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Significancy Test For The Control Parameters Considered In Weld Bead Geometry Optimization For Gas Metal Arc Welding Process Using Taguchi Method And Anova Technique

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Abstract: *Here in this work, an attempt has been made to find the interaction between control parameters and weld bead geometry for fillet welding in mild steel specimen using Gas Metal Arc Welding process. Accordingly control parameters have been adjusted to find the optimal bead geometry. Initially the equations involving control parameters and bead geometry were developed by multiple regression analysis method. The ANOVA technique is then employed to calculate the significant difference between the means of the control parameters ,Also this justifies the range of the control parameters considered for the experiment.*

Keywords: *ANOVA, GMAW process, Bead width, Left leg length, Re-inforcement height, Right leg length.*

I. Introduction

Nowadays Gas Metal Arc welding process (GMAW) has been widely used as a welding technique throughout the industrial world. GMAW uses a welding torch, an electric power source, shielding gas & a wire pool with wire drive control. GMAW process can be used to weld thicker metal plates with high productivity. Shielding gas is used to protect the weld pool from oxidation. The shielding gas used is either inert gas or carbon dioxide.

GMAW process is done in butt joints as well as fillet joints. The quality of weld is determined by the weld bead geometry characteristics (physical parameters); i.e., the weld bead width, weld bead penetration, weld re-inforcement height, weld left leg length and weld right leg length. This weld bead geometry characteristics is a function of input variables (control parameters) which are welding current, welding voltage, welding speed, wire tip distance, weld joint position, wire diameter, shielding gas composition, gas flow rate, material composition and material thickness. These control parameters affect the quality of the weld. Here for simplification the most influencing parameters welding current, welding voltage and welding speed are considered. Using ANOVA technique, the comparison of means of the control parameters are done. This technique is widely used nowadays to determine the significant difference of the means of the control parameters considered for the experiment. Also the calculation of F-ratio, the percentage contribution of control parameters on the effect of weld bead and the error calculation of the experiment are done in this study.

II. Experimental Work

The experimental work for predicting the relationship between control parameters & the weld bead geometry is done systematically by a defined process. Gas metal arc welding (GMAW) was conducted on mild steel plates. Three most important control parameters are identified which mostly determine the weld bead profile. These parameters are welding current, welding voltage & the welding speed. The operating range of each of the parameters is taken in accordance with the normal operating range for such kind of operation. The assigned control parameters are listed in the Table. 1

Table 1 : Control factors and their levels

PARAMETERS	SYMBOL	LEVEL		
		LOW	MIDDLE	HIGH
WELDING CURRENT (Amp)	I	160	220	280
WELDING VOLTAGE (Volt)	V	20	22.5	27
WELDING SPEED (mm/sec)	S	1.97	3.57	5.17

The mechanical and chemical properties of the base metal are given below.

Table 2: Mechanical properties of base metal

Ultimate Tensile Strength, Kpa	439885.514464
Yield Strength, Kpa	370248.465936
Elongation	15.00%
Rockwell Hardness	B71

Table 3: Chemical properties of base metal

Material	% Composition
Iron (Fe)	98.81 - 99.26%
Carbon (C)	0.18%
Manganese (Mn)	0.6 - 0.9%
Phosphorus (P)	0.04% max
Sulphur (S)	0.05% max

The weld bead geometry is shown in Fig 1.

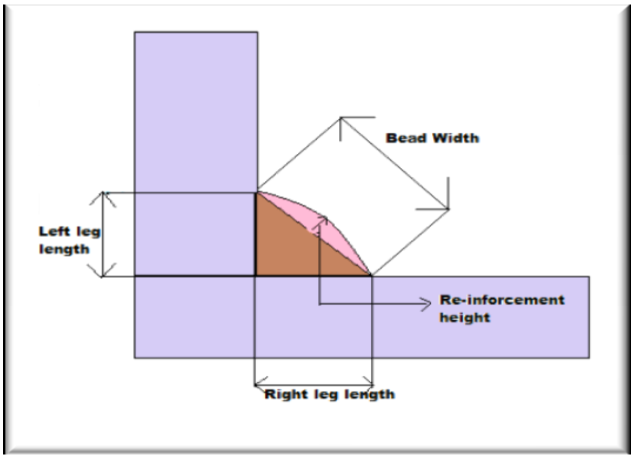

Fig 1. Weld bead geometry

III. Experimental Data Analysis

From the Taguchi design of experiment, a conclusion is made that for three number of independent experimental parameters, i.e, welding current, welding voltage & welding speed and three different levels of each parameter, i.e. low , mid & high, there has to be nine different observation sets.

Table 4: Measured Experimental Data as per Taguchi Design of Experiment

Experiment No	Welding Current (A)	Welding Voltage (V)	Welding Speed (mm/sec)	Bead Width (mm)	Re-inforcement Height (mm)	Left Leg length (mm)	Right leg length (mm)
1	160	21	1.97	10.2	0.5	7.4	7.4
2	180	20	2.58	10.1	0.7	6.3	5.8
3	190	21	2.30	10.4	0.9	8.6	8.1
4	200	23	2.88	11.1	1.2	8.0	8.4
5	210	24	1.97	10.1	1.5	7.1	7.2
6	220	22	2.02	12.1	1.5	9.0	8.6
7	240	22	2.72	10.5	0.9	7.1	8.4
8	250	26	4.28	11.0	1.3	7.6	7.2
9	280	27	5.17	12.5	1.1	9.1	8.6

From the experimental observations, multiple regression analysis is done to find the relationship between control parameters & physical parameters. The equations obtained are as follows:

Bead Width (BW) = $0.0123 + 0.0095 * I + 0.35005 * V + 0.00981 * S + 0.00092764 * I^2 + 0.000561 * V^2 - 3.8726 * S^2 - 0.4 * I * V + 0.01329 * I * S + 0.035 * V * S$ --(1)

$$\text{Re-inforcement height (RH)} = -0.0035197 + 0.003848444 * I + 0.0017637334 * V + 0.077151088 * S + 0.000048641 * I^{2} + 0.0000545898 * V^{2} - 14.186 * S^{2} + 0.0283 * I * V - 0.000778671 * I * S + 0.026906535 * V * S \tag{2}$$

$$\text{Left leg length (LLL)} = -0.044638867 + 0.281959034 * I + 2.840262884 * V - 5.583572 * S + 0.00001485 * I^{2} + 0.001725776 * V^{2} + 527.541 * S^{2} - 14.07151286 * I * V + 12.19315 * I * S + 0.039817247 * V * S \tag{3}$$

$$\text{Right leg length (RLL)} = -0.0154 + 0.0900 * I + 0.8077 * V + 1.7139 * S - 0.0002 * I^{2} - 0.0004 * V^{2} - 322.5063 * S^{2} - 3.3705 * I * V + 0.0034 * I * S - 0.0088 * V * S \tag{4}$$

IV. Anova Calculation And Result

In performing the ANOVA test, it is assumed that the means of different samples are equal. To do that, the différences of the sample means are compared with the variability within the sample observations. The test statistic is the ratio between the sample variation (MSB) and within the sample variation (MSW). If this ratio is close to 1, there is evidence that the means are equal which indicates that there is no difference between the sample means of the physical parameters. If the ratio F-ratio (calculated) > F-ratio (critical) then the null hypothesis is rejected which indicates that there is a significant difference between the means of the four physical parameters.

Table 5: Anova Data Table

WELDING CURRENT(KA)			WELDING VOLTAGE(KV)			WELDING SPEED (MM/SEC)		
A	B	C						
160	160	160	20	20	20	1.97	1.97	1.97
160	220	220	20	22.5	22.5	1.97	3.57	3.57
160	280	280	20	27	27	1.97	5.17	5.17
220	160	220	22.5	20	22.5	3.57	1.97	3.57
220	220	280	22.5	22.5	27	3.57	3.57	5.17
220	280	160	22.5	27	20	3.57	5.17	1.97
280	160	280	27	20	27	5.17	1.97	5.17
280	220	160	27	22.5	20	5.17	3.57	1.97
280	280	220	27	27	22.5	5.17	5.17	3.57

ANOVA calculation requires that a null hypothesis is to be taken which represents that there is no significant difference among the means of the four physical parameters. Let us consider, null Hypothesis $H_0 = U_1$ which represents no significant difference between the means of the four physical parameters for different possible combinations of control parameters

Table 6 : Anova calculation table for welding current

Level 1	Level 2	Level 3	Treatment Mean	Estimated Effects
160	160	160	160	-60
160	220	220	200	-20
160	280	280	240	20
220	160	220	200	-20
220	220	280	240	20
220	280	160	220	0
280	160	280	240	20
280	220	160	220	0
280	280	220	260	40

Table 7: Anova calculation table for welding voltage

Level 1	Level 2	Level 3	Treatment Mean	Estimated Effects
20	20	20	20	-3.166
20	22.5	22.5	21.66666667	-1.499333333
20	27	27	24.66666667	1.500666667
22.5	20	22.5	21.66666667	-1.499333333
22.5	22.5	27	24	0.834
22.5	27	22	23.83333333	0.667333333
27	20	27	24.66666667	1.500666667
27	22.5	20	23.16666667	0.000666667
27	27	22.5	25.5	2.334

Table 8: Anova calculation table for welding speed

Level 1	Level 2	Level 3	Treatment Mean	Estimated Effects
1.97	1.97	1.97	1.97	-1.6
1.97	3.57	3.57	3.036666667	-0.533333333
1.97	5.17	5.17	4.103333333	0.533333333
3.57	1.97	3.57	3.036666667	-0.533333333
3.57	3.57	5.17	4.103333333	0.533333333
3.57	5.17	1.97	3.57	0
5.17	1.97	5.17	4.103333333	0.533333333
5.17	3.57	1.97	3.57	0
5.17	5.17	3.57	4.636666667	1.066666667

Referring Table: 6 at 1% significant level F-ratio 2, 24 (critical) = 5.6136 (From table of Fisher`s distribution) & at 5% significant level F-ratio 2, 24 (critical) = 3.4028 (from table of Fisher`s distribution). Therefore for both 1% and 5% significant level F-ratio (calculated) is greater than F-ratio(critical) ; hence the null hypothesis is rejected which indicates that there is a significant difference among the means of the four physical parameters. The critical region for welding current is less than 3.4 and greater than 5.61. F- Ratio (calculated) is 6 which fall in the critical region. Thus it is concluded that, by varying the range of current from 160 A to 280 A for different possible combinations, there has been a significant difference in the physical parameter measurement.

Referring Table: 7 at 1% significant level F-Ratio 2, 24 (critical) = 5.6136 at 5% significant level F-ratio 2, 24 (critical) = 3.4028. Therefore for both 1% and 5% significant level F-ratio (calculated) > F-ratio (critical); hence the null hypothesis is rejected which indicated that there is a significant difference between the means of the three different levels of voltage. The critical region for welding voltage is less than 3.4 and greater than 5.61 . F- Ratio (calculated) is 5.99 which fall in the critical region. Thus it is concluded that, by varying the range of voltage from 20 V to 27 V, there has been a significant effect in the result.

Referring Table: 8 at 1% significant level F-ratio 2, 24 (critical) = 5.6136 & at 5% significant level F-ratio 2, 24 (critical) = 3.4028. Therefore for both 1% and 5% significant level F-ratio (calculated) > F-ratio (critical); hence the null hypothesis is rejected which indicated that there is a significant difference between the means of the physical parameters. The critical region for welding voltage is less than 3.4 and greater than 5.61. F- Ratio (calculated) is 5.9960 which fall in the critical region. Thus it is concluded that, by varying the range of voltage from 20 V to 27 V, for different possible combinations, there has been a significant difference in the physical parameter measurement.

Table 9: Anova result for welding current

CAUSE OF VARIATION	DEGREES OF FREEDOM(df)	SUM OF SQUARES (SS)	MEAN OF SQUARES (MS)	F-RATIO (calculated	F-RATIO (CRITICAL) at 1% significant level	F-RATIO (CRITICAL) at 5% significant level
Treatment	**2**	**21600**	**10800**	**6**	**5.6136**	**3.4028**
Residual	**24**	**43200**	**1800**			
Total	**26**	**64800**				

Table 10: Anova result for welding voltage

CAUSE OF VARIATION	DEGREES OF FREEDOM(df)	SUM OF SQUARES (SS)	MEAN OF SQUARES (MS)	F-RATIO (calculated	F-RATIO (CRITICAL) at 1% significant level	F-RATIO (CRITICAL) at 5% significant level
Treatment	**2**	**75.48**	**37.74**	**5.998410596**	**5.6136**	**3.4028**
Residual	**24**	**151**	**6.291666667**			
Total	**26**	**226.48**				

Table 11: Anova result for welding speed

CAUSE OF VARIATION	DEGREES OF FREEDOM(df)	SUM OF SQUARES (SS)	MEAN OF SQUARES (MS)	F-RATIO (calculated	F-RATIO (CRITICAL) at 1% significant level	F-RATIO (CRITICAL) at 5% significant level
Treatment	**2**	**15.35**	**7.675**	**5.99609375**	**5.6136**	**3.4028**
Residual	**24**	**30.72**	**1.28**			
Total	**26**	**46.07**				

The percentage contribution of the control parameters to affect changes in physical parameters is found to be as follows:

Table 12: Percentage contribution of control parameters

CONTROL PARAMETERS	TOTAL DEGREES OF FREEDOM	TOTAL SUM OF SQUARES BETWEEN TREATMENT GROUPS	% CONTRIBUTION
Welding current	**64800**	**21600**	**33.33333333**
Welding voltage	**226.48**	**75.48**	**33.32744613**
Welding speed	**46.07**	**15.35**	**33.3188626**

Total Error (%) in experiment = 100 - sum of % contribution of control parameters
= 100 – 99.9796 = 0.02035%

V. Conclusion

It can be concluded that the control parameters have nearly equal contributions on the effect of the physical parameters with .02% of error, which is very less.

Also from the ANOVA, it can be concluded that the calculated F-ratio falls in the critical region and there has been a significant difference between the means of the control parameters considered for the experiment which justifies the range of control parameters considered.

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