P, Sreeraj, T, Kannan, Subhasis Maji/ International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 3, Issue 1, January -February 2013, pp.1360-1373

Simulated annealing algorithm for optimization of welding variables for percentage of dilution and application of ANN for prediction of weld bead geometry in GMAW process.

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Abstract

This paper presents an integrated method with a new approach using experimental design matrix of experimental design techniques on experimental data available from conventional experimentation, application of neural network for predicting weld bead geometry and use of simulated annealing algorithm for optimizing percentage of dilution. Quality of weld is affected by large number of welding parameters .Modelling of weld bead geometry is important for predicting quality of weld.

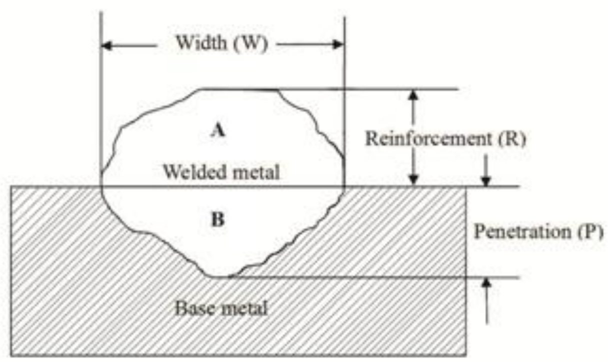
In this study an experimental work is conducted to optimize various input process parameters (welding current, welding speed, gun angle, contact tip to work distance and pinch) to get optimum dilution in stainless steel cladding of low carbon structural steel plates using Gas Metal Arc Welding (GMAW). 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. By using ANN models the welding output parameters predicted. Using Simulated annealing Algorithm (SA) the process parameters were optimized to get optimum dilution.

Key words: GMAW, Weld bead geometry, Multiple Regression, SA.

1. INTRODUCTION

Quality is a vital factor in today's manufacturing world. Quality can be defined as the degree of customer satisfaction. Quality of a product depends on how it performs in desired circumstances. Quality is a very vital factor in the field of welding. 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 [1]. 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.

Fig 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. This is an indication of bead geometry. It mainly depends on wire feed rate, welding speed, arc voltage etc [2]. 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 develop mathematical, ANN and SA models to predict and to optimize clad bead geometry, in stainless steel cladding deposited by GMAW.



Percentage dilution (D) = [B/(A+B)] X 100

Figure 1: Clad bead geometry

2. 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 [3]. 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.

Wire feed rate = 0.96742857 *current + 79.1 --------------------- (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 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

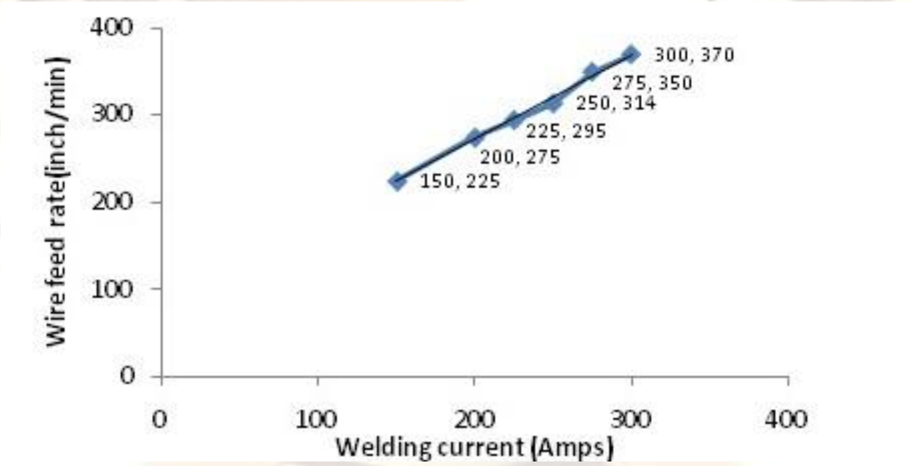


Figure 2: Relationship between Current and Wire Feed Rate

3. 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, development of mathematical models, checking adequacy of developed models, and predicting the parameters using ANN and optimizing the process parameters using GA.

3.1 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.

3.2 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)

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

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 2: 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

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 (-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].

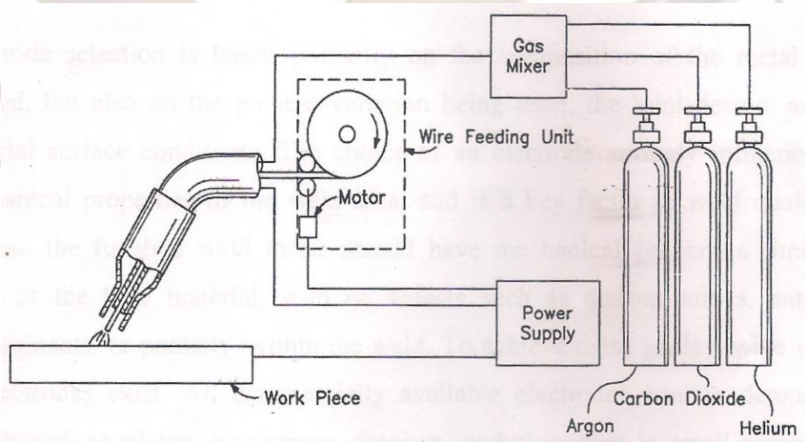


Figure 3: GMAW Circuit Diagram

Table 3: Design Matrix

Trial Number	Design Matrix				
	I	**S**	**N**	**T**	**Ac**
1	-1	-1	-1	-1	1
2	1	-1	-1	-1	-1
3	-1	1	-1	-1	-1
4	1	1	-1	-1	1
5	-1	-1	1	-1	-1
6	1	-1	1	-1	1
7	-1	1	1	-1	1
8	1	1	1	-1	-1
9	-1	-1	-1	1	-1
10	1	-1	-1	1	1
11	-1	1	-1	1	1
12	1	1	-1	1	-1
13	-1	-1	1	1	1
14	1	-1	1	1	-1
15	-1	1	1	1	-1
16	1	1	1	1	1
17	-2	0	0	0	0
18	2	0	0	0	0
19	0	-2	0	0	0
20	0	2	0	0	0
21	0	0	-2	0	0
22	0	0	2	0	0
23	0	0	0	-2	0
24	0	0	0	2	0
25	0	0	0	0	-2
26	0	0	0	0	2
27	0	0	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
30	0	0	0	0	0
31	0	0	0	0	0
32	0	0	0	0	0

I - Welding current; S - Welding speed; N - Contact tip to work distance; T - Welding gun angle; Ac – Pinch

3.4 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 3 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, 642109, India.

3.5 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 4.

Figure 4: Traced Profile of bead geometry

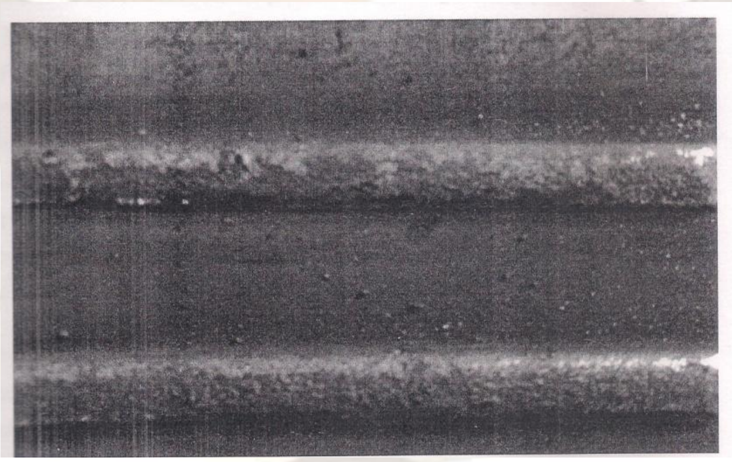


Figure 5: cladded specimen

Table 4: 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 %

3.6 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) -------------- (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

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

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

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

$\beta_i = 0.166338\ (\sum X_i Y)$ ------------ (6)

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

$\beta_{ij} = 0.125\ (\sum X_{ij} Y)$ -------------- (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 = $2.735 + 0.098A – 0.032B + 0.389C – 0.032D – 0.008E – 0.124A^2 – 0.109B^2 – 0.125C^2 – 0.187D^2 – 0.104E^2 – 0.33AB + 0.001 AC + 0.075AD + 0.005 AE – 0.018BC + 0.066BD + 0.087BE + 0.058CD + 0.054CE – 0.036DE$ ---------------------- (10)

Height of Reinforcement (R), mm = $5.752 + 0.160A – 0.151B – 0.060C + 0.016D – 0.002E + 0.084A^2 + 0.037B^2 – 0.0006C^2 + 0.015D^2 – 0.006E^2 + 0.035AB + 0.018AC – 0.008AD – 0.048AE – 0.024BC – 0.062BD – 0.003BE + 0.012CD – 0.092CE – 0.095DE$.------------------------(11)

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

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

3.7 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 5.

Table 5: 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

4. Artificial Neural Network

Artificial neural network models are generally comprised of three independent layers, input, hidden, and output. Each layer consists of several processing neurons. Each neuron in a layer operates in logical similarity. Information is transmitted from one layer to others in serial operations. The neurons in the input layer include the input values. Each neuron in the hidden layer processes the inputs into the neuron outputs. The pattern of hidden layers to be applied in the modelling can be either multiple layers or a single layer. The most widely used training algorithm for neural networks is the back-propagation algorithm [10].

The MLP is one of artificial neural networks that are extensively used to solve a number of different problems, including pattern recognition and interpolation. Each layer is composed of neurons, which are interconnected with each other in a previous layer by weights. In each neuron, a specific mathematical function called the activation function accepts a weighed sum of the outputs from a previous layer as the function's input, and generates the function's output. In the experiment, the hyperbolic tangent sigmoid transfer function [11] is used as the activation function. It is defined by

$$f(s) = \frac{1 - e^{-2s}}{1 - e^{-2s}}$$

Where S = $\sum_{i-1}^{n} wixi + b$, in which w_i are weights, x_i are inputs of neuron, b is bias and n is the number of variables.

The MLP is trained by using the Levenberg-Marquardt technique. This technique is more powerful than the conventional gradient descent technique [12].Neural network shown in Fig 6.

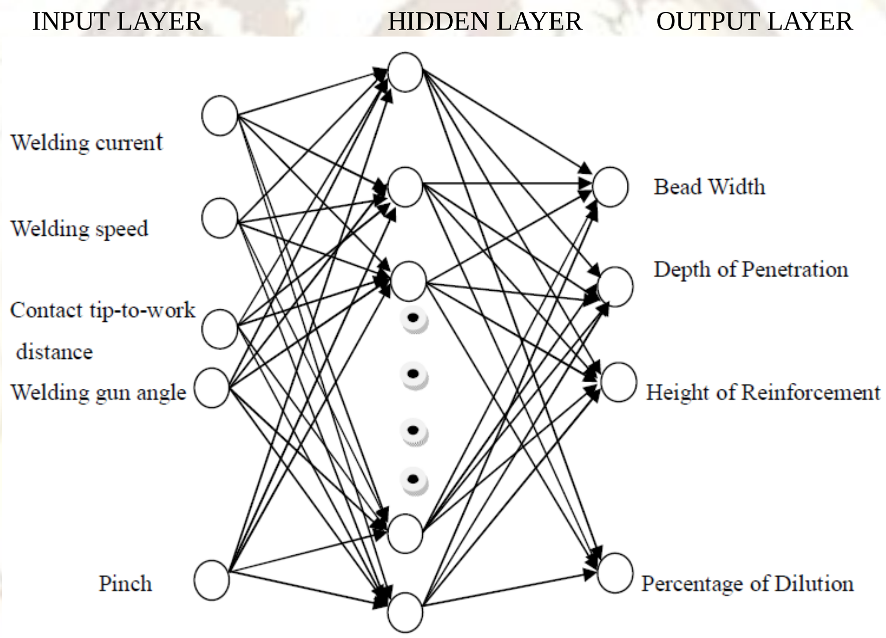


Fig. 6 Neural Network Architecture

MAT LAB 7 was used for training the network for the prediction of clad bead geometry. Statistical mathematical model was used compare results produced by the work. For normalizing the data the goal is to examine the statistical distribution of values of each net input and outputs are roughly uniform in addition the value should scaled to match range of input neurons [13]. This is basically range 0 to 1 in practice it is found to between 01 and 9 [12]. In this paper data base are normalized using the Equation (9) .Neural network shown in Fig 6.

$$X_{norm} = 0.1 + \frac{(X - X_{min})}{1.25\,(X_{\max} - (X_{min})} \quad .... (13)$$

X_{norm} = Normalized value between 0 and 1

X = Value to be normalized

X_{min} = Minimum value in the data set range the particular data set rage which is to be normalized.

X_{max} = Maximum value in the particular data set range which is to be normalized.

The accuracy of prediction may be decreased with the increase in the number of neurons in the hidden layer .in other words increase in number of neurons could not directly improve the capability of function approximation of network. In this study five welding process parameters were employed as input to the network. The Levenberg-Marquardt approximation algorithm was found to be the best fit for application because it can reduce the MSE to a significantly small value and can provide better accuracy of prediction [14]. So neural network model with feed forward back propagation algorithm and Levenberg-Marquardt approximation algorithm was trained with data collected for the experiment. Error was calculated using the equation (10).

$$\text{Error} = \frac{(Actual\ \ value - Predicted\ \ value\ )\ X\ 100}{Predicted\ \ value} \quad \text{....... (14)}$$

The difficulty using the regression equation is the possibility of over fitting the data. To avoid this the experimental data is divided in to two sets, one training set and other test data set [13] .The ANN model is created using only training data the other test data is used to check the behaviour the ANN model created. All variables are normalized using the equation (9).The data was randomized and portioned in to two one training and other test data.

$$y = \textstyle\sum_i w_{ij}\, \hbar_i + \theta \quad \text{.............................. (15)}$$

$$\hbar_i = \tanh\left(\textstyle\sum_j w_{ij}\, x_j + \theta_i\right) \quad \text{................ (16)}$$

Neural Network general form can be defined as a model shown above y representing the output variables and x_j the set of inputs, shown in equation [11, 12]. The subscript $_i$ represent the hidden units shown in Fig 6 and θ represents bias and w_j represents the weights. The above equation defines the function giving output as a function of input. Predicted data shown in table 6.First 11 data test set and next 17 data training data..

Table.6. Comparison of actual and predicted values of the clad bead parameters using neural network data (test)

Trial No	Actual Bead Parameters				Predicted Bead Parameters				Error			
	W (mm)	P (mm)	R (mm)	D (%)	W (mm)	P (mm)	R (mm)	D (%)	W (mm)	P (mm)	R (mm)	D (%)
1	6.9743	1.6735	6.0262	10.721	6.1945	1.85	5.9611	12.367	0.7798	-0.177	0.0651	-1.646
2	7.6549	1.9715	5.8873	12.167	7.1815	2.1507	6.5553	10.268	0.4734	-0.179	-0.668	1.899
3	6.3456	1.6986	5.4519	12.746	7.4954	1.5339	5.4923	9.3808	-1.15	0.1647	-0.04	3.3652
4	7.7635	1.7396	6.0684	10.611	6.4936	1.854	6.5573	9.4799	1.2699	-0.114	-0.489	1.1311
5	7.2683	2.443	5.7206	16.673	7.3354	2.6576	5.5657	19.104	-0.067	-0.215	0.1549	-2.431
6	9.4383	2.4905	5.9169	15.967	7.6066	2.1045	6.4342	18.49	1.8317	0.386	-0.517	-2.523
7	6.0823	2.4672	5.492	16.589	8.0417	2.1722	5.5126	16.874	-1.959	0.295	-0.021	-0.285
8	8.4666	2.0737	5.9467	14.985	8.3236	2.2349	5.9031	16.972	0.143	-0.161	0.0436	-1.987
9	6.3029	1.5809	5.9059	10.275	8.2381	1.7955	5.6022	11.219	-1.935	-0.215	0.3037	-0.944
10	7.0136	1.5662	5.9833	9.7073	7.5899	2.4579	6.542	13.415	-0.576	-0.892	-0.559	-3.708
11	6.2956	1.586	5.5105	11.117	7.7318	1.7647	5.8676	10.71	-1.436	-0.179	-0.357	0.407

4. SIMULATED ANNEALING ALGORITHM

Simulated annealing was originally inspired by formation of a crystal in solids during cooling. As discovered by long ago by Iron Age black smiths the slower cooling, the most perfect crystal is formed. By cooling complex physical systems naturally converge towards state of minimal energy. The systems move randomly, but probability to stay in a particular configuration depends directly on the energy of the system and on its temperature. Gibbs law stated as equation (17).

$$P = e^{\frac{E}{kT}} \text{.. (17)}$$

Where E stands for energy k is the Boltzmann constant and T is the temperature. The iteration of the simulated annealing consists of randomly choosing a new solution in the neighbourhood of actual solution. If the fitness function of the new solution is better than the fitness function of the current one the new solution is accepted as the new current solution. If the fitness function is not improved the new solution will be retained with probability shown in equation (18).

$$P = e^{\frac{-(f(y)-f(x))}{kT}} \text{... (18)}$$

Where f(y)-f(x) is the difference between new and old solution.

Simulated annealing behaves like a hill climbing method but with possibility of going downhill to avoid being trapped at local optima. When the temperature is high, the probability of deteriorating solution is quite important, and then a lot of large moves are possible to explore the search space. The more temperature decreases the more difficult to go to downhill, the algorithm tries to climb from the current solution to reach maximum. Usually simulated annealing starts from high temperature, which decreases exponentially .the slower cooling, the better it is to find good solutions. It has been demonstrated that with an infinitely slow cooling the algorithm is almost certain to find global optimum .the only point is that infinitely slow consists of finding the appropriate temperature decrease rate to obtain a good behaviour of the algorithm.

In this study Simulated Annealing (SA) which utilizes stochastic optimization is used for the optimization of clad bead geometry deposited by GMAW. The main advantage of using this stochastic algorithm is that global optimization point can be reached regardless of the initial starting point. Since the algorithm incorporates. The major advantage of SA is an ability to avoid being trapped at a local optimum point during optimization .The algorithm employs a random search accepting not only the changes that improve the objective function but also the changes that deteriorate it.Fig.7 shows simulated annealing algorithm.

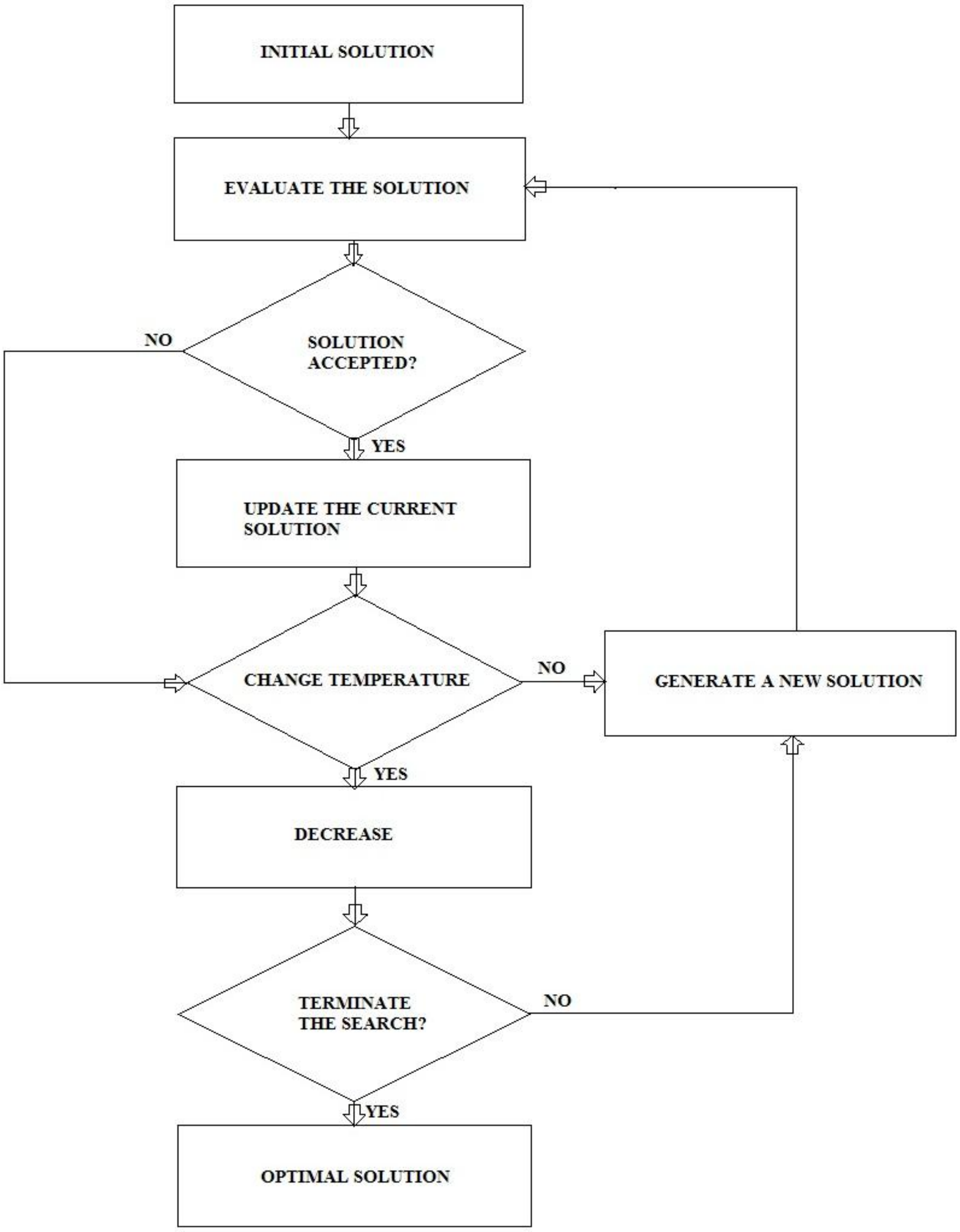


Fig. 7 Traditional Simulated Annealing Algorithm

Table 7 SA Search ranges

Parameters	Range
Welding current (I)	200 - 300 Amps
Welding Speed (S)	150 - 182mm/min
Contact tip to work distance(N)	10 - 26mm
Welding gun angle(T)	70 - 110deg
Pinch(Ac)	-10 - 10

5. OPTIMIZATION OF CLAD BEAD GEOMETRY USING SA.

The experimental data related to welding current(I), welding speed(S), welding gun angle(T), Contact tip to work distance(N) and pinch (Ac) is used in SASCBM (Simulated Annealing algorithm Stainless Steel clad bead geometry optimisation model) were obtained from the experiments conducted[15].

The aim of the study is to find optimum adjust welding current (I), welding speed (S), welding Gun angle (T), contact tip to work distance (N) and pinch (Ac) in a GMAW cladding process. The optimum parameters are those who deliver response, as close as possible of the cited values shown in Table 7. Table 8 shows the options used for study.

Table 8 Combination of SA Parameters Leading To Optimal Solution

Annealing Function	Boltzmann Annealing
Re annealing Interval	100
Temperature update Function	Exponential Temperature
Initial Temperature	100
Acceptance probability Function	Simulated Annealing Acceptance
Data Type	Double

The objective function selected for optimizing was percentage of dilution. The response variables bead width (W), Penetration (P), reinforcement (R) and Dilution (D) were given as constraint in their equation. The constrained non linear optimisation is mathematically stated as follows .

Minimize f(x)

Subject to f (X (1), X (2), X (3), X (4), X (5)) < 0

Optimization algorithm is becoming popular in engineering activities. They are extensively used in engineering problems where emphasizing maximizing or minimizing a goal. Importance of optimization is;

- Reducing wastage of material money and processing time.
- Decreases the fatigue of worker.
- Increased productivity.
- Satisfaction of employees and thereby increase of employee morale.

Simulated Annealing algorithms are nowadays popular tool in optimizing because SA uses only the values of objective function. The derivatives are not used in the procedure. Secondly the objective function values corresponding to a design vector plays the role of fitness in natural genetics. The aim of the study is to find the optimum adjusts for welding current, welding speed, pinch, welding angle, contact to tip distance. Objective function selected for optimization was percentage of dilution. The process parameters and their notation used in writing the programme in MATLAB 7 software are given below [15].

X (1) = Welding current (I) in Amps
X (2) = Welding Speed (S) in mm/min
X (3) = Contact to work piece distance (N) in mm
X (4) = Welding gun angle (T) in degree
X (5) = Pinch (Ac)

Objective function for percentage of dilution which must be minimized was derived from equation 9-12. The constants of welding parameters are given table 2

Subjected to bounds

$200 \leq X(1) \leq 300$

$150 \leq X(2) \leq 182$

$10 \leq X(3) \leq 26$
$70 \leq X(4) \leq 110$
$-10 \leq X(5) \leq 10$

5.1 Objective Function

f(x)=19.75+0.325*x(1)+0.347*x(2)+3.141*x(3)-0.039*x(4)-0.153*x(5)-1.324*x(1)^2-0.923*x(2)^2-1.012*x(3)^2-1.371*x(4)^2-0.872*x(5)^2-0.200*x(1)*x(2)+0.346*x(1)*x(3)+0.602*x(1)*x(4+0.203*x(1)*x(5)+ 0.011*x(2)*x(3) + 0.465*x(2)*x(4)+0.548*x(2)*x(5)+0.715*x(3)*x(4)+0.360*x(3)*x(5)+0.137*x(4)*x(5)…………(19)

(Which is the percentage of dilution),

5.2 Constraint Equations

W=(8.923+0.701*x(1)+0.388*x(2)+0.587*x(3)+0.040*x(4)+0.088*x(5)-0.423*x(1)^2-0.291*x(2)^2 0.338*x(3)^2-0.219*x(4)^2-0.171*x(5)^2+0.205*x(1)*x(2)+0.405*x(1)*x(3)+0.105*x(1)*x(4)+0.070*x(1)*x(5)-0.134*x(2)*x(3)+0.2225*x(2)*x(4)+0.098*x(2)*x(5)+0.26*x(3)*x(4)+0.086*x(3)*x(5)+0.12*x(4)*x(5)) -3…… .(20)

(Clad bead width (W) mm lower limit),

P=(2.735+0.098*x(1)-0.032*x(2)+0.389*x(3)-0.032*x(4)-0.008*x(5)-0.124*x(1)^2-0.109*x(2)^2-0.125*x(3)^2-0.187*x(4)^2-0.104*x(5)^2-0.33*x(1)*x(2)+0.001*x(1)*x(3)+0.075*x(1)*x(4)+0.005*x(1)*x(5)-0.018*x(2)*x(3)+0.066*x(2)*x(4)+0.087*x(2)*x(5)+0.058*x(3)*x(4)+0.054*x(3)*x(5)-0.036*x(4)*x(5))-3………………21)

(Depth of penetration (P) upper limit),

P=(2.735+0.098*x(1)-0.032*x(2)+0.389*x(3)-0.032*x(4)-0.008*x(5)-0.124*x(1)^2-0.109*x(2)^2-0.125*x(3)^2-0.187*x(4)^2-0.104*x(5)^2-0.33*x(1)*x(2)+0.001*x(1)*x(3)+0.075*x(1)*x(4)+0.005*x(1)*x(5)-0.018*x(2)*x(3)+0.066*x(2)*x(4)+0.087*x(2)*x(5)+0.058*x(3)*x(4)+0.054*x(3)*x(5)-0.036*x(4)*x(5))+2…....……..(22)

(Depth of penetration (P) lower limit),

W=(8.923+0.701*x(1)+0.388*x(2)+0.587*x(3)+0.040*x(4)+0.088*x(5)-0.423*x(1)^2-0.291*x(2)^2-0.338*x(3)^20.219*x(4)^20.171*x(5)^2+0.205*x(1)*x(2)+0.405*x(1)*x(3)+0.105*x(1)*x(4)+0.070*x(1)*x(5)+0.134*x(2)*x(3)+0.225*x(2)*x(4)+0.098*x(2)*x(5)+0.26*x(3)*x(4)+0.086*x(3)*x(5)+0.012*x(4)*x(5))-10……………………………………….(23)

(Clad bead width (W) upper limit),

R=(5.752+0.160*x(1)-0.151*x(2)-0.060*x(3)+0.016*x(4)-0.002*x(5)+0.084*x(1)^2+0.037*x(2)^2-0.0006*x(3)^2+0.015*x(4)^2-0.006*x(5)^2+0.035*x(1)*x(2)+0.018*x(1)*x(3)-0.008*x(1)*x(4)-0.048*x(1)*x(5)-0.024*x(2)*x(3)-0.062*x(2)*x(4)-0.003*x(2)*x(5)+0.012*x(3)*x(4)-0.092*x(3)*x(5)-0.095*x(4)*x(5))-6………. (24)

(Height of reinforcement (R) lower limit),

R=(5.752+0.160*x(1)-0.151*x(2)-0.060*x(3)+0.016*x(4)-0.002*x(5)+0.084*x(1)^2+0.037*x(2)^2-0.0006*x(3)^2+0.015*x(4)^2-0.006*x(5)^2+0.035*x(1)*x(2)+0.018*x(1)*x(3)-0.008*x(1)*X(4)-0.048*x(1)*x(5)-0.024*x(2)*x(3)-0.062*x(2)*x(4)-0.003*x(2)*x(5)+0.012*x(3)*x(4)-0.092*x(3)*x(5)0.095*x(4)*x(5))+6…………(25)

(Heights of reinforcement (R) upper limit),

f(x)-23……………………………….(26)

-f(x) +8………………………….. (27)

(Dilution Upper and lower limit),

x(1),x(2),x(3),x(4),x(5) ≤ 2; ....(28)

x(1),x(2),x(3),x(4),x(5) ≥ -2;...(29)

MATLAB program in SA and SA function was used for optimizing the problem. The program was written in SA and constraints bounds were applied. The minimum percentage of dilution obtained from the results obtained running the SA program.

X (1) = Welding current (I) = 1.8732Amps
X (2) = Welding Speed (S) = -.9801 mm/min
X (3) = Contact to work piece distance (N) = -1.0433 mm
X (4) = Welding gun angle (T) = 1.8922deg
X (5) = Pinch (Ac) = -1.8920

5.3 Optimal Process parameters

Table 9 Optimal Process parameters

Parameters	Range
Welding current (I)	200 Amps
Welding Speed (S)	155 mm/min
Contact tip to work distance(N)	10 mm
Welding gun angle(T)	86 deg
Pinch(Ac)	-5

5.4 Optimised Bead Parameters

Table 10 Optimal Bead parameters

Dilution (D)	2.7658%
Clad bead width (W)	1.952mm
Penetration (P)	1.017mm
Height of reinforcement(R)	5.11mm

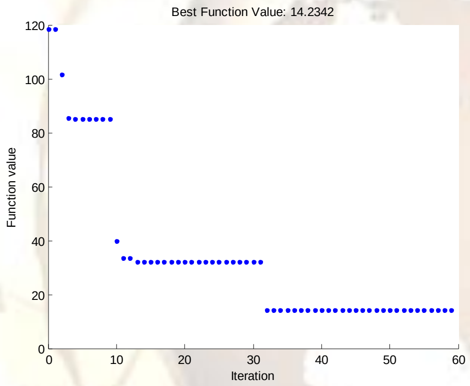


Fig 8 Best function value

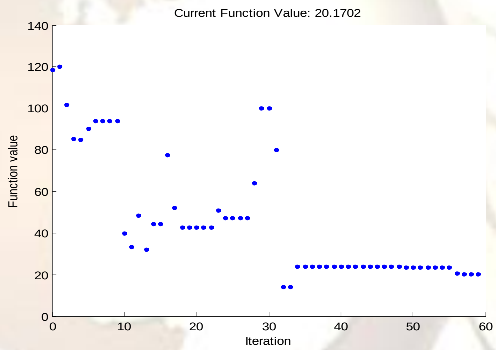


Fig. 9 Current function value

6. RESULTS AND DISCUSSIONS

1. A five level five factor full factorial design matrix based on central composite rotatable design technique was used for the mathematical development of model to optimize clad bead geometry of austenitic stainless steel deposited by GMAW.
2. Simulated Annealing algorithm tool available in MATLAB 7 software was efficiently employed for optimization of clad bead geometry. Table 9 and Table 10 shows optimal process and bead parameters
3. In cladding by a welding process clad bead geometry and dilution are very important for economising the material. This study effectively used SA to determine the cladding parameters to obtain optimum percentage of dilution and to predict bead geometry.
4. Increasing welding current increases depth of penetration and reducing percentage of dilution. This is because molten metal droplets transferring from electrodes to plate are strongly over heated and this extra heat contributes more melting of work piece as the current increased the temperature of droplets increases and consequently more heat is transferred to plate. The increase in penetration and decrease in dilution could be the result of enhanced arc force and heat input per unit length of clad bead resulting in higher current density causing melting larger volume of base metal and hence deeper penetration and reduced dilution.
5. Increase in welding speed increase in dilution. This is attributed to lesser heat input higher speeds.
6. Increase in angle resulted increasing depth of penetration and reduced dilution

8. CONCLUSIONS

Based on the above study it can be observed that the developed model can be used to predict clad bead geometry within the applied limits of process parameters. This method of predicting process parameters can be used to get minimum percentage of dilution. In this study ANN and SA was used for achieving optimal clad bead dimensions. In the case of any cladding process bead geometry plays an important role in determining the properties of the surface exposed to hostile environments and reducing cost of manufacturing. In this approach the objective function aimed for predicting weld bead geometry within the constrained limits.

ACKNOWLEDGEMENT

The authors sincerely acknowledge the help and facilities extended to them by the department of mechanical engineering SVS college of Engineering, Coimbatore, India.

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