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OPTIMIZATION OF WELDING PARAMETERS OF GTAW USING RESPONSE SURFACE METHODOLOGY

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Present investigation focused on the optimization of the process parameters of Tungsten inert gas welding operation. AISI 304 Stainless steel has been taken as the base metal. Taguchi's L_{27} orthogonal array has been chosen for the design of experiment. The selected input parameters are Current, Voltage, Root Gap and Gas flow rate. Further the mechanical testing was performed. Bending strength and micro-hardness values are chosen as the response values. The regression relation between input parameters and response values are designed with the help of Response surface methodology (RSM).

Keywords: TIG welding, AISI Stainless Steel 304, Taguchi, ANOVA, RSM

1. Introduction

This research is to make the thin sheet welding easy and compatible by optimizing the process parameters. We have explained about the suitable parameters for butt joining on AISI 304 Stainless Steel material of thickness 3 mm which has good inter-granular corrosion resistance tends to increase the life of pressure vessels and automobile components. AISI 304 has superior fracture toughness, leads to reduce the crack initiation and crack growth under high pressure.

Twenty-seven pairs of specimen were welded using Gas tungsten arc welding process (GTAW) based on design of experiment of L_{27} OA by MINITAB-17. The Taguchi method is a powerful tool that uses a special design to study the parameter space with small number of experiments through orthogonal arrays. In the factorial design, the number of factors and levels increases exponentially. This technique provides an efficient, simple and systematic approach to optimize design for quality, performance and cost. To reduce the large number of experiments, an orthogonal array is developed by Taguchi method. In present experiment, Signal-

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to-Noise ratio has been used to examine the effect of each factor on a particular response. The signal shows the effect of each factor on the response, whereas noise is the measure of the influence on the deviation from the average responses. S/N ratio is based upon the lower-the-better, larger- the- better and nominal-the better criteria [1-3]. The S/N ratio is based on the previous knowledge and expertise, so it must be carefully chosen. In current study, responses are associated with the strength of the weld joint, which should be high as possible so the larger-the- better criteria has been chosen. The strength of the weld joint which is generally expected to be high is examined by equation 1[4-6].

$$\frac{S}{N} = -10\log_{10}\left(\frac{1}{n}\sum_{i=0}^{n} 1/y_i^2\right) \tag{1}$$

Where n = number of measurements
y_i = response value for each noise factor.
i = number of design parameters in this study OA has 27 experiments (L_{27})

To study the influence of each parameter to the response value, Analysis of Variance (ANOVA) technique has been used. ANOVA states that total sum of squares of the deviation are equal to the sum of square of standard deviation caused by each input factor [7-9].
The ANOVA analysis was accomplished for a significance level alpha (α) of 0.05 (95% confidence level). Statistical significance to the response is considered when the P- value of its input sources is observed to be lower than 0.05.
Following are the various terms introduced in ANOVA analysis. The full description with their formulas is presented in following sections [7]:
(a) Sum of squares: - There are three possible sum of squares; (1) SS factor (SS_F) is the deviation of the estimated factor level, (2) error sum of squares (SS_E) is the deviation of the observation from its corresponding factor level and (3) total sum of squares (SS_T) is the total variation in data. Total sum of square is the summation of between group sum of squares and error sum of squares (eq. 2).

$$SS_T = SS_F + SS_E \tag{2}$$

SS factor (SS_F) can be calculated by equation 3and SS_E by equation 4.

$$SS_F = n\sum(\overline{Y_j} - \overline{Y}..)^2 \tag{3}$$

$$SS_E = n\sum\sum(\overline{Y_{ij}} - \overline{Y_j})^2 \tag{4}$$

<u>Notation:</u>

j = Used to denote a particular group.

Y_{ij} = Role of individual i in group j.

$\bar{Y}$ ..= mean of all observation

$\bar{Y}_j$ = **mean of a particular group.**

SS_F= the deviation of estimated factor level

SS_E= Error sum of squares

SS_T= Total sum of squares

SS= Sum of squares

(b) Degrees of freedom:-

It indicates the number of independent elements in the sum of squares. For each some of squares degree of freedom (DF) is deferent. The degrees of freedom for each component of the model are presented in equation (5, 6 and 7):

$$DF_{(Factor)} = r - 1 \quad (5)$$

$$DF_{Error} = nT - r \quad (6)$$

$$Total = nT - 1 \quad (7)$$

<u>Notation</u>

nT = total number of observation

r = number of factor levels

(c) Mean Squares (MS):

Mean squares represent an estimate of population variance. It is calculated by dividing the corresponding sum of squares by degree of freedom. Formulas used to calculate the MS is reported in equation 8 respectively.

$$MS = \frac{SS}{DF} \quad (8)$$

<u>NOTATION</u>

MS= Mean Squares; SS= Sum of squares

DF = Degree of freedom

(d) F-value:-

The F test statistic is simply a ratio of two variances. It is based on ratio of mean squares.

$$F = \frac{MS_{Factor}}{MS_{Error}} \quad (9)$$

<u>NOTATION</u>

MS_{Factor} = Mean square for a particular factor

MS_{Error} = Error mean square

(e) P-value:-

P- value is used in hypothesis tests to help you decide whether to reject or fail to reject a null hypothesis. The p-value is the probability of obtaining a test statistic that is at least as extreme as the actual calculated value, if the null hypothesis is true. A commonly used cut-off value for the p-value is 0.05. For example, if the calculated p-value of a test statistic is less than 0.05, you reject the null hypothesis.

(f) R-squared:- R-squared is a statistical measure of the closeness of the data are to fitted the regression line. It is also known is coefficient of determination. If, the data follows the regression line than model is significant. The formula for calculating the R-sq value is mentioned in equation 10.

$$1-\frac{SS_{Error}}{SS_{Total}} \tag{10}$$

NOTATION

SS_{Error} = Sum of squares of errors

SS_{Total} =Total sum of squares

Response surface methodology (RSM) is a combination of statistical and mathematical techniques to analyze, model and optimize the processes. It is useful for any field of engineering to determine the relationship between the independent process parameters (input factors) with the desired response and exploring the effect of these parameters on responses, including six steps [3,10-13]. These are, (1) define the independent input variables and the desired output responses, (2) adopt an experimental design plan, (3) perform regression analysis with the full quadratic model of RSM, (4) perform a statistical analysis of variance (ANOVA) of the independent input variables in order to find parameters which affect most significantly response, (5) determine the condition of the RSM model and decide whether this model needs screening variables or not and finally, (6) optimize, conduct confirmation experiment with verifying the predicted responses.

2. Material and methods

Gas tungsten arc welding (GTAW) operation has been used for butt joint of stainless steel AISI 304 plates of size 200×50×3 mm. The prescribed composition of the base metal is reported in table 1. The filler metal E-308L has been used as an electrode for GTAW process. The selected input parameters and there levels are presented in table 2. A set of 27 experiments has been designed by Taguchi method. The design of experiment of the L_{27} Orthogonal array (OA) is presented in table 3. The first column represent Current, 2^{nd} is voltage, 3^{rd} represents root gap and final input parameter is reported in column 4 which is gas flow rate. The response values hardness and bend strength is depicted in column 5 and 6 respectively. To study the effect of each input parameters ANOVA was applied. To generate the regression equation between input parameters and outcomes the response surface methodology was applied at the basis of full quadratic 6

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i\cdot} \sum_{j} \beta_{ij} X_i X_j \quad (11)$$

Where Y is the estimated response (here, hardness and bend strength), β_0 is the constant, β_i , β_{ii} and β_{ij} represents the coefficients of linear (here, I, V, R and G), quadratic (here, I^2, V^2,R^2 and G^2) and cross-product (here, I*V, V*R, R*G and G*I) terms respectively. X reveals the coded variables that correspond to the studied cutting parameters [3].

Hardness testing was done using a Brinell hardness machine with a 1000 kg force load applied. The hardness is measured at the different locations weld zone. The way the machine measures the hardness is through a microscope. The digital output displays the distance between the two points and takes that to measure the hardness of the material. Fig. 1 (a) shows the Brinell hardness machine and Bend testing machine with testing specimen is presented in fig. 1 (b). The bend testing was conducted by bended the specimen slowly and steadily from the centre around a certain radius. After the bend test some specimen experiences the outer surface cracks as the outside surface is more vulnerable to cracking due to the tension it experiences during bending, these specimen were not acceptable for the engineering purpose. The specimen is acceptable and having high bend strength if there are no visible cracks on the outside surface after the bend test. There are numerous different kinds of testing devices. The photographic picture of bending tested specimen is presented in Fig.1 (b).

Table 1

Chemical Composition of AISI 304 stainless Steel

Element	***Weight percentage***
Carbon	0.08 max
Manganese	2.00 max
Phosphorus	0.045 max
Sulphur	0.030 max
Silicon	0.75 max
Chromium	18.00-20.00
Nickel	8.00-12.00
Nitrogen	0.10 max
Iron	67-71

Table 2

Input parameters and its levels

Variables	Unit	Levels		
		1	**2**	**3**
Current (I)	A	60	70	80
Voltage (V)	V	30	40	50
Root Gap (R)	mm	0.5	1.0	1.5
Gas Flow Rate (G)	litre/min	16	18	20

Table 3

L_{27} Orthogonal Array Experimental Data

Sample Number	Current (I)	Voltage (V)	Root gap (R)	Gas flow rate (G)	Hardness (H)BHN	Bending (B)Strength
	(A)	(V)	(mm)	(lit/min)	BHN	N/mm^2
1	60	30	0.5	16	110.13	101.66
2	60	30	0.5	18	113.31	111.66
3	60	30	0.5	20	106.95	109.66
4	60	40	1	16	100.70	36.66
5	60	40	1	18	100.70	40.00
6	60	40	1	20	103.14	39.33
7	60	50	1.5	16	121.21	76.66
8	60	50	1.5	18	119.70	71.33
9	60	50	1.5	20	121.41	72.66
10	70	30	1.5	16	92.67	103.33
11	70	30	1.5	18	89.76	102.66
12	70	30	1.5	20	96.78	106.33
13	70	40	0.5	16	138.31	66.66
14	70	40	0.5	18	135.70	63.33
15	70	40	0.5	20	136.32	69.66
16	70	50	1	16	116.95	68.33
17	70	50	1	18	118.31	67.66
18	70	50	1	20	113.70	70.33
19	80	30	1	16	93.70	96.33
20	80	30	1	18	97.53	99.33
21	80	30	1	20	98.17	91.66

22	80	40	1.5	16	114.35	46.66
23	80	40	1.5	18	110.41	41.33
24	80	40	1.5	20	113.31	47.66
25	80	50	0.5	16	148.14	65.33
26	80	50	0.5	18	139.36	61.66
27	80	50	0.5	18	145.47	63.33

Fig.1. Brinell hardness machine and bend testing machine with welded specimen

3. Result and discussion

3.1. Analysis of micro-hardness

The micro-hardness testing as carried out on different welded specimens. Fig. 2 and table 4 showing that the most influencing factor for the hardness property is welding voltage at higher level (50 V) of voltage. The second affecting factor is root gap at its first level i.e. 0.5 mm, third affecting factor is welding current at its second level (70 A), and finally the last affecting factor is gas flow rate at its first level (16 liter/min). To validate the above result analysis of variance (ANOVA) was applied which is presented in table 5.

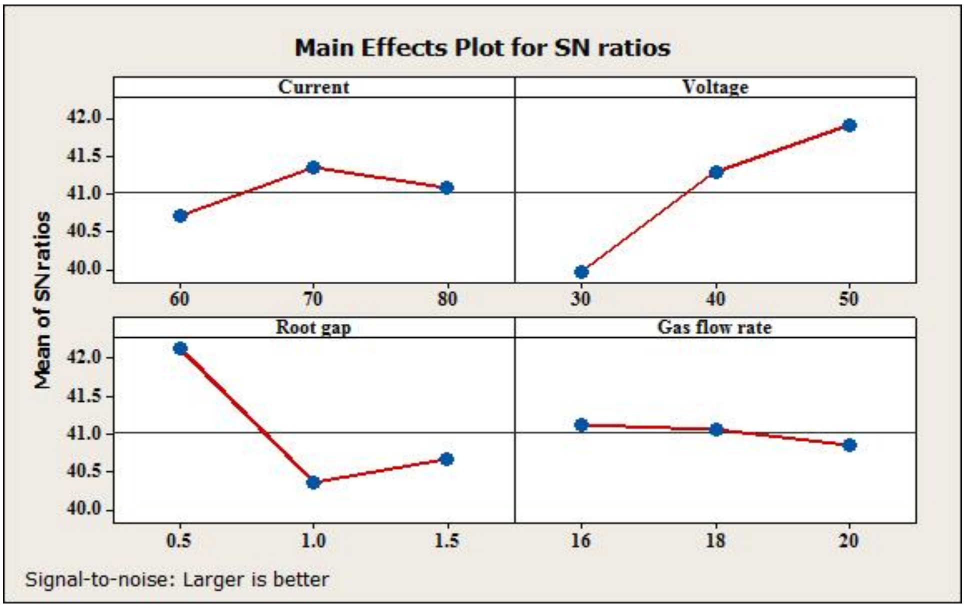

Fig. 2. Main effects plot for SN ratios for hardness property

Table 4

Response table for S/N ratio of hardness value

Level	Current	Voltage	Root Gap	Gas flow rate
1	40.72	39.96	42.14	41.12
2	41.36	41.30	40.38	41.07
3	41.08	41.92	40.68	40.87
Delta	0.64	1.95	1.77	0.25
Rank	3	1	2	4

Table 5

Analysis of variance Hardness

Source	DOF	Adj SS	Adj MS	F-Value	P-Value
Linear	4	2851.57	712.89	106.91	0.00
I	1	102.15	102.154	15.32	0.002
V	1	42.94	42.936	6.44	0.026
R	1	37.95	37.948	5.69	0.034
G	1	0.44	0.440	0.07	0.802
Square	4	1316.81	329.204	49.37	0.0000
I*I	1	60.64	60.643	9.09	0.011
V*V	1	104.02	104.023	15.60	0.002
R*R	1	66.65	66.648	10.00	0.008

G*G	1	0.40	0.400	0.06	0.811
Interaction	6	178.57	29.761	4.46	0.013
I*V	1	29.49	29.491	4.42	0.057
I*R	1	64.99	64.995	9.75	0.009
I*G	1	2.07	2.068	0.31	0.588
V*R	1	53.65	53.650	8.05	0.015
V*G	1	26.62	26.623	3.99	0.69
R*G	1	26.60	26.600	3.99	0.69
Residual Error	12	80.02	6.668		
Lack of fit	11	61.35	5.577		
Pure error	1	18.67	18.666	0.30	0.905
Total	26				
R- sq=97.13			**R-sq(adj)=96.27**		

R^2 (Coefficient of determination) is used to check the goodness of the model; it determines how close the predicted values with the experimental values [6,14]. The values of R^2 are mentioned in Table 5, for the hardness value R-sq = 97.13 and R- sq (adj) = 96.27. This value indicates the goodness of designed model at states that designed model is valid for the further investigation.

3.2. Analysis of Bend strength

The bending test was carried out on different welded specimens. The mean plot graph is presented in figure 3 and the response table is presented in table 6. In this investigation the most affecting factor was again voltage at its first level which indicates that when the voltage increases its strength reduces which is theoretically proved. As voltage is directly proportional to the arc gap when arc gap increases the voltage increases and in same way arc density reduces. The high voltage causes the welding defect known as lack of penetration and tends to reduce the welding strength. There is no cracks were found on the outer surface of the welded specimen which were welded under the low voltage condition. The second affecting input parameter is root gap at its first level, third is welding current at its second level (70 A) and finally the gas flow rate. The analysis of variance for the bending strength is presented in table 7. The values of R^2 are mentioned in Table 7, R-sq = 99.09 and R- sq (adj) = 98.04. The closeness of the R values indicates the goodness of designed model at states that designed model is valid for the further investigation.

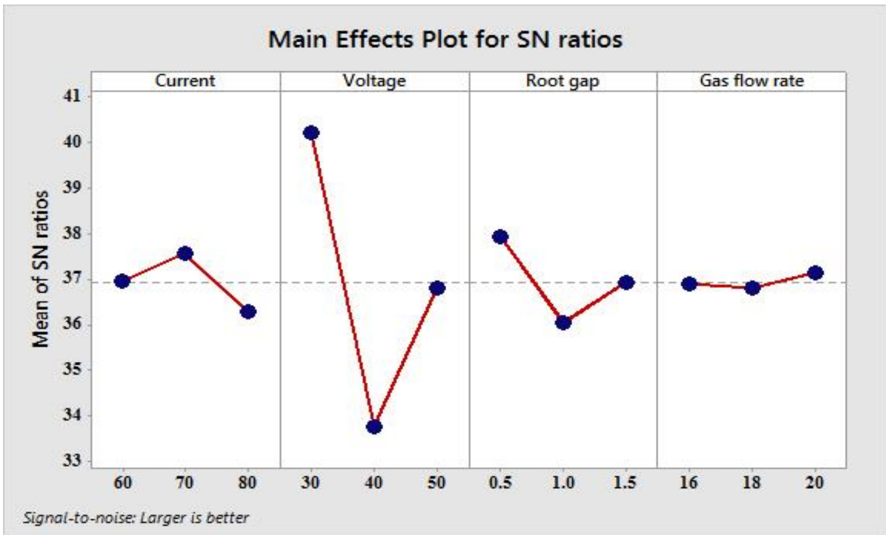

Fig. 3. Main effects plot for SN ratios for strength property

Table 6

Response table for S/N ratio of bending strength

Level	Current	Voltage	Root Gap	Gas flow rate
1	36.94	40.20	37.94	36.88
2	37.55	33.76	36.04	36.79
3	36.29	36.81	36.92	37.13
Delta	1.25	6.44	1.90	0.34
Rank	3	1	2	4

Table 7

Analysis of variance for bending strength

Source	DOF	Adj SS	Adj MS	F-Value	P-Value
Linear	4	3755.3	938.82	85.66	0.000
I	1	52.5	52.55	4.79	0.049
V	1	744.8	744.84	67.96	0.000
R	1	13.8	13.84	1.26	0.283
G	1	2.9	2.92	0.27	0.615
Square	4	5389.0	1347.25	122.93	0.000
I*I	1	303.4	303.43	27.69	0.000
V*V	1	577.1	577.15	52.66	0.000
R*R	1	8.1	8.07	0.74	0.408
G*G	1	3.5	3.46	0.32	0.584

Interaction	6	405.8	67.63	6.17	0.004
I*V	1	38.8	38.67	3.53	0.085
I*R	1	76.3	76.35	6.97	0.022
I*G	1	10.5	10.48	0.96	0.347
V*R	1	93.7	93.72	8.55	0.013
V*G	1	4.7	4.68	0.43	0.526
R*G	1	5.1	5.06	0.46	0.510
Residual Error	12	131.5	10.96		
Lack of fit	11	130.1	11.83	8.48	0.262
Pure error	1	1.4	1.39		
Total	26	14518.3			
R-sq = 99.09		**R- sq (adj) = 98.04**			

3.3. Regression analysis by RSM

Using the experimental results quadratic model was established for the hardness and bend strength with 95% of confidence level. As the hardness (H) and bend strength (B) are the function of welding current (I), Voltage (V), Root gap (R) and Gas flow rate (G), so it can be mathematically expressed as:

$$\mathrm{H} = f\,(\mathrm{I, V, R, G}) \tag{12}$$

$$\mathrm{B} = f\,(\mathrm{I, V, R, G}) \tag{13}$$

The quadratic regression equation that represents the response surface 'H' and 'B' is:

$$H = -391 + 12.97I + 1.14V - 36.6R + 0.9G - 0.0891I*I - 0.1156V*V + 37.0R*R + 0.069G*G + 0.1023I*V - 3.039I*R - 0.0230I*G + 3.25V*R - 0.0942V*G + 1.883R*G \tag{14}$$

$$B = -202 + 28.25I - 36.10V + 54.6R - 1.0G - 0.1993I*I + 0.2724V*V + 12.9R*R + 0.203G*G + 0.1172I*V - 3.29I*R - 0.0518I*G + 4.29V*R - 0.0395V*G - 0.82R*G \tag{15}$$

Equation 14 and 15 showing the regression equation for hardness (H) and bend strength (B). The fig. 4 and 5 shows the interaction plot of process parameters and their effects on the response values (hardness and bending strength). These plots are 3D plots explains the behaviour of response values at various conditions of process parameters. The response surface plots shows variation in hardness and bending strength when each welding parameter moves from there reference point.

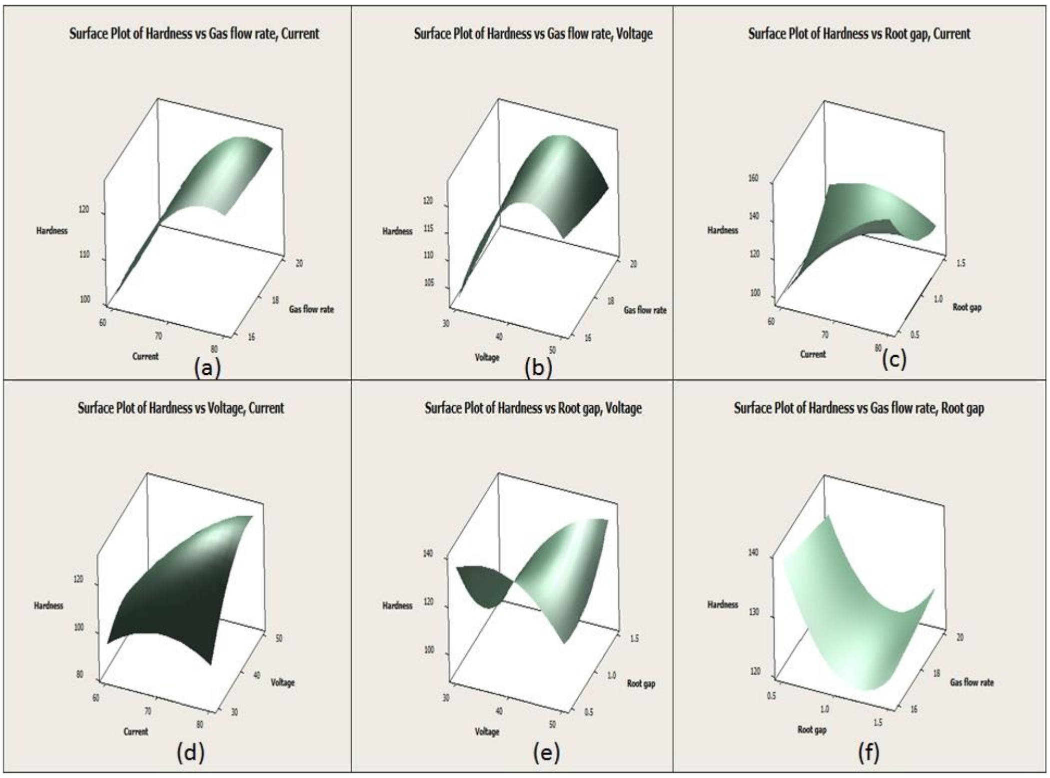

Fig. 4. 3D plot for hardness value

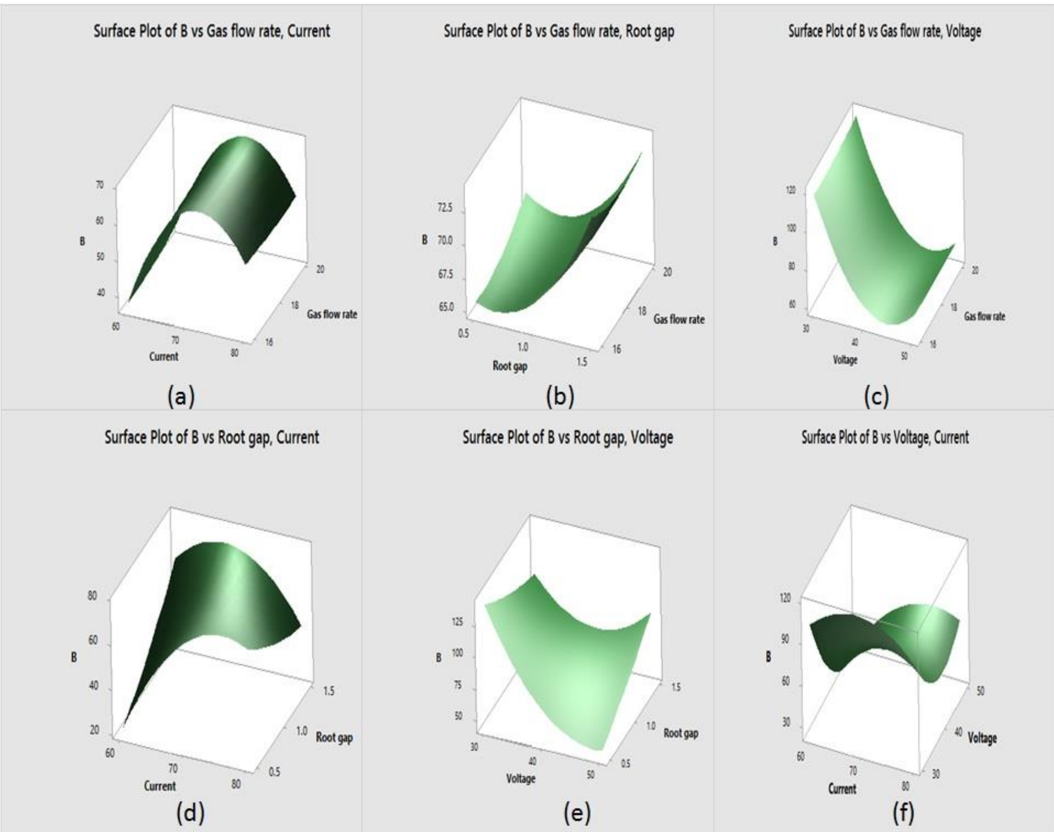

Fig. 5. 3D plot for bending strength

4. Conclusion

The present investigation developed an empirical relationship between input parameters and the response values at 95% of confidence level. The main effect plot shows that for the response value (both hardness and bending strength) the voltage parameter is most **effective** parameter. The **highest hardness** has been obtained at 70 A (2nd level of current), 50 V (3rd level of voltage), 0.5 mm (1st level of root gap) and 16 litter/min (1st level of gas flow rate). Whereas, the **highest bend strength** was found at 2nd level of current, 1st level of voltage, 1st level of root gap and 3rd level of gas flow rate. It is evident from ANOVA results that, voltage is most influencing factor for changing the mechanical properties of welded joints.

A regression relation was developed by the help of RSM and 3D plot was designed. 3D graph is showing the interactive effect of process parameters on the response values.

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