression equations were developed for predicting the following dimensions of the weld zone as a function of the three welding variables viz. voltage, current, travel speed :- depth of penetration(D), the height of weld bead(H), and the width of weld bead(W), HAZ depth (HA). From the regression equation we can conclude that linear fitting is worthwhile in all the cases.

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