STATISTICAL MODELING OF ELECTRON BEAM WELDING PROCESS FOR RECONSTRUCTION OF SHARPY SPESIMENS

МОДЕЛИРОВАНИЕ ПРОЦЕССА СВАРКИ ЭЛЕКТРОННОГО ЛУЧА ДЛЯ РЕКОНСТРУКЦИИ ОБРАЗЦИ ШАРПИ

Assoc. Prof. eng. Tabakova B.[1], eng. Yankova I. [2], Assoc. Prof. eng. P. Petrov [3],
Faculty of Machine Technology– Technical University of Sofia [1,2] , Institute of Electronics - Bulgarian Academy of Sciences[3]

Abstract: *This paper reports results connected with the reconstitution of the Charpy specimens by electron beam welding technology. The experiments were carried out using a 15 kW Leybold Heraus welding unit. Material used in this study is 15Kh2NMFA reactor pressure vessel steel. The models were developed to relate the important process controlled variables to a few important weld geometry parameters*

KEYWORDS: ELECTRON BEAM WELDING, SHARPY SPESIMENS, STATISTIC

Introduction

For electron beam welding reconstitution technology of Charpy specimens is very important to reduce heat affected zone (HAZ) and to obtain full penetration of the weld [1, 2]. One of the possibilities to reduce maximum temperature and HAZ is to optimize of the welding parameters, respectively heat input. This paper present result from statistical models for electron beam welding process during reconstitution of Charpy specimens. The models were developed to relate the important process controlled variables to weld geometry parameters. The models developed were checked for their adequacy with F-test. Using the models the main and interaction effects of variables on weld geometry parameters were determined quantitatively and presented graphically. The developed models and the graphs showing the direct and interaction effects of process variables on the bead geometry are very useful in selecting the process parameters to achieve the desired weld geometry parameters.

1. Experimental procedure

1.1 Identification of the Process Variables and Developing the Design Matrix

The independently controllable process parameters affecting weld geometry are beam current-I, current of focusing coils-I_f and the welding speed -V. The upper limit of a factor was coded as +1 and the lower limit as -1.

The process-variable levels with their units and notations are given in Table 1. Figure 1 shows the scheme of weld and measured geometry parameters. The selected design matrix is shown in Table 2.

Table 1
Factors and their levels

№	Parameter	Unit	Notation	Factor levels		
				-1	0	+1
1	beam current	mA	I	50	75	100
2	current of focusing coils	mA	I_f	490	520	550
3	welding speed	mm/s	V	5	22.5	40

1.2. Development of mathematical models

The response function representing any of the weld dimensions can be expressed as y=f (I, I_f, V). [3, 4]The relationship selected, being a second-degree response surface. For three factors the selected polynomial could be expressed as:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{11}x^2{}_1 + \\ + b_{22}x^2{}_2 + b_{33}x^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 \qquad (1)$$

Where y – response variable (depth of penetration, width of the weld in three sections);

x_1, x_2, x_3 – independent welding factors (beam current-I, current of focusing coils-I_f and welding speed -V);

b_0 – free term of the regression equation;

b_1, b_2, b_3 – linear terms of the regression equation;

b_{11}, b_{22}, b_{33} – quadratic terms of the regression equation;

b_{12}, b_{13}, b_{23} – interaction terms of the regression equation.

Table 2
Design matrix and observed values of weld geometry parameters

	Design matrix			Weld parameters			
S №	I (mA)	V (cm/s)	I_f (mA)	H (mm)	B (mm)	B_1 (mm)	B_2 (mm)
1	-1	-0.71	-0.266	10.1	4.8	2	2
2	-0.6	-0.71	-0.266	11	5.2	2	2
3	-0.2	-0.71	-0.266	11.2	6	3	3
4	0.2	-0.71	-0.266	12	6	3	3
5	0.6	-0.71	-0.266	12.5	7	4	3
6	1	-0.71	-0.266	13.5	7	4	3
7	-1	-0.71	-1	8	3	2	2
8	-1	-0.71	-0.833	7	3	2	2
9	-1	-0.71	-0.666	6.5	3	2	2
10	-1	-0.71	0	5	5	3	2
11	-1	-0.71	0.166	4	5	3	2
12	-1	-0.71	1	3	6	3	2
13	1	-0.71	-1	10	6	3	2
14	1	-0.71	-0.833	9.8	7	3	2
15	1	-0.71	-0.666	9.9	7	3	2
16	1	-0.71	-0.5	9.5	6	3	2
17	1	-0.71	-0.333	9.9	6	2	2
18	1	-0.71	-0.166	9.2	7	2	2.5
19	1	-0.71	0	9.1	7	3	2.5
20	1	-0.71	0.166	8.9	7	3	2.5
21	-1	-1	-0.266	12	6	3	2
22	-1	-0.71	-0.266	11	6	2	2
23	-1	-0.43	-0.266	8	4	2	2
24	-1	-0.14	-0.266	7	3	2	1.5
25	-1	1	-0.266	3	2	1.5	1.5

1.3 Calculation of coefficients of models and development of final mathematical models

The coefficients of the polynomial given in equations (2), (3), (4), (5) were calculated by regression method. SYSTAT software commercial package is used to calculate the values of these coefficients. The significance of the coefficients was tested and the reduced models with significant coefficients were developed. It was found the reduced models were better than the full models because the reduced models have higher values of R^2 and lesser values of standart-error estimates than that of the full models.

The final mathematical models as determined by this analysis are given by:

$$H = 8.50669 + 0.938067X_1 - 3.42348X_2 - 2.81051X_3 - 2.76189X_1^2 1 + 1.28932X_2^2 - - 2.98072X_3^2 \quad (2)$$

$$B = 4.5165 + 1.15387X_1 - 1.866X_2 + 1.249X_3 - 0.3308X_1^2 + 1.2088X_2^2 - 0.324X_3^2 \quad (3)$$

$$B_1 = 2.53743 + 0.3313X_1 - 0.5854X_2 + 0.4865X_3 - 0.4366X_1^2 + 0.4692_2^2 - 0.1855X_3^2 \quad (4)$$

$$B_2 = 2.67045 + 0.18217X_1 - 0.3375X_2 + 0.149765X_3 - 0.76067X_1^2 + 0.13449X_2^2 - 0.144632X_3^2 \quad (5)$$

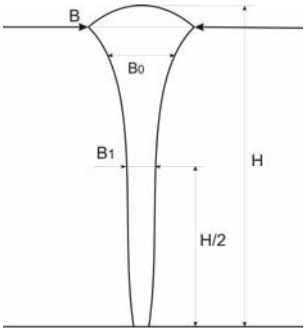

Fig.1 Scheme of weld and measured geometry parameters

Table 3
Regression summary

Geometry parameters of the weld	F-ratio	R
depth of penetration	7.65	0.8477
width of the weld in section I	22.27	0.9388
width of the weld in section II	2.87	0.6995
width of the weld in section III	22.27	0.9388

F(6,18,0.5)=2.6613

1.4 Checking adequacy of the models

The adequacy of the model was tested using the analysis of variance (ANOVA) technique. The calculated value of the F-ratio of the models developed does not exceed the standard tabulated value of F-ratio for a desired level of confidence (selected as 95%). If the calculated value of the R ratio of the models developed exceed the standard tabulated value of the R ratio for a desired level of confidence, then the models are adequate. From Table 3, it is evident that, for all the models, the above conditions are satisfied, hence, adequate.

In addition to adequacy test performed, the validity of the results was also tested with the help of scatter diagrams fig 2, 3. As is evident from the figures there is a fairy good correlation between the observed and predicted values.

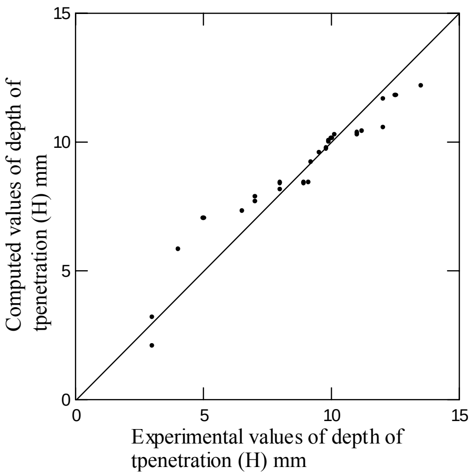

Fig. 2 Scatter diagram showing observed vs. predicted depth of penetration (H)

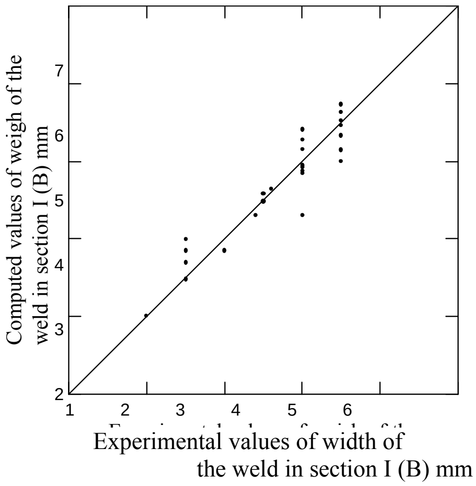

Fig. 3 Scatter diagram showing observed vs. predicted width of the weld in first section (B)

2. Results and discussion

The mathematical models above can be used to predict the weld geometry by substituting the values of the respective process parameters. Also, the values of the control factors can be obtained by substituting the value of the desired bead geometry.

The response resulted from models are represented graphically in fig 9-17; these show generally convincing tends between cause and effect.

For electron beam welding reconstitution technology of Charpy specimens is important to reduce heat affected zone (HAZ) and to obtain full penetration of the weld. The welds must be with minimum width and depth of weld penetration over 10 mm and less than 11 mm.

2.1 Direct effect of process variables

From fig. 9 it is apparent the welding speed (V) has a negative effect on weld penetration and positive effect on width of the welds. Fig. 10 shows that width in 3 section of the weld slightly increase, while the depth of penetration increase up to midlevel of beam current and then drops again.

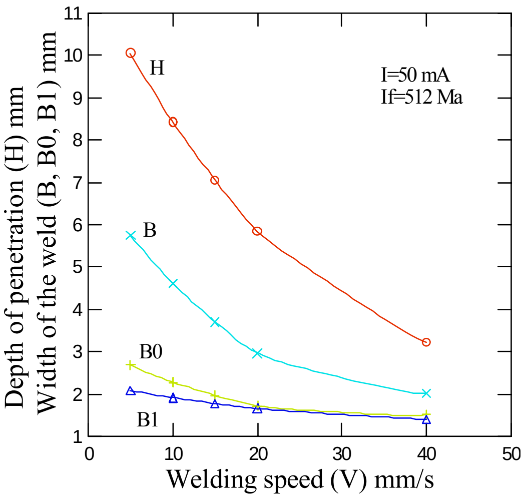

Fig. 9 Direct effect of welding speed (V) on weld geometry parameters H, B, B_0 and B_1

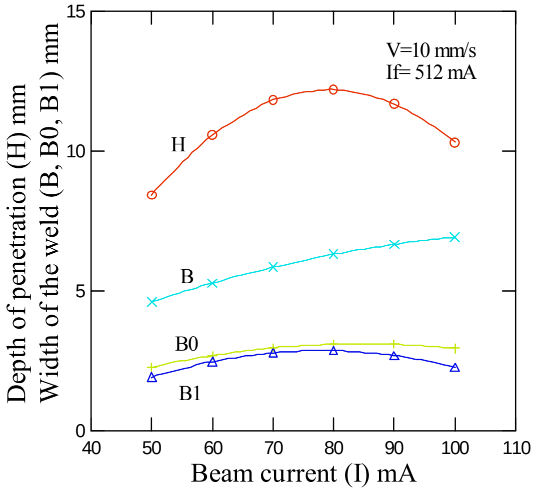

Fig. 10 Direct effect of beam current (I) on weld geometry parameters H, B, B_0 and B_1

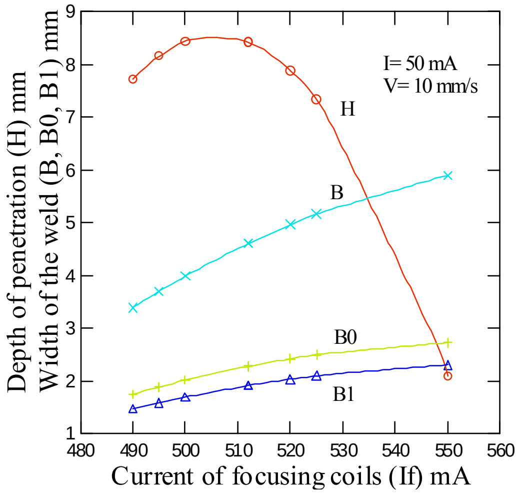

Fig. 11a Direct effect of current of focusing coils (If) on weld geometry parameters H, B, B_0 and B_1

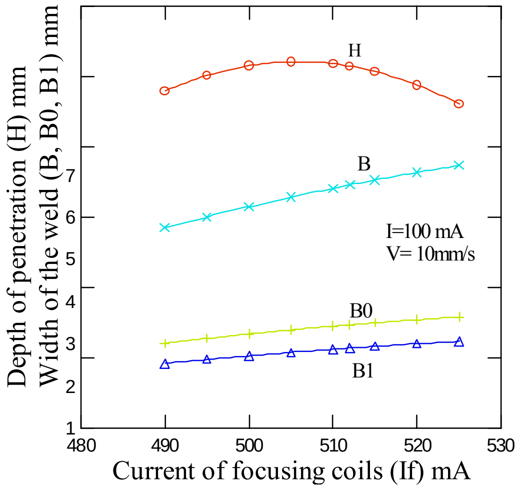

Fig. 11b Direct effect of current of focusing coils (If) on weld geometry parameters H, B, B_0 and B_1

Fig 11a shows that the incensement of current of focusing coils has a negative effect on weld parameters. Penetration does not reach values over 10 mm in all range when I=50mA and V=10mm/s. Fig 11b shows the same dependence. It is evident that the weld penetration is greater when If is between 490 and 525 mA.

From the figures above it is evident that the optimal weld parameters are range $50 \geq I \geq 100$; $490 \geq If \geq 525$; $15 \geq V \geq 5$

2.2 *Interaction effects of process variables on weld penetration (H) and on width of the weld in section one (B)*

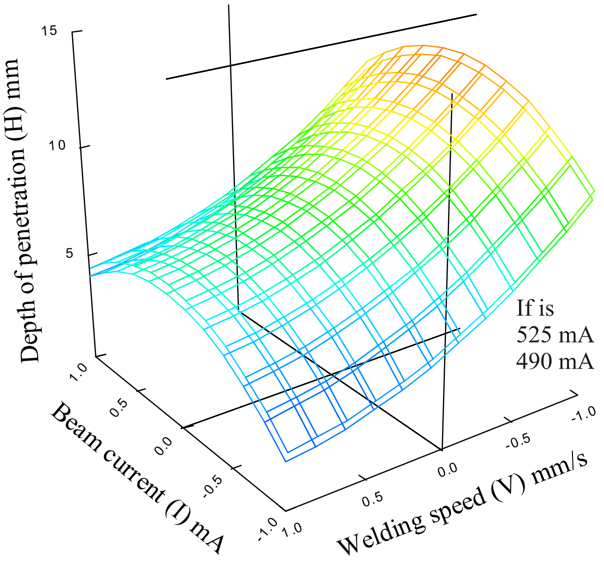

Fig. 12 Interaction effect of beam current and welding speed on weld penetration.

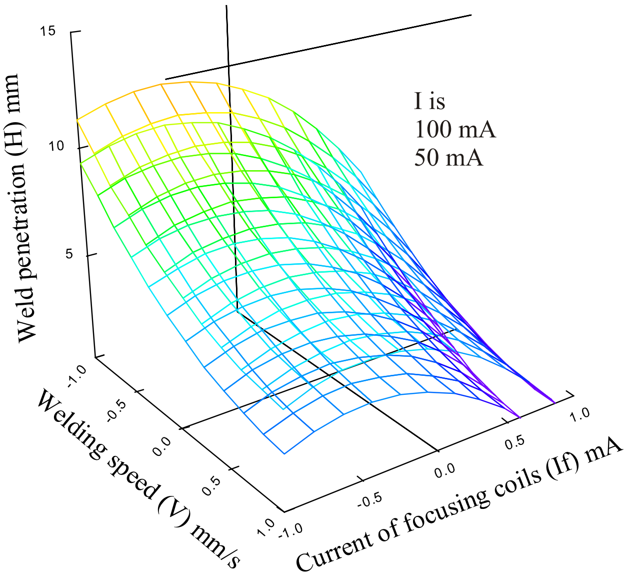

Fig. 13 Interaction effect of current of focusing coils and welding speed on weld penetration.

Fig. 12 shows the interaction effect of welding speed (V) and beam current (I) on weld penetration (H), when If is 490 and 525 mA. From the direct effects V and I (shown in Figs. 9 and 10) on H, it was found V has a negative effect but I has a positive effect close to its midlevel on H. Because of these effects, the value of H increases with the decrease in V.

Fig. 13 shows the response surface of weld penetration (H) for the interaction of welding speed (V) and current of focusing coils (If) when I is 50 and 100 mA. From this surface, it is found H is highest when V is at its minimum value with If at up to mid value; H is lowest when If is at its maximum and minimum value. It is evident that when I is 50mA, H can not reach the desired value over 10 mm.

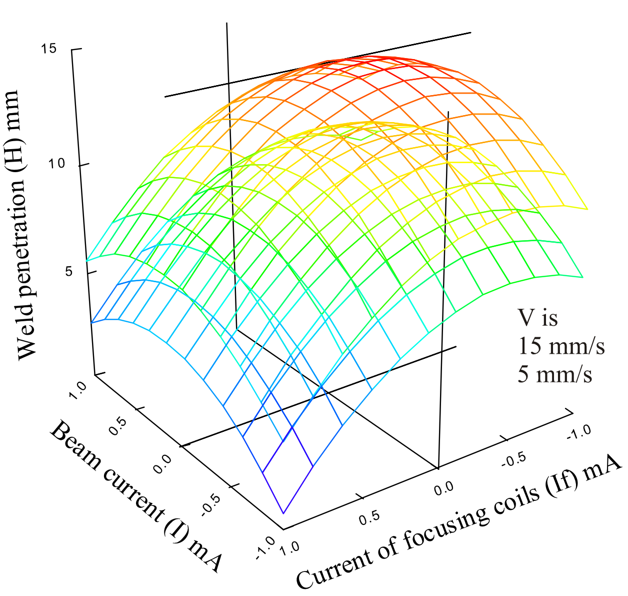

Fig. 14 Interaction effect of current of focusing coils and beam current on weld penetration (H)

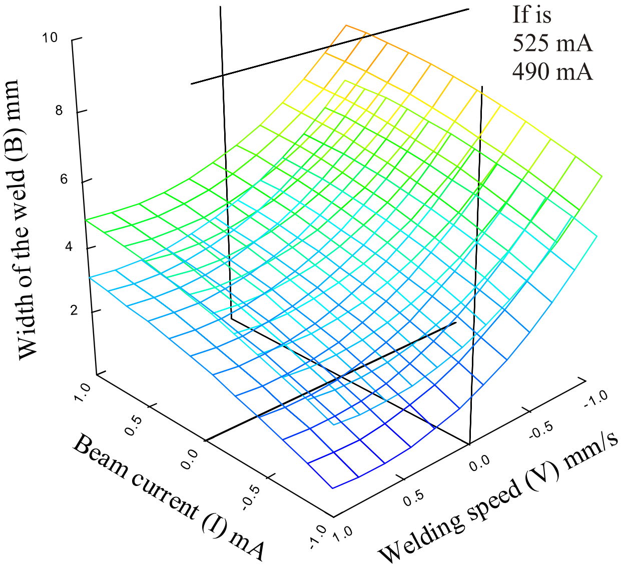

Fig. 15 Interaction effect of beam current and welding speed on width of the weld (B).

Fig. 14 shows the response surface of weld penetration (H) for the interaction of beam current (I) and current of focusing coils (If) when V is 5 mm/s and 15 mm/s. From this surface, it is found H is highest when I and If are at theirs midlevel. When V=5mm/s, H is below 10 mm. Figure15 shows the response surface of B due to the interaction effects of I and V. This graph shows B is minimum when I is at its lower level (-1) with V at its highest level (1). When If is at level (-1) the width of the weld (B) remains in wanted range with I and V up to their midlevel.

Figure16 shows the response surface of B due to the interaction effects of I and If. This graph shows B is minimum with I and If at their minimum levels with V=5mm/s.

Figure17 shows the response surface of B due to the interaction effects of V and If. B is minimum when If is at its upper level (+1) with V at its lower level (-1).

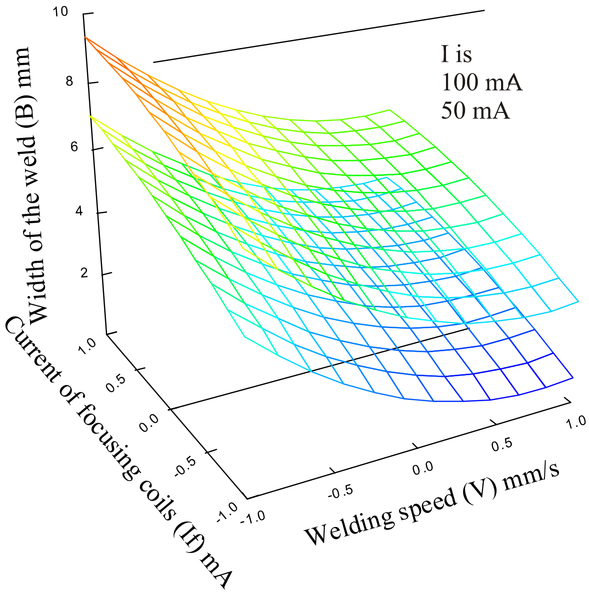

Fig. 16 interaction effect of current of focusing coils and welding speed on width (B).

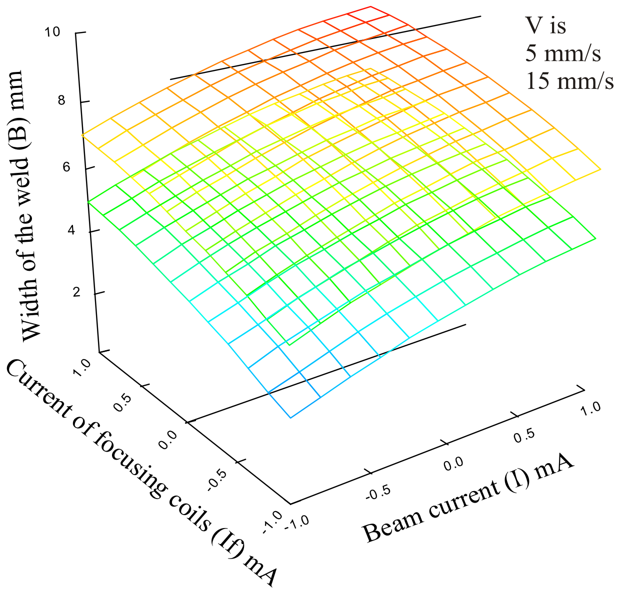

Fig. 17 Interaction effect of current of focusing coils and beam current on width (B)

Conclusions

The statistical models developed can be used to predict the weld geometry. The values of the control factors can be obtained by substituting the value of the desired bead geometry. The optimal weld parameters for reconstruction of charpy spesimens whit electron beam welding are: 50≥I≥100; 490≥If≥525; 15 ≥V≥5.

REFERENCE:

[1] Van Walle E " Reconstitution: Where do we stand?" Effects of Radiation on Materials: 17th International Symposium, ASTM STP 12XX, David S. Gelles, Randy K.Nanstad, Arvind S Kumar and Edward A.Little, Editors, American Society for Testing and Materials, Philadelphia, 1995

[2] Standard Guide for Reconstitution of Irradied Charpy Specimens : E 1253-99

[3] И. Вучков, Индентификация на експерименталните изследвания, Техника, София, 1990

[4] V.Gunaraj, N. Murugan, Prediction and optimization of weld bead volume for submerged arc process, Journal of applied electromagnetics&mechanics, 2000