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Analysis and Modeling of Process Parameters on Weld Bead Geometry in Saw Process

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ABSTRACT: In this research, a two-level half factorial design is used to create mathematical models that can effectively predict weld bead geometry and hardness in submerged arc welding of carbon steel. The research uses the Design Expert software to quantify major as well as interaction effects of significant process parameters – welding current, arc voltage, welding speed, and nozzle-to-plate distance – on weld properties. The findings indicate that welding current has positive impact on bead penetration, reinforcement, bead width, overall bead volume, and hardness and negative impact on weld pool surface finish (WPSF) and weld reinforcement factor (WRFF) and has a negligible impact on dilution. On the other hand, voltage improves bead width, WPSF, WRFF, and dilution but negatively affects penetration, reinforcement, bead volume, and hardness. Welding speed has a beneficial effect on hardness, dilution, and WRFF but at the expense of bead volume, width, penetration, and reinforcement, with little effect on WPSF. Nozzle-to-plate enhances hardness but loses bead volume, dilution, WPSF, WRFF, and bead width without having much effect on penetration and reinforcement. This thorough analysis is helpful for optimization of SAW process for the attainment of quality welds.

KEYWORDS: Bead geometry, Mathematical model, Response, Two-level half factorial design technique, Design Expert Software.

I. INTRODUCTION

In today's world, if we look for development the quality of the product play a vital role in the market value of the product and every manufacturing industry wants to produce their product of superior quality with minimum cost of the product. Therefore in this emerging world welding is the most widely used joining process in fabrication industries. It is more economical and is a much faster process compared to both casting and riveting. Welding make a strongest bond in combination of metals with help us to create sections of high dimensions which make our work easier and faster.

II. EXPERIMENTATION

An experiment's design is a rigorous, organised process for determining the relationship between the various components that influence a process and the outcome of that process. They also display information like whether the components communicate. The process of designing experiments is a method for accumulating empirical knowledge, which is defined as information that is derived from the examination of experimental data. The process of building a design involves selecting a limited number of experiments with great care, all of which are to be carried out under carefully monitored conditions. If you are creating an experiment, there are seven guidelines to follow:

1. The identification and statement of the problem, also known as the statement of an objective (such as the effect of process variables or the discovery of optimal parameters).
2. The selection of factors, levels, and ranges, which means defining the process variables that will be controlled throughout the laboratory experiment and the range in which they will operate.
3. Step three involves defining the response variables, which are the outcome measurements obtained from the experimental runs.

4. Step four entails selecting an appropriate experimental design from available standard designs that aligns with the study's objectives, considers the number of variables, ensures measurement precision, and maintains reasonable costs.
5. Carrying out the practical experiment.
6. The statistical analysis of data, which refers to the statistical procedure that is utilized in order to examine the data in such a way that the results and conclusions are objective rather than judgmental in style.
7. Conclusions and suggestions for further study -To put it another way, once the data have been examined, the experiments need to form a practical conclusion regarding the result and prescribe a plan of action.

The experiment design can be developed after determining the objectives, number and types of process variables, types of responses, and the number of experimental runs that are viable. This design will define all planned experiments and explain which process variables will be tweaked in each trial. To efficiently optimise resource utilisation, experiments must be designed with the proper level of precision prior to testing.

2.2 Experimental Design Techniques

The utilisation of mathematical models is imperative for the automation of a welding system and for the examination of the impact of welding variables on the geometry, quality, and hardness of the beads generated during submerged arc welding. Experiments are conducted to acquire information that can be utilised in the development of mathematical models. It is crucial to develop experiment procedures specifically tailored for conducting tests, rather than relying on the more common trial and error approach.

3.1 Result analysis Measurements of Weld Bead

Tables 3.1 and 3.2 provide in detail the measured and estimated parameters of bead geometry. The tables contain detailed information on the size and characteristics of the weld beads, allowing for a thorough analysis of both actual data and calculated values.

“Table 3.1: Measured values of bead geometry”

S.NO.	Penetration(mm)		Reinforcement(mm)		Bead width(mm)		Bead hardness (HRB)	
	1	2	1	2	1	2	1	2
1	3	3.2	2.05	2.1	16.2	16.2	134	132
2	1.41	1.5	1.4	1.2	11	11.08	130	130
3	3.32	3.39	2.5	2.9	15.7	15.2	144	141
4	1.5	1.61	1.64	1.5	11.2	11.42	130	127
5	3.77	3.55	2.7	2.52	20.8	21.2	111	112
6	1.46	1.58	1.72	1.74	11.62	11.4	120	122
7	3.61	3.88	3.2	2.9	12.13	12.42	126	132
8	1.52	1.72	1.54	1.62	12.66	12.88	109	110

“Table 3.2: Calculated values of bead geometry parameters”

Trial No.	WPSF		WREF		% Dilution		Total bead volume(mm ³)	
	1	2	1	2	1	2	1	2
1	5.4	5.06	7.9	7.71	78.32	77.22	620.52	671.37
2	7.8	7.39	7.86	9.23	74.38	87.22	208.52	190.55
3	4.73	4.48	6.28	5.24	65.7	56.54	793.39	911.31
4	7.47	7.09	6.83	7.61	65.05	73.31	258.24	250.8
5	5.52	5.97	7.7	8.41	76.55	81.83	1024.35	919.75
6	7.96	7.22	6.76	6.55	63.3	62.81	268.01	286.78
7	3.36	3.2	3.79	4.28	45.64	51.75	959.35	931.1
8	8.33	7.48	8.22	7.95	76.93	63.29	250.13	350.01

3.2 Model for Penetration

3.2.1 Selection of Significant Direct/ Interaction Effects for Penetration

Figure 2.1 show a Pareto chart that represents the impact on penetration. The chart unambiguously demonstrates that effects I, S, IS, and V exceed the t-limit, hence suggesting their substantial influence on penetration. Therefore, these effects will be integrated into the model for additional analysis and interpretation. On the other hand, effects N, IN, and IV are observed to be below the t-limit threshold, indicating that they do not significantly contribute to the variance in penetration. Consequently, these parameters will be omitted from the model in order to concentrate on the primary variables that influence penetration in the experimental design. This approach guarantees that the model remains efficient and highlights the most significant characteristics that impact the outcomes of the welding process.

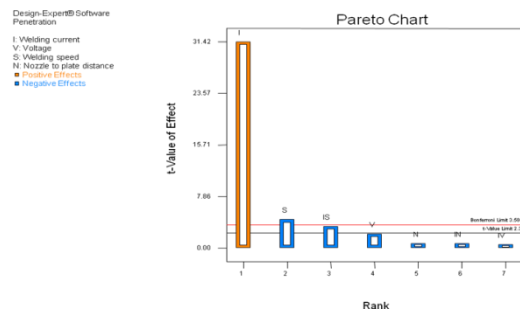


Figure 2.1: Pareto Chart for penetration

2.2.2 Checking the Adequacies of Model

Tables 2.3 and 2.4 display the ANOVA analysis findings for penetration. The model's F-value of 302.92 demonstrates its tremendous impact, with a likelihood of only 0.01% that such a high F-value could be attributed to chance. The p-value, which is below 0.05, provides evidence that the terms in the model (I, V, S, IS) are statistically significant. Crucially, the absence of a substantial lack of fit indicates that the model fits the data sufficiently. These findings emphasise the dependability and accuracy of the model in elucidating the differences in penetration depth.

Table 2.3: Result of ANOVA for penetration

Source	SS	DF	MS	F-value	p-value	Remarks
Model	15.39	4	3.85	302.92	<0.0001	significant
I	14.86	1	14.86	1169.74	<0.0001	significant
V	0.07	1	0.07	5.74	0.0355	significant
S	0.29	1	0.29	22.95	0.0006	significant
IS	0.17	1	0.17	13.23	0.0039	significant
Residual	0.14	11	0.013			
Lack of Fit	0.019	3	0.006	0.43	0.7381	not significant
Pure Error	0.12	8	0.015			
Cor Total	15.53	15				

Table 2.4: Model summary statistics for penetration

Parameters	Std. Dev.	Mean	C.V. %	PRESS	R ²	Adj R ²	Pred. R ²	Adeq. Precision
Penetration	0.112	2.501	4.506	0.295	0.991	0.988	0.981	37.018

The predictive R-squared value of 0.981 is in good agreement with the adjusted R-squared value of 0.988, suggesting that the model has a strong fit. Furthermore, the Adequate Precision score of 37.018 indicates that the model offers a satisfactory signal-to-noise ratio, confirming its dependability for producing predictions within the examined parameter range. This level of precision guarantees that the model accurately reflects the range of differences in the data, hence ensuring its practical applicability and facilitating further investigation of the factors involved in the welding process.

2.3 Coefficients of Penetration

Table 2.5: Coefficients of Model for Penetration

Factor	Coefficient
Intercept	2.5
I	0.96
V	-0.067
S	-0.13
IS	-0.1

2.2.4 Final Model for Penetration

“Penetration, $p = 2.50 + 0.96 \times I - 0.067 \times V - 0.13 \times S - 0.10 \times I S$ ”

2.3 Model for Reinforcement

2.3.3 Coefficients of Reinforcement

Table 2.8: Coefficients of Model for reinforcement

Factor	Coefficient
Intercept	2.08
I	0.53
V	-0.15
S	-0.17
IV	-0.12

2.5 Model for Weld Penetration Shape Factor (WPSF)

2.5.1 “Selection of Significant Direct/Interaction Effects for Weld Penetration Shape Factor”

The Pareto chart show the weld Penetration Shape Factor. The graphic shows that Effects I, IV, V, and N exceed the t-limit, confirming their significance as components that should be included in the model. On the other hand, the effects of IS, IN, and S, which do not surpass the t-limit, will be excluded from the model because they are not statistically significant.

2.5.2 Checking the Adequacies of Model

The ANOVA results for the weld penetration shape component are displayed in tables 2.12 and 2.13. The model's F-value, which is 57.83, indicates a significant impact. The probability of such a high F-value being attributed to random noise is only 0.01%. Furthermore, the fact that the p-value is less than 0.05 confirms the statistical significance of the model parameters I, IV, V, and N. Moreover, the presence of a significant lack of fit is an unfavourable outcome,

suggesting that the model does not match the data well and exhibits noticeable deviations. These findings emphasise the dependability of the model in elucidating fluctuations in the weld penetration shape factor.

Table 2.12: Result of ANOVA for Weld Penetration Shape Factor

Source	SS	DF	MS	F-value	p-value	Remarks
Model	39.4	4	9.85	57.83	< 0.0001	significant
I	33.1	1	33.1	194.31	< 0.0001	significant
V	2.37	1	2.37	13.93	0.0033	significant
N	1.53	1	1.53	8.99	0.0121	significant
IV	2.4	1	2.4	14.07	0.0032	significant
Residual	1.87	11	0.17			
Lack of Fit	0.89	3	0.3	2.39	0.1445	not significant
Pure Error	0.99	8	0.12			
Cor Total	41.28	15				

Table 2.13: Model summary statistics for Weld Penetration Shape Factor

Parameters	Std. Dev.	Mean	C.V. %	PRESS	R ²	Adj R ²	Pred. R ²	Adeq. Precision
WPSF	0.413	6.154	6.707	3.964	0.955	0.938	0.904	18.50

The forecasted R-Squared value of 0.955 indicates a strong correlation with the corrected R-Squared value of 0.938. Furthermore, a Precision score of 18.50 demonstrates a satisfactory signal strength, which reinforces the usage of this model.

2.5.3 Coefficients of Weld Penetration Shape Factor

Table 2.14: Coefficients of Model for Weld Penetration Shape Factor

Factor	Coefficient
Intercept	6.15
I	-1.44
V	0.39
N	-0.31
IV	0.39

6.5.4 Final Model for Weld Penetration Shape Factor

$$\text{WPSF} = 6.15 - 1.44 \times I + 0.39 \times V - 0.31 \times N + 0.39 \times IV$$

6.6 Model for Weld Reinforcement Form Factor (WRFF)

2.6.1 "Selection of Significant Direct/Interaction Effects for Weld Reinforcement Form Factor"

Figure 6.5 shows the Pareto chart for the weld reinforcement form factor. The image clearly shows that effects IV, V, I, N, and S exceed the t-limit, establishing them as relevant components to include in the model. In contrast, effects IN and IS that do not surpass the t-limit will be excluded from the model because they are not statistically significant.

6.6.2 Checking the adequacies of model

The ANOVA results for the weld reinforcement shape component may be found in table-6.15 and table-6.16. A model F-value of 25.73 signifies that the model is statistically significant. The likelihood of a "Model F-Value" becoming significant only as a result of random variation is merely 0.01%. The model terms I, V, S, N, and IV are statistically

significant as indicated by the p-value being less than 0.05. A lack of fit that is not statistically significant is considered advantageous.

“Table 6.15: Result of ANOVA for Weld Reinforcement Form Factor”

Source	SS	DF	MS	F-value	p-value	Remarks
Model	31.44	5	6.29	25.73	< 0.0001	significant
I	5.86	1	5.86	23.98	0.0006	significant
V	8.88	1	8.88	36.35	0.0001	significant
S	1.56	1	1.56	6.4	0.0299	significant
N	5.59	1	5.59	22.88	0.0007	significant
IV	9.54	1	9.54	39.03	< 0.0001	significant
Residual	2.44	10	0.24			
Lack of Fit	0.2	2	0.1	0.36	0.7071	not significant
Pure Error	2.24	8	0.28			
Cor Total	33.89	15				

III. CONCLUSION

The following conclusions were drawn from the above investigation:

The use of two-level half factorial approaches allows for the development of mathematical models that can accurately forecast the parameters of weld bead shape and bead hardness for carbon steel SAW, within the feasible range of process parameters. The Design Expert software accurately measures the primary and interactive impacts of variables. The welding current has a favourable impact on metrics such as bead penetration, reinforcement, bead width, total bead volume, and hardness. However, it has a negative effect on WPSF (weld pool surface finish) and WRFF (weld reinforcement factor), while it does not significantly affect the percentage of dilution. The arc voltage has a beneficial effect on the bead width, weld pool shape factor (WPSF), weld reinforcement factor (WRFF), and percentage of dilution. However, it has a negative impact on penetration, reinforcement, total bead volume, and hardness. The welding speed has a favourable effect on hardness, percentage of dilution, weld reinforcement factor factor (WRFF), and has a negative impact on total bead volume, bead width, penetration, and reinforcement. However, it does not have a significant influence on weld pool shape factor (WPSF). The distance between the nozzle and plate has a favourable effect on hardness, but a negative effect on total bead volume, percentage of dilution, weld pool surface fluidity (WPSF), weld reinforcement factor of fill (WRFF), and bead width. However, it does not have a significant impact on penetration and reinforcing.

IV. FUTURE SCOPE

- Metallurgical changes and the heat-affected zone are observable in bead geometry.
- Multiple wire electrodes can replace single wire electrodes to enhance metal deposition rates.
- Recycling slag can be utilized in the process.
- Preheating the base plate can be implemented.
- Adding iron particles with the flux can increase deposition rates.
- Alternative design of experiment methods can be employed for model development.

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