African Journal of Engineering Research
Vol. 8(3), pp. 29-37, August 2020
ISSN: 2354-2144
Full Length Research Paper

Optimization of submerged arc welding parameters for joining mild steel

Kishor Purushottam Kolhe*, Bonde Assefa and Boru Bedeya

Department of Industrial Engineering, College of Engineering and Technology, Bule Hora University, Ethiopia.

Accepted 13 August, 2020

ABSTRACT

In Ethiopia, nearly 85 *per cent* of people's morality depends on agriculture; the government of Ethiopia emphasis on Farm Mechanization for bringing improvement in crop production using modern equipments and tools. The present study is conducted to predict the weld geometry, mechanical properties and HAZ dimensions of welded joint by using automatic submerged arc welding. The mathematical models were developed by using the statistical methods, like Regression analysis. The important process control variables of welding; like voltage, current and travel speed were regressed with bead characteristics; like quality, penetration, reinforcement, bead width etc; and the mechanical properties; such as bead hardness, HAZ hardness etc. Nevertheless; these mathematical equations between the weld bead characteristics and mechanical properties with the welding parameters will be very useful during actual fabrication work. Moreover, the dimensions and shape of the weld bead largely determine the strength of welded joint. The relationship between welding variables and weld feature; like hardness, bead geometry and HAZ width also reduces the cost of weld procedure development by decreasing the number of trial runs. In order to ensure adequate weld bead quality, it is necessary that various welding variables should be in proper balance. Therefore, it is essential to know the effect of the process variables individually and in combination on the resulting weld bead dimensions. These dimensions not only control the type of microstructure but also determine the stress carrying capacity of a welded joint. 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. Statistical Analysis Software's like SPSS and MS Excel were used for the complete analysis.

Keywords: Submerged arc welding, statistical package for social Science, regression analysis, mathematical models.

*Corresponding author email: skishor75@gmail.com.

INTRODUCTION

The application of structural steel in Ethiopia is increasing, due to the globalization of transport bridge erection, manufacturing and process industries. However, the structural steel requirement in this country has highly demanded for fabrication work and erection of buildings and bridges. Although, submerged arc welding is one of the processes having high demand for joining structural steel due to its high deposition rate, welding speed and quality appearance. The important process control variables of submerged arc welding, viz voltage, current and travel speed were related with bead characteristics; like reinforcement, bead width, penetration, quality etc; and the mechanical properties, such as bead hardness, HAZ hardness etc. The purpose of such development of equation is to find the mathematical relation between the weld bead characteristics and the welding parameters. Nevertheless, using automatic submerged arc welding, it is essential to develop equations that express mathematically the weld bead parameters and their influences in HAZ dimensions and microstructure. The relationship between welding variables and weld features reduces the cost of weld procedure development by decreasing the number of trial runs. Moreover, to ensure adequate weld quality, it is necessary that various welding variables should be in proper balance. Therefore, it is essential to know the combined effect of the process variables on the resulting weld bead dimensions and shape relationship; these dimensions control mechanical properties of a welded joint. Although the developed mathematical models or equation can be programmed, feed to a computer; perforate to develop an expert welding system. Statistical analysis software (SPSS) and MS Excel were used for the complete analysis. Mostly; these techniques reported improved properties of refined microstructure and a consequence of effective weld pool stirring (Agarwal, 1994; McConnel and Pherson, 1997; Kolhe and Datta, 2007; Kolhe and Datta, 2004). The mechanical properties of a welded joint largely depend on the weld bead dimensions and shape relationships; which in turn are influenced by welding variables; like welding current, arc voltage and welding speed. The bead geometry is specified by depth of penetration (P), weld bead width (W), reinforcement height (R), the ratio of weld width to penetration (W/P), known as weld penetration shape factor (WPSF), dilution (D); that is, ratio of the area and contact angle (θ). However, a large number of research papers which have been published on the final mathematical models by deleting insignificant regression coefficients were used to show graphical relationships between the welding variable and weld bead dimension. Mostly, refined microstructure as consequence of effective weld pool stirring for the welding of steels using conventional TIG, MIG and submerged arc welding processes resulted improved properties. Moreover, submerged arc welding has huge application in the manufacturing of farm implements and tools like tractor mounted hydraulic elevator etc (Kolhe, 2009, 2010; Kolhe and Jadhav, 2011; Kolhe et al., 2011; Chandel et al., 1997; Apps et al., 1960). It has been found from these works that for submerged arc welding, the important process variables like welding current, arc voltage, welding speed, nozzle to plate distance and the type of flux-wire combination, affect the weld bead size and shape (Konkal and Koons, 1972; Box et al., 1978; Irwin and John, 1985; Grong, 1997; Sorin, 2006).

METHODOLOGY

An automatic submerged arc welding system was used for depositing the welds. The model was UP-11-Cp Quality engineering (Baroda) PVT. LTD made. It had thyristor controlled DC drive for both wire feed as well as for carriage. It enables stepless, fine control of current and travel speed through a simple potentiometer; it was a constant potential power source. It had the facility to check carriage speed and open circuit voltage prior to starting of welding sequence. Controls, like wire inch, forward/reverse and also ammeter, voltmeter and carriage speedometer were mounted on the control panel for easy adjustment and monitoring of parameters. The unit had been mounted on the rails fixed to a table of the designed dimensions for traversing at appropriate speeds to lay welds of the desired length. The equipment components required for submerged arc welding are shown in block diagram. These consists of (1) Power source, (2) the wire feeder and control system, (3) the welding torch for automatic welding, or the welding gun and cable assembly for semi-automatic welding, (4) flux feeding mechanism hopper with flux recovery system, and (5) travel mechanism. Figure 1 depicts an automatic submerged arc welding outfit, the power source and other details of the experimental set up used in the present research work.

The material selected in the present investigation is as per IS: 226/75, 0.25% C, which is in the category of structural steel most commonly known as Mild Steel. The experiments data used for the present study was used from the published literature (Kolhe and Datta, 2007, 2004). The response surface methodology is used, where Y consider as dependent factor and X is consider as independent factor, like Y = F(X). However; for the statistical analysis Regression analysis is used. And the final mathematical models are developed by using SPSS and Statistical analysis software.

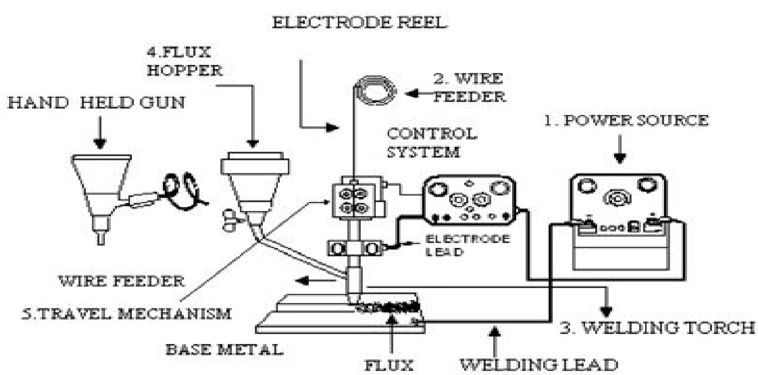
Assumptions for present study

1. The weld joint is considered to be defect free.
2. No preheat and post heat was used.
3. The weld bead is considered having same height to width ratio.
4. For low values of current, travel speed should be not be of high value and vice-versa for obtaining good weld bead and avoiding burn through.
5. Experimental readings were selected randomly to avoid systematic errors.

Identification of the SAW process variables and finding the limits of the process variables

The three process variables of SAW viz. Current (I), Voltage (V) and travel speed (S), were identified by deciding upper and lower limits, following statistical analysis method (Agarwal, 1994; McConnel and Pherson, 1997; Kolhe and Datta, 2007; Kolhe and Datta, 2004). This helps to carry out an experimental work on the above welding machine; and used the regression method to develop the mathematical model between the welding process variables and its characteristics. Moreover, it helps to reduce the cost of weld procedure development by decreasing the number of trial runs in order to ensure adequate weld bead quality. However; trial runs were conducted to find out the working limits for submerged arc welding. Based on the trial runs, the ranges of process variables of SAW viz. Current (I), Voltage (V) and travel speed (S), were decided as 300 to 650 amp, 25 to 40 volts and 40 to 120 cm/min, respectively.

a



b

Figure 1. (a, b) Experimental setup of submerged arc welding.

Although, based on the trial runs the ranges of process variables of eight levels of current, four levels of voltage and nine levels of travel speed were decided in the experiment which are given in Table 1 with their units, notations, and levels (lower and upper).

Table 1. Submerged arc welding process variables and its working limits.

S.N.	Parameter	Unit	Notation	Levels
1	Current	Amp	I	300, 350, 400, 450, 500, 550,600 and 650
2	Voltage	volt	V	25, 30, 35 and 40
3	Speed	cm/min	S	40, 50, 60, 70, 80, 90, 100, 110 and 120

Fitting of mathematical model

Let y be the response variable; i.e bead characteristic or mechanical property of SAW weld; which is influenced by "K" process variable say $X_1, X_2, \ldots X_k$. Let i^{th} value of response variable be y_i when the value of K process variables are $X_1i, X_{2i}, X_3i, \ldots X_{ki}$. As y_i is function of X_{1i}, X_{2i}, X_{3i}, ….S_{ki} can be written as

$$Y_i = f\,(X_{1i}, X_{2i}, X3i, \ldots . X_{ki}) + e \qquad (1)$$

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \text{---------} + \beta_{kx} X_k + e \qquad (2)$$

This type of regression equation is also known as multiple regression equation or the prediction equation, where Y stands as predictants; and X_1, X_2, … X_k were as predictors. e is the error which is distributed normally with mean 0 and variance σ^2, *i.e.* $e \sim N(0, \sigma^2)$.

RESULTS AND DISCUSSION

The results and findings are described and discussed in detail in this section. The results are supported by the literatures.

SN	Dependent Variable	Mathematical model Only significant equations and the equations which controls the malt ant 75%	Regression coefficient (R^2) %
	Constant Voltage: Variations in width, height, penetration, HAZ width are presented below.		
1	Width	Y = 11.117764 - 0.740625 × S	84.55
		Y = 10.508709-0.654278 × S + 0.06977 × S^2	87.37
		Y = 11.409574 - 0.653866 × S + 0.436509 × I	95.23
		Y = -2.415197 × I + 1.900971 × I^2	83.19
		Y = 10.98856192-0223175 × S + 0.4611400 × S^2 + 0.40888010 × I	96.42
2	Height	Y = 2.098761+0.481951 × I + 0.10680 × 8 × I^2	83.05
		Y = 2.032529 - 0.218139S + 0.520687 × I	94.85
		Y = -0.215259 × S + 0.144362 × S^2	84.18
		Y = -0.595004 × S + 0.019626 × S^2 - 1.246842 × I + 0.061017 × I^2 – 0.420751 × S × I	99.64
3	Penetration	Y = 3.567955 + 1.044712× I + 0.175855× I^2	94.06
		Y = 3.765753 – 0.207868× S +1.183129× I	92.84
		Y = - 0.252969 ×S + 0.255750× S^2	75.22
		Y = -0.942041 × S + 0.017880 × S^2 – 2.208698 × I + 0.138448 × I^2 – 0.804001 × I × S	99.12
4	HAZ Width	Y = 1.969594 + 0.350822 × I + 0.067680 × I^2	92.30
		Y = 2.011131 – 0.097037 × S + 0.395680 × I	93.75
		Y = 2.18218385 + 0.64881203 × I + 0.05132652 × I^2 +0.07858566 × I × S	97.80
	Constant speed		
5	Width	Y = 13.44132854+0.08367146 × V^2 - 0.13363727 × V × I	79.23
6	Height	Y = 2.657294 + 0.580086 × I	77.02
		Y = 2.283394 + 0.471690 × I + 0.096547 × I^2	85.53
		Y = 2.103416 + 0.510851 × I – 0.276939 × V	93.11
		Y = -0.318704 × V+0.239111 ×V^2	86.39
		Y = -1.176481 × I + 0.064087 × I^2 - 0.749608 × V + 0.048433 × V^2 - 0.53587 × V × I	99.62
		Y = 2.24882470 + 1.07234416 × I +0.06408691× I^2 + 0.04843255 V^2 + 0.21103813 × V × I	98.04
7	Penetration	Y = 4.545552 + 1.19385 × I	90.04
		Y = 3.951655 + 1.022211 × I + 0.153354 ×I×S	95.95
		Y = 4.308966 + 1.164812 I – 0.118293 V	90.85
		Y = 3.6326649 + 1.01511411 × I +0.14625697× I^2 + 0.04519215 × V^2	96.23
8	HAZ width	Y = 3.100997 + 0.398310 × I + 0.240988×V	85.73
		Y = 0.233033 × V +0.359305 × V^2	82.15
		Y = -2.329418 × I + 0.05411206 × I^2 - 0.18665486 × V + 0.04446952 × V^2 - 0.11241830 × V × I	95.93
9	Bead Hard	Y = 94.28026315 - 0.47145995 × I + 1.47533544 × V - 1.02172310 × V^2	76.22

	Constant current		
10	Width	$Y = 10.573085 - 0.607069 \times S+0.048313 \times S^2$	91.78
		$Y = 11.427020 - 0.396626S + 183085V$	92.25
		$Y = 10.419824 - 0.591738 \times S + 0.041344 \times S^2 + 0.172086 \times V + 0.076714 \times V^2$	94.08
		$Y = 0.750021 \times V + 1.505309 \times V^2$	82.61
		$Y = -0.321402 \times S+ 0.847501 \times S^2$	75.31
		$Y = -3.196694 \times S +0.041344 \times S^2 - 3.301188 \times V + 0.076714 \times V^2 - 0.868319 \times S \times V$	99.84
		$Y = 10.41982388 - 0.59173838 \times S + 0.04134429 \times S^2 + 0.17208636 \times V + 0.07671402 \times V^2$	94.08
11	Height	$Y = 0.825123 - 0.157903 \times S - 0.195442 \times V$	91.50
		$Y = 0.397276 - 0.160135 \times S + 0.013209 \times S^2 - 0.190420 \times V + 0.039842 \times V^2$	97.82
		$Y = -0.064494 \times V + 0.146108 \times$	83.30
		$Y = -0.264371 \times S - 0.416020 \times V$	90.51
		$Y = -0.259454 \times S + 0.013209 \times S^2 - 0.322845 \times V + 0.039842 \times V^2 - 0.033106 \times S \times V$	99.81
		$Y = 1.03781787 + 0.01320878 \times S^2 + 0.02309386 \times V + 0.03984172 \times V^2 + 0.05337850 \times S \times V$	97.81
12	Penetration	$Y = 2.194484 - 0.115832 \times S + 0.007785 \times S^2 + 0.018897 \times V + 0.026626 \times V^2$	87.83
		$Y = 0.133697 \times V + 0.323940 \times V^2$	8.442
		$Y = -0.047816 \times S + 0.186206 \times S^2$	73.57
		$Y = -0.664453 \times S+0.007785 \times S^2 - 0.712598 \times V + 0.026626 \times V^2 - 0.182874 \times S \times V$	99.76
		$Y = 2.13779381 - 0.13000463 \times S + 0.00778509 \times S^2 + 0.02662629 \times V^2 - 0.00472422S \times V$	87.83
13	HAZ Width	$Y = 2.562610 + 0.325034 \times V$	88.56
		$Y = 2.402276 + 0.344063 \times V + 0.025724 \times V^2$	89.60
		$Y= 2.395448 - 0.060410 \times S+ 0.280347 \times V$	93.99
		$Y = 2.070992 - 0.069912 \times S + 0.002125 \times S^2 + 0.301728 \times V + 0.043363 \times V^2$	96.67
		$Y = 0.377385 \times V + 0.306493 \times V^2$	81.39
		$Y = -0.083414 \times S + 0.138573\times S^2$	77.48
		$Y = -0.587660\times S+0.002125\times S^2-0.388603\times V+0.043363\times V^2-0.172583\times S\times V$	99.66
		$Y=2.10193773-0.07090809\times S+0.30396820\times V+0.04242992\times V^2$	96.64
14.	Bead Hard	$Y = 95.207120 + 0.206913\times S+0.028027\times S^2+1.658146\times V-1.097894\times V^2$	81.59
		$Y = 2.893026 \times V + 10.014698 \times V^2$	84.32
		$Y = -23.594867 \times S + 0.028027 \times S^2 - 30.077561 \times V - 1.097894 \times V^2 - 7.933927 \times S \times V$	99.91
15	HAZ Hard	$Y = 1.299901 \times V + 9.734938 \times V^2$	0.8665
		$Y = -21.584578 \times S + 0.083512 \times S^2 - 29.129518 \times V - 0.559502 \times V^2 - 7.335681 \times S \times V$	0.9994
	Combine effect of Speed, Voltage and Current		
16.	Width	$Y = -3.514363 - 0.024477 \times S$	88.87
		$Y = 6.887031 - 0.031373 \times I + 0.000045736 \times I \times S$	80.99
		$Y = -1.576431-0.062452\times V+0.012493\times I$	76.19
		$Y = 7.684082-0146214\times V-0.029798\times S$	84.41
		$Y = 0.005202 \times I$	86.96
		$Y = 0.208944V - 0.004782V^2$	78.06
		$Y = -0.002224 \times I + 0.000016184 \times I^2$	94.53
		$Y = 0.085702 \times S - 0.000720 \times S^2$	78.67
		$Y = -0.097919\times V + 0.011040 \times I$	93.82
		$Y = 0.008068 \times I – 0.022565 \times S$	94.82
		$Y = -0.117043 \times V – 0.014855 \times V^2 + 0.505328 \times S+ 0.000502 \times S^2 - 0.024389 \times V \times S$	89.45
		$Y = -0.007851 \times I + 0.000036223 \times I^2 - 0.0135694 \times S + 0.00030509 \times S^2$	97.55

		$Y = -3.78732431 + 0.40983364 \times V + 0.00004285 \times I^2 - 0.00115666 \times V \times I + 0.7662 \times I^2$ $0.0442 \times V \times I + 0.0227 \times V$	83.81
		$Y = 5.50879853 – 0.02205561 \times I + 00003644 \times I – 0.00003540 \times S \times I$	89.76
		$Y = 4.13319606 + 0.00753526 \times V^2 + 0.00002577 \times I^2 - 0.00091152 \times V \times I + 0.00018266 \times S^2 + 0.00020961 \times S \times I$	98.48
17	Height	$Y = 0.741957 \times V – 0.009611 \times V^2$	97.57
		$Y = 0.042380 I – 0.000028472 \times I^2$	97.98
		$Y = 0.4627 38 \times S – 0.003527 \times S^2$	96.99
		$Y = 0.215834 \times V + 0.016446 \times I$	98.33
		$Y = 0.541298 \times V – 0.031590 \times S$	97.03
		$Y = 0.032495 \times I – 0.025039 \times S$	97.50
		$Y = 0.345366 \times V + 0.18180 \times V^2 + 0.761395 S + 0.000671 \times S^2 – 0.037343 \times V \times S$	99.67
		$Y = 19.77758564 – 0.16708868 \times S + 0.00064292 \times S^2$	86.07
		$Y = 9.96599983 + 0.01346566 \times V^2 + 0.29218113 \times S + 0.00046536 \times S^2 + 0.00020383 \times S \times I – 0.02033944 \times V \times S$	94.48
18.	Penetration	$Y = -7.369827 + 0.025687 \times$	95.56
		$Y = 8.478344 - 0.042517$	93.92
		$Y = -5.751513 + 0.024299 \times I – 0.0179175 \times$	92.01
		$Y = 0.009006 \times I$	86.78
		$Y = -0.006633 \times I + 0.000034083 \times I^2$	97.95
		$Y = -0.164368 \times V + 0.018806 \times I$	93.21
		$Y = 0.304500 \times V + 0.001619 \times V^2 – 0.019209 \times I + 0.000071449 I^2 – 0.000966 \times V \times I$	98.45
		$Y = -0.013639 \times I + 0.000060232 \times I^2 + 0.168989 \times S + 0.000126 \times S^2 – 0.000505 \times S \times I$	99.14
19.	HAZ Width	$Y = -4.696011 + 0.115740 \times V + 0.008891 \times I$	85.75
		$Y = 0.082094 \times V$	89.29
		$Y = 0.005164 \times I$	93.52
		$Y = 0.002233 \times I + 0.000006386 \times I^2$	94.80
		$Y = 0.010088 \times V + 0.004562 \times I$	93.60
		$Y = 0.107901 \times V – 0.012374 \times S$	91.71
		$Y = 0.006878 \times I – 0.013498 \times S$	96.59
		$Y = -0.150845 \times V + 0.012907 \times V^2 + 0.319300 \times S + 0.000281 \times S^2 - 0.015081 \times V \times S$	93.00
		$Y = 0.30287844 + 0.00618715 \times V^2 + 0.00002652 \times I^2 – 0.00067140 \times V \times I$	92.73
		$Y = 2.71321460 - 0.13446408 \times V + 0.00720546 \times V^2 + 0.00002098 \times I^2 – 0.00048697 \times V \times I + 0.00003290 \times S^2$	97.30
20.	Bead Hardness	$Y = 3.065590 \times V$	98.84
		$Y = 0.185572$	95.88
		$Y = 4.740439 \times V – 0.060393 \times V^2$	99.85
		$Y = 0.361386 \times I-0.0000383 \times I^2$	99.55
		$Y = 2.636228 \times S - 0.017624 \times S^2$	98.23
		$Y = 2.317445 \times V + 0.047400 \times I$	99.20
		$Y = 2.772108 \times V + 0.140725 \times S$	99.08
		$Y = 0.295316 \times I - 0.000134 \times I^2 + 1.466063 \times S + 0.002334 \times S^2 - 0004660 \times S \times I$	99.68
21.	HAZ Hardness	$Y = 0.189699 \times I$	96.90
		$Y = 5.455727 \times V - 0.083696 \times V^2$	99.93
		$Y = 0.349196 - 0.000348 \times I^2$	99.83
		$Y = 2.658372 \times S - 0.017564 \times S^2$	98.56
		$Y = 1.874571 \times V + 0.077932 \times I$	99.01
		$Y = 2.690333 \times V + 0.198657 \times S$	98.52

Based on the theoretical study, the influences of submerged arc weld process variables on the bead characteristics and mechanical properties are observed in above developed models (1-21) are discussed as follows.

Bead height

Second degree orthogonal equation was fitted to find effect of speed, current and their product on height of SAW weld bead; when voltage was kept constant. It is observed from Equation 1 that 99.64% variations SAW bead height is attributed to speed, current, their squares and product of speed and current. However; if speed increased by one unit, height by 0.59 unit, and current by one unit; it influence on bead height decreased 1.24 units; the variations of 0.01 unit and 0.42 units are observed. Although; from equation 5, it is observed that 99 % variations in SAW bead height are due to voltage and current; at constant travel. Moreover; it is observed from the above equation that the effect of current is quadratic, that is, unit increase in current; decreased bead height by 1.17 units and increased the height by 0.04 unit by square of current. However; when voltage increased the height decreased by 0.74 units and increased by 0.04 units by square of voltage. Whereas decrease in height is 0.05 units by product of voltage and current. From equation 10 it is clear that variation in height of weld bead by 0.25 unit was due to speed whereas 0.01 unit by square of speed. Similarly the unit increase in volt decreased height by 0.32 unit and increased height by square of volt. Whereas product of voltage and speed decreased height by 0.031 units. Although, it is observed from equation 16, that 98.48% variations SAW bead height was attributed, due to square of speed, square of volt, square of current and product of speed and current was found to be conducive on height of SAW weld bead. Nevertheless, above variables increased height of weld bead by 0.007, 0.0001, 0.00002 and 0.0002 units due to speed and current respectively; whereas the product of voltage and current reduce height by 0.0009 units.

Bead width

It is observed from Equation 2, that 99.64% variation in SAW width was attributed to speed, current and speed square, when voltage was kept constant. Although, it was observed that the effect of speed was negative, that is, unit increased in speed decreased bead width by 0.022 units and increased width by 0.46 units by its square. Similarly, units increase in current decreased width by 0.40 units. However, second order orthogonal equation was fitted to find the effect of speed and voltage on SAW bead width, when current was kept constant. Moreover, it was observed from Equation 11 that 99.84% variation in bead width was contributed due to speed voltage, their square and their product. Nevertheless; if speed increased by one unit, width decreased by 31.196 units. Similarly if voltage increased by one unit, bead width decreased 3.30 unit, the variations of 0.041 and 0.076 units were seen due to square of speed and voltage respectively, whereas their product decreases width by 0.868 units. Furthermore, it is observed from Equation 17, that 95.56% variations in SAW bead width are observed due to the combine effect of current, voltage and Speed. Finally; it is clear from above equation; that the effect of speed, square of speed and volt, and their product were found to be condensive on bead width by 0.292, 0.013, 0.00046 and 0.00020 units; whereas product of speed and voltage reduces width by 0.020 units.

Penetration

Second-degree orthogonal equation was fitted to find the effect of speed and current on bead penetration. From Equation 3, it is observed those 99.12% variations in SAW bead penetration was contributed due to, speed and current, their square and product, if voltage was placed constant. However, if speed increased by one unit; that decreases penetration by 0.942 units; whereas, if current increased by one unit penetration decreased by 2.20 units. Although, the variations of 0.01 and 0.13 units were observed due to square of speed and current respectively, whereas their product decreased penetration by 0.804 units. Furthermore, from Equation 7, 96.23% of variation in bead penetration was attributed due to current and voltage, when speed was kept constant. Moreover, from the equation it was also observed that, if current, square of current and volt increased by one unit bead penetration was increased by 1.10, 0.14 and 0.045 units respectively. Whereas from Equation 12, it was observed that 99.76% variations in bead penetration was attributed due to speed and voltage; when current was constant. Nevertheless, from the equation, it was observed that when speed, voltage and their product, increased by one unit bead penetration was noted decreased by 0.66,0.712 and 0.182 unit respectively, and when square of speed square and volt increased by one unit, penetration was increased by 0.007 and 0.02 unit, respectively. From Equation 18, 99.70% variation in bead penetration was observed due to combine effect of all the process variables. Although, it was also observed from the above equation that when current and product of speed and current increased by one unit, bead penetration was decreased by 0.30 and 0.00008 unit respectively, whereas when square of current and speed increased by one unit bead penetration increased by 0.000060 and 0.00012 unit respectively.

HAZ width

It was observed from equation 4, that 97.80% variations in SAW HAZ width was attributed due to current, current square and product of current and speed when voltage was kept constant. However; it was observed from an above equation that; if above variables increased by one unit, HAZ width increased 0.64, 0.05 and 0.07 unit respectively. Whereas from Equation 8, it was observed that 95.93% variations in HAZ width was contributed due to, current, voltage, their square and their product. Although, it was noted from an above equation that, when these variables increased by one unit, exaggerated HAZ width decreased by 2.32, 0.18 and 0.11 unit respectively, whereas, if we increase their square by one unit HAZ width increased by 0.05 and 0.04 unit respectively. Furthermore, from Equation 13, 99.66% variation was observed, due to speed and voltage, when current was kept constant. Moreover, if speed and voltage increased by one unit, negative effects on HAZ width was observed, whereas positive effects was observed for increased in square of speed and voltage. Also, from Equation 19, 97.30% variations in HAZ width was contributed due to the combine effect of speed, voltage and current. Nevertheless, if all the process variables increased by one unit, it was noted that voltage and product of voltage and current acts negative effect on HAZ width whereas other process variables noted positive effect on HAZ.

Bead hardness

For constant voltage, if speed and current varied by one unit, null effect was noted on bead hardness; whereas 76.22% contribution of current and voltage was noted when speed was kept constant. Although increase in square of current and voltage recorded negative effect on bead hardness; whereas, increase in volt by one unit, noted positive effect on bead hardness as shown in Equation 9. Moreover, from Equation 14, it was observed that 99.91% contribution of speed and voltage was recorded, when current was kept constant. Furthermore, from above equation, it was observed that increase in speed, voltage, voltage square and product of voltage and speed by one unit, resulted in bead hardness by 23.59, 30.07, 1.09 and 7.93 unit respectively; whereas, increase in speed square increased, bead hardness by 0.028 unit. Also, from Equation 20, it is seen that 99.68% variations in bead hardness was contributed due to the combine effect of all the process variables like current speed and voltage.

HAZ hardness

From Equation 15, it is seen that 99.94% variations in HAZ hardness are due to speed, voltage, their square and product, when current was kept constant. However, from above equation it is observed that when speed, voltage, voltage square and product of volt and speed increased by one unit, HAZ hardness decreases by 21.58, 29.23, 0.55 and 7.33 units respectively. Whereas, if speed square increased by one unit HAZ hardness increases by 0.084 unit. Although, from Equation 21, it is observed that 99.92% variations in HAZ hardness were seen due to the combine effect of all the three process variables. Moreover, from above equation, it was observed that current, speed and speed square have positive effect on HAZ hardness; whereas, current square and product of voltage and current has overall negative effect on HAZ hardness.

The regressions lows give the geometrical parameters, height, width, penetration, HAZ width, Bead Hard, HAZ Hard function of welding principal parameters arc intensity current I, arc voltage V, arc speed S in Amperes, Volts and cm/min.

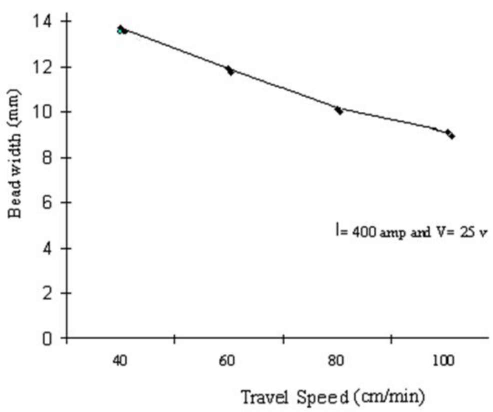
The welded joints geometry are diverse, butt and corner welds with and without processing of the joint, symmetrical and symmetrical less, with the deposition of layers in a certain order. In this aspect, some analyses were limited these combinations for a certain thickness of material and joint geometry. The articles do not give information about these welded joint aspects and even the electrode speed may be established by diverse methods, that parameter must be considerate in that analyze, in my opinion. The hardness of the HAZ depends on heat flow and chemical composition of the base material and his expression may be established easier using the linear welding energy. In my opinion the work may be increase in accuracy by using the electrode speed, linear energy of welded arc, polarity of current and by limit the analyze for some geometry of joints and thickness.

Verification of experimental results with theoretical results

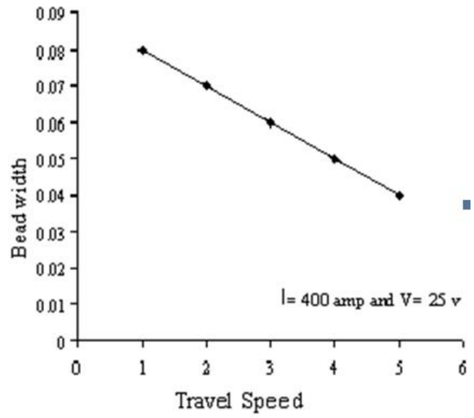
The verification of Published experimental results and theoretical studied results were done for bead width by varying travel speed at constant current and voltage (Kolhe and Datta, 2007; Kolhe and Datta, 2004). From Figure 2, in the experimental study, it is observed that for the increase in travel speed for a constant voltage and current the weld bead decreases. Whereas in theoretical as shown in Figure 2, it is observed that when increase travel speed by one unit the bead width decreases by 0.22 unit. Hence the similar results are obtained for bead width dimension by both experimental as well as theoretical method.

CONCLUSIONS

1. From the above developed models, the welding



(a) Experimental study



(b) Theoretical study

Figure 2. (a, b) Verification of experimental results with theoretical results.

parameters like Current and speed for constant voltage influences, 95.23, 99.64, 99.12, 97.80% on bead width, height, penetration, HAZ width, respectively. Also, for varying current and voltage for constant speed influences 79.23, 99.62, 96.23, 95.93 and 76.22% on bead width, height, penetration, HAZ width, bead hardness, respectively. Also, for varying voltage and current for constant current influences, 99.84, 99.81, 99.76, 99.64, 99.91 and 99.94% on bead width, height, penetration, HAZ width, Hardness, HAZ hardness, respectively.

2. Moreover, the combine effect of speed, voltage and current influences 98.48, 99.67, 99.14, 97.30, 99.85 and 99.93% on bead width, height, penetration, HAZ width, hardness and HAZ hardness, respectively.

3. The developed mathematical models find applications; to predict the bead dimensions for any combinations of welding parameters; within established range of mechanical properties. However; if a specific set of bead dimensions is available, then the welding variables can be set directly to achieve robust weld bead and welding quality. Moreover; the developed mathematical equations can be used in a computer programme to determine a combination or ranges of parameters that will meet the fabrication requirements of the industry.

REFERENCES

Agarwal BL (**1994**). Basic Statistics. 2nd edn Wiley Eastern Limited, New age International Limited New Delhi.

Apps RL, Gourd LM, Nelson KA (**1960**). Effect of welding variables upon bead shape and size in submerged arc welding. Weld Metal Fabricat, 39(8): 225s-230s.

Box GEP, Hunter WH, Hunter JS (**1978**). Statistics for Experiments. 10th Edn. John Wiley and Sons, New York.

Chandel RS, Seow HP, Cheong FL (**1997**). Effect of increasing deposition rate on bead geometry of submerged arc welds. J Mater Process Technol, 72(2): 124-128.

Grong O (**1997**). Metallurgical Modeling of Welding. 2nd The Institute of Materials. The University Press, Cambridge.

Irwin M, **John** EF (**1985**). Probability and Statistics for Engineers. 3rd Edn. Prentice Hall of India Pvt. Ltd. New Delhi.

Kolhe KP (**2009**). Development and testing of tree climbing and harvesting device for mango and coconut trees. Indian Coconut J, 52(3): 15-19.

Kolhe KP (**2010**). Mechanized harvesting device: A need of coconut growers in India. Indian Coconut J, 73(2): 15-19.

Kolhe KP, **Datta** CK (**2004**). Parametric study of submerged arc welding of mild steel. Indian Welding J, 37(3/4): 33-42

Kolhe KP, **Datta** CK (**2007**). Prediction of microstructure and mechanical properties of multipass SAW. J Mater Process Technol, 197(1-3): 241-249.

Kolhe KP, **Jadhav** BB (**2011**). Testing and performance evaluation of tractor mounted hydraulic elevator for mango orchard. Am J Eng Appl Sci, 4(1): 179-186.

Kolhe KP, Powar AG., Dhakane AD, Mankar SH (**2011**). Stability and ergonomic design features of tractor mounted hydraulic elevator. Am J Eng Appl Sci, 4(3): 380-389.

Konkal PJ, **Koons** GF (**1972**). Optimisation of parameter for two wires AC submerged arc welding. Weld J, 57(9): 367s-374s.

McConnel A, **Pherson** NA (**1997**). Application of statistical process design to a FCAW process. Weld J, 76(5): 412s - 416s.

Sorin LI (**2006**). Optimiz area Proceselor Tehnologice. Application general. (Technological Processes Optimization. 1(4) DOI: 10.13140/2.1.2304.1601.

Citation: Kolhe KP, Assefa B, Bedeya B (2020). Optimization of submerged arc welding parameters for joining mild steel. Afr J Eng Res, 8(3): 29-37.