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INVESTIGATION OF WELD BEAD GEOMETRY OF SUBMERGED ARC WELDING USING FLUX AND SLAG ON EN-24 STEEL ALLOY

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Abstract

Modernization of mechanical industry has lead to the increase in demand for hard and tough materials. SAW is a unique welding method since it involves the arc which is completely submerged under the layer of granular flux. During welding, this flux that contains lime, SiO_2, MnO, CaF_2 and other compounds reacts with the contaminants in the molten weld metal and forms slag. Thus, slag is considered as waste material
The objective of the present study will be the use of waste slag material and iron powder with the flux and to study the effect of different process parameters. The experiment has been conducted on EN24 steel alloy work piece with changing the different parameters like welding current, arc voltage & travel speed. The experimental layout is based on Taguchi design L9 orthogonal array. After that, the analysis of variance is used to analyze the results obtained from Taguchi design. After analysis of results obtained the most predominant factors for penetration is Current, rest two factors (voltage, travel speed) has less impact as compare to the current.

***Keywords**:* SAW, EL- 8 Flux , Penetration, Ar area of reinforcement, Ap Area Of Penetration

1. Introduction

Welding is one of the most popular methods of metal joining processes. The joining of the materials by welding provides a permanent joint of the components submerged arc welding is a method in which the heat required to fuse the metal is generated by arc formed by an electric current passing between the electrode and the work piece. There is no visible arc & no sparks, spatter. The electrode may be a solid or cored wire or a strip made from sheet or sintered material. The flux may be made by either fusing constituents to form a glassy slag (which is then crushed to form a powder) or by agglomerating the constituents using a binder and a corning process. The chemical nature and size distribution of the flux assists arc stability and determines the mechanical properties of the weld metal and the shape of the bead.

2. Selection of Material for the Experiment

Material selected for the SAW process is EN24. EN24 is a high quality, high tensile, alloy steel and combines high tensile strength, shock resistance, good ductility and resistance to wear. EN24 is most suitable for the manufacture of parts such as heavy-duty axles and shafts, gears, bolts and studs. EN24 is capable of retaining good impact values at low temperatures. En24 steel is a difficult-to-machine material because of its high hardness, low specific heat and tendency to get strain hardened.

Table 1:Chemical composition of EN24 alloy

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	V %	Mo %
0.3795	0.5717	0.04650	0.04961	0.2357	0.1104	1.26	1.066	0.0198	0.2177

The material dimensions were a flat bar of 400*80*20mm and it was divided into 9 equal sets of parts. Flux selected for the above experiment is EL-8 Flux

Table 2: Chemical composition of welding flux

C	Mn	Si	S	P
0.10 Max	1.0-1.60	0.55 Max	0.03 Max	0.03 Max

Presently slag generated during submerged arc welding is thrown away a waste and needs land fill space for dumping. It is not possible to stop the generation slag as it is a bio product of the process but could be reused. So an attempt has been made to recycle the slag. Slag has been processed in such a manner that allows it to be used as a flux and its effect on chemistry of weld metal has been investigated.

Slag was crushed and meshed to the granular size typical of fresh flux. I was prepared using this crushed slag in combination with EL-8 flux and iron powder.

Table 3: Mixture used slag iron powder and flux

Flux %	Slag %	Iron powder %
50	25	25

3. Method of Experiment

In this experimentations a total 9 experiments were being conducted. Experiments were conducted based on Taguchi's method and as per L_9 orthogonal array with considering three controllable factors (i.e. parameters). Each factor has three levels (Level 1, Level 2 and Level 3). The values taken by factor are termed to be levels.

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Table 4:Levels of Input Machining Parameters

S.NO.	INPUT PARAMETERS	LEVEL		
		1	**2**	**3**
1.	Welding current (amp.)	300	350	400
2.	Arc voltage(volts)	25	30	35
3.	Travel speed (m/hr)	20	25	30

After deciding the levels of all the three parameters that are welding current, arc voltage, and travel speed, the actual L_9 orthogonal array was being designed. On filling the values of all input parameters the following L_9 orthogonal array was being prepared

To assess the quality of weld bead, prepared by different values of current and voltage and travel speed, an experimental scheme was selected. Three input parameters and output parameters were selected for the experimentation. The detailed experimental scheme is shown in table

Table 5: Experimental Schemes

Weld sample	Input parameters	Output parameters
EN 24 flat bar	Welding current Arc voltage Travel speed	Penetration Dilution Rate

To assess the quality of weld bead, prepared by different values of current and voltage and travel speed, an experimental scheme was selected. Three input parameters and output parameters were selected for the experimentation.
The specimen is prepared for Measurement. All the process and machine/equipment used in the preparation of specimens from the initial to final are given in table form.

Table 6: Types of Process and Machines Used

Process used	**Machines /Device used**
Cutting of Specimen of Size 150mm X 100mm X 12mm Plates	Power hack SAW

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Grinding of Above Specified Specimens	Surface grinder
Weighing Required Flux, Slag Iron Powder	Weighing machine
Prepared Mixture of Flux, Slag and Iron Powder	Manually
SAW welding	SAW machine
Polishing of Specimens	Using Polishing papers
Etching of specimens	5% Nitrate Solution

4. Result and Discussion

The influence of different parameter like welding current, arc voltage, and travel speed with the mixture of slag, flux and iron powder and their effect on the penetration, and dilution rate was find out.

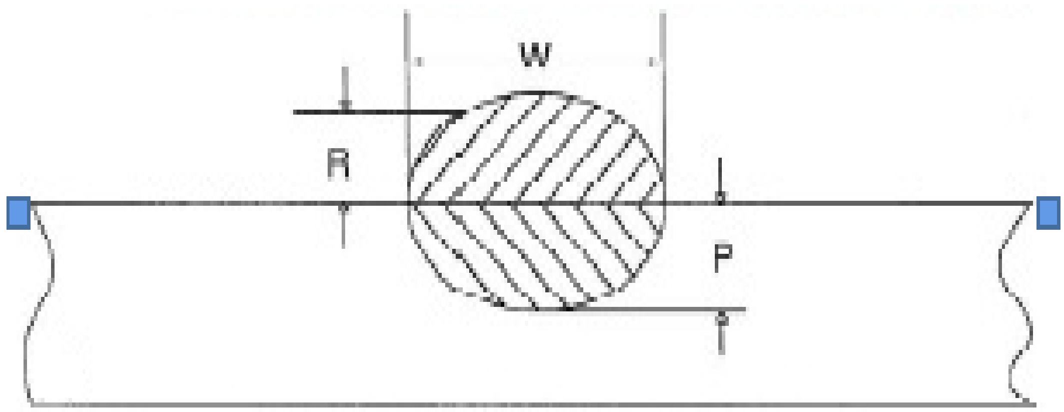

Figure 1: Cross Section View of Ideal Weld Bead

MIXTURE recommends analyzing data using the ANOVA that will offer two advantages; it provides guidance for selection the optimum level based on least variation around on the average value, which closest to target. The table show result after experiments

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Table 7: Results after Experiments

S. No.	After Experiments								
	Welding current in Amp.	Arc voltage in volts	Travel speed in meter/hour.	P	R	W	Ar (mm^2)	Ap (mm^2)	Dil (%)
1	300	25	20	5.2	1.9	21.75	22.62	47.8	0.678784
2	300	30	25	5.6	2.2	22.8	22.23	50.16	0.692913
3	300	35	30	5.8	2.3	23.8	27.60	54.74	0.66474
4	350	25	25	5.6	2.7	19.6	21.95	52.92	0.706806
5	350	30	30	5.7	2.2	23.6	23.2	51.92	0.691161
6	350	35	20	5.9	2.2	22.8	26.3	48.2	0.64698
7	400	25	30	7.9	2.9	21.9	32.23	63.51	0.663359
8	400	30	20	8.7	2.7	24.9	43.32	67.23	0.608108
9	400	35	25	8.6	2.6	27.8	47.81	72.28	0.601852

4.1 RESULT ANALYSIS FOR PENETRATION

Total 9 experiments were conducted for the L_9 experimental design. The penetrations of each experiment were calculated it means for every experiment there were values of penetration as shown in the Table 8.

Table 8: Average Table for Penetration for EN24 Alloy Steel Material

S. No.	After Experiments							
	Welding current in Amp.	Arc voltage in volts	Travel speed in meter/hour.	P	R	W	SNRA1	MEAN 1
1	300	25	20	5.2	1.9	21.75	14.3201	5.2

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2	300	30	25	5.6	2.2	22.8	14.9638	5.6
3	300	35	30	5.8	2.3	23.8	15.2686	5.8
4	350	25	25	5.6	2.7	19.6	14.9638	5.6
5	350	30	30	5.7	2.2	23.6	15.1175	5.7
6	350	35	20	5.9	2.2	22.8	15.4170	5.9
7	400	25	30	7.9	2.9	21.9	17.9525	7.9
8	400	30	20	8.7	2.7	24.9	18.7904	8.7
9	400	35	25	8.6	2.6	27.8	18.6900	8.6

So the analysis is based on the penetration. For the results of penetration, firstly S/N ratio is to be calculated. The effect of parameters i.e. welding current, arc voltage, travel speed some of their interactions was evaluated using ANOVA. A confidence interval of 95% has been used for the analysis. To measure Signal to Noise ratio (S/N ratio) calculated by used the software "MINITAB 17" to analyze the response data specially used for the design of experiment application.
(S/N) HB = -10 log (MSDHB)

Where MSDHB=1/r$\sum_i^r = (\frac{1}{y_i^2})$, r = the number of tests in a trial

yi = observed value of response characteristics

For penetration the S/N ratio is larger is better.

Where MSDHB = Mean Square deviation for higher the better response.
After analyzing the design of experiments response table for mean and response table for signal to noise ratio were calculated. Table 9&10 shows the response table for mean and signal to noise ratio.

Table 9: Response Table for Signal to Noise Ratios (Larger is Better)

Level	Welding Current (A)	Arc Voltage (B)	Travel Speed (C)
1	14.85	15.75	16.18
2	15.17	16.29	16.21

3	18.48	16.46	16.11
Delta	3.63	0.71	0.09
Rank	1	2	3

Table 10: Response Table for Mean (Larger is Better)

Level	Welding Current (A)	Arc Voltage (B)	Travel Speed (C)
1	5.533	6.233	6.600
2	5.733	6.667	6.600
3	8.400	6.767	6.467
Delta	2.867	0.533	0.133
Rank	1	2	3

Table 10 shows the major factor which affects the penetration. It is clearly shows in the response table for penetration that Current is ranked one; arc voltage is ranked second and travel speed third
It means that most predominant factor is Current and other has less impact to the earlier one. Now these values of S/N ratio and Mean are plotted in the shape of a graph which will tell individual parameter and its effect.
The figure 5.2 shows the S/N ratio for the penetration for the different level of input parameters.

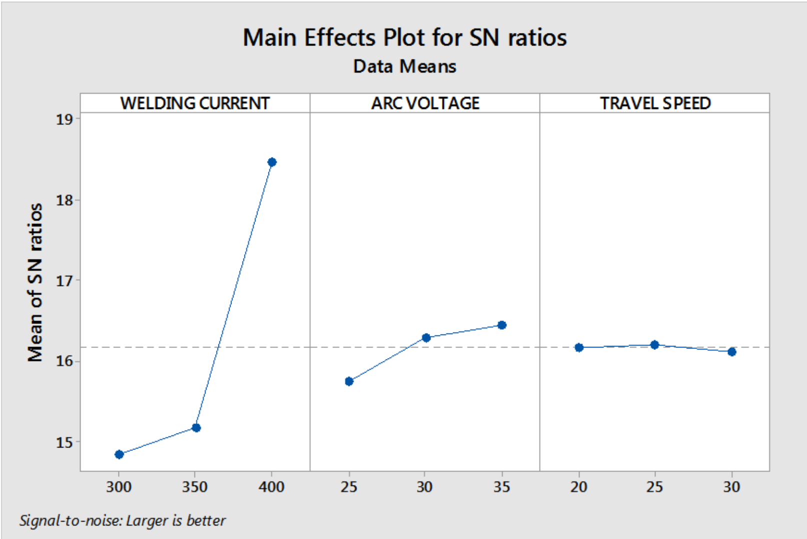

Figure 2: S/N ratio for the Penetration

It can be seen by the figure 2 clearly that the value increases sharply for the Current as their level increases. The value of voltage increases continuously, and travel speed decreases as their value increases.

The figure 3 shows the main effects plot for the mean for the penetration for the different level of input parameters.

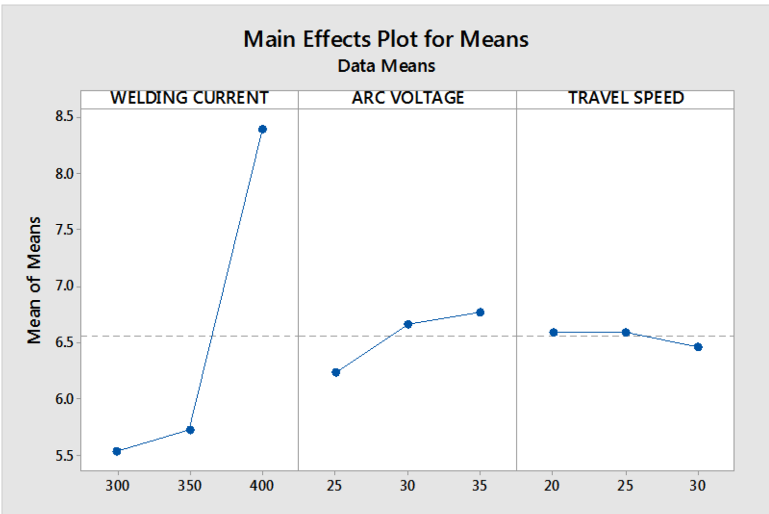

Figure 3: Main Effects Plot for Mean for the Penetration

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It can be seen by the figure 5.3 clearly that the value increases sharply for the Current as their level increases. The value of voltage increases continuously, and travel speed decreases as their value increases.
Figure 5.2&5.3 showing the SN ratio and main effects for mean for obtaining the optimal parameters. Which shows that larger the value of parameters better the penetration. Here A is current which is maximum at A3, B is Voltage which is maximum at B3, and C is travel speed which is maximum at.C1

4.3 ANALYSIS OF VARIANCE FOR PENETRATION

The results were analyzed using ANOVA for identifying the significant factors affecting the performance measures. The Analysis of Variance (ANOVA) for the mean penetration at 95% confidence interval is given in Table. The variation data for each factor and their interactions were F-tested to find significance of each calculated by the formula. The principle of the F-test is that the larger the F value for a particular parameter, the greater the effect on the performance characteristic due to the change in that process parameter where F is the fisher value. ANOVA table shows that current, voltage and travel speed are the factors that significantly affect the Penetration

Table 11: ANOVA for S/N Ratio Penetration

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Welding Current(A)	2	24.2196	24.2196	12.1098	165.27	0.006
Arc Voltage(V)	2	0.8338	0.8338	0.4169	5.69	0.149
Travel speed	2	0.0135	0.0135	0.0068	0.09	0.916
Residual error	2	0.1465	0.1465	0.0733		
Total	8	25.2135				
S=0.270690, R-Sq= 99.42%, R-Sq(adj) = 97.68% R-Sq(pred) = 88.23% Seq SS= Sum of squares, DOF= degree of freedom, Adj MS= adjusted mean square or variance ** Significant at 95% confidence level.						

Regression Equation

SNRA2 = 16.1648 - 1.314 WELDING CURRENT_300 - 0.999 WELDING CURRENT_350
+ 2.313 WELDING CURRENT_400 - 0.419 ARC VOLTAGE_25 + 0.126 ARC VOLTAGE_30
+ 0.294 ARC VOLTAGE_35 + 0.011 TRAVEL SPEED_20 + 0.041 TRAVEL SPEED_25
- 0.052 TRAVEL SPEED_30

Table 12: ANOVA for Mean of penetration

Source	DF	Seq SS	Adj SS	Adj MS	F	P
WeldingCurrent(A)	2	15.3689	15.3689	7.68444	160.84	0.006
Arc Voltage(V)	2	0.4822	0.4822	0.24111	5.05	0.165
Travell Speed	2	0.0356	0.0356	0.01778	0.37	0.729
Residual error	2	0.0956	0.0956	0.04778		
Total	8	15.9822	15.9822			
S=0.218581 , R-Sq= 99.40%, R-Sq(adj) = 97.61% R-Sq(pred) = 87.89% Seq SS= Sum of squares, DOF= degree of freedom, Adj MS= adjusted mean square or variance ** Significant at 95% confidence level.						

In table 11&12 columns 1 represents variable sources such as current, voltage, travel speed and the interactions between these three factors. Subsequently in the following columns degree of freedom (DF), Sum of squares (Seq SS), adjusted mean of square (Adj MS), F distribution and Probability are calculated respectively.
The standard deviation of errors in the modeling, S=0.218581. R-Sq=99.40% which indicates that the model is capable of predicting the response with a high accuracy.
After conducting P-test and F-test for the Anova for dilution, It was find out that the value of f test in maximum for current and the value of P is less than 0.05 that means the model is significant
Regression Equation
MEAN2 = 6.5556 - 1.022 WELDING CURRENT_300 - 0.822 WELDING CURRENT_350
+ 1.844 WELDING CURRENT_400 - 0.322 ARC VOLTAGE_25 + 0.111 ARC VOLTAGE_30
+ 0.211 ARC VOLTAGE_35 + 0.044 TRAVEL SPEED_20 + 0.044 TRAVEL SPEED_25
- 0.089 TRAVEL SPEED_30

Result Analysis for Dilution rate

Total 9 experiments were conducted for the L_9 experimental design. The dilution rate of each experiment was calculated it means for every experiment there were values of dilution as shown in the Table 5.20.

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Dilution = Ar/(Ar+Ap)
The effect of parameters i.e. Current, arc voltage, travel speed some of their interactions was evaluated using ANOVA. A confidence interval of 95% has been used for the analysis. To measure Signal to Noise ratio (S/N ratio) calculated by used the software "MINITAB 17" to analyze the response data specially used for the design of experiment application.
To measure Signal to Noise ratio (S/N ratio) calculated by the formula
(S/N) LB = -10 log (MSDLB)
Where MSDHB=1/r$\sum_{i=1}^{r} = (y_i^2)$, r = the number of tests in a trial
yi = observed value of response characteristics
For reinforcement the S/N ratio is smaller is better.
Where MSDLB = Mean Square deviation for smaller the better response.
So the analysis is based on the dilution. For the results of dilution, firstly S/N ratio and main effects for mean were calculated

Table 13: Results for dilution

S. No.	After Experiments								
	Welding current in Amp.	Arc voltage in volts	Travel speed in meter/ hour.	P	R	W	dilution	SNRA7	MEAN7
1	300	25	20	5.2	1.9	21.75	0.678784	-3.36536	0.678784
2	300	30	25	5.6	2.2	22.8	0.692913	-3.18642	0.692913
3	300	35	30	5.8	2.3	23.8	0.664740	-3.54697	0.664740
4	350	25	25	5.6	2.7	19.6	0.706806	-3.01399	0.706806
5	350	30	30	5.7	2.2	23.6	0.691161	-3.20842	0.691161
6	350	35	20	5.9	2.2	22.8	0.646980	-3.78218	0.646980
7	400	25	30	7.9	2.9	21.9	0.663359	-3.56503	0.663359
8	400	30	20	8.7	2.7	24.9	0.608108	-4.32038	0.608108
9	400	35	25	8.6	2.6	27.8	0.601852	-4.41021	0.601852

Table 14: Response Table for Signal to Noise Ratios (Larger is Better)

Level	Welding Current (A)	Arc Voltage (B)	Travel Speed (C)
1	-3.366	-3.315	-3.823
2	-3.335	-3.572	-3.537
3	-4.099	- -3.913	-3.440
Delta	0.764	0.598	0.383
Rank	1	2	3

Table 15: Response Table for Mean (Larger is Better)

Level	Welding Current (A)	Arc Voltage (B)	Travel Speed (C)
1	0.6788	0.6830	0.6446
2	0.6816	0.6641	0.6672
3	0.6244	0.6379	0.6731
Delta	0.0572	0.0451	0.0285
Rank	1	2	3

Table 15 shows the major factor which affects the dilution. It is clearly shows in the response table for dilution rate that welding current is ranked one; arc voltage is ranked second and travel speed third

It means that most predominant factor is welding current and other has less impact to the earlier one. Now these values of S/N ratio and Mean are plotted in the shape of a graph which will tell individual parameter and its effect.

The figure 4 shows the S/N ratio for the dilution rate for the different level of input parameters.

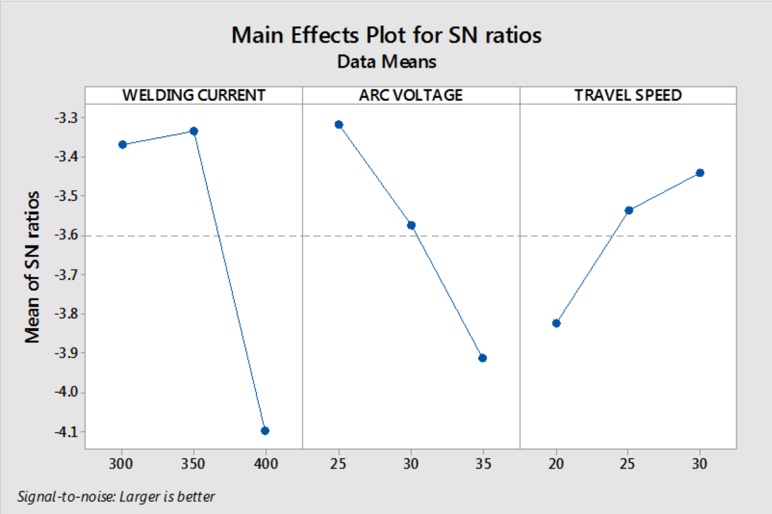

Figure 4: S/N ratio for the dilution rate

It can be seen by the figure 4 clearly that the value first increases and then decreases for the Current as their level increases. The value of voltage decreases and for travel speed increases as their value increases.

The figure 5 shows the main effects plot for the mean for the dilution rate for the different level of input parameters.

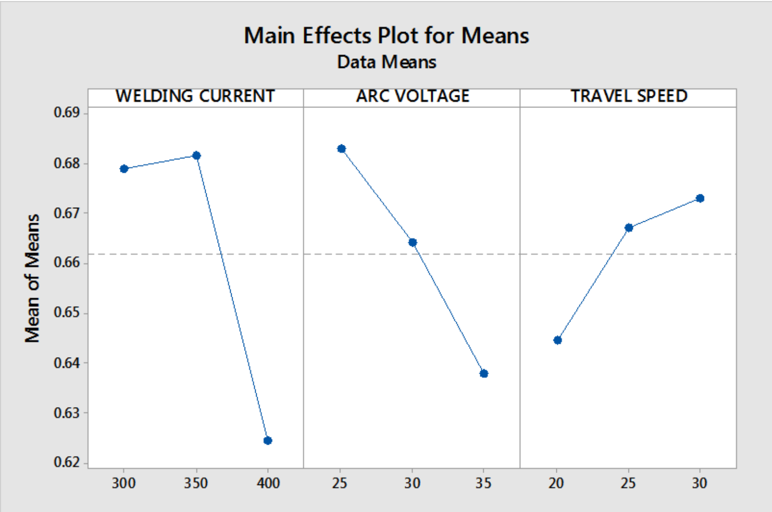

Figure 5: Main Effects Plot for Mean for the dilution rate

It can be seen by the figure 5 clearly that the value first decreases then increases for the Current as their level increases. The value of voltage decreases and for travel speed first increase continuously as their value increases.

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Figure 4& 5 showing the S/N ratio and main effects for mean for obtaining the optimal parameters. Which shows that larger the value of parameters better the dilution rate. Here A is current which is maximum at A2, B is Voltage which is maximum at B1, and C is travel speed which is maximum at C3.

5.13 ANALYSIS OF VARIANCE FOR DILUTION RATE

The results were analyzed using ANOVA for identifying the significant factors affecting the performance measures. The Analysis of Variance (ANOVA) for the mean penetration at 95% confidence interval is given in Table. The variation data for each factor and their interactions were F-tested to find significance of each calculated by the formula. The principle of the F-test is that the larger the F value for a particular parameter, the greater the effect on the performance characteristic due to the change in that process parameter where F is the fisher value. ANOVA table shows that current, voltage and travel speed are the factors that significantly affect the dilution

Table 16: ANOVA for S/N Ratio of dilution rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P
WeldingCurrent(A)	2	1.12043	1.12043	0.56022	30.17	0.032
Arc Voltage(V)	2	0.54055	0.54055	0.27028	14.55	0.064
Travell Speed	2	0.23733	0.23733	0.11867	6.39	0.135
Residual error	2	0.03714	0.03714	0.01857		
Total	8	1.93546	1.93546			

S=0.136272 , R-Sq= 98.08%, R-Sq(adj) = 92.32% R-Sq(pred)= 61.14%

Seq SS= Sum of squares, DOF= degree of freedom, Adj MS= adjusted mean square or variance

** Significant at 95% confidence level.

In table 16 column 1 represents variable sources such as current, voltage and travel speed and the interactions between these four factors. Subsequently in the following columns degree of freedom (DF), Sum of squares (Seq SS), adjusted mean of square (Adj MS), F distribution and Probability are calculated respectively.
The standard deviation of errors in the modeling, S=3136272, R-Sq=98.08% which indicates that the model is capable of predicting the response with a high accuracy.

Regression Equation

SNRA7 = -3.5999 + 0.2336 WELDING CURRENT_300 + 0.2650 WELDING CURRENT_350
- 0.4987 WELDING CURRENT_400 + 0.2851 ARC VOLTAGE_25 + 0.0281 ARC VOLTAGE_30
- 0.3132 ARC VOLTAGE_35 - 0.2228 TRAVEL SPEED_20 + 0.0630 TRAVEL SPEED_25
+ 0.1597 TRAVEL SPEED_30

Table 17: ANOVA for Mean of dilution rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P
WeldingCurrent(A)	2	0.006237	0.006237	0.003119	34.91	0.028
Arc Voltage(V)	2	0.003081	0.003081	0.001541	17.24	0.055
Travell Speed	2	0.001354	0.001354	0.000677	7.58	0.117
Residual error	2	0.000179	0.000179	0.000089		
Total	8	0.010851				
S=0.0094517 , R-Sq= 98.35%, R-Sq(adj) = 93.41% R-Sq(pred) = 66.66%						
Seq SS= Sum of squares, DOF= degree of freedom, Adj MS= adjusted mean square or variance						
** Significant at 95% confidence level.						

In table 17 column 1 represents variable sources such as current, voltage, travel speed and the interactions between these four factors. Subsequently in the following columns degree of freedom (DF), Sum of squares (Seq SS), adjusted mean of square (Adj MS), F distribution and Probability are calculated respectively.
The standard deviation of errors in the modeling, S=0.0094517. R-Sq=98.35% which indicates that the model is capable of predicting the response with a high accuracy.
After conducting P-test and F-test for the Anova for dilution, It was find out that the value of f test in maximum for current and the value of P is less than 0.05 that means the model is significant

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Regression Equation

MEAN7 = 0.66163 + 0.01718 WELDING CURRENT_300 + 0.02002 WELDING CURRENT_350
- 0.03719 WELDING CURRENT_400 + 0.02135 ARC VOLTAGE_25 + 0.00243 ARC VOLTAGE_30
- 0.02378 ARC VOLTAGE_35 - 0.01701 TRAVEL SPEED_20 + 0.00556 TRAVEL SPEED_25
+ 0.01145 TRAVEL SPEED_30

Conclusion

In this paper, saw welding process and the effect of current, voltage and travel speed has been investigated. The effect of input parameter on output response like penetration, reinforcement, weld penetration shape factor, weld reinforcement shape factor and dilution rate were analyzed for work material EN24 Alloy Steel. L9 orthogonal array based on Taguchi design and ANOVA was performed for analyzing the result. On the basis of experimental observations made on saw welding components following conclusions can be drawn

a) The maximum penetration is 8.7 mm and it is noted at the value of current 400A, voltage 30 V, travel speed 20 meter /hour.
b) The most predominant factors for penetration is Current, rest two factors (voltage , travel speed) has less impact as compare to the current.
c) It is concluded that for optimize penetration the parametric combination is current third (A3), Voltage at second Level (B 3), travel speed (C2) i.e. 400A current, 35V voltage, 25 meter/hour travel speed
d) It is concluded that after using ANOVA general linear model F-test were conducted the maximum value of F was 165.27 and the minimum value of P was 0.006 that is less than 0.05 that means the model is significant
e) The maximum dilution rate is 0.70 and it is noted at the value of current 300A, voltage 25 V, travel speed 25 meter /hour.
f) The most predominant factors for dilution rate is Current, rest two factors (voltage , travel speed) has less impact as compare to the current.
g) It is concluded that for optimize dilution rate the parametric combination is current third (A2), Voltage at second Level (B1), travel speed (C3) i.e. 350A current, 25V voltage, 30 meter/hour travel speed
h) It is concluded that after using ANOVA general linear model F-test were conducted the maximum value of F was 34.91 and the minimum value of P was 0.028 that is less than 0.05 that means the model is significant
i) The regression equation for both responses was find out

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