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EFFECT OF ELECTRODE STICK OUT ON QUALITY AND PERFORMANCE OF SUBMERGED ARC WELDMENT-EXPERIMENTAL AND STATISTICAL ANALYSES

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ABSTRACT
Submerged arc welding (SAW) is one of the chief metal fabrication processes in industry, which involves high current density and effects high metal deposition rate. The present work emphasizes the influence imposed due to variation of electrode stick out, one of the important process parameters of submerged arc welding, on quality and performance of submerged arc weldment by incorporating one of the traditional methods of statistical data analysis i.e. ANOVA. Based on factorial design without replication, experiments were conducted with different levels of process parameters like voltage, current and electrode stick out to obtain butt joints from mild steel plates. Experimental results were examined analytically by exploring statistical software package MINITAB and represented graphically to show the effect of electrode stick out on bead quality as well as performance in terms of hardness, impact value, yield strength and ultimate tensile strength of the weldment. The direct and interaction effects of electrode stick out on some specific response variables are brought about illustratively by the above analysis and graphical plots.

Keywords: SAW, ANOVA, Factorial design.

1. INTRODUCTION
Submerged arc welding is one of the major metal fabrication techniques in industry. The ability to join thick plates with high metal deposition rate has made this process useful in large structural applications. Indeed various research works have been explored on various aspects of submerged arc welding but still investigations are being carried out to study the phenomenon that occurs during the operation of submerged arc welding so that the process becomes controllable more precisely, and can be monitored effectively both manually as well as automatically. Jackson, C.E. [1] established that penetration decreased with the increase in electrode diameter at constant current because of reduced current density. Renwick, B.G. & Patchett, B.M. [2] studied the characteristics of the weld bead, penetration and melting rate under variable operating current conditions and found that those increased with the increase in current. Gupta, S.R. & Arora, N. [3] also studied the effect of welding parameters on weld bead geometry and HAZ. Gunaraj , V. & Murugan, N. [4,5] determined the main & interaction effects of process control variables on important bead geometry parameters quantitatively and represented the same graphically. Marlin, V. [6] established relationships between shape of the root weld and variations in joint geometry. The work revealed the effects of joint geometry in terms of root opening, included angle, root face and plate misalignment on root welds including the root bead (deposit inside the groove) and root reinforcement (deposit outside the groove). Kim, I.S. and et al. [7] developed an intelligent system of Artificial Neural Network in gas metal arc welding process that was capable of receiving the desired weld dimensions as input and delivering the optimal welding parameters as output to achieve the desired weld quality. The literature review depicts that huge investigations have been performed so far in the area of submerged arc welding in which concentrations have been made, mainly to study the effect of process parameters on bead geometry, with some work on quality and performance aspects of submerged arc weldment as well. It is however, felt that more studies are required to establish the relationships between process parameters and quality/performance characteristics of submerged arc weldment. In the present study an attempt has been made to evaluate the effect of electrode stick out on mechanical properties of the weldment.

2. DESIGN OF EXPERIMENT
The independent controllable process parameters

affecting bead geometry, bead quality and performance are voltage, current, stick out, wire feed rate, welding speed or travel, stand off distance etc. In the present study three independent process parameters: voltage, current and electrode stick out have been considered for experimentation. Other parameters were assumed to be constant over the experimental domain. Trial runs have been carried out by varying one of the process parameters while keeping the rest at constant values. The process variables with their units, notations and values on different levels are listed in Table 1. Based on 3^3 factorial design, the selected design matrix constitute a three level-three factor central composite rotable factorial design consisting of 27 sets of coded conditions.

Table 1: Process Control Parameters and their Limits

Parameters	*Unit*	*Notation*	*-1*	*0*	*1*
For Backing Pass					
Current	A	C1	450	465	470
Electrode Stick out	mm	C2	22	24	26
Voltage	V	C3	30	32	34

3. EXPERIMENTAL DATA COLLECTION

In the present work, experiments were performed to obtain butt joints from mild steel plates (100x40x12mm), by applying various levels of process parameters like voltage, current and electrode stick out. Bead quality and its performance have been evaluated in terms of hardness, impact value, yield strength and ultimate tensile strength of the joint for each of the specimens. The welding was carried out, by using SAW machine (Maker - IOL Ltd., India). The toughness of the weldment were measured in terms of impact value in FIE Impact Testing Machine. Hardness tests were carried out in Vickers Hardness Tester. Universal Testing Machine was employed to determine tensile strength of the joint. In order to illustrate the method for analyzing the effects of process parameters, the entries made in the Tables 2-5 are used in the following context.

4. STATISTICAL ANALYSIS

The most important statistic in the analysis of variance table is the p-value (P). There is a p-value for each term in the model (except for the error term). The p-value for a term tells whether the effect for that term is significant. If P is less than or equal to the selected α-level, then the effect for the term is significant.

If P is larger than the α-level, the effect is not significant. If the effect of an interaction term is significant, then the effects of each factor are different at different levels of the other factor(s). For this reason, it does not make much sense to try and interpret the individual effects of terms, which are involved in significant higher-order interactions. ANOVA for different response variables are tabulated in the Tables 6-9 with relevant graphical representations showing main effects and interactive effects of various process parameters on the response variables. In the ANOVA table C1 indicates current, C2 represents electrode stick out and C3 the welding voltage.

5. RESULTS AND DISCUSSION

The ANOVA Table 6 shows that, direct effects of current, stick out and voltage on hardness (response C7) of the weld are significant because each has p-value 0.000 which is less than pre assumed α level i.e. 0.05. Two factor interactions between current-stick out (p-value=0.067) and stick out-voltage (p-value=0.057) are insignificant on hardness of the weld (p-value is greater than 0.05). It is interesting to note that the interactive effect between current and voltage is significant on hardness of the weldment. ANOVA for impact value of the weld (Response C8;Table 7) depicts that the main effects of the selected process parameters like current, stick out and voltage are significant on impact value of the weld. The effects of two factor interactions are insignificant here. ANOVA for yield strength of the joint (Response C9;Table 8) reveals that main effects of current, stick out and voltage on yield strength of the joint are significant at 95% confidence level. Two factor interactions are insignificant here. ANOVA for ultimate tensile strength of the joint (Response C10;Table 9) exhibits that, main effects of current and voltage are significant on ultimate tensile strength of the joint. Here p-value for the main effect of stick out is 0.738 which is greater than 0.05. Therefore stick out does not impose any effect on ultimate tensile strength of the joint individually. Same can be concluded for the effect of the two factor interactions on ultimate tensile strength of the joint.

MINITAB can be efficiently used to draw the main effects and interaction effects of process parameters on the selected response variables. Fig 1. shows direct effect of electrode stick out on hardness of the weldment. It is clear from the figure that, with increase in electrode stick out, hardness of the weldment increases provided welding current and voltage are kept at constant levels.

Interaction effects of current and stick out on hardness of the weldment are shown in Fig 2. It reveals that at constant current with increase in electrode stick out; hardness of the weld increases, but rate of increase of hardness with increase in stick out is different for different levels of current. Fig 3. depicts the interactive effects of stick out and voltage on hardness of the weldment. It is evident from the figure that with increase in welding voltage hardness increases provided electrode stick out is kept constant.

Direct effect of electrode stick out on impact value of the weldment is shown in Fig 4. With increase in electrode stick out impact value decreases provided current and voltage are kept at constant levels. Fig 5. exhibits the interaction effect of stick out and current on impact value of the weldment. At constant current level increase in stick out results decrease in impact value of the weld. The interaction effect of stick out and voltage is shown in Fig 6. It can be concluded that, at constant electrode stick out; increase in welding voltage causes decrease in impact value of the weld. Main effect of electrode stick out on yield strength of the joint is shown in Fig 7. At constant levels of current and voltage, increase in stick out results decrease in yield strength of the joint. Fig 8 exhibits the interactive effects of stick out and current on yield strength of the joint. At constant currents of 450 A and 470 A, with increase in stick out, yield strength first increases then decreases. With increase in stick out, yield strength first decreases and then increases at the current level of 465 A. So it is impossible to predict the behavior of variation of yield strength with increase in stick out at constant current. This requires further experimentation and analysis. Figure 9. shows the interactive effects of stick out and voltage on yield strength of the joint. At constant electrode stick out, with increase in welding voltage, yield strength first increases, then decreases. Fig 10. exhibits direct effects of electrode stick out on ultimate tensile strength of the joint. It is clear from the figure that with increase in electrode stick out ultimate tensile strength of the joint initially decreases but thereafter increases at constant current and voltage level. Interaction effects of stick out and current on ultimate tensile strength of the joint are shown in Fig 11. The relationship is not clear and inconsistent. This may be the result of insufficient data obtained from the limited domain of the experiment. Interaction effect of stick out and voltage on ultimate tensile strength of the joint is shown in Fig 12, which reveals that at constant electrode stick out, with increase in welding voltage ultimate tensile strength of the joint first increases at lower range of voltage; thereafter it has a downward trend.

Table 2: Hardness (Data obtained from experiment)

Levels of factor C1	Levels of factor C3								
	-1			0			1		
	Levels of factor C2			Levels of factor C2			Levels of factor C2		
	-1	0	1	-1	0	1	-1	0	1
-1	340.496	344.661	353.224	373.696	390.875	393.426	406.561	409.267	409.267
0	328.444	342.569	355.414	359.857	362.109	380.917	406.561	398.603	417.549
1	320.761	322.656	336.406	346.772	348.903	359.857	378.487	373.696	380.917

Table 3: Impact Value (Data obtained from experiment)

Levels of factor C1	Levels of factor C3								
	-1			0			1		
	Levels of factor C2			Levels of factor C2			Levels of factor C2		
	-1	0	1	-1	0	1	-1	0	1
-1	16	15.8	15.4	14.8	14.6	14.4	13.8	13.8	13
0	16.4	16.2	15.8	15.6	15.2	14.8	14.2	14	13.6
1	16.4	16.2	16.2	15.6	15.6	15	14.6	14	14

Table 4: Yield Strength (Data obtained from experiment)

Levels of factor C1	Levels of factor C3								
	-1			0			1		
	Levels of factor C2			Levels of factor C2			Levels of factor C2		
	-1	0	1	-1	0	1	-1	0	1
-1	248.26	235.2	228.66	283.86	278.10	274.4	225.13	273.33	249.93
0	349.04	370.81	361.74	385.46	361.05	398.75	398.53	287.46	350.94
1	357.56	407.78	446.66	443.64	469.29	386.66	432.55	410.54	384.05

Table 5: Ultimate Tensile Strength (Data obtained from experiment)

Levels of factor C1	Levels of factor C3								
	-1			0			1		
	Levels of factor C2			Levels of factor C2			Levels of factor C2		
	-1	0	1	-1	0	1	-1	0	1
-1	339.73	235.2	346.26	425.79	410.54	446.26	231.75	280.00	256.51
0	456.43	476.75	453.82	496.53	477.10	500.13	509.6	365.86	490.00
1	476.75	539.32	473.33	496.62	545.21	480.00	513.65	490.00	516.48

5. CONCLUSIONS

Based on experimental investigations and foregoing analysis in the context of SAW, the following conclusions can be drawn within the domain and limitations of the present work. ANOVA of experimental data has established the main and interaction effects of the various input parameters on the response variables relating to weld bead quality and joint performance. # Electrode stick out seems to be an important process parameter in submerged arc welding with its direct significant effects on bead quality as well as bead performance parameters like hardness and impact value, yield strength and ultimate tensile strength of the joint. # ANOVA shows that, the direct effect of electrode stick out is insignificant for yield strength and ultimate tensile strength of the weldment. Graphical plots obtained through MINITAB software, using the data of the present work, give useful information regarding individual and combined effects of the process parameters on some important output parameters of the process results in terms of hardness, impact value, yield strength and ultimate tensile strength of the joint. This may provide additional data in the field of submerged arc welding to make the process more controllable both manually and automatically.

Table 6: ANOVA for Hardness

Source	DF	SS	MS	F	P
C1	2	3797.7	1898.9	149.16	0.000
C2	2	943.8	471.9	37.07	0.000
C3	2	15978.4	7989.2	627.57	0.000
C1*C2	4	172.1	43.0	3.38	0.067
C1*C3	4	426.9	106.7	8.38	0.006
C2*C3	4	185.4	46.4	3.64	0.057
Error	8	101.8	12.7		
Total	26	21606.2			

Table 7: ANOVA for Impact Value

Source	DF	SS	MS	F	P
C1	2	2.1067	1.0533	32.69	0.000
C2	2	1.5289	0.7644	23.72	0.000
C3	2	20.9689	10.4844	325.38	0.000
C1*C2	4	0.0711	0.0178	0.55	0.704
C1*C3	4	0.0711	0.0178	0.55	0.704
C2*C3	4	0.0356	0.0089	0.28	0.886
Error	8	0.2578	0.0322		
Total	26	25.0400			

Table 8: ANOVA for Yield Strength

Source	DF	SS	MS	F	P
C1	2	119980	59990	44.75	0.000
C2	2	106	53	0.04	0.962
C3	2	5488	2744	2.05	0.191
C1*C2	4	3450	862	0.64	0.647
C1*C3	4	670	168	0.13	0.969
C2*C3	4	3056	764	0.57	0.692
Error	8	10724	1341		
Total	26	143473			

Table 9: ANOVA for Ultimate Tensile Strength

Source	DF	SS	MS	F	P
C1	2	152178	76089	35.86	0.000
C2	2	1338	669	0.32	0.738
C3	2	23593	11796	5.56	0.031
C1*C2	4	7264	1816	0.86	0.0529
C1*C3	4	24936	6234	2.94	0.091
C2*C3	4	2182	545	0.26	0.897
Error	8	16973	2122		
Total	26				

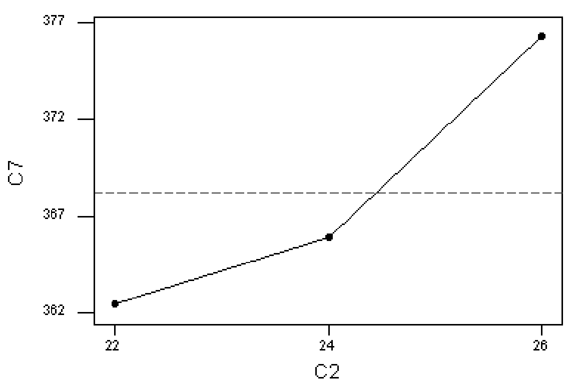

Fig 1. Direct Effect of Stick out (C2) on Hardness of Weldment (C7)

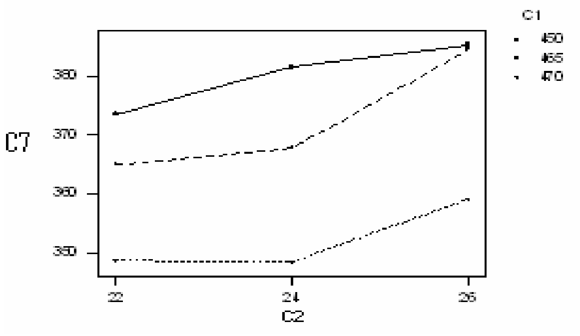

Fig 2. Interaction Effect of Stick out (C2) and Current (C1) on Hardness of the Weldment (C7)

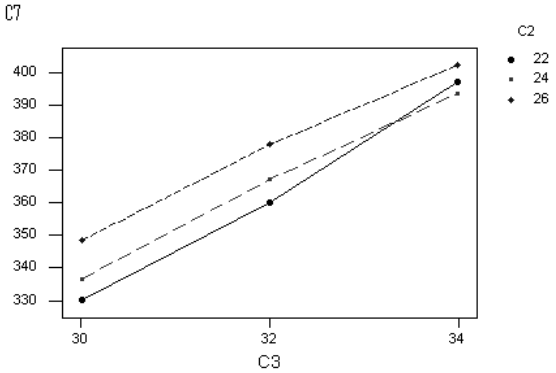

Fig 3. Interaction Effect of Stick out (C2) and Voltage (C3) on Hardness of the Weldment (C7)

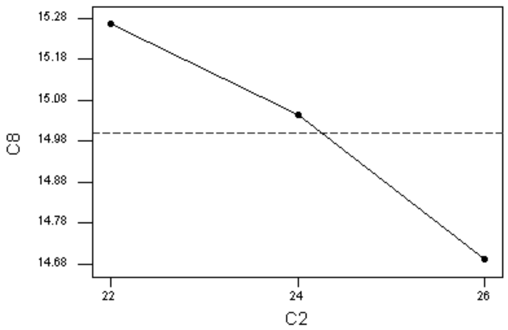

Fig 4. Direct Effect of Stick out (C2) on Impact Value (C8) of the Weldment

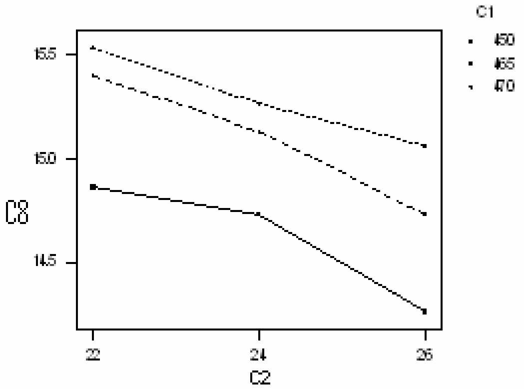

Fig 5. Interaction Effect of Stick out (C2) and Current (C1) on Impact Value (C8) of the Weldment

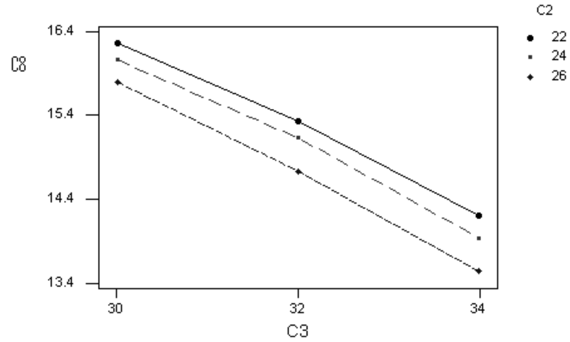

Fig 6. Interaction Effect of Stick out (C2) and Voltage (C3) on Impact Value (C8) of the Weldment

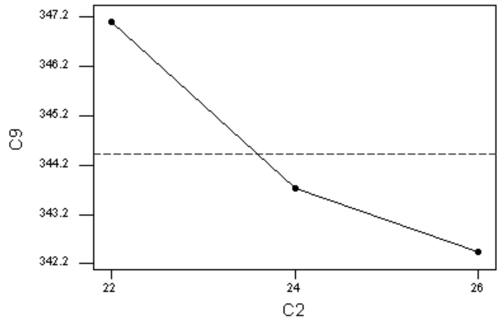

Fig 7. Direct Effect of Stick Out (C2) on Yield Strength of the Joint (C9)

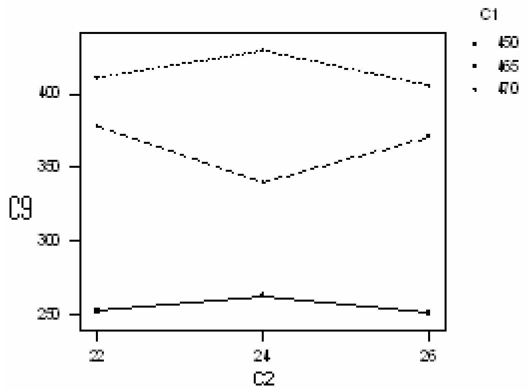

Fig 8. Interaction Effect of Stick Out (C2) and Current (C1) on Yield Strength of the Joint (C9)

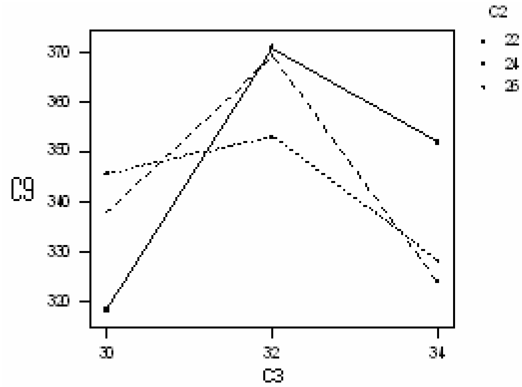

Fig 9. Interaction Effect of Stick out (C2) and Voltage (C3) on Yield Strength of the Joint (C9)

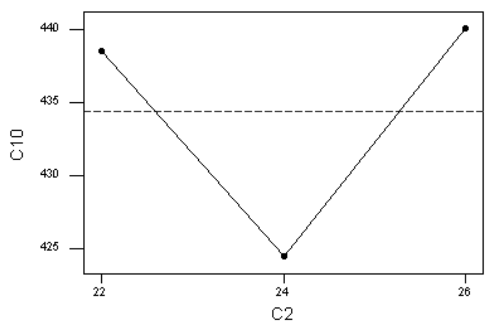

Fig 10. Direct Effect of Stick out (C2) on Ultimate Tensile Strength of the Joint (C10)

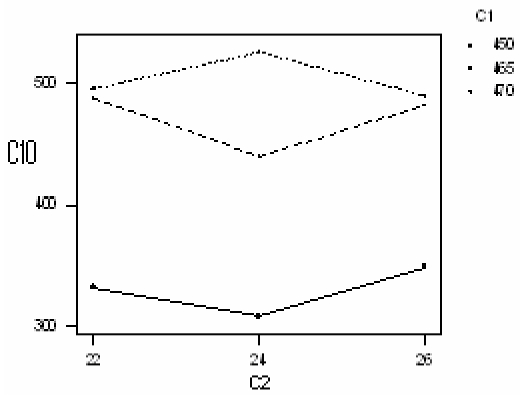

Fig 11. Interaction Effect of Stick Out C2) and Current (C1) on Ultimate Tensile Strength of the Joint (C10)

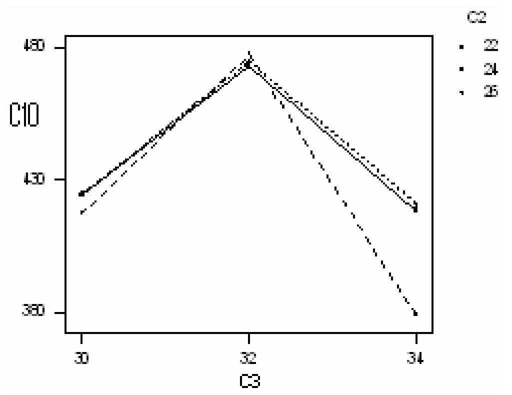

Fig 12. Interaction Effect of Stick Out (C2) and Voltage(C3) on Ultimate Tensile Strength of the Joint (C10)

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8. NOMENCLATURE

Symbol	Meaning	Unit
C1	Current	(A)
C2	Stick out	(mm)
C3	Voltage	(V)
C7	Hardness	(VHN)
C8	Impact Value	(kg-m)
C9	Yield Strength	(N/mm^2)
C10	Ultimate Tensile Strength	(N/mm^2)
DF	Degree of Freedom	
SS	Sum of Squares	
MS	Mean Square	
F	MS of each source / MS for error term	