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Application of Two-Level Half Factorial Design Technique for Developing Mathematical Models of Bead Width and Bead Hardness in SAW Process

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ABSTRACT

The quality of weld is depicted by weld bead geometry. In submerged arc welding (SAW) bead geometry closely related to the process parameters namely welding current, open circuit voltage, welding speed and nozzle to plate distance. So it is necessary to develop the mathematical models for bead geometry in automatic SAW machine. In the present work mathematical models are developed for bead width and bead hardness by making bead on plate (12 mm thick ASTM SA 516 Grade 60). Experiments were conducted according to the two level half factorial technique and analysis of direct and interactive effect of parameters on responses are presented with the help of Design expert software. Results were clearly illustrated that bead width increases with welding current and voltage, but decreases with welding speed and nozzle to plate distance. Bead hardness increases with Welding current, welding speed and nozzle to plate distance, but decreases with voltage.

1. Introduction

Submerged arc welding is an arc welding process wherein coalescence is produced by heating an electric arc setup between a bare metal electrode and the job. The arc, end of the electrode and molten pool remain completely hidden and are invisible being submerged under a blanket of flux. The continuously fed bare metal electrode melts and acts as filler rod [1]. SAW process is extensively used in heavy steel plate fabrication, because of its high quality weld metal and extremely high deposition rate and welding speed. SAW welding used in fabrication of pipes, pressure vessel, boilers, storage tank, heavy structural, ships, railways wagons and coaches and surfacing and build- up work [2]. In today's manufacturing world, quality is of vital importance. In the field of welding, weld quality mainly depends on mechanical properties of weld metal and HAZ. This in turn is influenced by metallurgical characteristics and chemical composition of the weld. Moreover, these mechanical – metallurgical features of the weldment depends on bead geometry which are directly related to welding process parameters. In other words, weld quality depends on welding process parameters [3]. The important process variable in submerged arc welding are welding current, arc voltage, welding speed and nozzle to plate distance. The effects of these parameters are determined through their effect on bead width and bead hardness. For developing the relation between process variables and the bead geometry to the weld quality, mathematical models were developed for the response by the various researchers. L. J.Yang, R.S.Chandel and M.J.Bibby et al [1993] conducted experiments to find the result of bead-on-plat submerged arc welding to determine the effect of process variable on the weld deposit area.V.Gunraj and N.Murgan et al [2000] Study and analysis of various process control variables and important weld bead quality parameters in SAW of pipes manufactured. S. Kumanan, J.Edwin Dhas & K.Gowthamanet et al [2007] Apply Taguchi technique and regression analysis to determine the optimal process parameters for submerged arc welding. S.P.Tewari**,** Ankur Gupta, Jyoti Prakash et al [2010] study the effect of various welding parameters on the weldability of Mild Steel specimens welded by metal arc welding. Deepak Kumar Chaudhary, Sandeep Jindal and N.P.Mehta et al [2011] conducted experiment on submerged arc welding by making bead on steel(SS -304) plate to investigate the effect of welding parameters on bead geometry.

This article addresses the use of two level half factorial techniques for developing the mathematical models for bead width and bead hardness in SAW. The direct effect and interaction effect of process variable on the responses is represented on graph by using design expert software. The experiment is conducted by automatic SAW machine and making bead on 150mm×75mm×12mm thick carbon steel (ASTM SA 516 Grade 60) plate. The material is widely used for making pressure vessels and boilers.

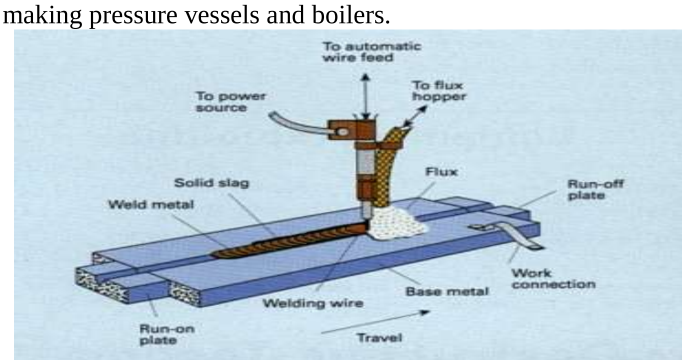

Figure 1: Process diagram-Submerged Arc Welding

2 Design of Experiment based on Two-Level Half Factorial Design Method

Two level half factorial design techniques is most widely used type of designs for product and process design and for process improvement. Two level half factorial design (2^{k-1}) technique reduces experimental cost and provides required

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information about the main and interactions effect of welding parameters on response (Pandey 2003; 2004 and Kim 2001). Therefore a two level half fractional factorial design (2^{4-1}) = 8 weld runs, was selected in the present work to develop mathematical models and to get the main and interaction effects of welding parameters on bead width and hardness. This technique yields satisfactory results while investigating the effect of welding parameters on bead geometry in submerged arc welding (Gupta et al. 1991, Deepak Kumar Choudhary et al. 2011). The design required two set of eight weld runs for calculating the mathematical models and main and interaction effect of process parameters on to the responses by Design expert software.

3 Experimentation

The research work was planned to be carried out in the following steps.

❖Identification of the important variable and finding their working range.
❖Development of design matrix
❖Conducting experiment as per design matrix.
❖Recording the response parameters.
❖Checking the significance of models and arriving at the final models
❖Presenting the direct and interaction effect of process parameters on bead geometry in graphical form.
❖Analysis of results.

3.1 Identification of the Process Variable and finding their Working Range

The process variables were selected on the basis of their effect on bead geometry and ease of control. Four independently controllable process variables were selected namely the welding current (I), arc voltage (v), welding speed(s) and nozzle to plate distance (N). The working range was fixed by conducting trail and run by varying one of the process variables at a time while keeping the rest of them at constant value. The upper and lower limits were called as +1and -1, respectively. The selected process parameters and their upper and lower limits together with notations and units are given in table 1.

Table 1: Welding Parameters with levels:

S.No.	Parameters	Unit	Symbol	Levels	
				Low (-1)	High (+1)
1	Welding current	Amp	I	250	450
2	Arc Voltage	Volt	V	30	32
3	Welding Speed	m/hr	S	27.4	36.6
4	Nozzle-to-Plate distance	mm	N	20	25

3.2 Development of Design Matrix

The design matrix as shown in table 2-3, was developed according to the half factorial design approach to which the number of experiment combination becomes 2^{k-1} (2^{4-1}=8). The first three column were generated by standard 2^3 two level full factorial and the fourth column was generated by the relation N=I×V×S.

Table 2: Design Matrix show in coded values

S.No.	I	V	S	N = I×V×´S
1	1	1	1	1
2	-1	1	1	-1
3	1	-1	1	-1
4	-1	-1	1	1
5	1	1	-1	-1
6	-1	1	-1	1
7	1	-1	-1	1
8	-1	-1	-1	-1

Table 3: Design Matrix show in actual values

S.No.	I	V	S	N = I×V×´S
1	450	32	36.6	25
2	250	32	36.6	20
3	450	30	36.6	20
4	250	30	36.6	25
5	450	32	27.4	20
6	250	32	27.4	25
7	450	30	27.4	25
8	250	30	27.4	20

3.3 Conducting Experiment as per Design Matrix

The experiments were conducted on automatic submerged arc welding machine at MMEC Mullana. A constant potential transformer rectifier type power source with a current capacity of 800 amperes at 60% duty cycle and an open circuit voltage of 20-50 volt was used. The experiments were performed in a random manner to avoid any systematic error. The complete sets of eight trials were repeated for the sake of determining the variance of parameters and variance of adequacy for the model with help of design expert software. The weld samples of 20mm length were removed from the middle of the weld plate and polished by series of finer grades of emery paper (grades P-80, P-100, P-200, P-300, P-400, P-600, P-800, P-1000). The properly polished specimens have been etched with 2% Nital solution, which has been followed by investigation and analysis. The chemical composition of base plate is shown in table-4.

- **Electrode used:** AWS- 5.17 EL-8, 3.2 mm diameter
- **Work piece**: Carbon steel plate (ASTM SA 516 GRADE 60) of 150mm×75mm×12mm size.
- **Fluxes**: Agglomerated fluxes.
- **Electrode to work angle**: 90°

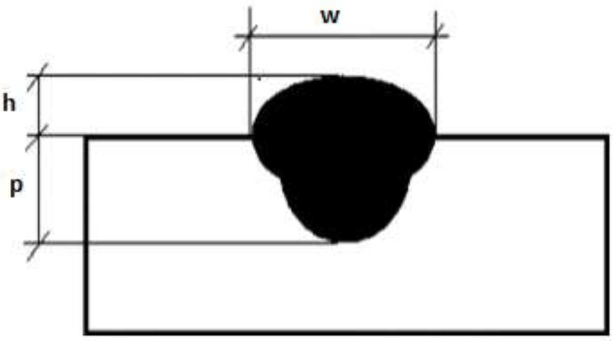

Figure 2: Bead Geometry

3.4 Recording of Responses

One transverse specimen of 20mm width is cut from mid position of the each plate as shown in fig.3.These specimen were polished and etched with 2% Nital. The weld bead width is measured with vernier calipers and hardness of bead is tested on Brinnel Hardness testing machine with 5mm diameter ball. The responses recorded are shown in table 5.

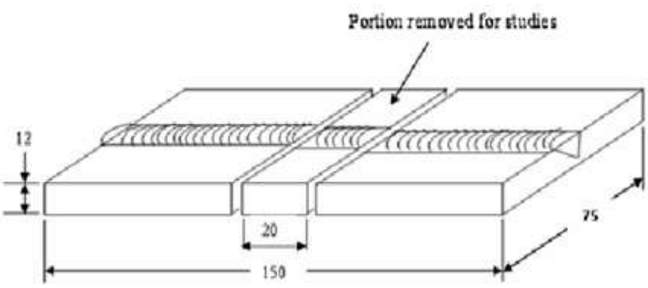

Figure 3: Cutting plan

3.5 Selection of Mathematical Model

The response function representing any of the weld bead dimensions could be expressed as:

Y=f (I, V, S, N) where Y is the response function like bead width (w) and bead hardness. I, V, S and N are welding current, arc voltage, travel speed and nozzle to plate distance respectively. Assuming a linear relationship in the first instant and taking into account possible two factors interactions only, the above expression could be written as:

$Y=b_0+b_1I+b_2V+b_3S+b_4N+b_5IV+b_6IS+b_7IN$……….. (1)

3.6 Checking the Significance of the Model

ANOVA is a statistical technique, which can infer some important conclusions based on analysis based on analysis of the experimental data. The method is very useful to investigate the level of significance of influence of factors or interactions of factors on a particular response. The analysis of variance (ANOVA) test was performed to evaluate the statistical significance of the fitted linear models and factors involved in the response factors bead width and bead hardness. The goodness of fit of the fitted linear model was evaluated through lack of fit test. The results obtained are shown in tables 4-6.

Both the fitted models are found to be significant. since for both the responses, the probability of F (PROB. >F) are observed to be less then 0.0001 i.e. there is only a 0.01% chance that "Model F-Value" larger could occurs due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. Values greater than 0.1000 indicate the model terms are not significant. In bead width model I, V, S, N, IV, IN are significant model terms and in case of bead hardness I, V, S, N, IV are significant model terms. For both the models lack of fit is not significant relative to the pure error. There are 46.96% and 25.01% chance respectively for bead width and bead hardness that a “LACK OF FIT F-VALUE” larger could occur due to noise. Non significant lack of fit is good.

3.7 Evaluation of the Coefficients of the Models

The values of the coefficients of the models were calculated by design expert software package. All the coefficients were tested for their significance at 95% confidence level applying student’s t- test. Coefficients are shown in table 7-8.

3.8 Development of Mathematical Model

The final mathematical models for the responses are presented in table- 9

4 Analysis of Result and Discussions

The predicted effects of the welding parameters on the weld bead width and hardness within the range of the parameters are represented in fig.4-17.

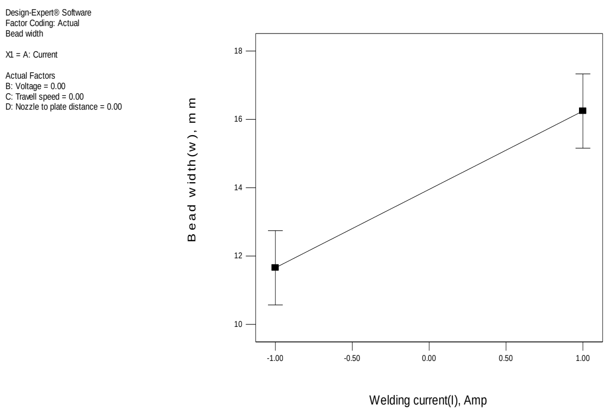

Figure 4: Effect of Welding Current on Bead Width

4.1 Main Effect of Parameters on Bead Width Direct effects of parameters on bead width are represented in fig.3-6. Bead width increases significantly with the increase in welding current and voltage but decreases slightly with the welding speed and significantly with the increase in nozzle to plate distance.

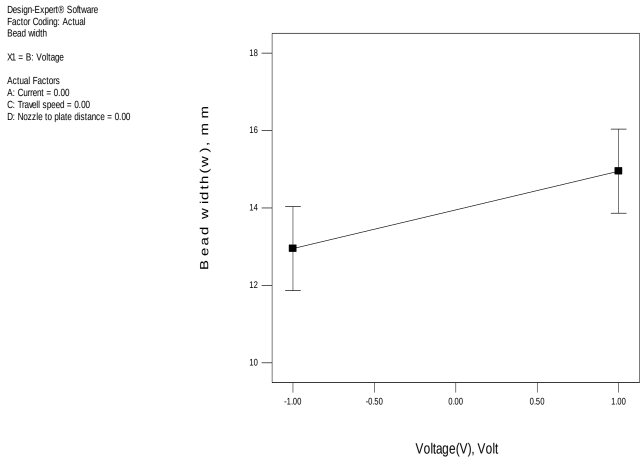

Figure 5: Effect of Voltage on Bead Width

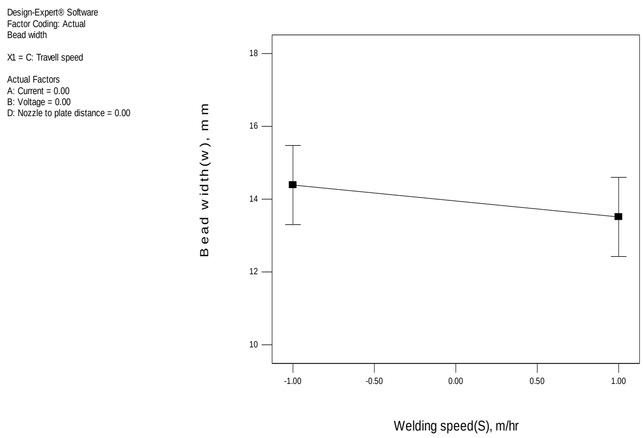

Figure 6: Effect of Welding Speed on Bead Width

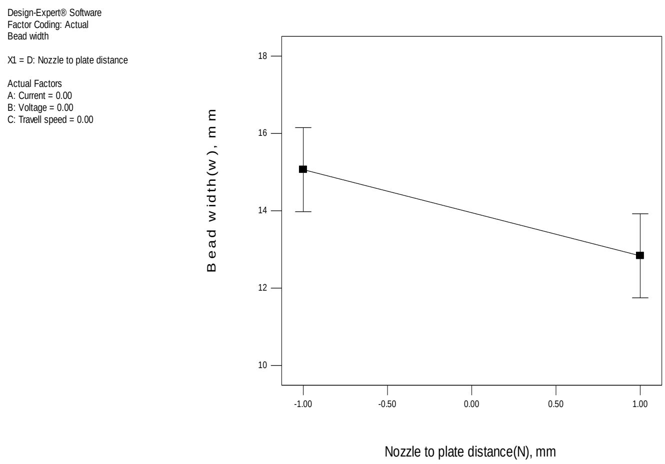

Figure 7: Effect of Nozzle to Plate Distance on Bead Width

4.2 Main Effect of Parameters on Bead Hardness

Direct effect of process parameters on bead hardness are represented in fig.7-10. Bead hardness increases significantly with the increase in welding current and welding speed and slightly increases with the increase with nozzle to plate distance but decreases significantly with the voltage.

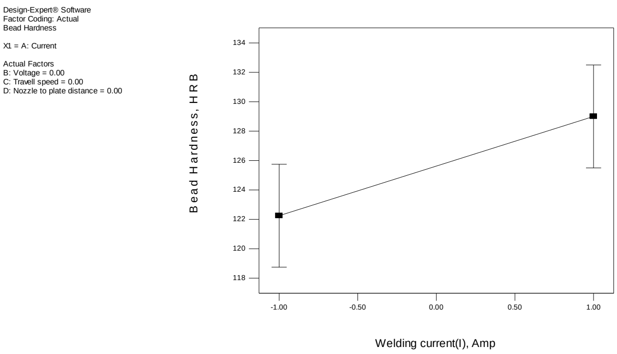

Figure 8: Effect of Welding Current on Bead Hardness

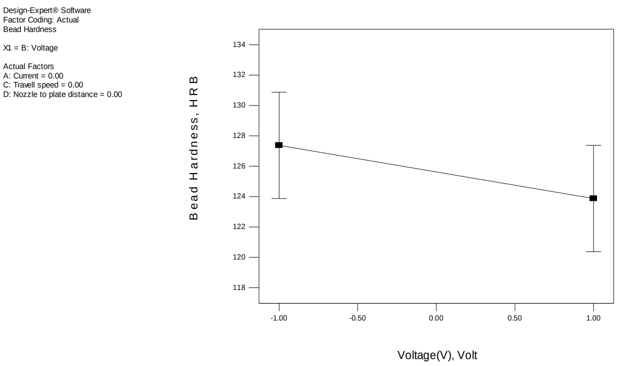

Figure 9: Effect of Voltage on Bead Hardness

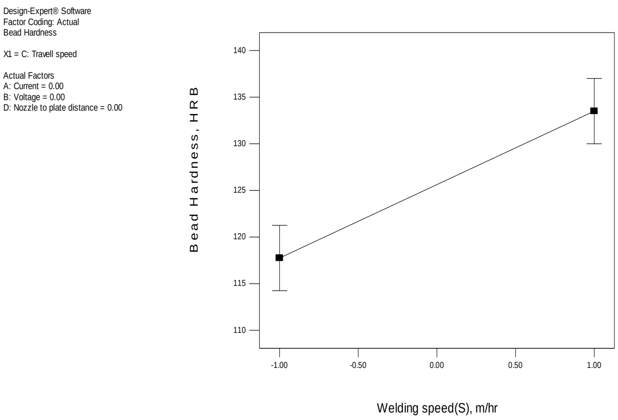

Figure 10: Effect of Welding Speed on Bead Hardness

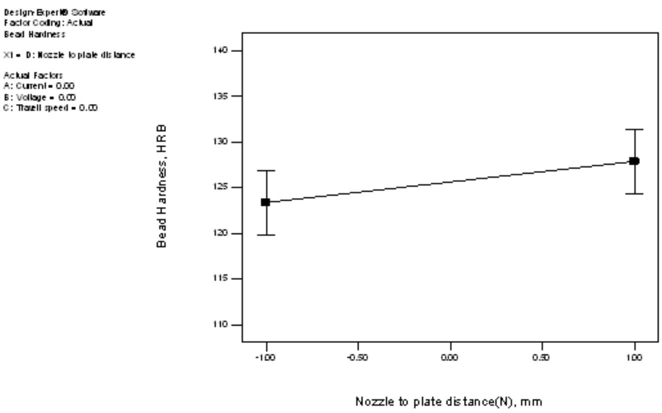

Figure 11: Effect of Nozzle to Plate Distance on Bead Hardness

4.3 Interaction Effect of Welding Current and Voltage on Bead Width

Fig.11-12 shows the interaction effect of current and voltage on bead width. Bead width increases with the increase of current for all values of voltage but the rate of increase of bead width with increase in current is higher at high voltage. Response surface due to interaction effect of welding current and voltage on bead width is shown in figure -12.

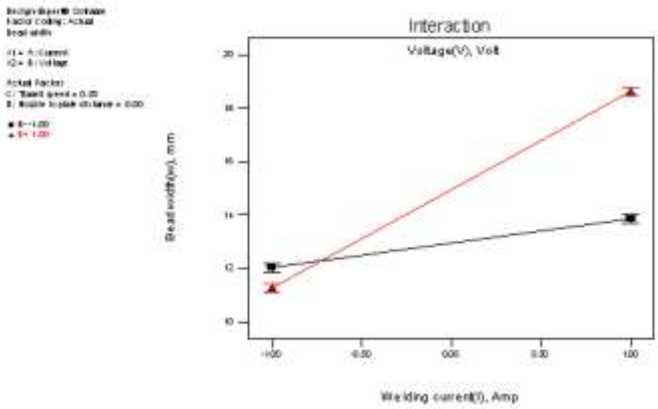

Figure 12: Interaction effect of Welding Current and Voltage on Bead Width

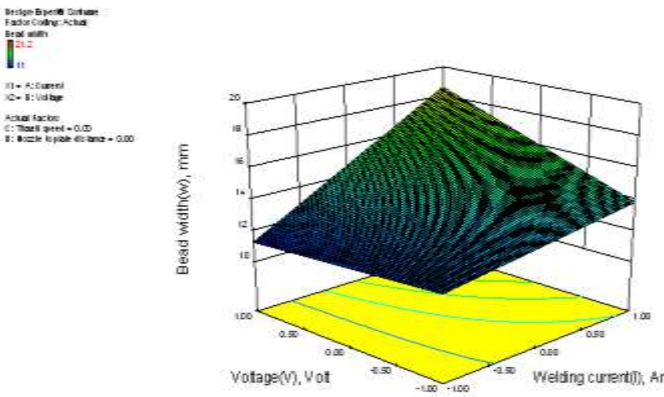

Figure 13: Interaction effect of Welding Current and Voltage on Bead Width (Response Surface)

4.4 Interaction Effect of Welding Current and Nozzle to Plate Distance on Bead Width

Fig.13 -14 shows the interactive and response surface graph by which it is clear that bead width increases with the increase of welding current but the rate of increase is higher at low value of nozzle to plate distance i.e. nozzle to plate distance have negative effect and welding current have positive effect on bead width.

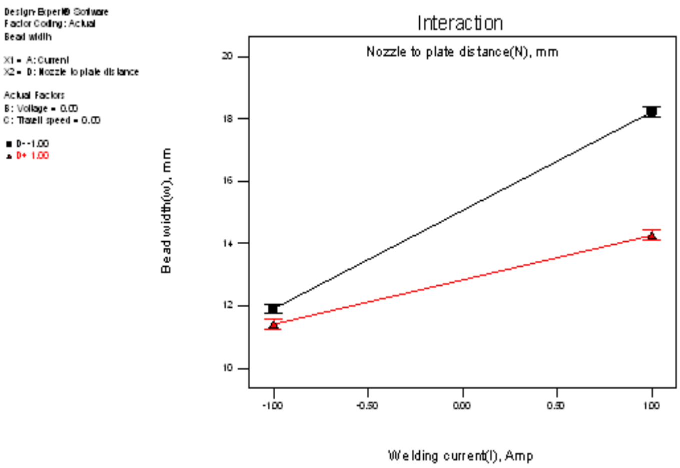

Figure 14: Interaction effect of Welding Current and Nozzle to Plate Distance on Bead Width

Table 4: Chemical Composition of Base Plate

Composition	C	Si	Mn	P	S	Al	Cr	Cu	Ni	Mo	Nb	Ti	V
Percentage	0.2	0.4	1.4	0.03	0.03	0.02	0.3	0.3	0.3	0.8	0.01	0.03	0.02

Table 5: Observed values of Bead Width and Hardness

Trial No.	Bead width (mm)		Bead hardness(HRB)	
	1	2	1	2
1	16.2	16.2	134	132
2	11	11.08	130	130
3	15.7	15.2	144	141
4	11.2	11.42	130	127
5	20.8	21.2	111	112
6	11.4	11.62	120	122
7	12.13	12.42	126	132
8	12.66	12.88	109	110

Table 6: Result of Analysis of Variance for Bead Width

Source	Sum of Square	Degree of Freedom	Mean Square	F Value	P-value	Remarks
Model	165.185	6	27.531	715.9	< 0.0001	significant
I -current	83.677	1	83.677	2175.9	< 0.0001	significant
V –Arc voltage	15.781	1	15.781	410.36	< 0.0001	significant
S –Welding speed	3.160	1	3.160	82.158	< 0.0001	significant
N -nozzle to plate distance	20.093	1	20.093	522.48	< 0.0001	significant
IV	30.278	1	30.277	787.32	< 0.0001	significant
IN	12.198	1	12.198	317.18	< 0.0001	significant
Residual	0.346	9	0.038			
Lack of Fit	0.023	1	0.023	0.576	0.4696	not significant
Pure Error	0.323	8	0.040			
Cor Total	165.531	15				

Table 7: Result of Analysis of Variance for Bead Hardness

Source	Sum of square	Degree of freedom	Mean square	F-value	p-value	Remarks
Model	1704.5	5	340.9	75.337	< 0.0001	significant
I -Welding current	182.25	1	182.25	40.276	< 0.0001	significant
V –Arc Voltage	49	1	49	10.829	0.0081	significant
S -Welding speed	992.25	1	992.25	219.28	< 0.0001	significant
N -Nozzle to plate distance	81	1	81	17.901	0.0017	significant
IV	400	1	400	88.398	< 0.0001	significant
Residual	45.25	10	4.525			
Lack of Fit	13.25	2	6.625	1.6563	0.2501	not significant
Pure Error	32	8	4			
Cor Total	1749.8	15				

Table 8: Model summary statistics for responses

Parameters	Std. Dev.	Mean	C.V. %	PRESS	R-Squared	Adj R-Squared	Predicted R-Squared	Adeq Precision
Bead width	0.196	13.94	1.41	1.09	0.998	0.997	0.993	76.787
Bead hardness	2.127	125.63	1.69	115.84	0.974	0.961	0.933	24.949

Table 9: Coefficients of Model for bead width

Factor	Coefficient
Intercept	13.94
I -Welding current	2.29
V –Arc Voltage	0.99
S -Welding speed	-0.44
N -Nozzle to plate distance	-1.12
IV	1.38
IN	-0.87

Table 10: Coefficients of Model for Bead Hardness

Factor	Coefficient Estimate
Intercept	125.625
I -Welding current	3.375
V –Arc Voltage	-1.75
S -Welding speed	7.875
N -Nozzle to plate distance	2.25
IV	-5

Table 11: Developed Mathematical Models

S.NO.	Response	Developed model
1	Bead width	13.95 + 2.29 × I + 1.00 × V - 0.44 × S- 1.11 × N + 1.38 × IV - 0.87 × IN
2	Bead hardness	125.63 + 3.38 × I-1.75 × V + 7.88 × S + 2.25 × N - 5.00 × IV

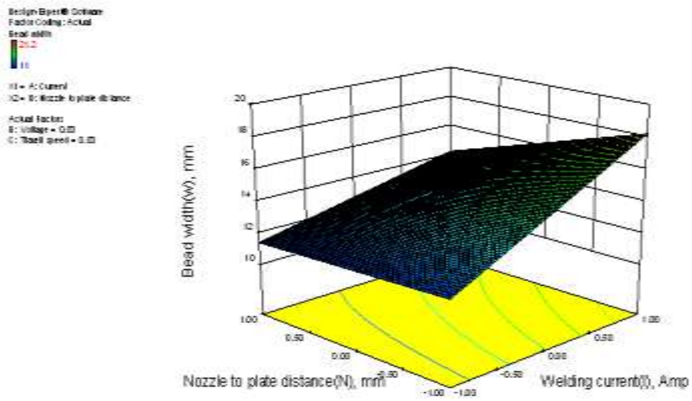

Figure 15: Interaction effect of Welding Current and Nozzle to Plate Distance on Bead Width (response surface)

4.5 Interaction Effect of Welding Current and Voltage on Bead Hardness

Interactive effect of welding current and voltage on bead hardness are shown in fig- 15. It is observed from the figure that bead hardness increases with the increase of current at low value of voltage and decreases with the increase of current at high value of current. So voltage has negative effect on bead hardness and welding current has positive effect. Response surface due to interactive effect is shown in fig.-16.

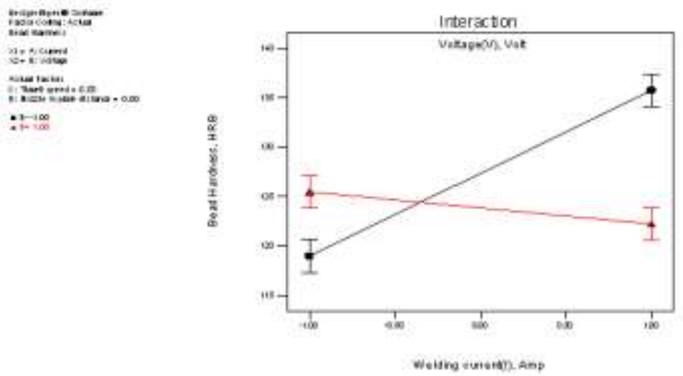

Figure 16: Interaction effect of Welding Current and Voltage on Bead Hardness

5 Conclusions

The following conclusions were drawn from the above investigation:

1. The two level half factorial techniques with design expert software can be employed easily for developing mathematical models for predicting weld bead width and hardness within the workable range of process parameters for SAW of carbon steel.
2. Design expert software is found to be effective tool for quantifying the main and interaction effect of variable on weld bead width and hardness.
3. Welding current and voltage have positive effect, but welding speed and nozzle to plate distance have negative effecton bead width.
4. Welding current, welding speed and nozzle to plate distance have positive effect, but voltage has negative effect on bead hardness.

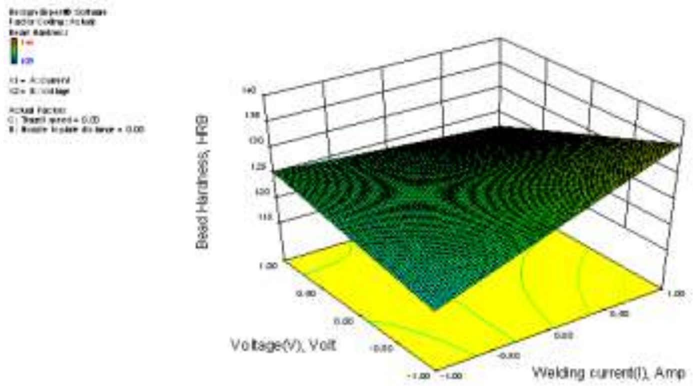

Figure 17: Interaction effect of Welding Current and Voltage on Bead Hardness (Response Surface)

References

1. O.P.Khanna, A text book of Welding Technology, Dhanpat Rai Publications Ltd., 2006.
2. S.V.Nandkarni, Modern Arc Welding Technology, (Oxford & IBH Publishing Co. Pvt. Ltd, New Delhi), 1998.
3. D.C.Montgomery. Design and Analysis of Experiment. John Wiley, New York, N.Y.
4. http://www.google.co.in
5. Gupta, S.R. and Arora, N., Indian Welding Journal. 24(7), 1991, pp. 127-133.
6. L.J.Yang, M.J. Bibby, R.S. Chandal, AWS, Welding Journal, 1993 pp 11-18.
7. V. Gunraj, N. Murugan, welding Journal. 79(11), 2000, pp. 331-338.
8. Sunil Pandey et al" Welding Current in Submerged Arc Welding", Indian Welding Journal, Jan 2003.
9. S. Kumanan, J.E. Dhas Raja & K. Gowthaman, Indian Journal of Engineering & Materials Sciences, Vol. 14, 2007, pp. 177-183.
10. S. Datta, A. Bandhopadhayay, P.K. Pal, International Journal of Advance Manufacturing technology (2008) 39: 1136-1143.
11. S.P. Tewari, Ankur Gupta, Jyoti Prakash, International Jouranal of Engineering Science and Technology, Vol. 2(4), 2010, 512-516.
12. Vinod Kumar, Jardon Journal of Mechanical and Industrial Engineering, Vol. 5, No. 5, 2011, 1995-6665.
13. Deepak Kumar Choudhary et al/ Elixir Mech. Engg. 40 (2011) 5519 – 5524.