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Development of mathematical model for identifying bead geometry of arc welding for fabrication of farm machines

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ABSTRACT

This study was conducted to predict the weld geometry, mechanical properties and HAZ dimensions by developing mathematical models following statistical methods. The important process control variables of welding *viz.*, 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. The purpose of such development of equation is to find the mathematical relation between the weld bead characteristics and mechanical properties with the welding parameters, as the dimensions and shape of the weld bead largely determine the strength of welded joint. For using automatic Submerged Arc Welding effectively, it is essential to develop equations that express mathematically the weld bead parameters in terms of process variables, the variation in HAZ dimensions and microstructure. 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 and MS Excel were used for the complete analysis.

Key words : Submerged arc welding, Statistical package for social science, Regression analysis, Mathematical models

INTRODUCTION

The important process control variables of 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. For using automatic submerged arc welding, it is essential to develop equations that express mathematically the weld bead parameters to the process variables and the variation in HAZ dimensions and microstructure. The relationship between welding variables and weld features also reduce the cost of weld procedure development by decreasing the number of trial runs. In order 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, as these dimensions control mechanical properties of a welded joint. The developed mathematical models or equation can be programmed and feed to a computer and so as to develop a expert system. Statistical analysis software (SPSS) and MS Excel were used for the complete analysis. As this technique is reported to result in improved properties as a result of refined microstructure as a consequence of effective weld pool stirring (Agarwal, 1994; Connel and Pherson, 1997; Ravussanka *et al.*, 2005; Reddy *et al.*, 2001). 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) *i.e.* ratio of the area and contact angle (θ). A large number of research papers have been published for the final mathematical models by deleting insignificant regression coefficients were used to show graphical relationships between the welding variable and weld bead dimension. Refined microstructure as a consequence of effective weld pool stirring for the welding of steels using conventional TIG, MIG and submerged arc welding processes resulted improved properties (Mohandas and Reddy, 1996; Chandel *et al.*, 1997; Kolhe and Dutta, 2004;

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Gunaraj and Murgan, 2002; Rewnurick and Patchett, 1976; Apps *et al.*, 1960). It has been found from these works that for submerged arc welding the important process variables that affect the weld bead size and shape are welding current, arc voltage, welding speed, nozzle to plate distance and the type of flux-wire combination. The effects of various welding variables on weld bead dimensions as reported by some investigators are as follows.

MATERIALS AND METHODS

Experimental procedure :

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 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) welding machine or 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) the flux hopper and feeding mechanism and usually a flux recovery system, and (5) travel mechanism. Fig. 1 show an automatic submerged arc welding outfit, the power source and other details of the experimental set up used in the present research work.

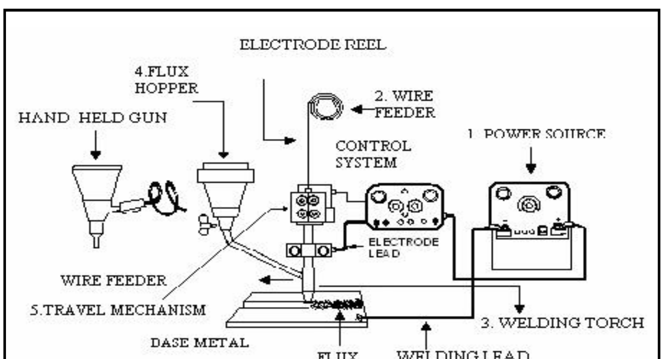

Fig. 1 : Experimental setup of submerged arc welding

Assumptions for present study :

- The weld joint is considered to be defect free.
- No preheat and postheat were used.
- The weld bead is considered having same height to width ratio.
- 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.
- 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 usual statistical analysis method, which enabled us to carryout experimental work and develop the mathematical model and reduce the cost of weld procedure development by decreasing the number of trial runs in order to ensure adequate weld bead quality. 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. 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 : Welding process variables and their limits

Sr. No.	Parameters	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————————,$X_{k.}$ Let i[th] value of response variable be y_i when the value of K process variables are X_1i, X_{2i}, X_3i, ….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, ….X_{ki}) +e

$Y_i = b_0 + b_1X_1 + b_2X_2 +$ ————— $+ b_{kx}X_k + e$ (3. 1)

This type of regression equation is also known as multiple regression equation or the prediction equation, where Y stands as predictant and X_1, $Y_{2,}$ ———, X_k were as predictors. e is the error which is distributed normally with mean 0 and variance s^2, *i.e.* e ~ N (0, σ^2).

RESULTS AND DISCUSSION

Based on the theoretical study, the influences of

Sr. No.	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.			
	Width	$y=11.117764-0.740625\times S$	84.55
		$y= 10.508709-0.654278\times S+0.06977\times S^2$	87.37
		$y=11.409574-0.653866\times S+0.436509\times I$	95.23
		$y= -2.415197\times I +1.900971\times I^2$	83.19
		$y=10.98856192-0223175\times S+0.4611400\times S^2+0.40888010\times I$	96.42
	Height	$Y=2.098761+0.481951\times I +0.10680\times 8 I^2$	83.05
		$Y=2.032529-0.218139S +0.520687 I$	94.85
		$Y=-0.215259 \times S + 0.144362 \times S^2$	84.18
		$Y=-0.595004 \times S +0.019626 \times S^2-1.246842\times I + 0.061017 \times I^2 -0.420751 \times S\times I$	99.64
	Penetration	$Y =3.567955 + 1.044712\times I + 0.175855\times I^2$	94.06
		$Y= 3.765753 - 0.207868\times S +1.183129\times I$	92.84
		$Y=- 0.252969 \times S + 0.255750\times S^2$	75.22
		$Y=-0.942041 \times S + 0.017880 \times S^2 -2.208698 \times I + 0.138448 \times I^2 - 0.804001\times I\times S$	99.12
	HAZ Width	$Y=1.969594 + 0.350822\times I + 0.067680 \times I^2$	92.30
		$2.011131 - 0.097037 \times S +0.395680\times I$	93.75
		$y=2.18218385 +0.64881203 \times I+0.05132652 \times I^2 +0.07858566 \times I\times S$	97.80
Constant speed			
	Width	$Y=13.44132854+0.08367146\times V^2-0.13363727\times V\times I$	79.23
	Height	$Y=2.657294+0.580086\times I$	77.02
		$Y=2.283394+0.471690\times I +0.096547\times I^2$	85.53
		$Y=2.103416 +0.510851\times I -0.276939\times V$	93.11
		$Y=-0.318704 \times V+0.239111 \times V^2$	86.39
		$y=-1.176481 \times I + 0.064087\times I^2-0.749608\times V+0.048433\times V^2-0.53587\times V\times I$	99.62
		$y=2.24882470 + 1.07234416\times I +0.06408691\times I^2 + 0.04843255 V^2 +0.21103813\times V\times I$	98.04
	Penetration	$Y=4.545552 + 1.19385 \times I$	90.04
		$Y=3.951655 + 1.022211\times I + 0.153354 \times I\times S$	95.95
		$Y=4.308966 + 1.164812 I - 0.118293 V$	90.85
		$Y=3.6326649 +1.01511411\times I +0.14625697\times I^2 +0.04519215 \times V^2$	96.23
	HAZ width	$Y=3.100997 + 0.398310\times I + 0.240988\times V$	85.73
		$Y=0.233033 \times V +0.359305\times V^2$	82.15
		$Y=-2.329418\times I +0.05411206 \times I^2-0.18665486 \times V +0.04446952 \times V^2-0.11241830 \times V\times I$	95.93
	Bead hard	$Y=94.28026315-0.47145995\times I+1.47533544\times V-1.02172310\times V^2$	76.22
Constant current			
	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
		$Y=-3.196694 S+0.041344 \times S^2-3.301188\times V+ 0.076714\times V^2-0.868319\times S\times V$	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
	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

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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
	$Y=2.13779381-0.13000463 S+0.00778509\times S^2+0.02662629\times V^2-0.00472422S\times V$	87.83
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
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
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	
	$Y=-3.514363-0.024477\times S$	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
Width	$Y=0.741957 \times V – 0.009611\times V^2$	97.57
	$Y= 0.042380 I – 0.000028472 I2$	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

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Table contd.….

Penetration	Y=-7.369827+0.025687×	95.56
	Y=8.478344-0.042517	93.92
	Y=-5.751513+0.024299× I – 0.0179175×	92.01
	Y= 0.009006 I	86.78
	Y= -0.006633× I +0.000034083× I^2	97.95
	Y=-0.164368 ×V + 0.018806 ×I	93.21
	Y=0.304500 ×V + 0.001619× V^2 –0.019209 ×I +0.000071449 I^2 –0.000966 ×V×I	98.45
	Y=-0.013639 ×I +0.000060232 ×I^2 +0.168989 ×S +0.000126× S^2 –0.000505 ×S×I	99.14
HAZ width	Y=-4.696011+0.115740 ×V+ 0.008891× I	85.75
	Y=0.082094 ×V	89.29
	Y=0.005164×I	93.52
	Y=0.002233× I+ 0.000006386 ×I^2	94.80
	Y= 0.010088×V+0.004562 ×I	93.60
	Y=0.107901 ×V –0.012374 ×S	91.71
	Y= 0.006878 ×I – 0.013498 ×S	96.59
	Y=-0.150845 V +0.012907× V^2 + 0.319300S+0.000281 ×S^2-0.015081 ×V×S	93.00
	Y=0.30287844 +0.00618715×V^2 +0.00002652 ×I^2 –0.00067140×V×I	92.73
	Y=2.71321460-0.13446408×V+0.00720546×V^2+0.00002098×I^2–0.00048697×V×I+ 0.00003290 ×S^2	97.30
Bead hardness	Y=3.065590× V	98.84
	Y=0.185572	95.88
	Y=4.740439×V –0.060393 ×V^2	99.85
	Y=0.361386× I-0.0000383× I^2	99.55
	Y=2.636228× S-0.017624 ×S^2	98.23
	Y=2.317445×V+0.047400× I	99.20
	Y=2.772108× V+0.140725× S	99.08
	Y=0.295316×I-0.000134×I^2+1.466063×S+0.002334×S^2-0004660×S×I	99.68
HAZ hardness	Y=0.189699×I	96.90
	Y=5.455727×V-0.083696×V^2	99.93
	Y=0.349196-0.000348×I^2	99.83
	Y=2.658372× S-0.017564× S^2	98.56
	Y=1.874571×V+0.077932×I	99.01
	Y=2.690333×V+0.198657×S	98.52

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 was observed from equation 1 that 99.64 % variations SAW bead height was attributed to speed, current, their squares and product of speed and current. If speed increased by one unit, height increased 0.59 unit, and if current increased by one unit then height decreased by 1.24 units. The variations of 0.01 unit and 0.42 units are observed. From equation 5, it is observed that 99% variations in height of SAW weld bead were due to voltage and current when travel speed was kept constant. Here it was also observed that the effect of current is quadratic *i.e.* unit increase in current decreased height by 1.17 unit and increased the height by 0.04 units by square of current, 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. It was 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. 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 was observed from equation 2, that 99.64 % variation in SAW width was attributed to speed, current and speed square, when voltage was kept constant. Here it was observed that the effect of speed was negative *i.e*. 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. Second order orthogonal equation was fitted to find the effect of speed and voltage on SAW bead width, when current was kept constant. It was observed from equation 11 that a 99.84% variation in bead width was contributed due to speed voltage, their square and their product. If we increase speed by one unit, width decreased by 31.196 units. Similarly if we increased voltage by one unit bead width decreased 3.30 unit, the variations of 0.041, 0.076 units were seen due to square of speed and voltage, respectively, whereas their product decreased width by 0.868 units. It is observed from equation 17, that 95.56 % variations in SAW bead width were observed due to the combine effect of current, voltage and Speed. 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 unit.

Penetration :

Second-degree orthogonal equation was fitted to find the effect of speed and current on bead penetration. From equation 3, it was observed that 99.12% variations in SAW bead penetration was contributed due to, speed and current, their square and product, if voltage was placed constant. If speed increased by one unit, penetration decreased by 0.942 units whereas if current increased by one unit penetration decreased by 2.20 units. The variation of 0.01 and 0.13 unit was due to square of speed and current, respectively, whereas their product decreased penetration by 0.804 units. From equation 7, 96.23% variations in bead penetration was attributed due to current and voltage when speed was kept constant. 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 unit, 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. From the equation it was observed that when speed, voltage and their product, increased by one unit bead penetration was 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, 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. It was also observed from above equation that if we increase above variables by one unit, HAZ width increased 0.64, 0.05, 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. It was also observed from above equation that when these variables increased by one unit 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 0.04unit, respectively. From equation 13, 99.66 % variations was observed due to speed and voltage when current was kept constant. 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. From equation 19 97.30 % variations in HAZ width was contributed due to the combine effect of speed, voltage and current. If all process variables increased by one unit then 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 where as 76.22% contribution of current and voltage was noted when speed was kept constant. 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.From equation 14, it was observed that 99.91 % contribution of speed and voltage was recorded when current was kept constant. 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 units. From equation 20 it was 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 were due to speed, voltage, their square and product, when current was kept constant. From above equation it was observed that when speed, voltage, voltage square and product of volt and speed increased by one unit HAZ hardness decreased by 21.58, 29.23, 0.55 and 7.33 units, respectively. Where as when speed square increased by one unit HAZ hardness increased by 0.084 unit. From equation 21, it was observed that 99.92% variations in HAZ hardness were seen due to the combine effect of all the three process variables. From above equation it was also observed that current, speed and speed square has positive effect on HAZ hardness whereas current square and product of voltage and current has overall negative effect on HAZ hardness.

Conclusion :

The statistical softwares like SAS, SPSS, MS Excel etc., were the major and economical tool for the prediction of weld bead geometry and its mechanical properties.

The developed models find application to predict the bead dimensions for any combinations of welding parameters within established range. If a specific set of requirements of bead dimensions is given, then the requirements and the equation can be used in a computer programme to determine a combination or ranges of parameters that will meet the requirements.

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