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RESEARCH ARTICLE OPEN ACCESS

Sensitivity Analysis of Process Parameters In Cladding of Stainless Steel By Gmaw

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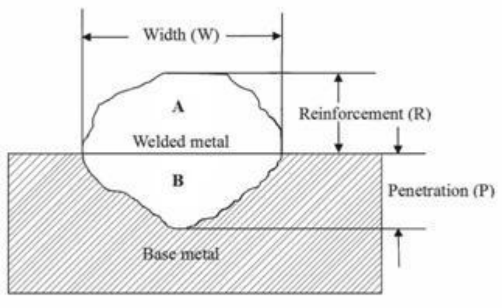
Abstract:
To improve the corrosion resistant properties of carbon steel usually cladding process is used. It is a process of depositing a thick layer of corrosion resistant material over carbon steel plate. Most of the engineering applications require high strength and corrosion resistant materials for long term reliability and performance. By cladding these properties can be achieved with minimum cost. The main problem faced on cladding is the selection of optimum combinations of process parameters for achieving quality clad and hence good clad bead geometry.
In this study Sensitivity analysis was performed to identify various input process parameters (welding current, welding speed, gun angle, contact tip to work distance and pinch) exerting most influence in stainless steel cladding of low carbon structural steel plates using Gas Metal Arc Welding (GMAW) and the bead geometry. Experiments were conducted based on central composite rotatable design with full replication technique and mathematical models were developed using multiple regression method. The developed models have been checked for adequacy and significance. Studies reveal that a change in process parameters affects bead geometry.
Key words: Mathematical model, cladding, GMAW, Sensitivity Analysis, Clad bead geometry, corrosion.

I. INTRODUCTION

Prevention of corrosion is a major problem in Industries. Even though it cannot be eliminated completely it can be reduced to some extent. A corrosion resistant protective layer is made over the less corrosion resistant substrate by a process called cladding. This technique is used to improve life of engineering components but also reduce their cost. This process is mainly now a day's used in industries such as chemical, textiles, nuclear, steam power plants, food processing and petro chemical industries [1]. Most accepted method of employed in weld cladding is GMAW. It has got the following advantages [2].

High reliability
All position capability Ease to use
Low cost
High Productivity
Suitable for both ferrous and non-ferrous metals
High deposition rate

Absences of fluxes
Cleanliness and ease of mechanization
The mechanical strength of clad metal is highly influenced by the composition of metal but also by clad bead shape. This is an indication of bead geometry. Fig 1 shows the clad bead geometry. It mainly depends on wire feed rate, welding speed, arc voltage etc. Therefore it is necessary to study the relationship between the process parameters and bead parameters to study clad bead geometry. Using mathematical models it can be achieved. This paper highlights the study carried out to develop mathematical and Sensitivity models to optimize clad bead geometry, in stainless steel cladding deposited by GMAW. The experiments were conducted based on four factor five level central composite rotatable designs with full replication technique [3]. The developed models have been checked for their adequacy and significance. Again sensitivity analysis was performed to identify various input parameters exerting influence on the bead parameters.



Percentage dilution (D) = [B/ (A+B)] X 100
Fig 1. Clad bead geometry

II. EXPERIMENTAL PROCEDURE

The following machines and consumables were used for the purpose of conducting experiments.

1) A constant current gas metal arc welding machine (Invrtee V 350 – PRO advanced processor with 5 – 425 amps output range)
2) Welding manipulator.
3) Wire feeder (LF – 74 Model).
4) Filler material Stainless Steel wire of 1.2mm diameter (ER – 308 L).
5) Gas cylinder containing a mixture of 98% argon and 2% of oxygen.
6) Mild steel plate (grade IS – 2062).

Test plates of size 300 x 200 x 20mm were cut from mild steel plate of grade IS – 2062 and one of the surfaces is cleaned to remove oxide and dirt before cladding. ER- 308 L stainless steel wire of 1.2mm diameter was used for depositing the clad beads through the feeder. Argon gas at a constant flow rate of 16 litres per minute was used for shielding.

The properties of base metal and filler wire are shown in Table 1. The important and most difficult parameter found from trial run is wire feed rate. The wire feed rate is proportional to current. Wire feed rate must be greater than critical wire feed rate to achieve pulsed metal transfer. The relationship found from trial run is shown in equation (1). The formula derived is shown in Fig 2.

$$\textit{Wire feed rate} = 0.96742857 * \textit{current} + 79.1 \quad (1)$$

The selection of the welding electrode wire based on the matching the mechanical properties and physical characteristics of the base metal and weld size [4]. A candidate material for cladding which has excellent corrosion resistance and weldability is stainless steel. These have chloride stress corrosion cracking resistance and strength significantly greater than other materials. These have good surface appearance, good radiographic standard quality and minimum electrode wastage. Experimental design procedure used for this study is shown in Fig 3 and importance steps are briefly explained.

Table 1. Chemical Composition of Base Metal and Filler Wire

	Elements, Weight %								
Materials	C	SI	Mn	P	S	Al	Cr	Mo	Ni
IS 2062	0.150	0.160	0.870	0.015	0.016	0.031	-	-	-
ER308L	0.03	0.57	1.76	0.021	1.008	-	19.52	0.75	10.02

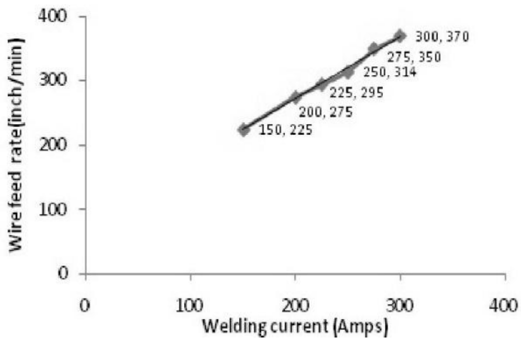


Fig.2. Relationship between Current and Wire Feed Rate

III. PLAN OF INVESTIGATION

The research work was planned to be carried out in the following steps [5]:

1) Identification of factors and responses.
2) Finding limits of process variables.
3) Development of design matrix.
4) Conducting experiments as per design matrix.
5) Recording the responses.
6) Development of mathematical models.
7) Checking the adequacy of developed models.
8) Conducting conformity tests.

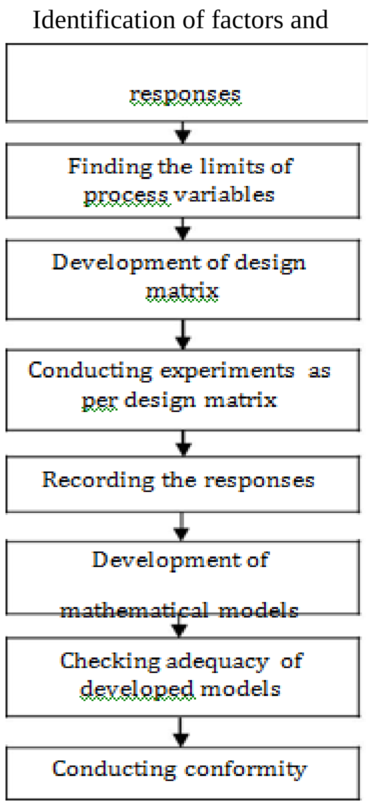


Fig.3. Experimental design procedure

3.1. Identification of factors and responses

The following independently controllable process parameters were found to be affecting output parameters. These are wire feed rate (W), welding speed (S), welding gun angle (T), contact tip to work to distance (N) and pinch (Ac), The responses chosen were clad bead width (W), height of reinforcement (R), Depth of Penetration.
(P) and percentage of dilution (D). The responses were chosen based on the impact of parameters on final composite model.
The basic difference between welding and cladding is the percentage of dilution. The properties of the cladding are significantly influenced by dilution obtained. Hence control of dilution is important in cladding where a low dilution is highly desirable. When dilution is quite low, the final deposit composition will be closer to that of filler material and hence corrosion resistant properties of cladding will be greatly improved. The chosen factors have been selected on the basis to get minimal dilution and optimal clad bead geometry.
Few significant research works have been conducted in these areas using these process parameters and so these parameters were used for experimental study.

3.2. Finding the limits of process variables

Working ranges of all selected factors are fixed by conducting trial runs. This was carried out by varying one of factors while keeping the rest of them as constant values.
At each run settings for all parameters were disturbed and reset for next deposit. This is very essential to introduce variability caused by errors in experimental set up.

Table 2. Welding Parameters and their Levels

Parameters	Unit	Notation	Factor Levels				
			-2	**-1**	**0**	**1**	**2**
Welding Current	A	1	200	225	250	275	300
Welding Speed	mm/min	S	150	158	166	174	182
Contact tip to work distance	mm	N	10	14	18	22	26
Welding gun Angle	Degree	T	70	80	90	100	110
Pinch	-	Ac	-10	-5	0	5	10

Parameters were decided upon by inspecting the bead for smooth appearance without any visible defects. The upper limit of given factor was coded as -2. The coded value of intermediate values was calculated using the equation (2).

= ―――――――― (2)

Where X_i is the required coded value of parameter X is
any value of parameter from $X_{min} - X_{max}$. X_{min} is the lower limit of parameters and X_{max} is the upper limit parameters
[4].
The chosen level of the parameters with their units and notation are given in Table 2.

3.3. Development of design matrix

Design matrix chosen to conduct the experiments was central composite rotatable design. The design matrix comprises of full replication of 2^5(= 32), Factorial designs. All welding parameters in the intermediate levels
(o) Constitute the central points and combination of each welding parameters at either is highest value (+2) or lowest value (-2) with other parameters of intermediate levels (0) constitute star points. 32 experimental trails were conducted that make the estimation of linear quadratic and two way interactive effects of process parameters on clad geometry [5].

3.4. Conducting experiments as per design matrix

The experiments were conducted at SVS College of Engineering, Coimbatore,India. In this work, thirty two experimental runs were allowed for the estimation of linear quadratic and two-way interactive effects of

3.5. Recording of Responses

In order to measure clad bead geometry of transverse section of each weld overlays were cut using band saw from mid length. Position of the weld and end faces were machined and grinded. The specimen and faces were polished and etched using a 5% nital solution to display bead dimensions. The clad bead profiles were traced using a reflective type optical profile projector at a magnification of X10, in M/s Roots Industries Ltd. Coimbatore. Then the bead dimension such as depth of penetration height of reinforcement and clad bead width were measured [6]. The traced bead profiles were scanned in order to find various clad parameters and the percentage of dilution with help of AUTO CAD software. This is shown in Fig 4.

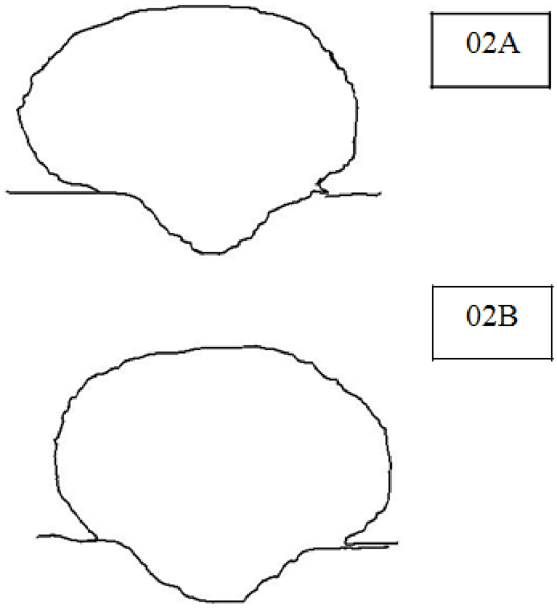


Fig.4. Traced Profiles (Specimen No.2)

02A represents profile of the specimen (front side) and
02B represents profile of the specimen (rear side). The measured clad bead geometry is shown in Table 3.

Table 3. Design Matrix and Observed Values of Clad Bead Geometry

Trial No.	**Design Matrix**					**Bead Parameters**			
	I	**S**	**N**	**T**	**Ac**	**W (mm)**	**P (mm)**	**R (mm)**	**D (%)**
1	-1	-1	-1	-1	1	6.9743	1.67345	6.0262	10.72091
2	1	-1	-1	-1	-1	7.6549	1.9715	5.88735	12.16746
3	-1	1	-1	-1	-1	6.3456	1.6986	5.4519	12.74552
4	1	1	-1	-1	1	7.7635	1.739615	6.0684	10.61078
5	-1	-1	1	-1	-1	7.2683	2.443	5.72055	16.67303
6	1	-1	1	-1	1	9.4383	2.4905	5.9169	15.96692
7	-1	1	1	-1	-1	6.0823	2.4672	5.49205	16.5894
8	1	1	1	-1	-1	8.4666	2.07365	5.9467	14.98494
9	-1	-1	-1	1	-1	6.3029	1.5809	5.9059	10.2749
10	1	-1	-1	1	1	7.0136	1.5662	5.9833	9.707297
11	-1	1	-1	1	1	6.2956	1.58605	5.5105	11.11693
12	1	1	-1	1	-1	7.741	1.8466	5.8752	11.4273

13	-1	-1	1	1	1	7.3231	2.16475	5.72095	15.29097
14	1	-1	1	1	-1	9.6171	2.69495	6.37445	18.54077
15	-1	1	1	1	-1	6.6335	2.3089	5.554	17.23138
16	1	1	1	1	1	10.514	2.7298	5.4645	20.8755
17	-2	0	0	0	0	6.5557	1.99045	5.80585	13.65762
18	2	0	0	0	0	7.4772	2.5737	6.65505	15.74121
19	0	-2	0	0	0	7.5886	2.50455	6.4069	15.77816
20	0	2	0	0	0	7.5014	2.1842	5.6782	16.82349
21	0	0	-2	0	0	6.1421	1.3752	6.0976	8.941799
22	0	0	2	0	0	8.5647	3.18536	5.63655	22.94721
23	0	0	0	-2	0	7.9575	2.2018	5.8281	15.74941
24	0	0	0	2	0	7.7085	1.85885	6.07515	13.27285
25	0	0	0	0	-2	7.8365	2.3577	5.74915	16.63287
26	0	0	0	0	2	8.2082	2.3658	5.99005	16.38043
27	0	0	0	0	0	7.9371	2.1362	6.0153	15.18374
28	0	0	0	0	0	8.4371	2.17145	5.69895	14.82758
29	0	0	0	0	0	9.323	3.1425	5.57595	22.8432
30	0	0	0	0	0	9.2205	3.2872	5.61485	23.6334
31	0	0	0	0	0	10.059	2.86605	5.62095	21.55264
32	0	0	0	0	0	8.9953	2.72068	5.7052	19.60811

W - Width; P - Penetration; R - Reinforcement; D - Dilution %

3.6. Development of Mathematical Models

The response function representing any of the clad bead geometry can be expressed as [7, 8, 9],

$$Y = f(A, B, C, D, E) \qquad (3)$$

where, Y = Response variable
A = Welding current (I) in amps
B = Welding speed (S) in mm/min
C = Contact tip to Work distance (N) in mm
D = Welding gun angle (T) in degrees
E = Pinch (Ac)

The second order surface response model equals can be expressed as below

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_4 D + \beta_5 E + \beta_{11} A^2 + \beta_{22} B^2 + \beta_{33} C^2 + \beta_{44} D^2 + \beta_{55} E^2 + \beta_{12} AB + \beta_{13} AC + \beta_{14} AD + \beta_{15} AE + \beta_{23} BC + \beta_{24} BD + \beta_{25} BE + \beta_{34} CD + \beta_{35} CE + \beta_{45} DE \qquad (4)$$

Where, β_0 is the free term of the regression equation, the coefficient $\beta_1,\beta_2,\beta_3,\beta_4$ and β_5 is are linear terms, the coefficients β_{11},β_{22}, β_{33},β_{44} and $ß_{55}$ quadratic terms, and the coefficients $\beta_{12},\beta_{13},\beta_{14},\beta_{15}$,etc are the interaction terms. The coefficients were calculated using Quality America six sigma software (DOE – PC IV). After determining the coefficients, the mathematical models were developed. The developed mathematical models are given as follows.

Clad Bead Width (W), mm = 8.923 + 0.701A +0.388B + 0.587C + 0.040D + 0.088E – 0.423A^2 – 0.291B^2 – 0.338C^2 – 0.219D^2 – 0.171E^2 + 0.205AB + 0.405AC + 0.105AD+ 0.070AE – 0.134BC + 0.225BD + 0.098BE +
0.26 CD + 0.086 CE + 0.012 DE. (5)

Depth of Penetration (P), mm = 2.735 + 0.098A – 0.032B + 0.389C – 0.032D – 0.008E – 0.124A^2– 0.109B^2
– 0.125C^2 – 0.187D^2 – 0.104E^2 – 0.33AB + 0.001 AC + 0.075AD + 0.005 AE – 0.018BC + 0.066BD + 0.087BE +
0.058CD + 0.054CE – 0.036DE. (6)

Height of Reinforcement (R), mm = 5.752 + 0.160A – 0.151B – 0.060C + 0.016D – 0.002E + 0.084A^2+ 0.037B^2
– 0.0006C^2 + 0.015D ^{2} – 0.006E^2 + 0.035AB + 0.018AC – 0.008AD – 0.048AE – 0.024BC – 0.062BD – 0.003BE +
0.012CD – 0.092CE – 0.095DE. (7)

Percentage Dilution (D), % = 19.705 + 0.325A + 0.347B + 3.141C – 0.039D – 0.153E – 1.324A^2 – 0.923B^2
– 1.012C^2 – 1.371D^2 – 0.872E^2 – 0.200AB + 0.346 AC + 0.602 AD + 0.203 AE + 0.011BC + 0.465BD + 0.548 BE
+ 0.715 CD + 0.360CE + 0.137DE. (8)

3.7. Checking the adequacy of the developed models

The adequacy of the developed model was tested using the analysis of variance (ANOVA) technique. As per this technique, if the F – ratio values of the developed models do not exceed the standard tabulated values for a desired level of confidence (95%) and the calculated R – ratio values of the developed model exceed the standard values for a desired level of confidence (95%) then the models are said to be adequate within the confidence limit [10]. These conditions were satisfied for the developed models. The values are shown in Table 4.

Table 4. Analysis of variance for Testing Adequacy of the Model

Parameter	1st Order terms		2nd order terms		Lack of fit		Error terms		F-ratio	R-ratio	Whether model is adequate
	SS	DF	SS	DF	SS	DF	SS	DF			
W	36.889	20	6.233	11	3.513	6	2.721	5	1.076	3.390	Adequate
P	7.810	20	0.404	11	0.142	6	0.261	5	0.454	7.472	Adequate
R	1.921	20	0.572	11	0.444	6	0.128	5	2.885	3.747	Adequate
D	506.074	20	21.739	11	6.289	6	15.45	5	0.339	8.189	Adequate

SS - Sum of squares; DF - Degree of freedom; F Ratio (6, 5, 0.5) = 3.40451; R Ratio (20,5,0.05) = 3.20665

IV. SENSITIVITY ANALYSIS FOR BEAD GEOMETRY

From the above developed mathematical equations 5-8 to be used for the estimation of bead geometry, sensitivity equations obtained by differentiating them with respect to the process parameters of interest such as welding current (I), welding speed (S), contact tip to work distance (N), welding gun angle (T) and pinch (Ac).Mathematical models shown in Equations 9-12.

W= 8.923+ 0.701*I+ 0.388*S+0.587*N+ 0.040*T+ 0.088*P - 0.423*I*I – 0.291*S*S- 0.338*N*N-0.219*T*T - 0.171* P*P+ 0.205I*S + 0.405*I*N+ 0.105*I*P+ 0.070I*P - 0.134Xp - 0.134x5*N+ 0.225*T+ 0.0985*P + 0.26 N*T+ 0.086 N*P+ 0.015*P

P = 2.735+ 0.098*I - 0.032*S + 0.389*N-0.032*T - 0.008*P- 0.124*I*I - 0.109*S*S- 0.125*N*N - 0.187*T*T - 0.171*P*P- 0.33*I*S+ 0.001*I*N+ 0.075*I*T+ 0.005*I*P- 0.018*S*N+ 0.066*S*T+ 0.087*S*P+ 0.058*N*T+ 0.054N*P- 0.036T*P (10)

R=5.572+ 0.160*I – 0.151*S- 0.060*N+ 0.016T- 0.002*P+ 0.084*I*I+0.037*S*S- 0.0006*N*N+ 0.015*T*T-0.006*P*P+ 0.035I*S+ 0.018I*N- 0.008*I*T- 0.048*I*P- 0.024*S*N- 0.062*S*N- 0.062*S*T- 0.005S*P+ 0.012N*T- 0.092N*P- 0.095T*P (11)

D = 19.75+ 0.325*I+ 0.34*S+3.141*N- 0.039*T- 0.153*P-1.324*I*I-0.925*S*S-1.012*N*N-1.371*T*T- 0.872*P*P- 0.200 I*S-1.346 I*N+ 0.602 I*T- 0.048I*P+ 0.011S*N+ 0.46TS*T+ 0.548*S*P+ 0.715*N*T+ 0.360N*P - 0.137*T*P (12)

From the above developed Mathematical equations 9-12 to be used for the estimating bead geometry. The sensitivity equations are obtained by differentiating the equations with respect to the process parameters of interest, Such as welding current (1), welding speed (S), Contact tip to work distance (N), welding gun angle (T), Pinch (Ac)[11]. The sensitivity equation for welding current obtained by differentiating equations 9-12 with respect to welding current(I) are given below:

=0.701 - 0.423*2*I+ 0.205* S+ 0.405*N+ 0.105*T+ 0.070*P (13)

=0.098- 0.12*2*I – 0.335*S+ 0.001*N+ 0.075*T+ 0.005*P (14)

=0.160+ 0.084*2*I + 0.35* S+ 0.018 *N - 0.008*T - 0.048* P (15)

= 0.325-1.32*4*2*I–200*S+ 0.346*N+ 0.602*T- 0.045* P (16)

Sensitivity equation for welding speed were obtained by differentiating equations 9-12 with respect to welding speed(S) and are given below:

= 0.388 - 0.291*2*S + 0.205*S - 0.134* N + 0.225* T + 0.098* P (17)

The sensitivity equations for contact tip to work distance were obtained by differentiating equation 9-12 with respect to contact tip to work distance (N) are given below.

= 0.587 + 0.358*2*N + 0.405*I - 0.134*S + 0.26*T + 0.086*P (21)

= 0.389 - 0.125*2*N + 0.001*I - 0.018* S + 0.058 *T + 0.054* P (22)

= -0.60 - 0.0006*2*N + 0.018* I - 0.062* S + 0.012* T -0.092*P (23)

=0.389-0.250*N+0.001*I-+0.054*P (24)

The sensitivity equation for Welding gun angle were obtained by differentiating equations 9-12 with respect to Welding gun angle (N) are given below:

= 0.040 - 0.219*2*T + 0.105 *I + 0.225* S + 0.26 *N + 0.01 *P (25)

= -0.032 - 0.187*2*T + 0.075 *I + 0.066* S + 0.058 *N - 0.036 *P (26)

= 0.061 S - 0.015*2*T - 0.008* I - 0.062*S - 1.012 *N - 0.095* P (27)

= -0.039 – 1.371*2*T + 0.602 *I + 0.46 *T* S + 0.715* N + 0.137* P (28)

The sensitivity equations for Pinch were obtained by differentiating equations 9-12 with respect to pinch (Ac) given below:

= 0.088 - 0.171*2 P + 0.070* I + 0.985*S + 0.086*N + 0.01* T (29)

= 0.32 - 0.109*2*S - 0.33* I - 0.081*N + 0.066*T+ 0.087 *P (18)

= 0.151 + 0.03*2*S + 0.03 T*I - 0.024*N - 0.062*N - 0.062* T - 0.003*P (19)

= 0.34 - 0.923*2*S - 0.200 *I + 0.011* N + 0.465 *T - 0.548* P (20)

= -0.008 - 0.171*2*P + 0.005* I + 0.087 *S + 0.054* N - 0.036 *T (30)

= -0.002 - 0.006*2*P - 0.048* I - 0.003 *S - 0.075 *N - 0.095* T (31)

= - 0.153 - 0.872*2*P - 0.048 8I+ 0.548* S + 0.360*N + 0.1375*T (32)

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Table 5. Bead width sensitivity of process parameters

Welding speed (S) =166, Welding gun angle (T) = 90, Pinch (Ac)= 0, contact tip to work distance (N) =18.

Welding current	—	—	—	—	—
(-2) 200	2393	0.388	-0.225	-0.170	-0.052
(-1) 225	1.547	0.388	0.182	-0.055	-0.018
(0) 250	0.701	0.388	0.587	0.040	0.088
(1) 275	-0.145	0.388	0.992	0.145	0.158
(2) 300	-0.991	0.388	1.387	0.250	0.228

Table 6. Depth of penetration sensitivities of process parameters

Welding speed (S) = 166, Contact tip to work distance
(N)= 18, Welding gun angle(T) = 90, Pinch(Ac) = 0

Welding current	—	—	—	—	—
200	.594	-.628	-.391	-.182	-.018
225	.346	-.298	.390	-.109	-013
250	.098	-.032	.389	.032	.008
275	-.150	-.362	.388	+.042	.003
300	-.398	-.692	-.387	.118	.002

Table 7. Reinforcement sensitivities of process parameters

Welding speed (S)= 166, Contact tip to work distance (N) =18,Welding gun angle(T)= 90, Pinch(Ac) = 0

Welding current	—	—	—	—	—
200	-.176	-.221	-.096	-.044	0.094
225	-.008	-186	-.078	-.014	0.046
250	.160	-.151	-.066	.016	-.002
275	.328	-.116	-.042	.040	-.050
300	.496	-.081	-.024	.076	-.098

Table 8. Dilution sensitivities of process parameters

Welding speed(S) =166, Contact to tip distance (N) =18, Welding gun angle (T) =90, Pinch (Ac) =0

Welding current	$\frac{dD}{dS}$	$\frac{dD}{dI}$	$\frac{dD}{dN}$	$\frac{dD}{dT}$	$\frac{dD}{dV}$
200	.740	5.661	2.449	-1.243	-.057
225	.540	2.993	2.795	-.641	-.105
250	.340	.325	3.141	-.391	-.153
275	.140	-2.363	3.487	.563	-.201
300	-.060	-5.011	3.831	1.165	-.249

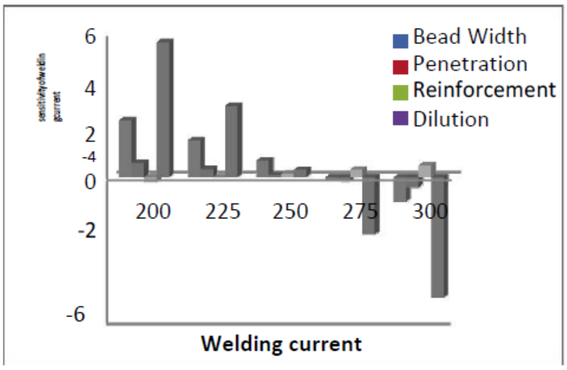

Fig.5. Sensitivity Analysis of Welding current on Bead width, Penetration, Reinforcement, Dilution S=166, N=18, T=90, Ac=0

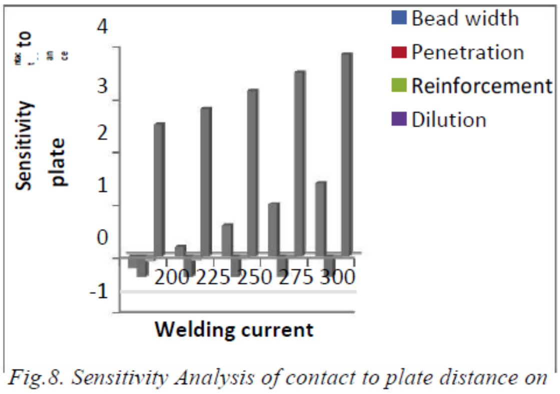

Fig.8. Sensitivity Analysis of contact to plate distance on Bead width, Penetration, Reinforcement, Dilution S=166, N=18, T=90, Ac=0

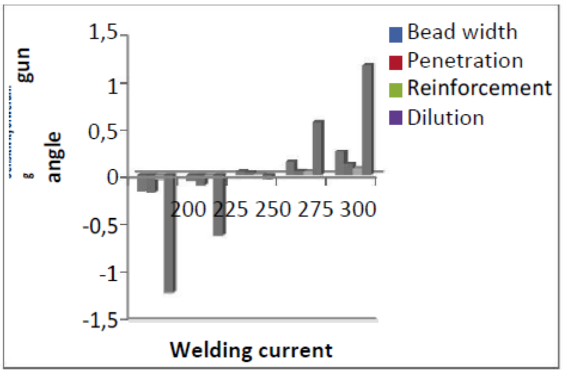

Fig.6. Sensitivity Analysis of Welding gun angle on Bead width,Penetration,Reinforcement,Dilution S=166,N=18,T=90,Ac=0

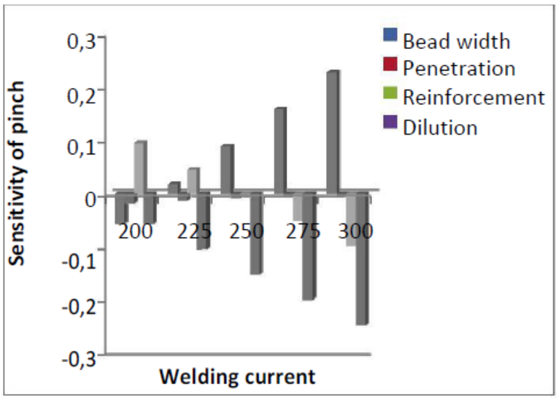

Fig.9. Sensitivity Analysis of pinch on Bead width,Penetration,Reinforcement,DilutionS=166, N=18, T=90,Ac=0

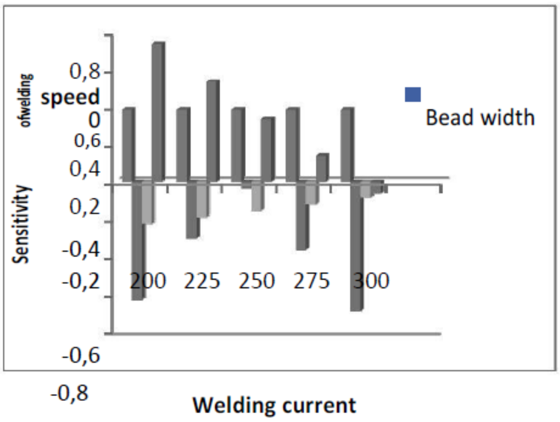

Fig.7. Sensitivity Analysis of Welding speed on Bead width, Penetration, Reinforcement, Dilution S=166, N=18, T=90, Ac=0

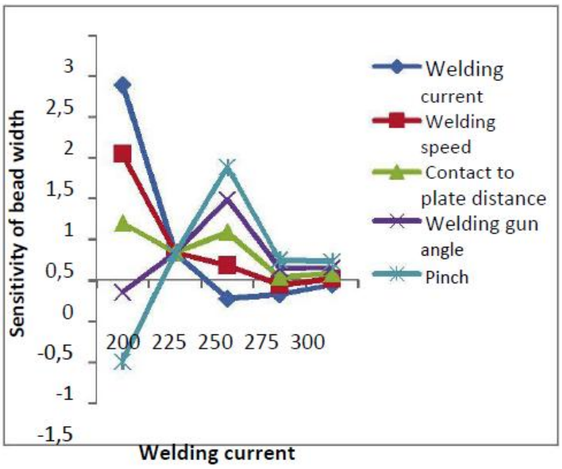

Fig.10. Sensitivity of Bead width

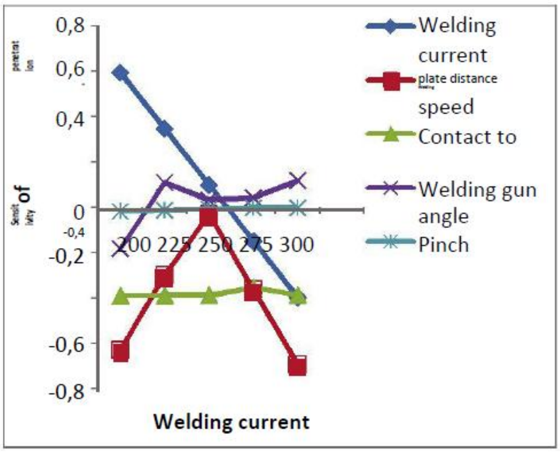

Fig.11. Sensitivity of penetration

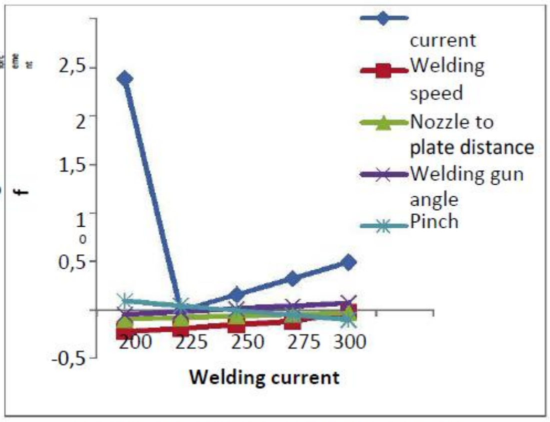

Fig.12. Sensitivity of Reinforcement

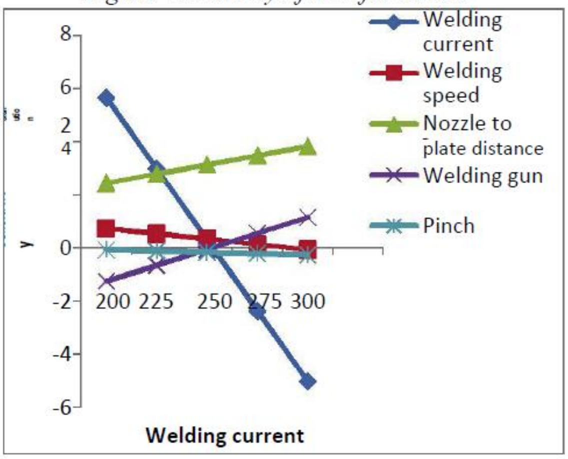

Fig.13. Sensitivity of dilution

V. RESULTS AND DISCUSSION

5.1. Sensitivities of welding current on bead geometry.

They are presented in Table 5-8 and are shown in Fig 5-9.Fig 5 shows sensitivity of welding current on weld bead geometry viz bead width, penetration, reinforcement, dilution. Of all welding parameters dilution is more sensitive to welding current than others. When welding current is constantly increased beyond 200 amps; the dilution changes to negative value. When welding current increased; penetration goes on decreasing. It is interesting to note that bead width decreasing in regular manner with the increasing in welding current. With the increasing in welding current reinforcement becomes positive.

5.2. Sensitivity of welding speed on bead geometry

Fig 7 depicts the sensitivity of welding speed on weld bead geometry. It is evident from the figure that dilution remains less sensitive to welding speed and it is almost constant at slight changes of welding speed. Reinforcement is gradually increasing to positive value when welding speed is increased.

5.3. Sensitivity of contact to plate distance on weld geometry

Fig 8 shows the sensitivity of contact to plate distance on weld bead geometry; the percentage of dilution is more sensitive to contact to plate distance. Variation in contact to plate distance shows a considerable change in dilution. When contact to plate distance is increased bead width gradually increased. The penetration remains unchanged and reinforcement has no considerable effect on contact to plate distance.

5.4. Sensitivity of welding gun angle on weld bead geometry

Fig 6 shows with increasing in welding gun angle the bead width becomes positive. The same happens with penetration also. With increase in welding gun angle penetration becomes positive. With increase in welding angle the dilution is increasing gradually. The dilution is more sensitive than other parameters.

5.5. Sensitivity of pinch on bead geometry

Fig 9 shows the sensitivity of pinch on. With the bead geometry increase in pinch bead width is increasing in a constant manner and it is more sensitive than other parameters. With the decreasing of pinch the dilution becomes negative. The penetration first decreases and then becomes constant throughout.

VI. CONCLUSION

Experiments were conducted using GMAW to produce cladding on austenitic stainless steel material. From the experimental results a mathematical model was developed using regression models, which were checked for their accuracy and found to be satisfactory.

Sensitivity analysis was performed to identify process parameters exerting the most influence on bead geometry. The change in welding current has more significant effect on bead geometry than welding speed. Percentage of dilution can be easily controlled with minimal change in the value of N, while the other parameters are kept at desired level.

Height of reinforcement is more sensitive to changes in welding speed than other process parameters .Hence it is reasonable to control the welding speed to get desired reinforcement.

Figures 10-13 shows some typical sensitivity plots. From these figures it can be observed that sensitivity of penetration is more prominent for changes in welding current, whereas changes in sensitivity of dilution and bead width are prominent changes in contact to plate distances compared to changes in welding current and welding speed.

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