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PREDICTION AND OPTIMIZATION OF YIELD PARAMETERS FOR SUBMERGED ARC WELDING PROCESS

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Original scientific paper
This study is conducted to predict the weld bead geometry, mechanical properties and HAZ dimensions by developing mathematical models following statistical methods. The developed mathematical models in which the data is represented can be programmed, fed to a computer and used to develop an expert welding system. MATLAB and MS Excel are used for the complete analysis. Finally optimum setting of output responses was investigated through graphical method.

Keywords: *mathematical model, regression analysis, submerged arc welding, weld bead quality*

Predviđanje i optimizacija parametara popuštanja za proces potopnog elektrolučnog zavarivanja

Izvorni znanstveni članak
Ova studija je provedena kako bi se predvidjela geometrija zavarenog sloja, mehanička svojstva i dimenzija zone oko zavara u kojoj toplina uzrokuje trajne promjene, razvojem matematičkih modela slijedeći statističke metode. Razvijeni matematički modeli u kojima su predstavljeni podaci mogu biti programirani, učitani u računalo i rabljeni za razvoj ekspertnih sustava za zavarivanje. MATLAB i MS Excel rabljeni su za potpunu analizu. Na kraju su istražene optimalne postavke izlaznih odgovora pomoću grafičke metode.

Ključne riječi: *kvaliteta zavarenog sloja, matematički model, potopno zavarivanje, regresijska analiza*

1 Introduction

Submerged Arc Welding is one of the major welding processes in industry because of its inherent advantages, including deep penetration and a smooth bead. Lots of critical sets of input parameters are involved in Submerged Arc Welding Process which needs to be controlled to get the required weld bead quality [1 ÷ 4]. Detailed information on effects of input parameters on weld bead quality parameters and finding out the relationship between them are very essential for decreasing trial run of SAW process. Reducing of trial run is essential to reduce the cost of welding procedure also [5, 6]. For the submerged arc welding plates, engineers often face the problem of selecting appropriate combination of input process control variables for achieving the required weld bead quality or predicting the weld bead quality for the proposed process control values [7]. For automatic SAW, the control parameters must be fed to the system according to some mathematical formula to achieve the desired results [8 ÷ 13]. These important problems can be solved with development of mathematical models through effective and strategic planning, design of execution of experiments. These models facilitate optimization of the process. Development of mathematical models also helps to improve the understanding of the effect of process parameters on bead quality and HAZ width to obtain a high-quality, to evaluate the interaction effects of bead parameters and to optimize the bead quality and HAZ width, to obtain a high-quality welded joint at a relatively low cost with high productivity. In the present work, prediction of the weld bead geometry and HAZ dimensions by developing mathematical models following statistical methods was done and optimum setting of output responses was investigated through graphical method to get better bead quality and minimum HAZ width.

2 Experimental method

The experiments were conducted as per the design matrix randomly to avoid errors due to noise factors. The mild steel work piece (150 × 150 × 12 mm – 2 pieces) is cut and V groove of angle 60° as per the standards is prepared. The chemical composition of work piece material is described in Table 1. The job was firmly fixed to a base plate by means of tack welding and then the submerged arc welding was finally carried out. The welding parameters were recorded during actual welding to determine their fluctuations, if any. The slag was removed and the job was allowed to cool down. Welding is carried out for the square butt joint configuration. The job is cut at three sections for similar welding conditions.

Table 1 Welding process variable and their limits

No.	Parameters	Unit	Notation	Levels
1	Current	A	I	200, 400, 600
2	Voltage	V	U	24, 42, 60
3	Travel speed	cm/min	v	39, 57, 75

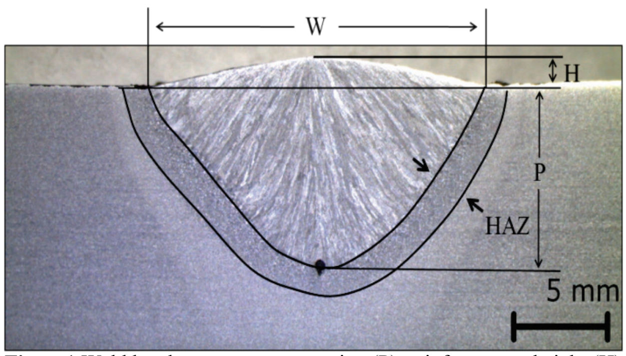

Figure1 Weld bead geometry: penetration (P), reinforcement height (H), Width (W) and HAZ.

Table 2 Details of mathematical model

No	Dependent variable (mm)	Independent variable	Constant input parameter(s)	Values of constant input parameter(s)	Mathematical model	R^2 (%)
1	*P*	*I*	*U*, *v*	*U* = 25 V *v* = 39 cm/min	$P = 3{,}6 - 0{,}002 \cdot I + 4{,}2 \times 10^{-6} \cdot I^2$	96,6
2	*P*	*U*	*I*, *v*	*I* = 400 A *v* =39 cm/min	*P* = CONSTANT	-
3	*P*	*v*	*I*, *U*	*I* = 400 A *U* = 25 V	$P = 3 - 0{,}002 \cdot v - 0{,}00074 \times 10^{-6} \cdot v^2$	97
4	*W*	*I*	*U*, *v*	*U* = 25 V *S* = 39 cm/min	$W = 17 - 0{,}017 \cdot I + 2{,}3 \times 10^{-6}$	96
5	*W*	*U*	*I*, *v*	*I* = 400 A *v* = 39 cm/min	$W = -50 + 4{,}4 \cdot U - 0{,}065 \cdot U^2$	98
6	*W*	*v*	*I*, *U*	*I* = 400 A *U* = 25 V	$W = 12 + 0{,}37 \cdot v - 0{,}0084 \cdot v^2$	95,5
7	*H*	*I*	*U*, *v*	*U* = 25 V *v* = 39 cm/min	$H = 1{,}1 + 0{,}022 \cdot I - 2{,}1 \times 10^{-6} \cdot I^2$	96
8	*H*	*U*	*I*, *v*	*I* = 400 A *v* = 39 cm/min	*H* = CONSTANT	-
9	*H*	*v*	*I*, *U*	*I* = 400 A *U* = 25 V	$H = 2{,}2 + 0{,}035 \cdot v + 0{,}00045 \cdot v^2$	98
10	*P*	*U*, *v*	*I*	*I* = 400 A	$P = 2{,}14 - 0{,}13 \cdot v + 0{,}0078 \cdot v^2 + 0{,}026 \cdot U^2 + 0{,}005 \cdot U$	88
11	*P*	*I*, *v*	*U*	*U* = 25 V	$P = -0{,}95 \cdot v + 0{,}018 \cdot v^2 - 2{,}21 \cdot I + 0{,}14 \cdot I^2 - 0{,}8 \cdot I \cdot v$	99
12	*P*	*I*, *U*	*v*	*v* = 39 cm/min	$P = -0{,}1542 \cdot U + 0{,}0518 \cdot I + 0{,}0052 \cdot U^2 - 0{,}001 \cdot U \cdot I$	99
13	*B*	*U*, *v*	*I*	*I* = 400 A	$W = 10{,}4 - 0{,}6 \cdot v + 0{,}04 \cdot v^2 + 0{,}17 \cdot U + 0{,}076 \cdot v \cdot U$	94
14	*B*	*I*, *v*	*U*	*U* = 25 V	$W = 11 - 0{,}02 \cdot v + 0{,}46 \cdot v^2 + 0{,}4 \cdot I$	96
15	*B*	*I*, *U*	*v*	*v* = 39 cm/min	$W = 0{,}7001 \cdot U + 0{,}0256 \cdot I - 0{,}0076 \cdot U^2 - 0{,}0008 \cdot U \cdot I$	99
16	*L*	*U*, *v*	*I*	*I* = 400 A	$H = 1 + 0{,}01 \cdot v^2 + 0{,}02 \cdot U + 0{,}04 \cdot U^2 + 0{,}05 \cdot U \cdot v$	96
17	*L*	*I*, *v*	*U*	*U* = 25 V	$H = -0{,}6 \cdot v + 0{,}02 \cdot v^2 - 2{,}2 \cdot I + 0{,}06 \cdot I^2 - 0{,}42 \cdot v \cdot I$	95
18	*L*	*I*, *U*	*v*	*v* = 39 cm/min	$H = -0{,}072 \cdot U + 0{,}0175 \cdot I + 0{,}0023 \cdot U^2 - 0{,}0004 \cdot U \cdot I$	98
19	*P*	*I*, *U*, *v*	-	-	$P = 201{,}22 - 38{,}9 \cdot v + 211{,}09 \cdot U - 16{,}4 \cdot I + 0{,}94 \cdot v^2 - 8{,}35 \cdot U^2 +$ $+ 0{,}05 \cdot I^2 + 0{,}43 \cdot v \cdot U + 0{,}07 \cdot v \cdot I - 0{,}03 \cdot U \cdot I - 0{,}02 \cdot v^3 +$ $+ 0{,}11 \cdot U^3 \cdot U + 0{,}07 \cdot v \cdot I - 0{,}03 \cdot U \cdot I - 0{,}02 \cdot v^3 + 0{,}11 \cdot U^3$	99
20	*H*	*I*, *U*, *v*	-	-	$H = -139{,}85 - 7{,}52 \cdot v - 16{,}79 \cdot U + 2{,}81 \cdot I - 0{,}03 \cdot v^2 +$ $+ 0{,}35 \cdot U^2 - 0{,}01 \cdot I^2 + 0{,}4 \cdot v \cdot U + 0{,}03 \cdot v \cdot I + 0{,}03 \cdot U \cdot I$	98,8
21	*MDR*	*I*, *U*, *v*	-	-	$MDR = 83{,}63 - 1{,}79 \cdot v - 2{,}54 \cdot U - 16{,}4 - 0{,}4 \cdot I +$ $+ 0{,}02 \cdot v^2 + 0{,}06 \cdot U^2 + 0{,}05 \cdot v \cdot U$	97
22	*HW*	*I*, *v*	*U*	*U* = 25 V	$HW = 2 + 0{,}35 \cdot I + 0{,}05 \cdot I^2 + 0{,}08 \cdot I \cdot v$	97
23	*HW*	*I*, *U*	*v*	*v* = 39 cm/min	$HW = 0{,}0803 \cdot U - 0{,}0012 \cdot I - 0{,}0011 \cdot U^2$	98
24	*HW*	*v*, *U*	*I*	*I* = 400 A	$HW = 2 - 0{,}07 \cdot v + 0{,}3 \cdot U + 0{,}04 \cdot U^2$	78
25	*HH*	*I*, *v*, *U*	-	-	$HH = 4{,}1 + 0{,}007 \cdot U^2 + 0{,}000025 \cdot I^2 - 0{,}0009 \cdot I \cdot U +$ $+ 0{,}00018 \cdot v^2 + 0{,}0002 \cdot I \cdot v$	89
26	*BH*	*v*, *U*	*I*	*I* = 400 A	$BH = -23{,}6 \cdot v - 0{,}08 \cdot v^2 - 29 \cdot U - 0{,}5 \cdot U^2 - 7{,}3 \cdot v \cdot U$	89

The samples are prepared by a standard metallographic process and the average values of the penetration, reinforcement height, and width are measured using digital venire caliper of least count 0,02 mm. Fig. 1 depicts the weld dimensions of SAW considered in present work. The measured values of weld dimensions and corresponding welding conditions are described in Table 2. With the help of optical research microscope HAZ width(s) are measured. Mathematical models (Table 2) have been developed by following multi regression method.

3 Results and discussions

Optimization of yield parameters of SAW process: Every machine has some limitations. It cannot run any value of input variable. Every machine is able to run with the same range of values input variables. Suppose a submerged arc welding machine is able to work between 25 V to 35 V but optimum value of one of input variables (voltage) is 1 V. It is not acceptable because this machine cannot work in 1 V. So, in present work, graphs of output responses (comp. Figs. 2÷9) of SAW process were drawn with the help of mathematical model (described in Tab. 2), considering input variables with their range (described in Tab. 1) and from these graphs (Figs. 2÷9) optimum setting of input variables and values of output responses were presented in Tab. 3. From Figs. 2 and 3, it has been found that when the value of current is high then the penetration is high and when the current is low then the value of penetration is low and there is nominal effect of voltage on penetration.

Table 2 Results of optimum solution of SAW process

Sl. No.	Current (A)	Voltage (V)	Travel speed (const. assumed) cm/min	Output response	Figure No.
1	599	47	39	Penetration = 7,22 mm	2&3
2	600	50	39	Reinforcement height = 0,68 mm	4&5
3	597	50	39	Bead width = 0,68 mm	6&7
4	600	50	39	HAZ width = 0,55 mm	8&9

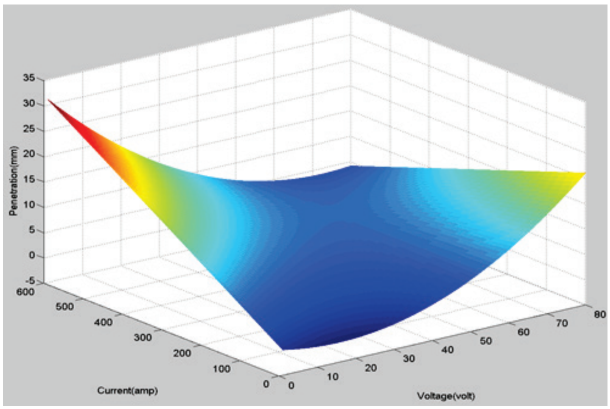

Figure 2 3D plot when input variables are voltage and current and output variable is Penetration

From Figs. 4 and 5, it has been found that reinforcement height increases with the increase of current but reinforcement height is not so affected by voltage. From Figs. 6 and 7, it has been found that current has negative effect on bead width but voltage has a positive effect on bead width. From Figs. 8 and 9, it has been found that, up to a certain value of voltage, HAZ width increases after that voltage has a negative effect on HAZ width and HAZ width is more affected by voltage with respect to current.

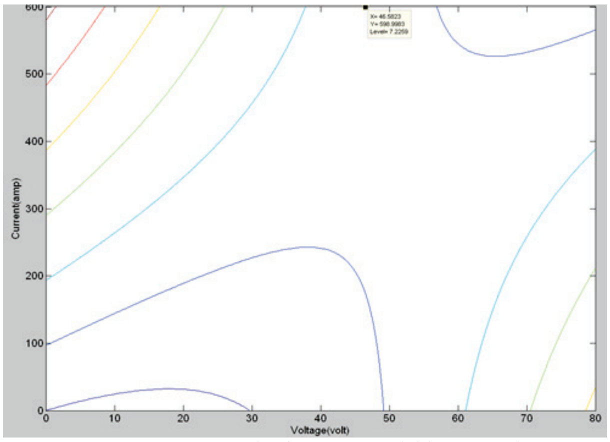

Figure 3 Contour plot for output variable penetration

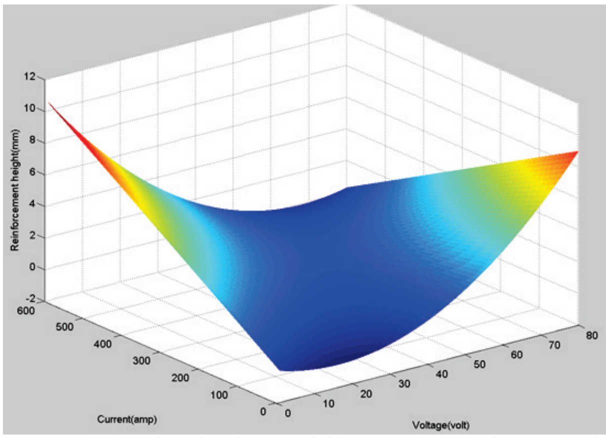

Figure 4 3D plot when input variables are voltage and current and output variable is Reinforcement height

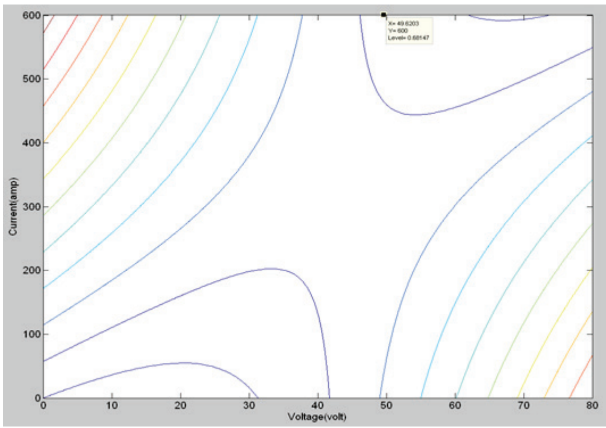

Figure 5 Contour plot for output variable Reinforcement height

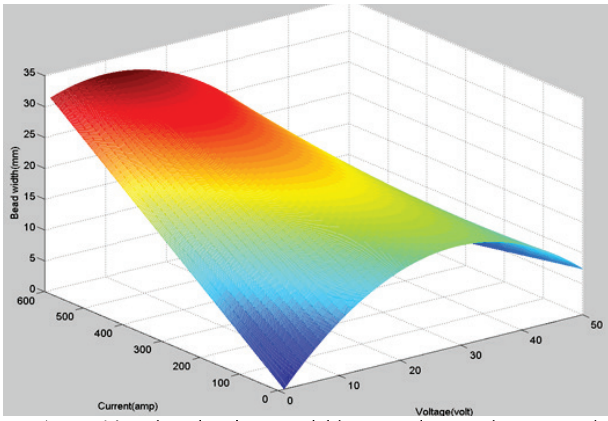

Figure 6 3D plot when input variables are voltage and current and output variable is bead width

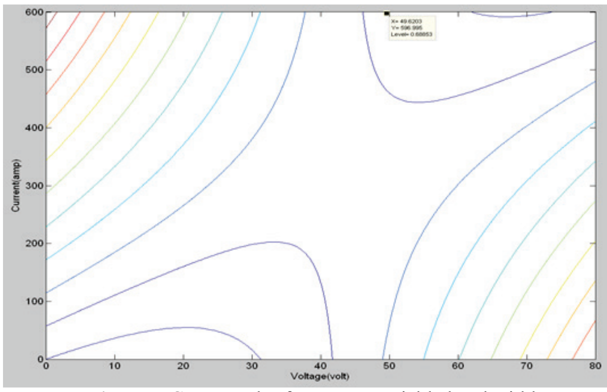

Figure 7 Contour plot for output variable bead width

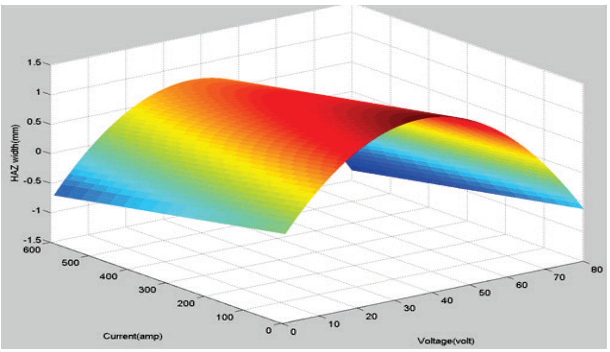

Figure 8 3D plot when input variables are voltage and current and output variable is HAZ width

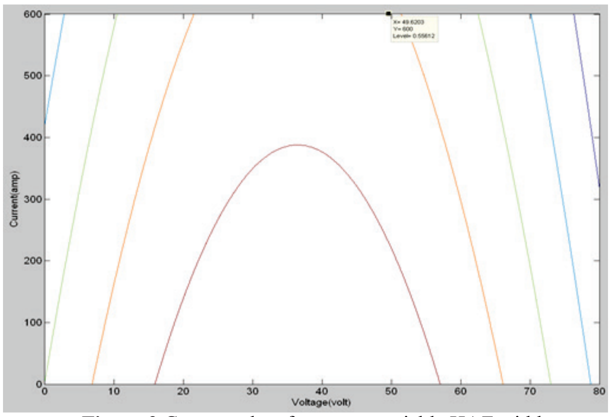

Figure 9 Contour plots for output variable HAZ width

4 Conclusion

Condition for optimization of submerged arc welding process is maximum penetration, minimum reinforcement height, bead width and HAZ width. It has been found from graphs (Figs. 2 ÷ 9) for this case maximum penetration is 7,22 mm, minimum reinforcement height is 0,68 mm, minimum bead width is 0,68 mm and minimum *HAZ* width is 0,55 mm. So optimum input parametric setting is 50 V (voltage), 600 A (current), 39 cm/min (travel speed).

5 References

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Nomenclature

P – penetration (mm), H – reinforcement height (mm), W – bead width (mm), HW – HAZ width (mm), I – current (A), U – voltage (V), v – travel speed (cm/min), MDR – metal decomposition rate (kg/min), HH – HAZ hardness (HB), BH – bead hardness (HB) and R^2 – regression coefficient (–).

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