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Parametric optimization of submerged arc welding process by using Response Surface Methodology

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Abstract : Submerge arc welding (SAW) has become a natural choice in industries for fabrication, especially for welding of pipes because of its deep penetration, smooth finish and high productivity. Optimum ranges of bead parameters are required for better economy and to ensure the desired mechanical properties. The above objectives can easily be achieved by development of mathematical model and execution of the experiments by response surface methodology. Response surface methodology (RSM) is a technique to determine and represent the cause and effect relationship between true mean responses and input control variables influencing the responses as a two or three dimensional hyper surface. This paper highlights the use of (RSM) by designing a four-factor two-level design matrix for planning, execution and development of mathematical model. For Experiment [SA-516 (Gr-70)] is used as a base metal. Main and interaction effects of the process variables on bead geometry and shape factors are presented in graphical form. From the experimental results, it is found that speed and voltage plays major role in finding weld bead dimensions. .

IndexTerms **:**SAW, optimization, Regression analysis, Response surface methodology, weld bead geometry

INTRODUCTION

The submerged arc welding process is often preferred because it offers high production rate, high melting efficiency, ease of automation and low operator skill requirement.[4] the desired welding parameters are obtained based from charts or handbook value which are difficult cumbersome and they does not ensure that chosen welding parameters are optimal for particular welding environmental.[1]Even smaller change in the welding process parameters may causes unexpected welding performance. Therefore, it is important to study stability of welding parameters to achieve high quality welding. [5] Optimum process parameters selection has been investigated by some significant studies via establishing a mathematical model correlating welding parameters with quality characteristics using different approaches [1]In this study, mathematical relations (empirical equations) between submerged arc welding process parameters and weld bead characteristics were constructed based upon the experimental data obtained by four parameters-two levels factorial analysis. The empirical equations, simulating the submerged arc welding process approximately, were carried out by Multiple Regression Analysis and sensitivity equations were derived from these basic models. An analysis generally requires a definition of an objective function and design parameters. In this study, the objective function (quality function) was chosen as weld bead characteristics (the width, height of the weld bead) whereas process parameters (arc current, voltage, welding speed and stick-out) were selected as the design variables. The present study mainly focuses on the determination of sensitivity characteristics of design parameters and the prediction of fine-tuning requirements, of these parameters in submerged arc welding process. The results revealed considerable information about process parameter tendencies and optimum welding conditions appearance and the absence of any visible defects. For deciding the working range, several trial welds were made. For determining the range of one variable, the other three variables were kept constant during trial runs. A similar procedure was adopted for determining the upper and lower limits for the welding speed and nozzle-to-plate distance. Also, trial welds were made, keeping the values of all the parameters both at their minimum and maximum values to were kept constant during trial runs. A similar procedure was adopted for determining the upper and lower limits for the welding speed and nozzle-to-plate distance. Also, trial welds were made, keeping the values of all the parameters both at their minimum and maximum values to verify quality of the weld bead, after determining the working range of the process parameters, the upper limit was coded as +1 and -1

After determining the working range of the process parameters ,the upper limit was coded as +1 and lower limit as -1.The coded value of the intermediate levels were calculated from the relationship[4-9]

Xi=2 x−(Xmax+Xmin)/(Xmax−Xmin) Where Xi the required coded value of a variable X; and X is is any value of the variable from X min to *X* max. .

3.DEVELOPING THE DESIGN MATRIX:

The selected design matrix, shown in Table 2, factorial design [4] consisting of 16 sets of coded conditions. Design matrix is blocked with their result to reduce irrelevant source of variation. Response variables bead width and reinforcement are measured by using scale and venire caliper. The selected process parameters with their limits, units and notations are given. Cross sectional picture of weld bead is given below.

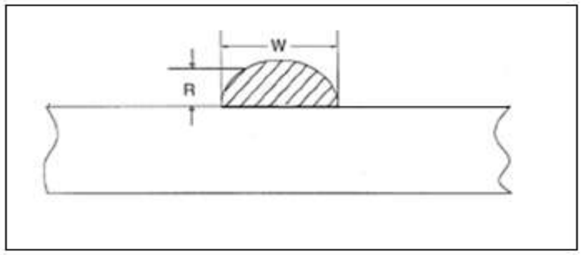


Fig:1Cross-Sectional of weld bead, where W be weld width in mm, R be the Reinforcement in mm.

4.DEVELOPMENT OF MATHEMATICAL MODEL:

The response function representing any of the weld bead dimensions can be expressed as [2-9]

Y=F(S, V, I, N)

Where

Y is the response (Bead width, reinforcement)

I is the welding currents, amps

S is the welding speed, Inch/min.

N is the nozzle to plate distance, mm.

The relationship selected being a First degree response surface expressed as follows:

$Y=B_0+B_1X_{1+}B_2X_2+.............+B_KX_K+\varepsilon$

5.CHECKING THE ADEQUACY OF THE MODELS DEVELOPED:

The adequacy of the models was tested using the analysis-of-variance technique (ANOVA). As per this technique [2-7]: The estimated coefficients obtained above were used to construct models for the response parameters. The adequacy of the models so developed was then tested by using the analysis of variance technique (ANOVA). Using this technique, it was found that calculated F ratios were larger than the tabulated values at a 95% confidence level; hence, the models are considered to be adequate

The adequacy of a fitted regression model are the coefficient of determination (R'). For the models developed, the calculated R2 and adjusted R2 values were above 80% and 70%, respectively. These values indicate that the regression models are quite adequate the validity of regression models developed were further tested by drawing scatter diagrams.The observed values and predicted values of the responses are scattered close to the 45 ° line, indicating an almost perfect fit of the developed empirical models. To improve the reliability of result, experiment were planned on the basis of response surface methodology (RSM) techniques for statistical design of experiment.

6.EXPERIMENTAL SET UP :

The equipment is conducted on ESAB submerged arc-welding equipment.EH-14, 2. 4mm diameter of welding rods are used. SA-516 Gr-70 steel plates of 500mm× 150mm×12mm size are selected as a working material and bead on joint with single V butt joint with 0.5–1mm root gap is consider.Flux: ADOR make F7P2 granular type is used.

Fig:2 ESAB Submerged Arc Welding Machine

7.Response Surface Methodology:

RSM is sequential procedure often when we are at a point on the response surface that is remote from the optimum; our object here is to lead the experimenter rapidly and efficiently along a path of improvement towards the general vicinity of the optimum. Once the region of the optimum has been found a more elaborate model such as second-order model may be employed& an analysis may be performed to locate optimum. The eventual object of RSM is to determine the optimum operating conditions for the system or to determine a region of the factor space in which operating requirements are satisfied. chemical composition of work piece is given below.

Table 1 Chemical composition of work piece (SA-516 Gr: 70)

Carbon	Manganese	Phosphorus max4	Sulfur max4	Silicon
0.27	0.79-1.30	0.035	0.035	0.13-0.45

Process parameters and their limits are given below.

Table: 2. Process control parameters and their limits

Variables	Natural Value		Coded Value	
Speed	20	24	-1	+1
Voltage	32	40	-1	+1
Current	30 0	360	-1	+1
Distance	22	25	-1	+1

Coded design matrix of weldments are given below.

Table: 3. Coded design matrix of weldments

Weld	Block I						Weld	Block II					
conditions	Sp	Vot	Cu	Dis	Rein	Width	Cindition	Sp	Vot	Cu	Dis	Rein	Width
1	-1	-1	-1	-1	1.5	20.02	2	1	-1	-1	-1	1.3	17.66
4	1	1	-1	-1	1.0	18.42	5	-1	-1	1	-1	1.6	20
6	1	-1	1	-1	2.4	18.1	8	1	1	1	-1	1.8	19
7	-1	1	1	-1	1.4	18.6	9	-1	-1	-1	1	1.2	19.26

10	1	-1	-1	1	1.9	18.14	11	-1	1	-1	-1	2.1	18.54
11	-1	1	-1	1	2.1	18.20	12	1	1	-1	1	1.4	18.08
13	-1	-1	1	1	2.0	17.60	14	1	-1	1	1	2	18.06
16	1	1	1	1	1.9	19.20	15	-1	1	1	1	2.2	18.60

7.1Regression Analysis [With blocking]

the regression equation for Block-I is

$Reinforcement_2$ = 1.78-0.0250sp2-0.150 vol2+0.200cu2+0.325dis2

Table 5 Significance table

Predictor	Coef	SE coef	T	P
Constant	1.77500	0.04330	40.99	0.000
Sp2	-0.02500	0.04330	-0.58	0.604
Vol2	-0.1500	0.04330	-3.46	0.041
Cu2	0.20000	0.04330	4.62	0.019
Distance2	0.32500	0.04330	7.51	0.005

S=0.122474 R-Sq=96.8% R-SQ(adj)=92.5%

Then the regression equation for Block-II is

$Reinforcement_3$=1.70-0.225sp3-0.100vol3+0.100cu3+0.225dis3

Table 5.1Significance table

Predictor	Coef	SE Coef	T	P
Constant	1.70000	0.04564	37.25	0.000
Sp3	-0.22500	0.04564	-4.93	0.016
Vol3	-0.10000	0.04564	-2.19	0.116
Cu3	0.10000	0.04564	2.19	0.116
Dist3	0.22500	0.04564	4.93	0.016

S=0.129099 R2=95.1% R-SQ(adj)=88.6%

By comparing First block and second block it is seen that Voltage, Current, distance is significant and its R-Sq=96.8% R-SQ(adj)=92.5%,whereas in block-II Speed and distance is significant whereas its R2=95.1% R-SQ(adj)=88.6% so comparing Block I and Block-II, Block-I gives better results so further result analysis is done with Block-I ,and scatterplot of reinforcement verses nozzle to plate distance and voltage are given below.

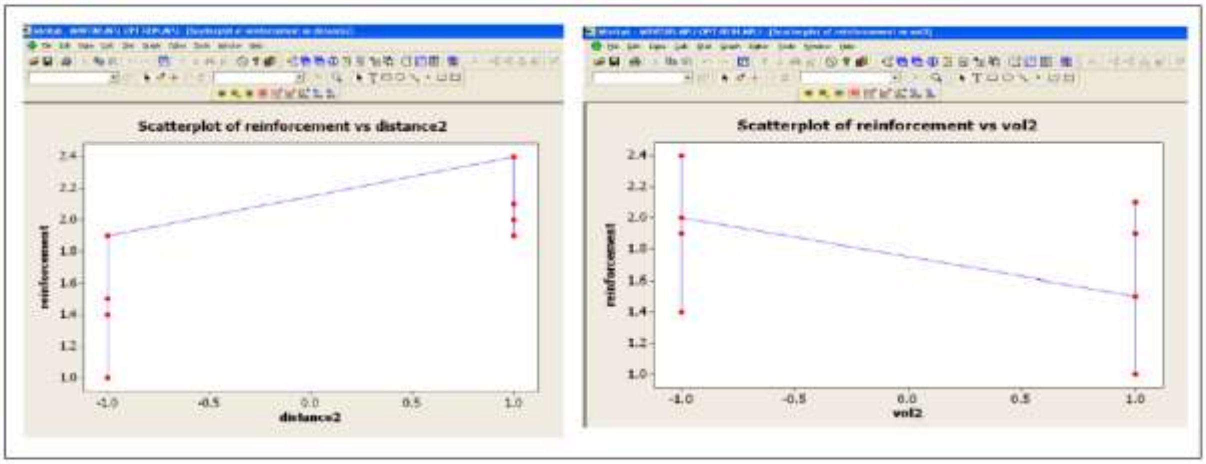
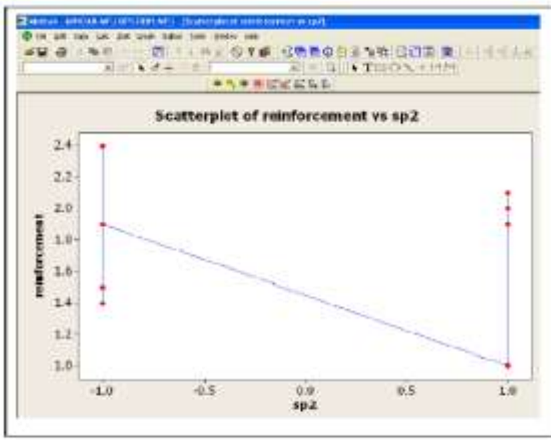


Fig3:Scatterplot of reinforcement Vs distance between plate and nozzle.and Scatterplot of reinforcement Vs voltage.



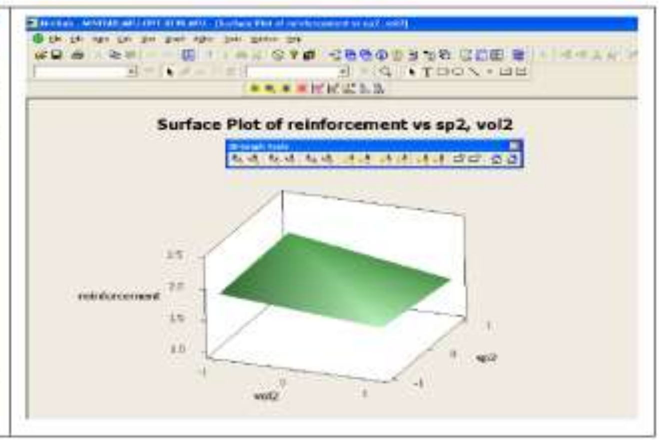
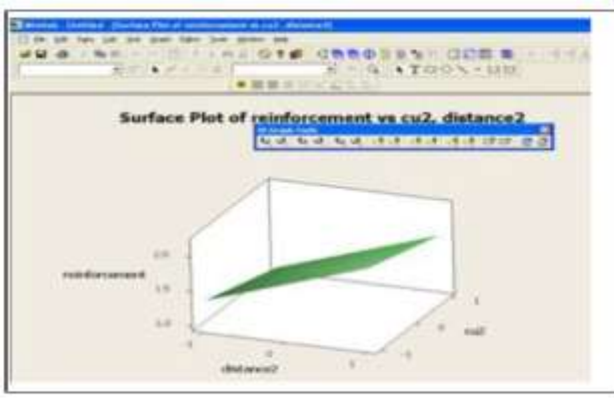


Fig4:Scatter plot of reinforcementVs Speed Fig5:Surface plot of reinforcement Vs speed, voltage.



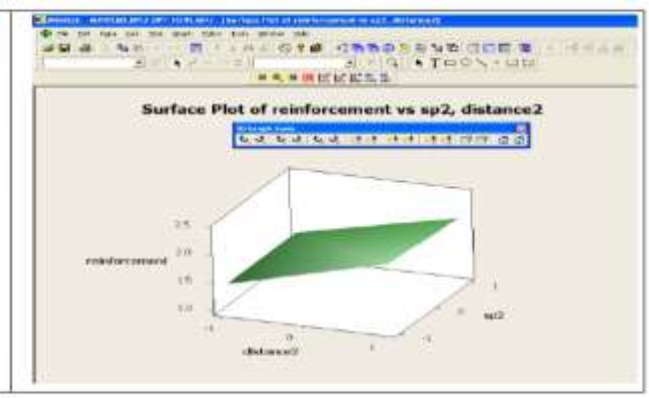


Fig:6 Surface plot of reinforcement Vs current, distance Fig:7Surface plot of reinforcement Vs speed, distance

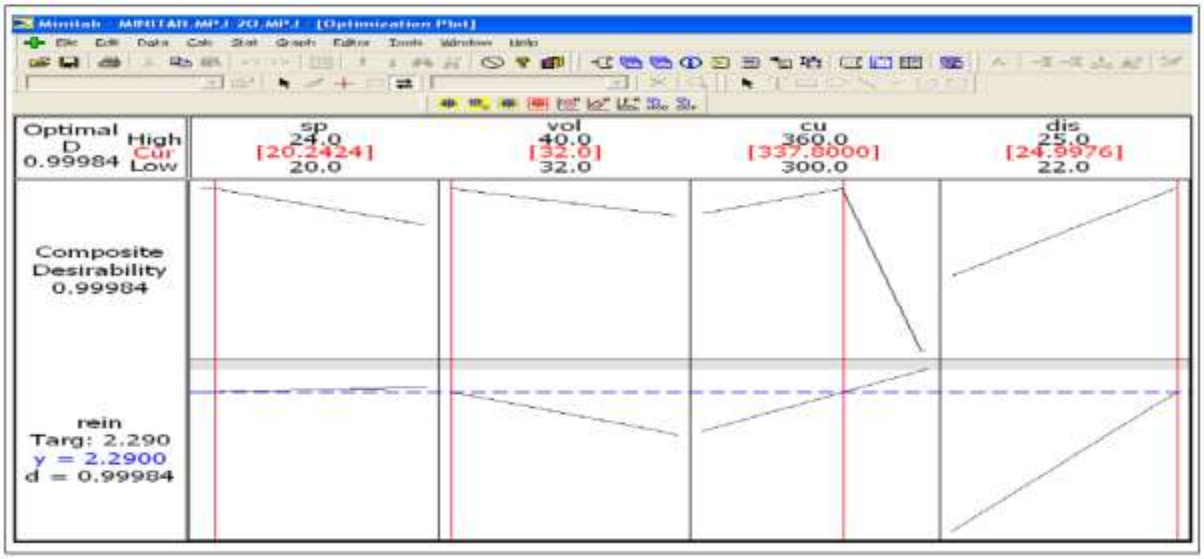
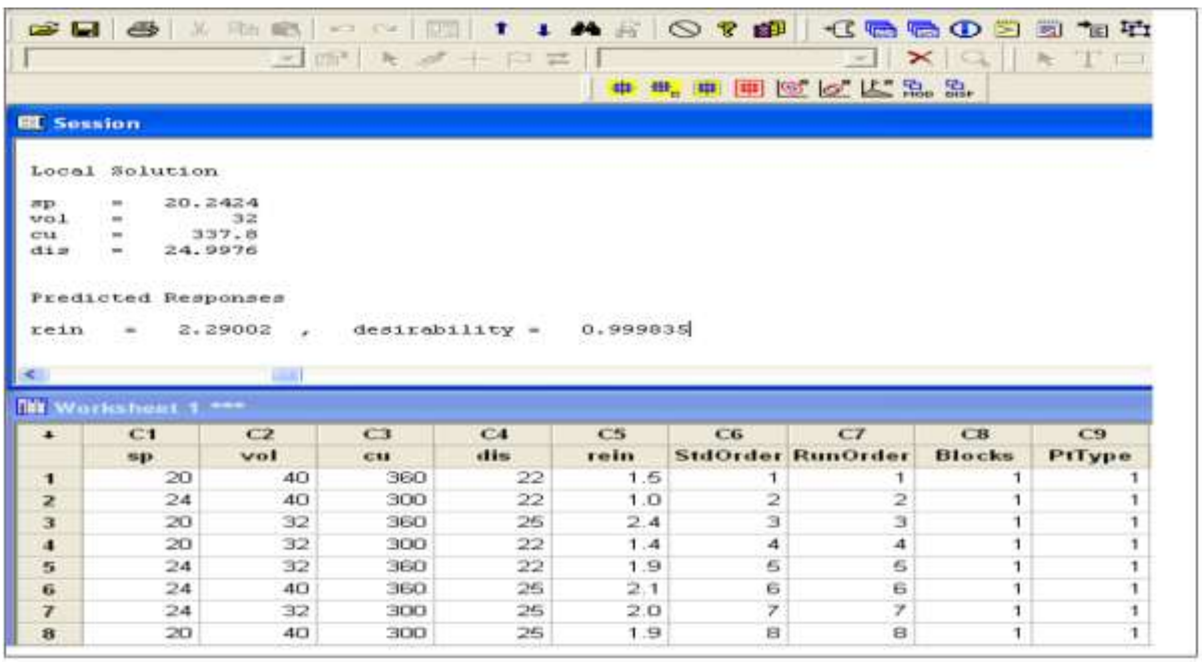


Fig:7 Optimization Plot for Reinforcement.



↓	C1 sp	C2 vol	C3 cu	C4 dis	C5 rein	C6 StdOrder	C7 RunOrder	C8 Blocks	C9 PtType
1	20	40	360	22	1.5	1	1	1	1
2	24	40	300	22	1.0	2	2	1	1
3	20	32	360	25	2.4	3	3	1	1
4	20	32	300	22	1.4	4	4	1	1
5	24	32	360	22	1.9	5	5	1	1
6	24	40	360	25	2.1	6	6	1	1
7	24	32	300	25	2.0	7	7	1	1
8	20	40	300	25	1.9	8	8	1	1

Fig:8 Optimization Value for Reinforcement

7.2.1Optimization Value for Reinforcement

Conduction of Experiments by considering optimality loss the optimise value becomes

Table 5.4 Reinforement table

Voltage	Current	Distance	Reinforcement
32	340	25	2.3

7.2.2 Scatter plot for width verses current,Voltage and nozzle to plate distance are given below.

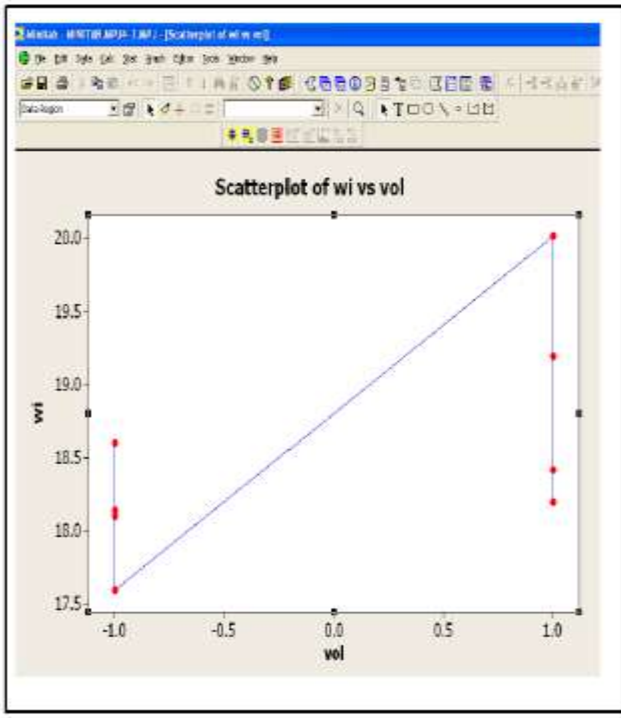


Fig:9 Scatterplot of width Vs Voltage.

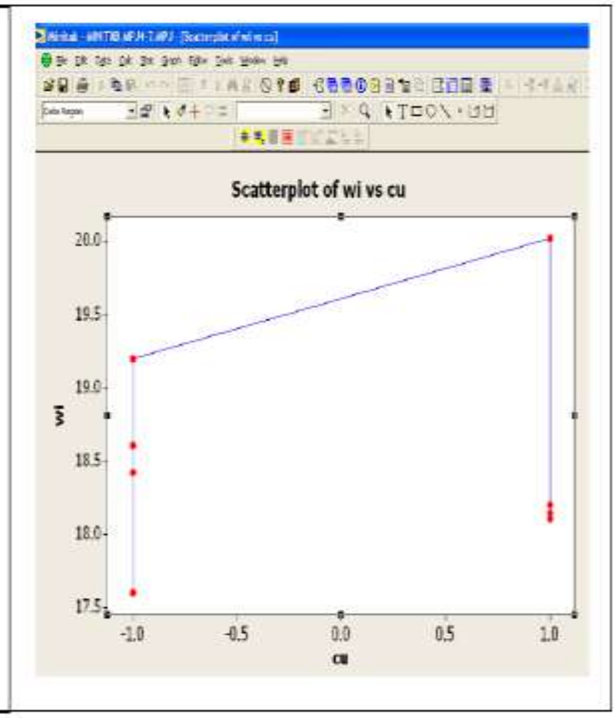


Fig:10 Surface plot of width Vs Current.

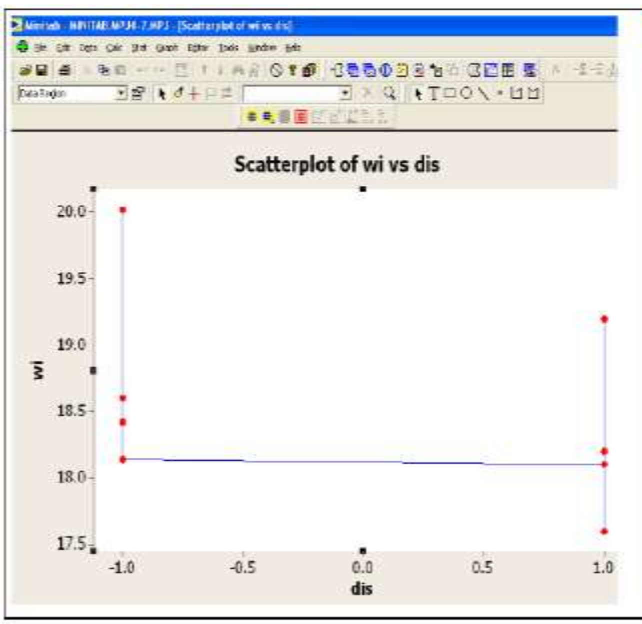


Fig:11 Scatterplot of width Vs distance.

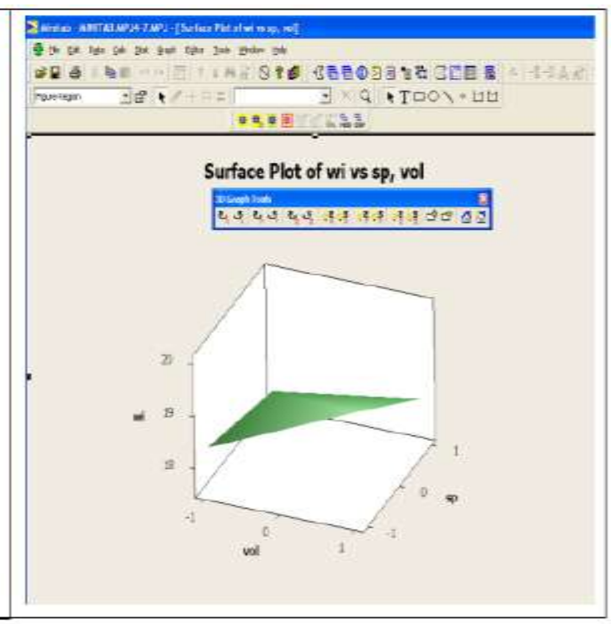
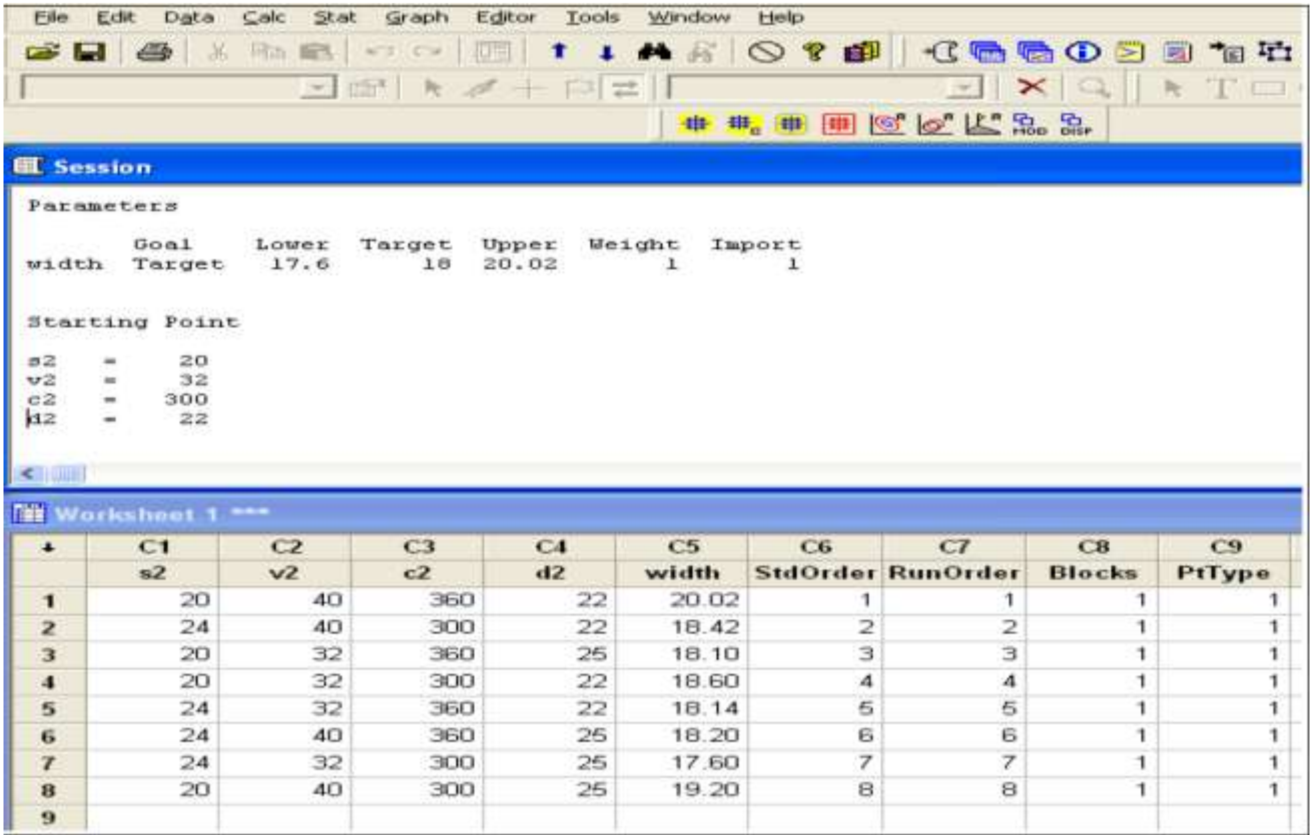


Fig12:Surface plot of width Vs speed, voltage.



↓	C1	C2	C3	C4	C5	C6	C7	C8	C9
	s2	v2	c2	d2	width	StdOrder	RunOrder	Blocks	PtType
1	20	40	360	22	20.02	1	1	1	1
2	24	40	300	22	18.42	2	2	1	1
3	20	32	360	25	18.10	3	3	1	1
4	20	32	300	22	18.60	4	4	1	1
5	24	32	360	22	18.14	5	5	1	1
6	24	40	360	25	18.20	6	6	1	1
7	24	32	300	25	17.60	7	7	1	1
8	20	40	300	25	19.20	8	8	1	1
9									

Fig13:Optimum Value for Width

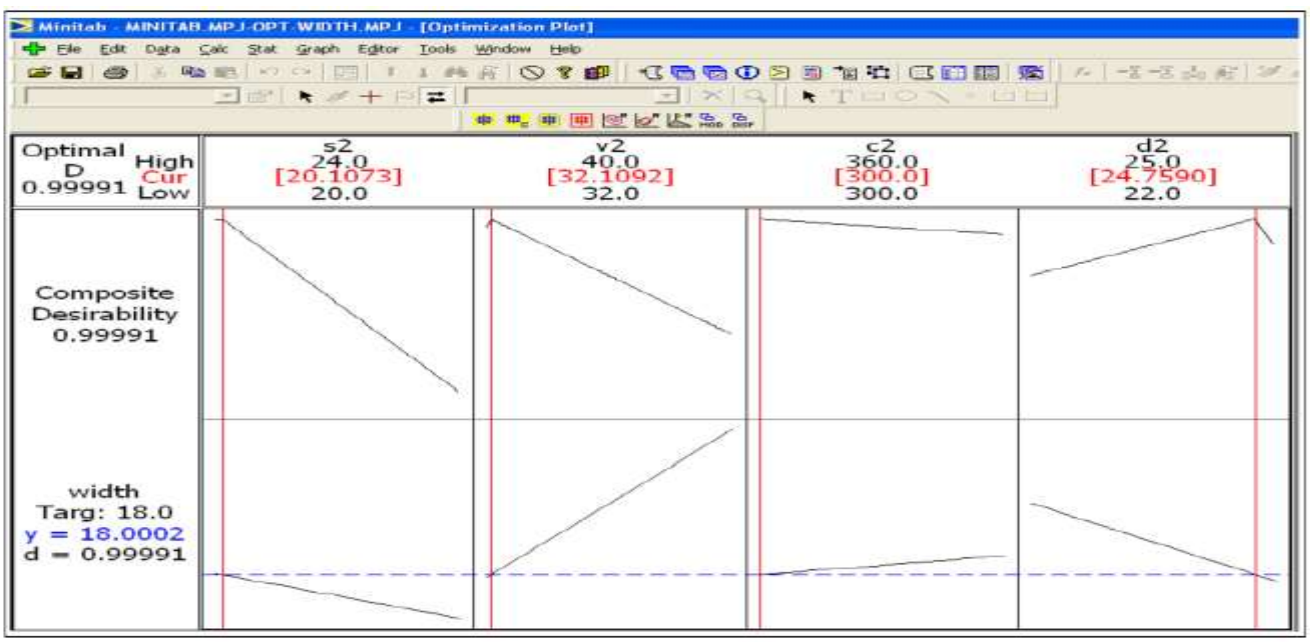


Fig14:Optimization Plot for Width

7.2.3 Optimum value for width.

Conduction of Experiments by considering optimality loss the optimise value becomes

Voltage	Current	Width
20	32	18

8 Results:

Mathematical model is used to predict the weld bead geometry by substituting the values in the coded form of the respective factors. The responses calculated from these models for each set of coded welding variable in graphical form .Substituting the values of the desired bead geometry, the value of the control factor in coded form can be obtained. In general the result show convincing trends between cause & the effect.

8.1.1 Direct effect of the process parameters

- As the voltage increases reinforcement decreases and Bead width increases.
- As the current increases reinforcement and bead width increases.
- .As the speed increases reinforcement decreases
- As the stick out increases reinforcement is increases and bead width decreases

8.1.2Interaction Effect on reinforcement & bead width:

- **Speed and Voltage on Reinforcement:** Combined effect of speed and voltage is shown in figure 5. from figure it is clear that, Reinforcement gradually decreases with increases in speed, as speed is increased heat input per length of weld is decreased, Due to that weld deposition is smaller so as the Speed increases reinforcement and width also decreases. As voltage increased reinforcement decreased, because voltage is directly to the length of the current path between the welding wire and work-piece.so as the stick-out increases voltage is also increases, due to that bead width is gradually increases and reinforcement is decreases. .

- **Current and stick-out on reinforcement:** Combined effect of current and stick-out on reinforcement is shown in figure 6.From figure it is clear that, As the current increases reinforcement Increases. Too high current also means waste of power & waste of welding wire in the form of reinforcement .if the current is too low then there is insufficient reinforcement occurred where as stick-out having positive effect on reinforcement.

- **Speed and Stick-out on Reinforcement:** Combined effect of speed and stick-out on reinforcement is shown in figure 7. From figure it is clear that, Reinforcement Gradually decreases with increases in speed. But as the stick-out increases reinforcement gradually increases so from this it is clear that speed having negative result on reinforcement where as stick-out having positive effect on reinforcement. As the speed is increased heat input per length of weld is decreased, due to that weld deposition is smaller so as the Speed increases reinforcement decreases.

- **Speed and Voltage on width:** Combined effect of speed and voltage on width is shown in figure 12. From figure it is clear that, Voltage is having Positive effect on bead width and Speed having Negative effect on width. Width is gradually decreases with increases in speed, as speed is increased heat input per length of weld is decreased, Due to that weld deposition is smaller so as the Speed increases width and reinforcement also decreases. As voltage is directly to the length of the current path between the welding wire and work-piece.so as the stick-out increases voltage is also increases, due to that bead width is gradually increases

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