PREDICTION OF WELD BEAD PENETRATION FOR STEEL USING SUBMERGED ARC WELDING PROCESS PARAMETERS

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Abstract:
In these research paper the Design of experiment using 2-level full factorial technique has been used to conduct experiments and to develop relationships mathematical models for predicting the weld bead penetration in single wire submerged arc welding of 12 mm thick mild steel plates . The response factor, namely bead penetration, as affected by arc voltage, current, welding speed, wire feed rate and nozzle-to-plate distance have been investigated and analyzed.. The models developed have been checked for their adequacy and significance by using the analysis of variance, F-test and the t-test, respectively. Main and interaction effects of the process variables on weld bead penetration have also been presented in graphical form. The developed models could be used for the prediction of important weld bead penetration and control of the weld bead quality by selecting appropriate process parameter values. And the model-predicted penetration values have been compared with their respective experimental values.

Keywords*: *Submerged arc welding, welding process parameters, Weld bead penetration, Mathematical modelling and full factorial technique.

1. Introduction

Submerged arc welding as arc welding in which a continuous consumable electrode is used and the arc is submerged in a granulated flux, some of which fuses to form a removable covering of slag on the weld. It is one of the main welding processes used in the industries for the purpose of fabrication of huge structures is Submerged Arc Welding process. The key features of this process are high deposition rates and long weld runs. The important process variables in submerged arc welding are: welding current, arc voltage, welding speed, nozzle to plate distance and wire feed rate. The effects of these process variables are determined through their effects on weld bead penetration. Submerged arc welding is widely employed as one of the major fabrication processes in industries to-day due to its inherent advantages of deep penetration, smooth bead, superior joint quality, speed excellent weld appearance (without spatter) and high utilisation of electrode feed wire. It is one of the oldest automatic welding processes introduced during 1930s.[1,2,3] In SAW, researchers are often faced with the problems of relating the process variables and bead geometry to the weld bead quality because there are some unknown, nonlinear process parameters[4] .Many efforts have been made to develop a mathematical model to study these relationships and best way to solve this problem is by using experimental model .A multiple regression technique has been utilized to establish the models for various welding processes [5,6] .**R.S. Chandel et al.**[7] presented theoretical predictions of the effect of current, electrode polarity, electrode diameter and electrode extension on the melting rate, bead height, bead width and weld penetration. **Datta et al.** [8] proposed multiple regression model for predicting volume of submerged arc deposit per unit time.**Gupta V.K& Pramar** [9] used fractional factorial technique to predict geometric dimensions of the weld bead in SAW.**Ravindra & Pramar** [10] used a mathematical model to predict weld bead geometry for the flux cored welding process.

Fig.-1 Experimental Set- up

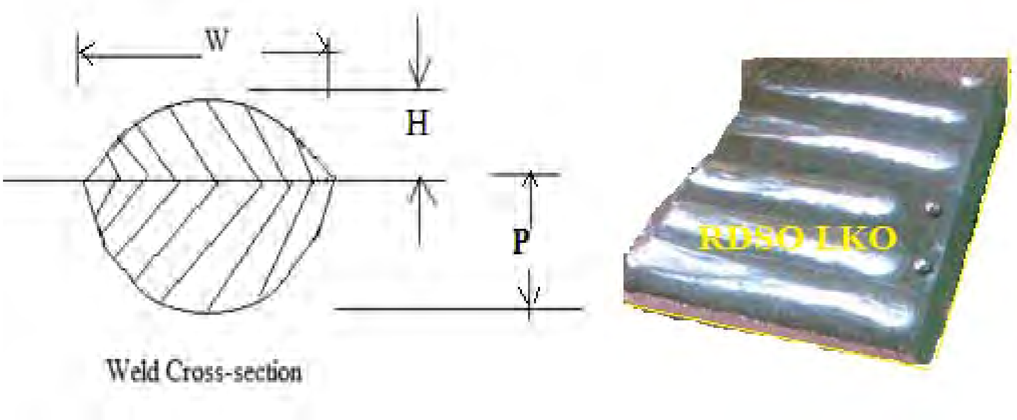

Fig.2 Weld bead Penetration (P)

2. Plan of investigation.

2.1. Identification of important parameters

Review of literature and a large number of trial runs indicate that the dominant factors which are having greater influence on the responses are open circuit voltage (OCV), welding current (I) , wire feed rate (F), welding speed (S) and nozzle- to- plate distance (C) (15).

2.2. Determining the working limits of the parameters

Extensive trial runs have been carried out to find out the feasible working limits of submerged arc welding parameters on mild steel. Different combinations of open circuit voltage (OCV), welding current (I) wire feed rate (F), welding speed (S) and nozzle- to- plate distance (C) were used to observe the effect on desired response. The weld zones were inspected with visual inspection to identify the working limits of the welding parameters.

2.3. Developing the experimental design matrix

The feasible limits of the parameters were selected in such a way that the welds obtained were free from surface defects. A two level full factorial design of ($2^{5-1} = 32$) thirty two experimental runs, which is a standard statistical tool to investigate the effects of number of parameters on the required response, was selected for determining the effect of five independent direct welding parameters. This technique reduces the costs and provides the required information about the main and interaction effects. The commonly employed method of varying one parameter at a time, though popular, does not give any information about interaction among parameters. Table -1 presents the working range of factors considered. For the convenience of the recording and processing the experimental data the upper and lower levels of the factors are coded as -1 and +1 respectively.

2.4. Conducting the experiments as per designed matrix

The experiments were conducted at welding research division, RDSO (Research design and standard organization Lucknow (U.P) India. The experiments have been performed on constant voltage fully automatic submerged arc welding machine of a constant potential transformer-rectifier type (ESAB) with a maximum welding current of 1000-1200 Amp. Experimental set-up shown in Fig.1.A 3.2mm copper coated mild steel feed wire electrode was used with composition of, (C-0.10%, Mn-0.45%, Si-0.02%). Welding was carried out in single pass using bead on- plate technique. Weld beads were deposited according to the conditions directed by the design matrix using 2- level 2^{5-1} full factorial technique as given in table.2. The signs under the columns 1, 2, 3, 4 were arranged in standard full factorial order, while those other columns were obtained by taking treatment product of parameters. A standard procedure was followed for designing such a matrix. The plates were cleaned mechanically and chemically so as to remove oxide layer or any other sources of impurities, before welding. The experiments were performed in a random order in order to avoid any systematic error. In 32 trials, beads were laid on 32 plates. Two specimens of 16mm width were cut transverse to the welding direction from each welded plates. These specimens were cleaned, ground, polished and etched with 10% nital (90% alcohol + 10% of nitric acid). All specimens of first set were macro etched to reveal the bead profile and some specimens of second set were micro etched to reveal the microstructures. Weld bead profiles were traced by using an optical profile projector/Image at 20X magnification and the magnified view was drawn on the transparencies for further analysis. Measurements were made for bead penetration (P). The observed values of the responses are given in table.3.

2.4.1. Base Metal

Test specimens were prepared from 12 mm thickness Mild steel plate, 295x145x12mm size with a composition of (C-0.102%,S-0.179%,Mn-0.466%,S-0.0705%,Cr-0.036%,Ni-0.022%).

2.4.2. Flux used

The study was carried out by using the available agglomerated flux, automelt GR-4 with a composition of (C-0.08%, Mn-1.00%, Sn-0.25%).

Table1. Important process control variables

S.no	**Parameters**	**Units**	**Notations**	**High (+1)**	**Low (-1)**
1	Voltage	volts	V	35	29
2	Current	amp	I	550	400
3	Wire feed rate	Mm/min	F	3400	1600
4	Welding speed	Mm/min	S	600	360
5	Nozzle to plate distance	mm	C	30	25

2.5. Selection of the useful limits of the welding parameter:

Trial runs were carried out by varying one of the process parameters whilst keeping the rest of them at constant values. The working range was decided upon by inspecting the bead for smooth appearance and the absences of any visible defects. The upper limit of a factor was coded as +1 and lower limit as -1. The selected process parameters with their limits, units and notation are given in Table.1 above.

2.6. Developing the design matrix

The designed matrix is given below the level (or signs) for the parameter C (nozzle to plate distance) are derived by the relation **C=V*I*F*S**

Table 2. Design matrix

Weld. no	**V volts**	**I amp**	**F mm/min**	**S mm/m**	**C* mm**	**Treatment combination+ve**
1	-1	-1	-1	-1	+1	C
2	-1	-1	-1	+1	-1	S
3	-1	-1	-1	-1	+1	C
4	-1	-1	-1	+1	-1	S
5	-1	-1	+1	-1	-1	F
6	-1	-1	+1	+1	+1	FSC
7	-1	-1	+1	-1	-1	F
8	-1	-1	+1	+1	+1	FSC
9	-1	+1	-1	-1	-1	I

10	-1	+1	-1	+1	+1	ISC
11	-1	+1	-1	-1	-1	I
12	-1	+1	-1	+1	+1	ISC
13	-1	+1	+1	-1	+1	IFC
14	-1	+1	+1	+1	-1	IFS
15	-1	+1	+1	-1	+1	IFC
16	-1	+1	+1	+1	+1	VIFSC
17	+1	-1	-1	-1	-1	V
18	+1	-1	-1	+1	+1	VSC
19	+1	-1	-1	-1	-1	V
20	+1	-1	-1	+1	+1	VSC
21	+1	-1	+1	-1	+1	VFC
22	+1	-1	+1	+1	-1	VFS
23	+1	-1	+1	-1	+1	VFC
24	+1	-1	+1	+1	-1	VFS
25	+1	+1	-1	-1	+1	VIC
26	+1	+1	-1	+1	-1	VIS
27	+1	+1	-1	-1	+1	VIC
28	+1	+1	-1	+1	-1	VIS
29	+1	+1	+1	-1	-1	VIF
30	+1	+1	+1	+1	+1	VIFSC
31	+1	+1	+1	-1	-1	VIF
32	+1	+1	+1	+1	+1	VIFSC

The numbers in the first column indicate the number of trial run

Table- 3. The observed values of the responces.

Weld. No	**V volt**	**I Amp**	**F mm/min**	**S mm/min**	**C mm**	**Penetration (P)mm**
1	29	400	1600	360	30	2.80
2	29	400	1600	600	25	3.16
3	29	400	1600	360	30	2.70
4	29	400	1600	600	25	3.06
5	29	400	3400	360	25	5.11
6	29	400	3400	600	30	2.80
7	29	400	3400	360	25	5.01
8	29	400	3400	600	30	2.70
9	29	550	1600	360	25	4.69
10	29	550	1600	600	30	4.52
11	29	550	1600	360	25	4.59
12	29	550	1600	600	30	4.42
13	29	550	3400	360	30	4.62
14	29	550	3400	600	25	4.61
15	29	550	3400	360	30	4.52
16	29	550	3400	600	30	4.52
17	35	400	1600	360	25	5.50
18	35	400	1600	600	30	3.66
19	35	400	1600	360	25	5.50
20	35	400	1600	600	30	3.56

21	35	400	3400	360	30	5.51
22	35	400	3400	600	25	5.40
23	35	400	3400	360	30	5.41
24	35	400	3400	600	25	5.50
25	35	550	1600	360	30	8.22
26	35	550	1600	600	25	7.49
27	35	550	1600	360	30	8.12
28	35	550	1600	600	25	7.39
29	35	550	3400	360	25	11.48
30	35	550	3400	600	30	8.22
31	35	550	3400	360	25	11.58
32	35	550	3400	600	30	8.12

2.7. Development of mathematical models

Mathematical models can now be developed for the SAW process to predict weld bead penetration and to establish the interrelationship between welding process parameters to weld bead penetration. The experimental data were used to develop linear models, and analysis of the models was carried out through ANOVA and Minitab software was used for this purpose.

The general response function representing any of the weld-bead dimensions can be

Expressed as Y. = f (V, I, F, S, C)

Where, Y= Weld bead response, V= Open Arc voltage, I= Current=Wire feed rate, S= Welding speed, and C= Nozzle-to-plate distance.

The effect caused by change in five main factors and their first order interaction can be expressed as the relationship selected being a first order linear equation

Y=b0+b*V+b2*I+b3*F+b4*S+b5*C+b12*VI+b13*VF+b14*VS++b15*VC+b23*IF+b24*IS+b25*IC+b34*FS +b35*FC+b45*SC

Where Y represents any of the weld bead dimensions , b0 is constant and b1,b2,b3,b4,b5,b11 , b12,b13,b14,b15,b23,b24,b25,b34,b35,b45 are co-efficient of the model.

Signs for calculating effects of parameters and their interactions. The signs for the interaction were obtained by multiplying the corresponding signs of the involved factors (Table.4)

Table 4. The signs for main and interaction effects.

Trial no	**X0**	**V**	**I**	**F**	**S**	**C**	**VI**	**VF**	**VS**	**VC**	**IF**	**IS**	**IC**	**FS**	**FC**	**SC**
1	+1	-1	-1	-1	-1	+1	+1	+1	+1	-1	+1	+1	-1	+1	-1	-1
2	+1	-1	-1	-1	+1	-1	+1	+1	-1	+1	+1	-1	+1	-1	+1	-1
3	+1	-1	-1	-1	-1	+1	+1	+1	+1	-1	+1	+1	-1	+1	-1	-1
4	+1	-1	-1	-1	+1	-1	+1	+1	-1	+1	+1	-1	+1	-1	+1	-1
5	+1	-1	-1	+1	-1	-1	+1	-1	+1	+1	-1	+1	+1	-1	-1	+1
6	+1	-1	-1	+1	+1	+1	+1	-1	-1	-1	-1	-1	-1	+1	+1	+1
7	+1	-1	-1	+1	-1	-1	+1	-1	+1	+1	-1	+1	+1	-1	-1	+1
8	+1	-1	-1	+1	+1	+1	+1	-1	-1	-1	-1	-1	-1	+1	+1	+1
9	+1	-1	+1	-1	-1	-1	-1	+1	+1	+1	-1	-1	-1	+1	+1	+1
10	+1	-1	+1	-1	+1	+1	-1	+1	-1	+1	-1	+1	+1	-1	-1	+1
11	+1	-1	+1	-1	-1	-1	-1	+1	+1	+1	-1	-1	-1	+1	+1	+1
12	+1	-1	+1	-1	+1	+1	-1	+1	-1	+1	-1	+1	+1	-1	-1	+1
13	+1	-1	+1	+1	-1	+1	-1	-1	+1	+1	+1	-1	+1	-1	+1	-1
14	+1	-1	+1	+1	+1	-1	-1	-1	-1	+1	+1	+1	-1	+1	-1	-1

15	+1	-1	+1	+1	-1	+1	-1	-1	+1	+1	+1	-1	+1	-1	+1	-1
16	+1	-1	+1	+1	+1	+1	-1	-1	-1	+1	+1	+1	+1	+1	+1	+1
17	+1	+1	-1	-1	-1	-1	-1	-1	-1	-1	+1	+1	+1	+1	+1	+1
18	+1	+1	-1	-1	+1	+1	-1	-1	+1	+1	+1	-1	-1	-1	-1	+1
19	+1	+1	-1	-1	-1	-1	-1	-1	-1	-1	+1	+1	+1	+1	+1	+1
20	+1	+1	-1	-1	+1	+1	-1	-1	+1	+1	+1	-1	-1	-1	-1	+1
21	+1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	-1	+1	-1
22	+1	+1	-1	+1	+1	-1	-1	+1	+1	-1	-1	-1	+1	+1	-1	-1
23	+1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	-1	+1	-1
24	+1	+1	-1	+1	+1	-1	-1	+1	+1	-1	-1	-1	+1	+1	-1	-1
25	+1	+1	+1	-1	-1	+1	+1	-1	-1	+1	-1	-1	+1	+1	-1	-1
26	+1	+1	+1	-1	+1	-1	+1	-1	+1	-1	-1	+1	-1	-1	+1	-1
27	+1	+1	+1	-1	-1	+1	+1	-1	-1	+1	-1	-1	+1	+1	-1	-1
28	+1	+1	+1	-1	+1	-1	+1	-1	+1	-1	-1	+1	-1	-1	+1	-1
29	+1	+1	+1	+1	-1	-1	+1	+1	-1	-1	+1	-1	-1	-1	-1	+1
30	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
31	+1	+1	+1	+1	-1	-1	+1	+1	-1	-1	+1	-1	-1	-1	-1	+1
32	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1

Table 5. Coefficients of the models

Serial no	**Coefficients Bj**	**Penetration (P)**
1	B0	5.50251
2	B1	1.41374
3	B2	1.29126
4	B3	0.50756
5	B4	-0.49119
6	B5	-0.42275
7	B12	0.61999
8	B13	0.22869
9	B14	-0.25756
10	B15	-0.13480
11	B23	0.03881
12	B24	-0.00994
13	B25	0.14600
14	B34	-0.22114
15	B35	-0.24520
16	B45	0.26605

2.8. Evaluation of the co-efficient of the model

The values of the coefficients of the linear equation were calculated by the regression method. The Minitab and SPSS software package were used to calculate the values of these coefficients for different responses. All the coefficients were tested for their significance at 95% confidence level applying student's t-test.

2.9. Response

Penetration has been expressed as a linear function of the input process
Parameters (in coded form) as follows:

Y=5.50+1.41*V+1.29*I+0.508*F-0.491*S-0.423*C+0.620*VI+0.229*VF-0.258*VS-0.135*VC+0.0388*IF-0.0099*IS+0.146*IC-0.221*FS-0.245*FC+0.266*SC

2.10. Checking adequacy of the model

The analysis of variance (ANOVA) technique has been used to check the adequacy of the developed model. Analysis of variance tests for models, t-test, p- value, standard error of estimate, coefficient of multiple correlations, has been estimated and the results are given in Table.6.

Table .6

source	DF	SS	MS	F	P
regression	15	164.852	10.990	844.60	0.000
Residual error	16	0.208	0.013		
total	31	165.060			

Model name	SEE	R	100R² (adj)
Penetration	0.1141	.999	99.8

From the above tests it is evident that the model are adequate.

2.11. T- Test for significance of regression coefficients

The determination of co-efficient (R^2) indicates the goodness of the fit for the model. In the case of penetration, the value of the determination co-efficient (R^2 = 0.999) indicates the high level of significance. Scatter diagram between actual and predicted values of reinforcement height has been presented in Fig.3. It can be observed that there is a good correlation between the actual and predicted values which further supports the validity of developed model.

2.12. Predicted response: The final mathematical model

Penetration was expressed as a linear function of the input process

Parameters (in coded form) as follow as:

Y=5.50-1.41*V-1.29*I+0.508*F-0.491*S-0.423*C+0.620*VI+0.229*VF-0.258*VS-0.135*VC+0.146*IC-0.221*FS-0.245*FC+0.266*SC

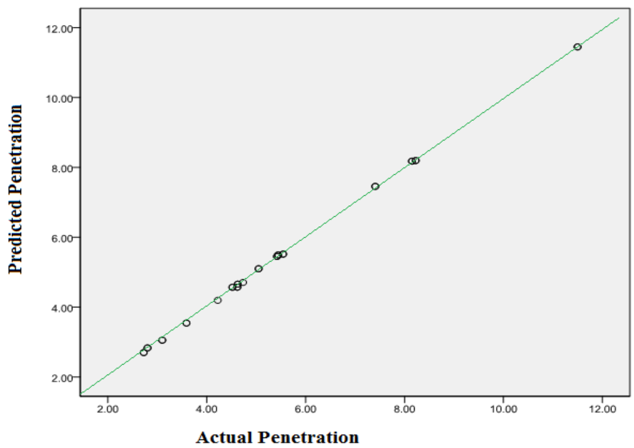

Fig.3 Plot of actual vs. predicted response of penetration.

3. Results and discussion:

The predicted influences of the welding parameters on the weld bead penetration within the range of investigation are shown in Fig.4.and the interaction effects between variables are shown in Fig.5.1 to Fig.5.5.

3.1. Direct effect or main effect of process parameters on penetration:

Figure 4 shows the effect of input parameters on bead penetration in submerged welding process. As shown in the figure the penetration increases rapidly with increase in voltage and welding current. Significantly increases with increase in wire feed rate and decreases with welding speed and further significantly decreases with increase of nozzle to plate distance.

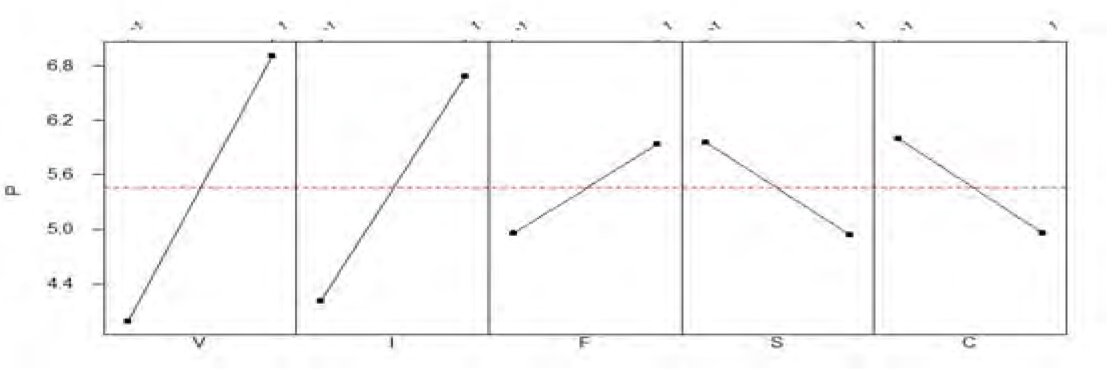

Fig.4 Main effect plot for penetration.

3.2. Major interaction effect of process parameters on penetration:

It is seen from Fig.5.1 that at high voltage value the penetration rapidly increases with increase in current, however at low voltage value penetration increase at very slow rate with increase in current. Fig.-5.2 shows that as the high voltage value the penetration increases with increase in wire feed rate, however at lower voltage value the penetration increases at very slow rate with increase in wire feed rate. It evident from Fig.-5.3 that the penetration decreases with increase in welding speed at high voltage value and penetration is very less at low voltage value ,it is due to that at high welding speed, the heat input per unit length decreases and so penetration will also decreases. Fig.-5.4 show that as the high wire feed rate, the penetration decreases rapidly with increases in nozzle to plate distance, however at low wire feed rate the penetration decrease in significantly with increase in nozzle to plate distance, It is due to resistance heating of the wire before the formation of an arc which results in higher metal deposition rate owing to higher heat input. Fig.-5.5 show that as the low welding speed , the penetration decreases rapidly with increases in nozzle to plate distance, however at high welding speed the penetration decreases insignificantly with increase in nozzle to plate distance.

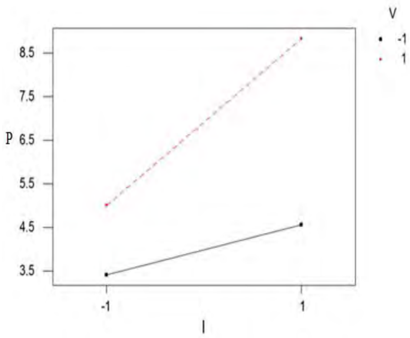

Fig.5.1

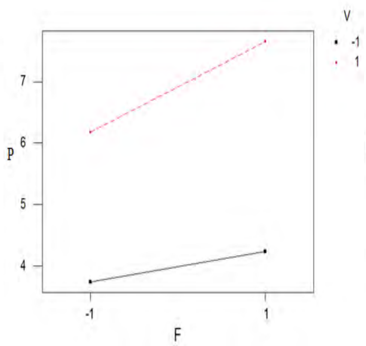

Fig.5.2

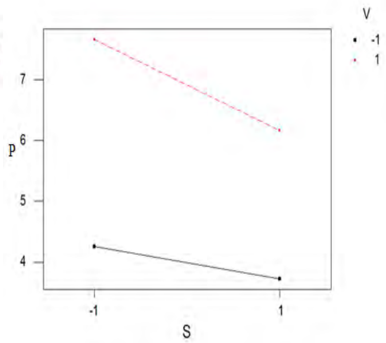

Fig.5.3

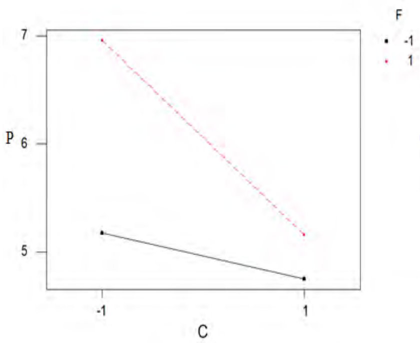

Fig.5.4

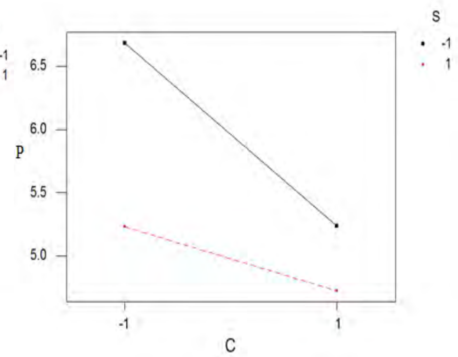

Fig.5.5

4. Conclusions

- The two level full factorial designs are found to be an effective tool for quantifying the main and interaction effect of variables on weld bead penetration.

- The developed model can be effectively used to predict the penetration in the submerged arc welding within the range of parameters used.
- Proposed models are adequate to predict with confidence level of 95%.
- Penetration increase significantly with increase in voltage, current and wire feed rate .decrease with increase in welding speed and nozzle to plate distance.

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