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Optimization of Weld Bead Geometry in Gas Metal Arc Cladded Austenitic Stainless Steel Plates Using Genetic Algorithm

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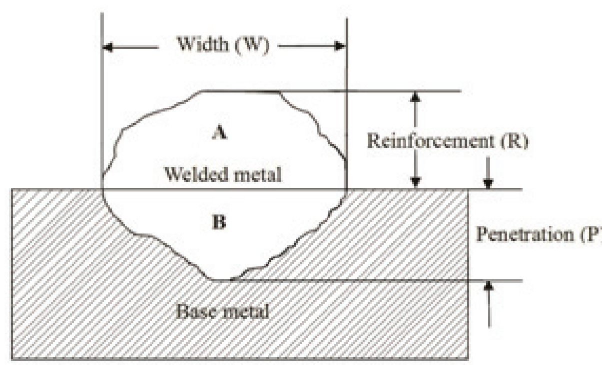
Abstract **– Gas metal arc welding (GMAW) process has attracted increasing attention in industry because of high reliability, easiness in operation, high penetration good surface finish and high productivity. The quality of gas metal arc welding (GMAW) components depends on weld bead geometry and dilution. Cladding process, this is widely used in industries for preventing corrosion. For cladding GMAW process, is mostly used. For economising the operation bead geometry and dilution must be optimized. These objectives can be achieved by developing mathematical equations using multiple regression analysis. The experiments were conducted based on a five factor five level central composite rotatable design matrix. A genetic algorithm (GA) was developed to optimize various process parameters for achieving desired weld bead geometry.**

Keywords: **GMAW, Weld bead geometry, GA**

I. Introduction

Gas metal arc welding (GMAW) process finds wide industrial application due to high reliability, easiness in operation, high penetration and good surface finish. The process is mainly characterized by multiple process parameters influencing multiple performance outputs such as percent of dilution and bead geometry[1]. The quality of a weld depends on mechanical properties of the weld metal which in turn depends on metallurgical characteristics and chemical composition of the weld. The mechanical and metallurgical feature of weld depends on bead geometry which is directly related to welding process parameters. In other words quality of weld depends on in process parameters. GMA welding is a multi objective and multifactor metal fabrication technique. The process parameters have a direct influence on bead geometry.

Figure 1 shows the clad bead geometry. Mechanical strength of clad metal is highly influenced by the composition of metal but also by clad bead shape [2]. This is an indication of bead geometry. It mainly depends on wire feed rate, welding speed, arc voltage etc. Therefore it is necessary to study the relationship between in process parameters and bead parameters to study clad bead geometry. This paper highlights the study carried out to optimize process parameters in stainless steel cladding deposited by GMAW using genetic algorithm[3].



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

II. Experimentation

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

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.

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

The selection of the welding electrode wire based on the matching the mechanical properties and physical characteristics of the base metal, weld size and existing electrode inventory [4]. A candidate material for cladding which has excellent corrosion resistance and weld ability 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 used for this study is shown in Fig 3 and importance steps are briefly explained.

Table I 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

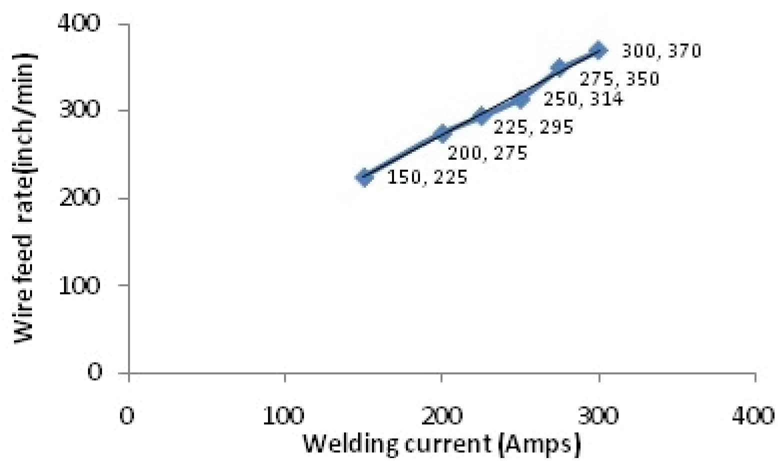


Fig.2. Relationship between Current and Wire Feed Rate

III. Plan of Investigation

The research work is carried out in the following steps [5] .Identification of factors, finding the limit of process variables, development of design matrix, conducting experiments as per design matrix, recording responses, application of MINITAB 15 and genetic algorithm for optimizing the parameters.

A. *Identification of Factors and Responses*

The basic difference between welding and cladding is the percentage of dilution. The properties of the cladding is the 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 [1]. These are wire feed rate (W), welding speed (S), welding gun angle (T), contact tip to work to The following independently controllable process parameters were found to be affecting output parameters 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.

B. ***Finding the Limits of Process Variables***

Working ranges of all selected factors are fixed by conducting trial run. This was carried out by varying one of factors while keeping the rest of them as constant values. Working range of each process parameters was 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 were calculated using the equation (2).

$$X_i = \frac{2[2X-(X_{max}+X_{min})]}{(X_{max}-X_{min})]} \qquad (2)$$

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.

Table II Welding Parameters and Their Levels

Parameters	Factor Levels						
	Unit	Notation	-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

C. ***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 (-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].

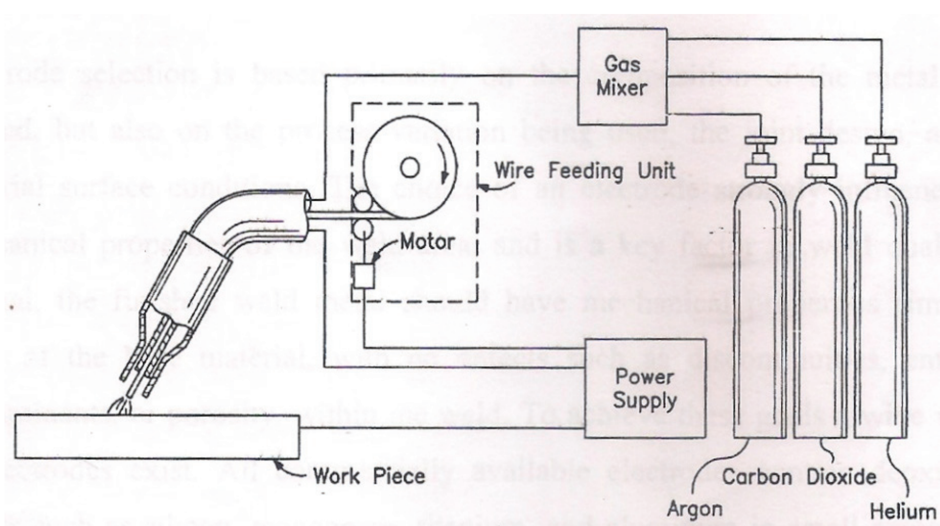


Fig.3. GMAW Circuit Diagram

D. Conducting Experiments as Per Design Matrix

In this work Thirty two experimental run were allowed for the estimation of linear quadratic and two-way interactive effects of correspond each treatment combination of parameters on bead geometry as shown Table III at random. 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. The experiments were conducted at SVS College of Engineering, Coimbatore, India.

E. Recording of Responses

For measuring the clad bead geometry, the transverse section of each weld overlays was 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 profiles traced using AUTO CAD software. This is shown in Fig 4. This represents profile of the specimen (front side).The cladded specimen is shown in Fig. 5. The measured clad bead dimensions and percentage of dilution is shown in Table III.

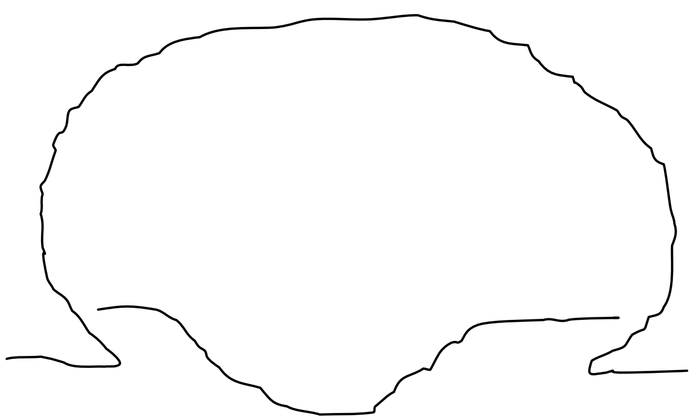


Fig.4. Traced Profile of bead geometry

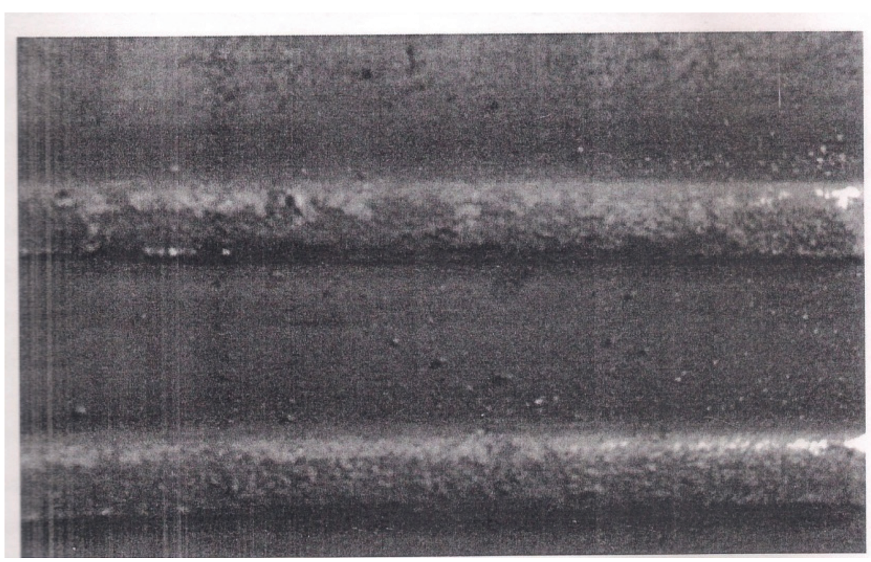


Fig.5 Cladded Specimen

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

F. Development of Mathematical Models

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

$$Y = f(A, B, C, D, E) \tag{3}$$

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 exp

$$Y = \beta_0 + \sum_{i=0}^{5} \beta_i X_i + \sum_{i=0}^{5} \beta_{ii} X_i^2 + \sum_{i=0}^{5} \beta_{ij} X_i X_j$$

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

Where, β_0 is the free term of the regression equation, the coefficient β_1, β_2, β_3, β_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 β_{12}, β_{13}, β_{14}, β_{15}, etc are the interaction terms. The coefficients were calculated by using MINITAB 15. After determining the coefficients, the mathematical models were developed. The developed mathematical models are given as follows.

$$\beta_o = 0.166338(\sum X_0 Y) + 0.05679(\sum\sum X_{ii} Y)) \tag{5}$$

$$\beta_i = 0.166338(\sum X_i Y) \tag{6}$$

$$\beta_{ii} = 0.0625((\sum X_{ii} Y) + 0.06889(\sum\sum X_{ii} Y) - 0.056791(\sum\sum X_0 Y)) \tag{7}$$

$$\beta_{ij} = 0.125(\sum X_{ij} Y) \tag{8}$$

Clad Bead Width (W), mm = $8.923 + 0.701A + 0.388B + 0.587C + 0.040D + 0.088E - 0.423A^2 - 0.291B^2 - 0.338C^2 - 0.219D^2 - 0.171E^2 + 0.205AB + 0.405AC + 0.105AD + 0.070AE - 0.134BC + 0.225BD + 0.098BE + 0.26CD + 0.086CE + 0.012DE$ (9)

Depth of Penetration (P), mm = $2.735 + 0.098A - 0.032B + 0.389C - 0.032D - 0.008E - 0.124A^2 - 0.109B^2 - 0.125C^2 - 0.187D^2 - 0.104E^2 - 0.33AB + 0.001AC + 0.075AD + 0.005AE - 0.018BC + 0.066BD + 0.087BE + 0.058CD + 0.054CE - 0.036DE$ (10)

Height of Reinforcement (R), mm = $5.752 + 0.160A - 0.151B - 0.060C + 0.016D - 0.002E + 0.084A^2 + 0.037B^2 - 0.0006C^2 + 0.015D^2 - 0.006E^2 + 0.035AB + 0.018AC - 0.008AD - 0.048AE - 0.024BC - 0.062BD - 0.003BE + 0.012CD - 0.092CE - DE$. (11)

Percentage Dilution (D), % = $19.705 + 0.325A + 0.347B + 3.141C - 0.039D - 0.153E - 1.324A^2 - 0.923B^2 - 1.012C^2 - 1.371D^2 - 0.872E^2 - 0.200AB + 0.346AC + 0.602AD + 0.203AE + 0.011BC + 0.465BD + 0.548BE + 0.715CD + 0.360CE + 0.137DE$ (12)

Co-efficient of the above polynomial equation where calculated by regression as given by equations (5) to (8)

G. Checking the Adequacy of the Developed Models

Analysis of variance (ANOVA) technique was used to test the adequacy of the model. 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 IV.

TABLE IV 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	3.51 3	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. Implementation Of Ga

The genetic algorithm (GA), a computerized search procedure, inspired by Darwin's theory of biological evolution, survival of the fittest, has been recognized as a general optimization method to produce global and robust solutions to optimization problems[11,12]. A random population with ten chromosomes was initially generated. The chromosomes generated were selected by using the Roulette wheel selection scheme and then the selected chromosomes were subjected to genetic operations, crossover, and mutation. We have employed single-point crossover in this work. The chromosomes were tested for acceptability of solutions. The generation was stopped when the end condition was satisfied. The procedure was repeated until the termination criterion was reached. In the present study, the termination criterion is the number of generations.

A. Evaluation of Fitness Function Values

The optimization of bead parameters was carried out by considering their respective mathematical equations as their objective functions [12]. The program was developed using MATLAB 7. It is desirable to minimize penetration and dilution and to maximize reinforcement and bead width. The fitness function was taken as the inverse of objective function for minimizing problems and the objective function itself was taken as the fitness function for maximizing problems.

B. Bounds

Table V The Bounds or Constraints Were Set to The Weld Parameters

Penetration	1.6 mm < P < 2.8 mm
Reinforcement	5.4 mm < R < 7.5 mm
Bead width	6.1 mm < W < 10 mm
Dilution	8 < %D < 23

For dilution, the constraints were applied based on the bounds of penetration, reinforcement, and bead width as mentioned above. Similarly, the constraints of other objective functions were based on the bounds of remaining weld parameters. Chromosomes not found within the bounds were not considered or eliminated. Bounds shown in Table V.

V. RESULTS AND DISCUSSION

In order to select the genetic algorithm parameters such as crossover probability, mutation probability, population size, chromosome length, and maximum number of generations, a parametric study was carried out[12]. The values of population size, chromosome length, and number of generations were taken as 10, 5, and 100, respectively, for all the bead geometry variables. Based on several test runs, the GA parameters were selected and optimization was carried out until the termination criterion was satisfied. The obtained results were also compared with the results obtained using MINITAB 15.

A. Minimization of Penetration

The cross over and mutation probability values were selected as 0.85 and 0.3, respectively, for the attempt on minimization of penetration. The results of generations for minimizing penetration using GA is 1.60 mm and the corresponding optimum process parameters are I=225 A, S=182 mm/min, N=26mm, T= 110degree, Ac=-10. The minimum penetration attained from optimization using MINITAB 15was 1.60 mm and the corresponding process parameters were same as GA.Fig.6 shows single based optimization plot for penetration using MINITAB 15.

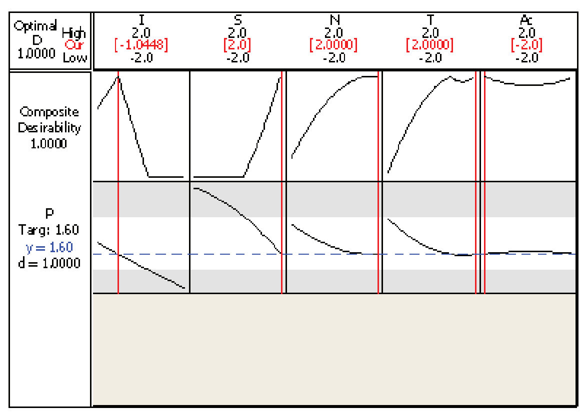


Fig. 6 Single based optimization plot for penetration

B. Maximization ofRreinforcement

The cross over and mutation probability values were selected as 0.85 and 0.28, respectively, for the study on maximization of reinforcement [12]. The maximum reinforcement obtained from GA is 7.3 mm and the predicted process parameters are I=182 A, S=146mm/min, N=24mm, T=100 degree and Ac=8.The maximum reinforcement attained using MINITAB 15 is 7.2875 and corresponding process parameters are I=200A, S=150mm/min, N=26mm, T=110 degree and ac=10. Fig. 7 shows single based optimization plot for reinforcement.

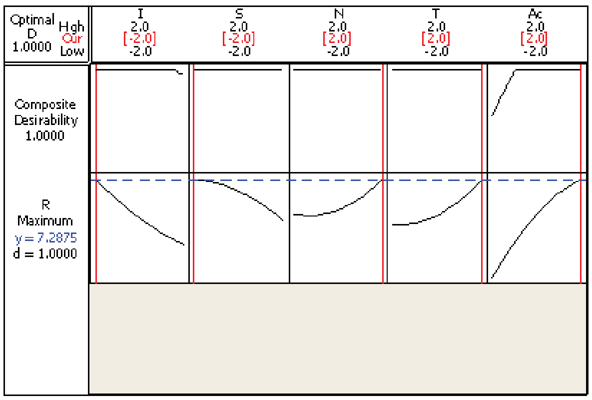


Fig.7. Single based optimization plot for reinforcement

C. Maximization of Bead Width

For the maximization of bead width, cross over and mutation probability values were selected as 0.89 and 0.23, respectively[12]. The maximum bead width that can be obtained using GA is 8.8972 mm and the corresponding process variables are I=300 A, S=150 mm/min, N=26 mm, T=70degree, Ac=-10 g. The maximum bead width that can be attained from optimization using MINITAB 15 is also 8.8972 mm with the same predicted values of process parameters. Fig 8 shows the GA results.

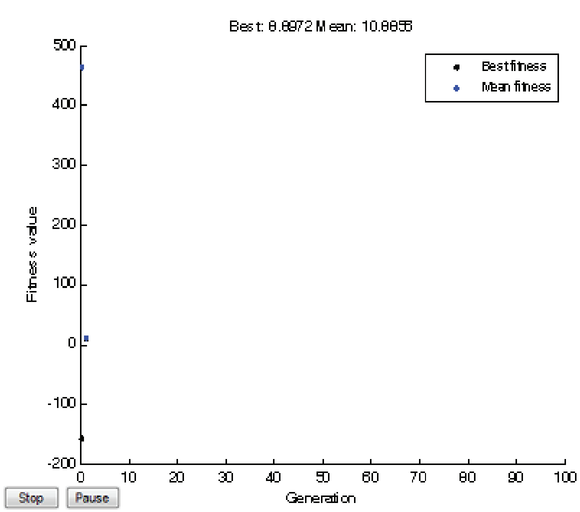


Fig.8 Generations against bead width

D. Minimization of Dilution

The cross over and mutation probability values were selected as 0.82 and 0.25, respectively, for the attempt on minimization of dilution. GA results for dilution with generations are shown in Fig 9. The minimum percentage of dilution that can be obtained is 11.7 and the corresponding process parameters are I=180 A, S=140 mm/min, N=20 mm, T=90degree and Ac=8 g/min. The minimum percentage of dilution that can be optimized using solver is 11.83 and the corresponding process parameters are I=200 A, S=150mm/min, N=26mm, T=100degree and Ac=10.

Ac=10.

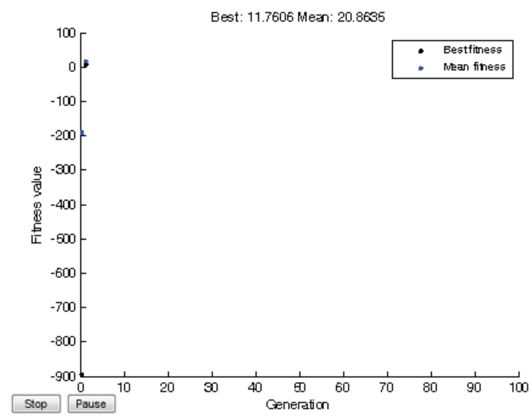


Fig.9 Generations against dilution

VI. Conclusion

Genetic algorithm was used to achieve optimal weld bead dimensions in an effective manner. In the case of gas metal arc welding process for cladding, bead geometry plays an important role in determining the properties of the surface exposed to the hostile environments and in reducing the cost of manufacturing. In this computational approach, the objective functions are aimed at minimizing penetration and dilution, and maximizing reinforcement and weld width. The results obtained from GA are better than the results obtained using MINITAB 15.

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