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Optimization of process parameters of Stainless steel clad bead geometry deposited by GMAW using integrated SA-GA.

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Abstract

There are many established techniques such as Genetic Algorithm (GA), Simulated Annealing (SA),Taboo Search, (TS), Ant Colony Optimization (ACO).In this study GA and SA techniques are used for optimization purpose. 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. In order to achieve minimum cost the process parameters has to be optimized.

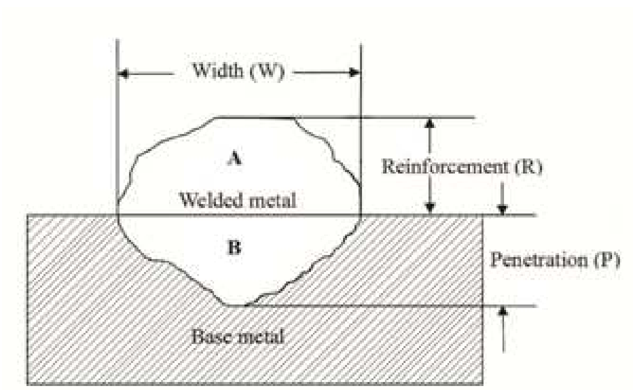
This paper highlights an experimental study to optimize various input process parameters (welding current, welding speed, gun angle, contact tip to work distance and pinch) to get optimum dilution in stainless steel cladding of low carbon structural steel plates using Gas Metal Arc Welding (GMAW). Experiments 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. In this study Simulated Annealing (SA) and Genetic Algorithm (GA) techniques are integrated to estimate optimal process parameters that to a minimum parameters that lead to optimum value of Dilution.

Key words: Mathematical model, cladding, GMAW, GA, SA, Clad bead geometry, corrosion.

1. Introduction

General problem faced by metallurgical industries is how to prevent corrosion. 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 many advantages [2] such as high reliability, low cost, easy to use etc. Nowadays in order to compete in the market industries have to reduce the cost of the product. to achieve this the process parameters have to be optimized to get minimum values.
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 optimize these process parameters to reduce cost. This paper highlights the study carried out to optimize the process parameters using SA, GA and integrated SA-GA.



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

Fig 1. Clad bead geometry

2. Experimental setup

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 – 2.425 amps output range).
3. Welding manipulator.
4. Wire feeder (LF – 74 Model).
5. Filler material Stainless Steel wire of 1.2mm diameter (ER – 308 L).
6. Gas cylinder containing a mixture of 98% argon and 2% of oxygen.
7. 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[3]. 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.

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	-	-	-
ER 308L	0.03	0.57	1.76	0.021	0.008	-	19.52	0.75	10.02

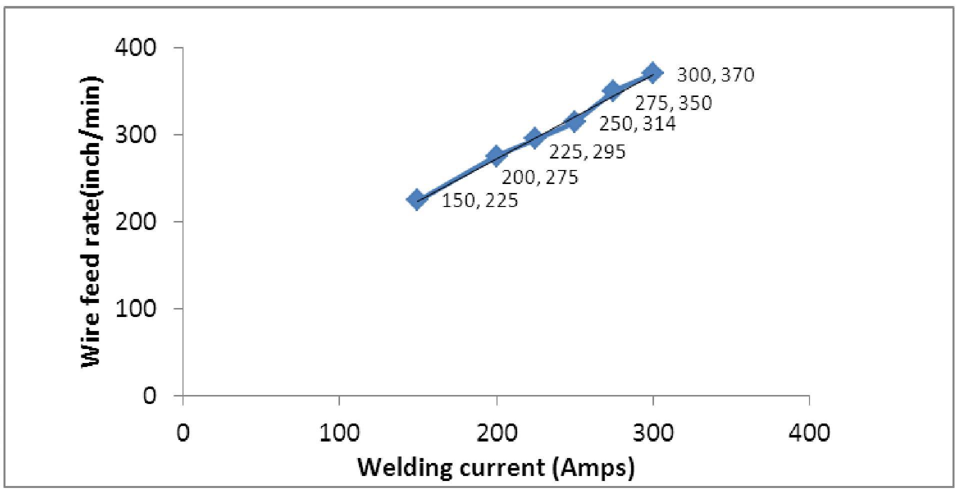


Fig 2 Relationship between Current and Wire Feed Rate

3. Plan of Investigation

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

1. Prediction of regression equation.
2. Optimization using Simulated Annealing.
3. Optimization using Genetic Algorithm.
4. Optimization using Integrated SA-GA Type A.
5. Optimization using Integrated SA-GA Type B.
6. Comparison of results.

3.1 Prediction of regression equation

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.

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)

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

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	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

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 [6].

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

The experiments were conducted at SVS College of Engineering, Coimbatore,642109,India. In this study Thirty two experimental run were allowed for the estimation of linear quadratic and two-way interactive effects of corresponding 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.

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 3.

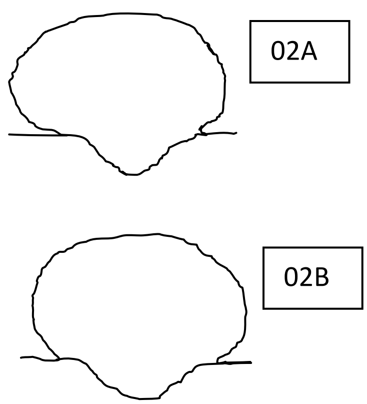


Fig. 3 Traced Profiles (Specimen No.2)

02A represents profile of the specimen (front side) and 02B represents profile of the specimen (rear side).

The measured clad bead dimension and percentage of dilution is shown in Table 4.

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

3.2 Development of Mathematical Models

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

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

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

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

Where, β_0 is the free term of the regression equation, the coefficient β_1,β_2,β_3,β_4 andβ_5 is are linear terms, the coefficients β_{11},β_{22}, β_{33},β_{44} andβ_{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.

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

3.3 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 5.

Table 5 Analysis of variance for Testing Adequacy of the Model

Parameter	1^{st} Order terms		2^{nd} 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

4. Methodology of optimization using integrated SA-GA

Following steps are used for the proposed integration system.
In the optimization of using GA, the predicted equation of the Regression defined as the optimization objective function. The constraints are defined as the minimum and maximum values process parameters obtained from experimental data. Based on this optimized value of percentage of dilution is obtained.
In the optimization using SA same above method is used .The process parameter values of the regression model will define the initial constraints which is required for SA optimization. Then percentage of dilution is optimized
Integrated SA-GA type-A which is the modified form GA optimization, proposed for this study. Similar to GA optimization the predicted model of regression equation would define the objective function. The constraints are obtained from the combined optimization results of process parameters of the SA and GA.
Integrated SA-GA type- B which is modified from SA, proposed for this study.

5. Optimization process

This section will discuss the process of optimization using GA, SA, and Integrated SA-GA Type -A, Integrated SA-GA Type B.

5.1 Simulated annealing algorithm optimization

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 (13).

$$P = e^{\frac{E}{kT}} \text{ ---------- (9)}$$

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 (14).

$$P = e^{\frac{-(f(y)-f(x))}{kT}} \text{ -------- (10)}$$

Where f(y)-f(x), being the difference between new and old solutions.

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.4 shows simulated annealing algorithm. [11]

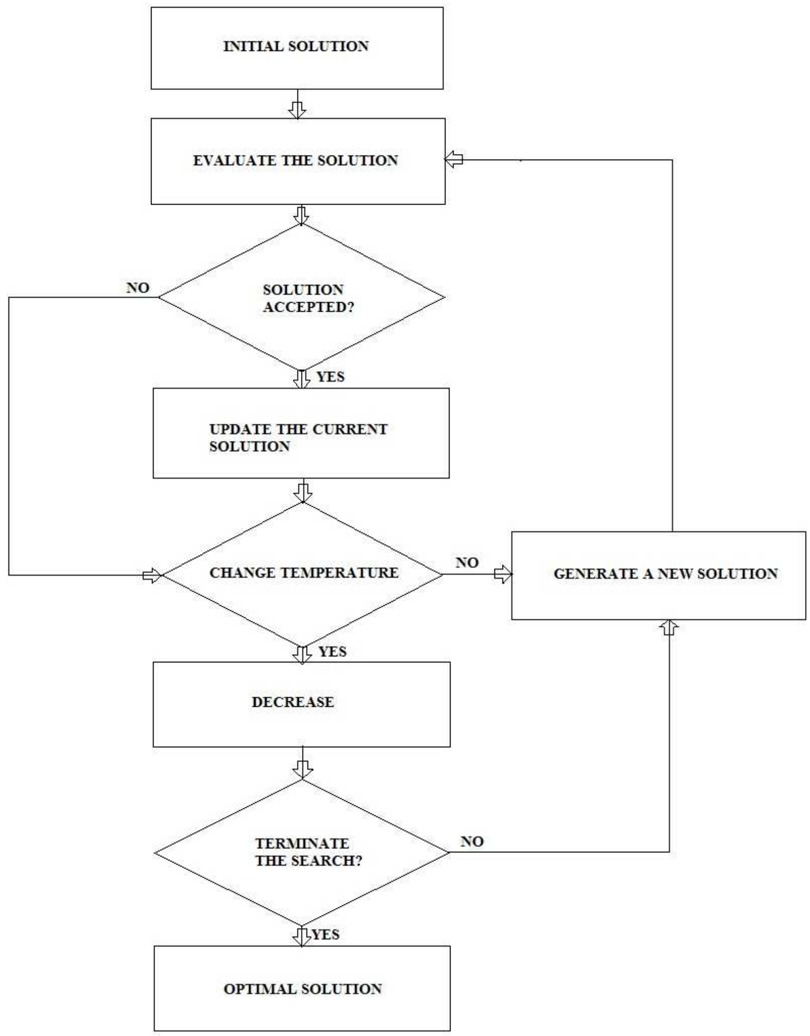


Fig. 4 Traditional Simulated Annealing Algorithm

5.2 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) are used in the experiments conducted [12].

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 6. Table 7 shows the options used for study.

Table 6 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

Table 7 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	SimulatedAnnealing 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

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 [13].

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 [14]

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

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

$10 \leq X(3) \leq 26$

$70 \leq X(4) \leq 110$

$-10 \leq X(5) \leq 10$

5.3 Objective Function [14]

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)^20.872*x(5)^20.200*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)
------------- (11)

5.4 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
------------ (12)

(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
----------- (13)

(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
-------------- (14)

(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
------------- (15)

(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
-------------- (16)

(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 --------------- (17)

(Heights of reinforcement (R) upper limit),

f(x)-23 --------------------(18)
-f(x) +8 ------------------ (19)

(Dilution Upper and lower limit),

x(1),x(2),x(3),x(4),x(5) ≤ 2; --------------- (20)
x(1),x(2),x(3),x(4),x(5) ≥ -2; -------------- (21)

MATLAB program in SA and SA function was used for optimizing the problem. The program was written inSA and constraints bounds were applied. The minimum percentage of dilution obtained from the results obtained running the SA program [15, 16].

X (1)=Welding current (I) = 0.2944Amps

X (2)=Welding Speed (S) = -1.3362 mm/min

X (3)=Contact to work piece distance (N) = 0.7143 mm

X (4)=Welding gun angle (T) = 1.6236deg

X(5) =Pinch(Ac) = -0.6918

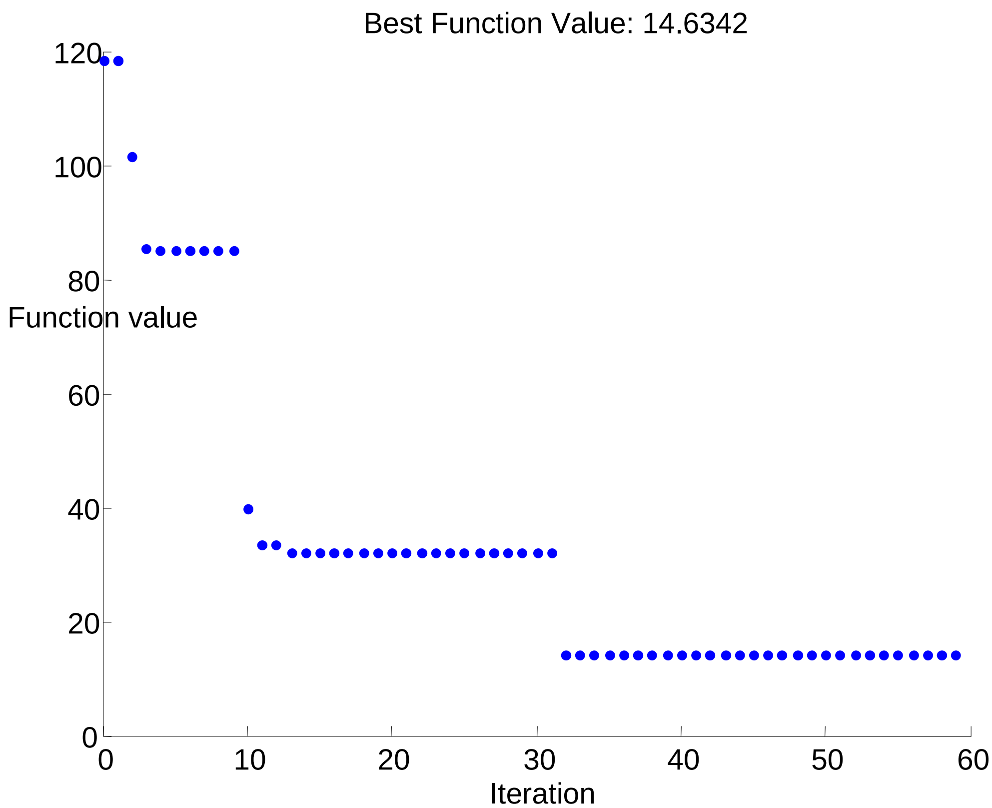


Fig 5 Fitness function plot for SA

As shown in fig 5 it was observed that minimum value of dilution is 14.6432 .The process parameters that lead to minimum value of dilution are welding current 257 Amps, Welding Speed 155 mm/min, contact tip to work distance 19.7mm,Welding gun angle 106,Pinch -4, respectively. The minimum iteration obtained is 59 in SA algorithm.

5.5. GENETIC ALGORITHM OPTIMIZATION

Genetic Algorithm is a Meta heuristic searching techniques, which mimics the principle of evaluation and natural genetics. These are guided random search which scans through entire sample space and therefore provide a reasonable solution. It was introduced by Holland (1975). It is also considered as a heuristic technique inspired by natural biological evolution process comprising selection, cross over mutation etc.

In biological population genetic information is stored in the form of binary strings. The basic process which affect the binary strings make up in natural evolution are selection, a crossover of genetic information between reproducing parents, a mutation of genetic information and an elitist strategy that keep the best individual to next generate. The main operations of GA are characterized a follows [17].

Selection is a method that randomly picks up chromosomes out of the population according to the evolution function. Higher the fitness function the more chance of an individual has to be selected. The selection pressure is defined as the degree to which the better individuals are favoured.

It takes two individuals and put their chromosome strings at some randomly chosen position to produce two head segments and two tail segments. The tail segments are then supposed over to produce two new full length chromosomes as shown in Fig 6. Two off spring each inherit some genes has each parent. This is known as single point cross over. Cross over is not usually applied to all pair of individuals selected or mating. A random choice is made where likelihood of cross over being appeared is typically between 6 and 10. If cross over is not applied off spring are produced the simply by duplicating the parents. This gives each individual a chance of passing on its genes without duplication of cross over.

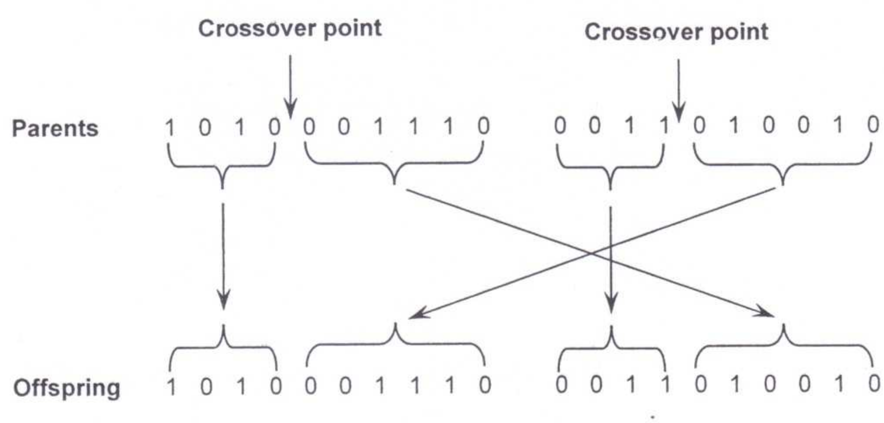


Fig.6Single – Point cross over

Mutation is applied to each child individually after cross over. It randomly alters each gene with small probability (typically .001) Table 6 Shows the fifth gene of a chromosome being mutated. Traditional view is that cross over is more important of the two techniques for rapidly exploring a search space. Mutation provides a small amount of random search and help, to ensure that no point in the space has zero probability of being examined. Two individuals reproducing to give two off spring in shown in Fig 6.

The fitness function is an exponential function of one variable with a maximum x = .2 is coded as a 10 bit binary number in table 7. Shows two parents as off spring they produce crossed over after second bit.

If Genetic Algorithm has been correctly implemented the population will evolve over successive generation so that fitness of the best and the average individual in each generation increases towards the global optimum. Convergence is the progression towards increasing uniformity. A gene is said to have converged when 95% of the population share the same value (Dejony 1975). The population is said to have converged when all of the genes have converged. Traditional genetic algorithm shown in Fig.7.Table 8 shows single mutations and Table 9 shows details of individual.

Table. 8 Single Mutations

Offspring	1	0	1	0	0	1	0	0	1	0
Mutual offspring	1	0	1	0	1	1	0	0	1	0

Table. 9 Details of Individual

Individual	X	Fitness	Chromosome
Parent I	0.08	0.05	0001010010
Parent II	0.73	0.000002	1011101011
Offspring I	0.23	0.47	0011101011
Offspring II	0.58	0.00007	1001010010

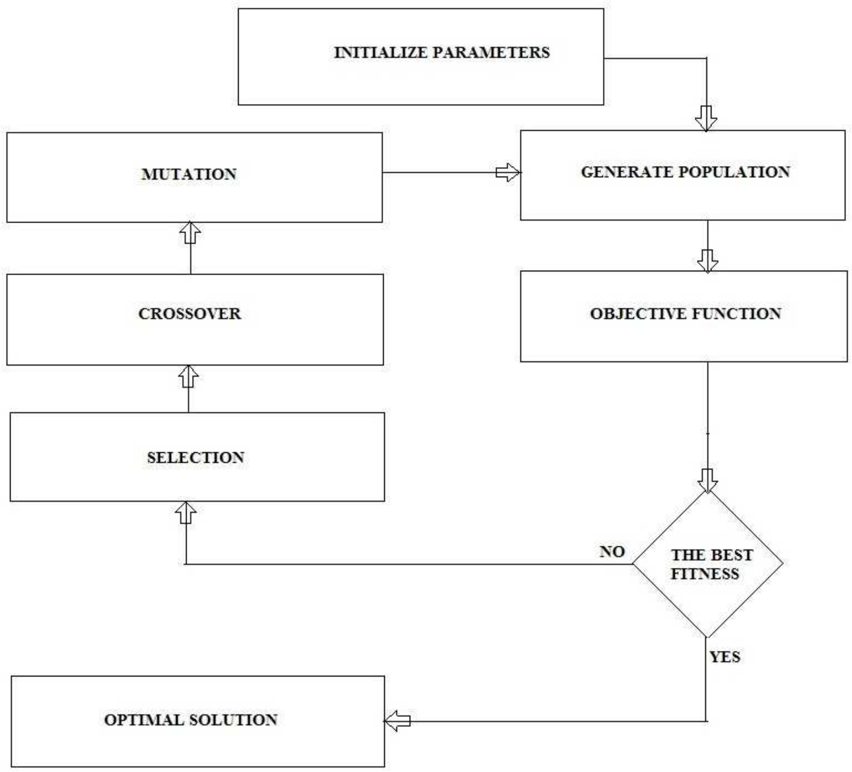


Fig. 7 Traditional Genetic Algorithm

6.1. OPTIMIZATION OF CLAD BEAD GEOMETRY USING GA.

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 the experiments conducted [11].

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 10. Table 11 shows the options used for study.

Table 10 GA 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

Table 11 for GA Computation

Population Type	Double Vector
Population size	30
Fitness scaling function	Rank
Selection function	Roulette
Reproduction elite count	2
Cross over rate	100
Cross over function	Intermediate
Mutation Function	Uniform
Mutation rate	1%
Number of Generation	52
Migration	Forward

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

Genetic algorithms are nowadays popular tool in optimizing because GA 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 [12].

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 [13]

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

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

$$10 \leq X(3) \leq 26$$

$$70 \leq X(4) \leq 110$$

$$-10 \leq X(5) \leq 10$$

6.2 Objective Function [14]

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)^20.872*x(5)^20.200*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)
-------- (22)

(This is the percentage of dilution)

Constrained equations are same as equations 11-16

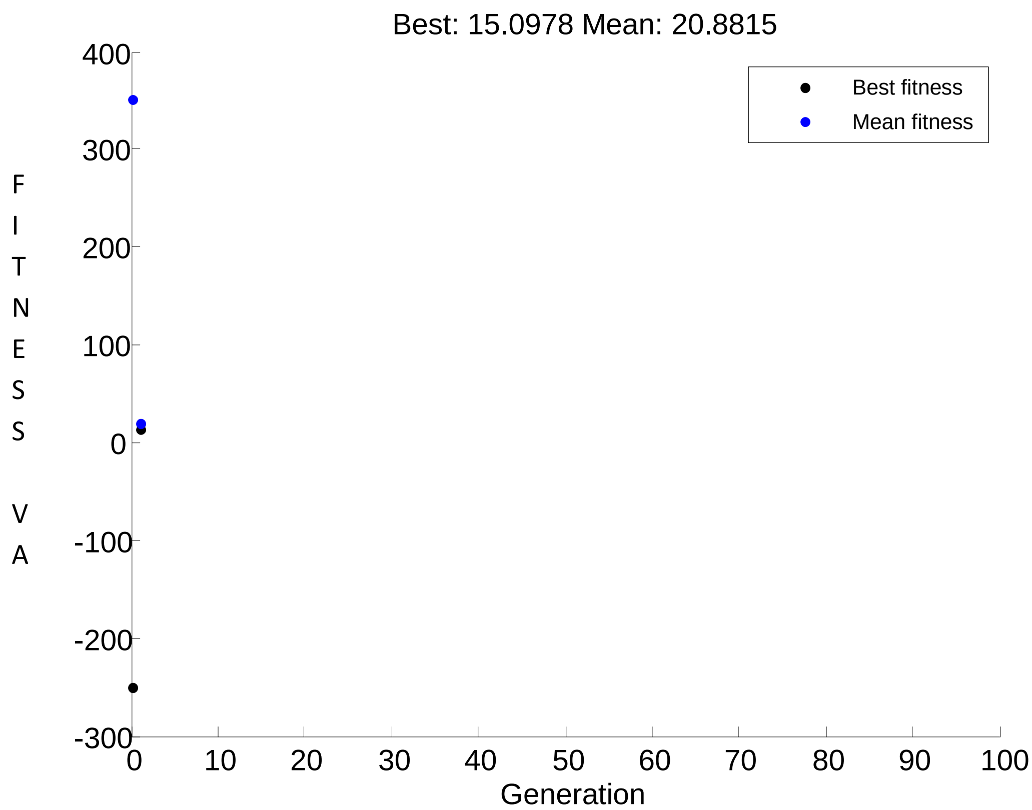


Fig 8. Fitness function for Integrated SA-GA

From the fig 8 It is seen that optimal value of dilution is 15.0978. the parameters that lead to minimum dilution is welding current 260 Amps, Welding speed 150 mm/min, Contact tip to work distance 19 mm, Welding gun angle 108and pinch -3.5 respectively.

6.1 Integrated SA-GA Type B Optimization solutions

The optimization initial constraints of integrated SA-GA Type B could be given as follows;

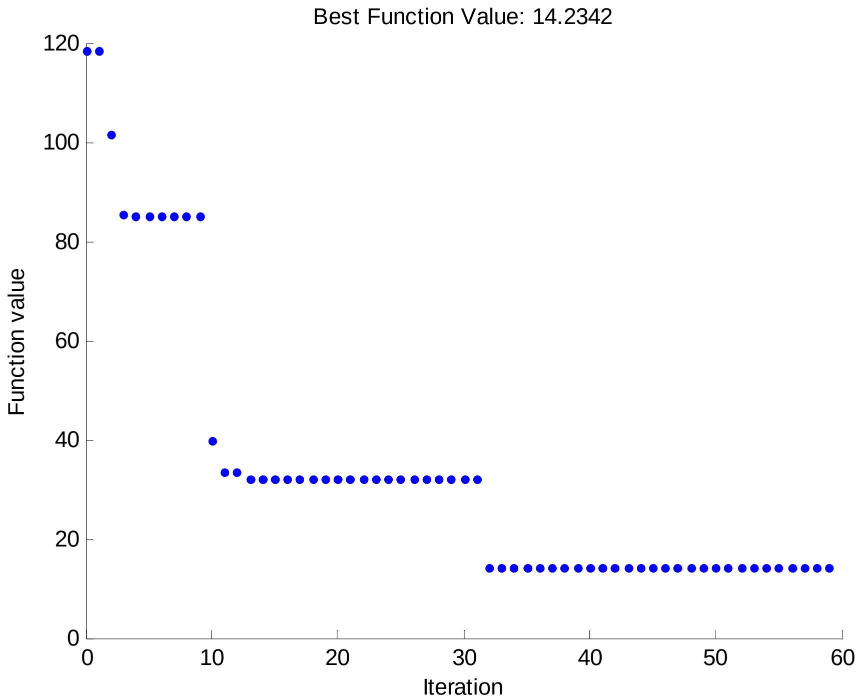


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Fig 11. Fitness function for Integrated SA-GA Type B

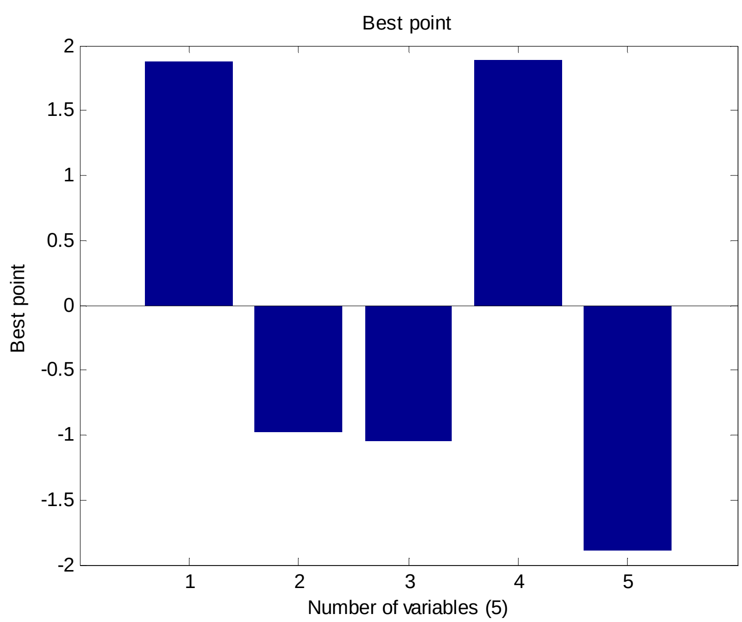

Fig 12 Best point.

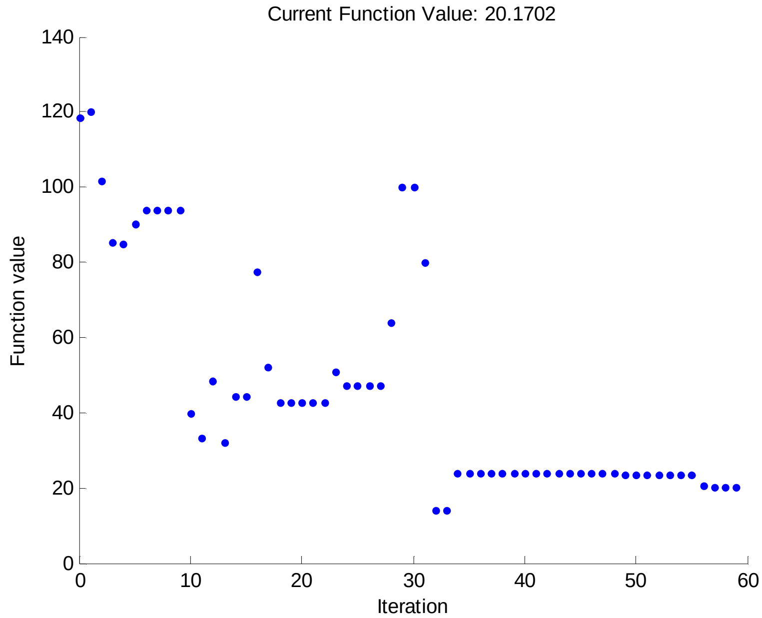

Fig 13. Current function value

The results of the integrated SA-GA Type B using MATLAB 7 Toolbox are shown in Fig11.The best fitness value obtained from this is 14.2342.It can be seen that optimal process parameters that lead to the optimal solution of From the fig 4 it is seen that optimal value of dilution is 14.2432. the parameters that lead to minimum dilution is welding current 260 Amps, Welding speed 1150 mm/min ,Contact tip to work distance 18.mm,,Welding gun angle 116 and pinch 4 respectively. The number of iterations obtained is 59.

6.2. Validation of the integrated SA-GA result.

In order to validate the result of the proposed model, the optimal process parameters values of integrated SA-GA will be transferred to regression equation (12).With I is the welding current, S is the welding speed, T is the contact to work distance, N is the welding angle and Ac is the pinch and percentage of dilution is the optimal solution .Calculation for the validation of the integrated SA-GA Type A and integrated SA –GA Type B results shown below.

By transferring the optimal process parameter values into Regression equation (9), it was obtained the minimum percentage of dilution of Integrated SA –GA Type A and Integrated SA-GA Type B is shown in table 8.The compared values of integrated SA-GA type A, Integrated SA-GA Type B obtained from

MATLAB 7 optimization Tool box is also shown in Table 8.

Optimum dilution for Integrated SA-GA Type A

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

Optimum dilution obtained is 14.5637

Optimum dilution for Integrated SA-GA Type B

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

Optimum dilution obtained is 14.6578

Table 13 comparison of results

Approach SA-GA	Dilution	Process parameters	Number of iterations
Integrate SA-GA Type A	14.3657	By regression Type A	52
Integrated SA-GA Type B	14.2432	By Regression Type B	57

7. Integrated SA-GA Type- A optimization solution

The steps in order to implement the integrated SA-GA –type-A and integrated SA-GA type-B in fulfilling the three objectives are:

1. In the experimental data module the values of dilution for different combinations of process parameters used for modelling.
2. In the regression modelling schedule model was developed using cladding process parameters. A multilinear regression analysis was performed to predict dilution and a governing equation was constructed.
3. In the single based GA optimization, the predicted equation of the regression model would become the objective function .The minimum and maximum coded values of the process parameters of the experimental design would define the boundaries for minimum and maximum values of the optimal solution. Based on some criteria the optimum value of dilution is obtained.
4. In the SA based optimization similar to GA optimization the predicted regression would define the objective function. The extra information required is about the initial constraints. The process parameters value of regression model defines the initial constraints.
5. In the integrated SA-GA-type-Module that it was the first integration system proposed in this study. Similar to SA single based optimization process the predicted equation of the regression would become the objective function. This integration system process the optimal process parameters value of the single based SA optimization process combined with the process parameters of SA system would define the boundries if minimum and maximum values for optimal solution.

In the integrated SA-GA-type-B system which is the second integration system proposed in this study. Similar to type A the predicted regression equation would become the objective function and the optimal process parameters value of single based SA optimization combined with process parameters value of the GA model would define the boundaries for the minimum and maximum values of the optimal solution .This integration system proposes the process parameters values of the best GA model to define the initial point for optimization solution.

The three conditions which used for defining the limitation constraints of the proposed integrated SA-GA Type A optimization are shown in Table 8.The Opt GA and Opt SA are the optimal process parameter value of GA optimization respectively. As per the conditions of Table 8 limitation constraints of integrated SA-GA Type A proposed. The proposed system is shown in Fig 9.Optimization process shown in Table 12.

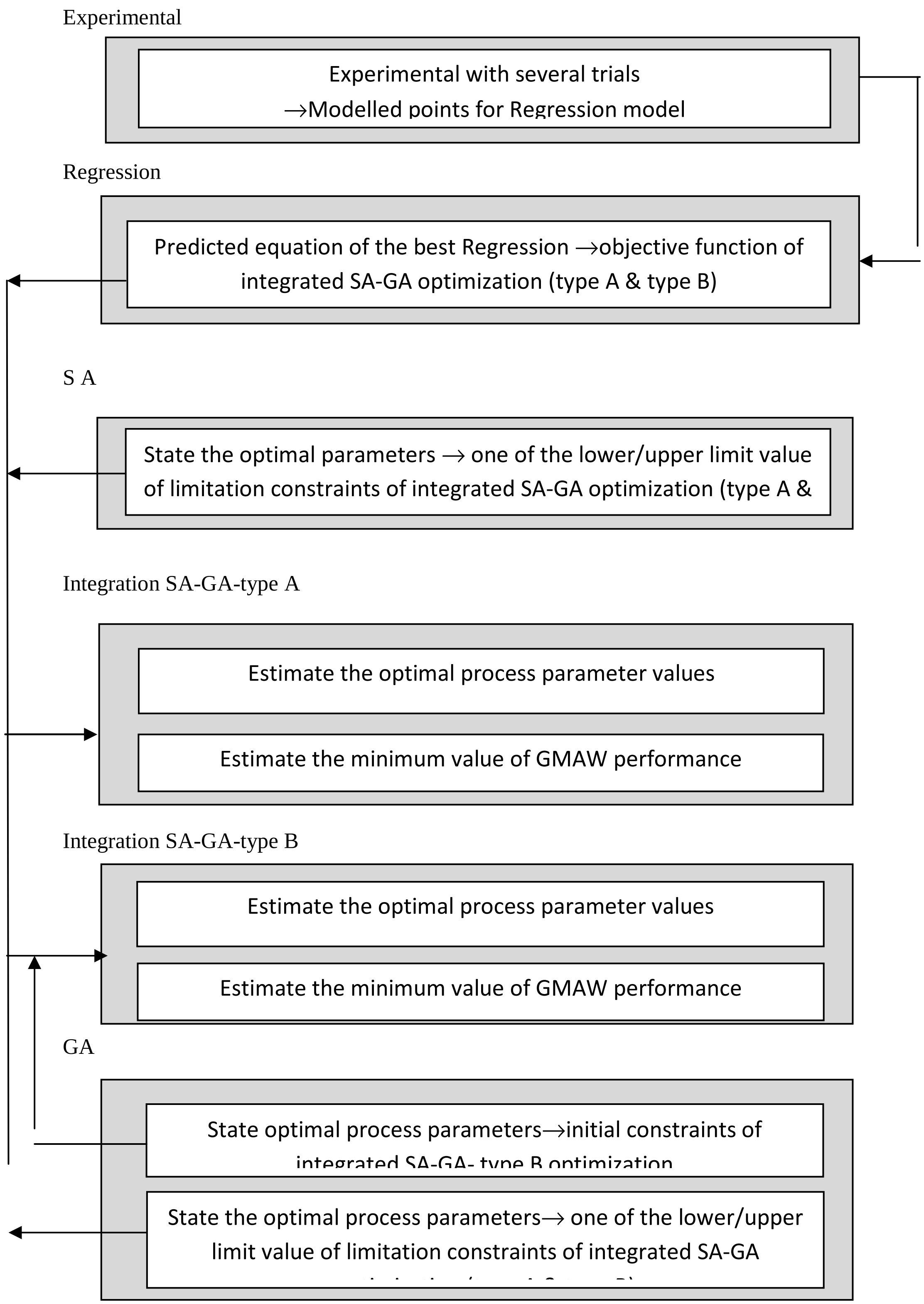
Experimental
Experimental with several trials
→Modelled points for Regression model
Regression
Predicted equation of the best Regression →objective function of integrated SA-GA optimization (type A & type B)
S A
State the optimal parameters → one of the lower/upper limit value of limitation constraints of integrated SA-GA optimization (type A &
Integration SA-GA-type A
Estimate the optimal process parameter values
Estimate the minimum value of GMAW performance
Integration SA-GA-type B
Estimate the optimal process parameter values
Estimate the minimum value of GMAW performance
GA
State optimal process parameters→initial constraints of
State the optimal process parameters→ one of the lower/upper limit value of limitation constraints of integrated SA-GA

Fig.9. The flow of the proposed integrated SA-GA optimization

The results obtained by running integrated SA-GA Type A MATLAB 7 optimization tool shows in Table 9.The fitness function graph Fig 10 shows the best Fitness Value

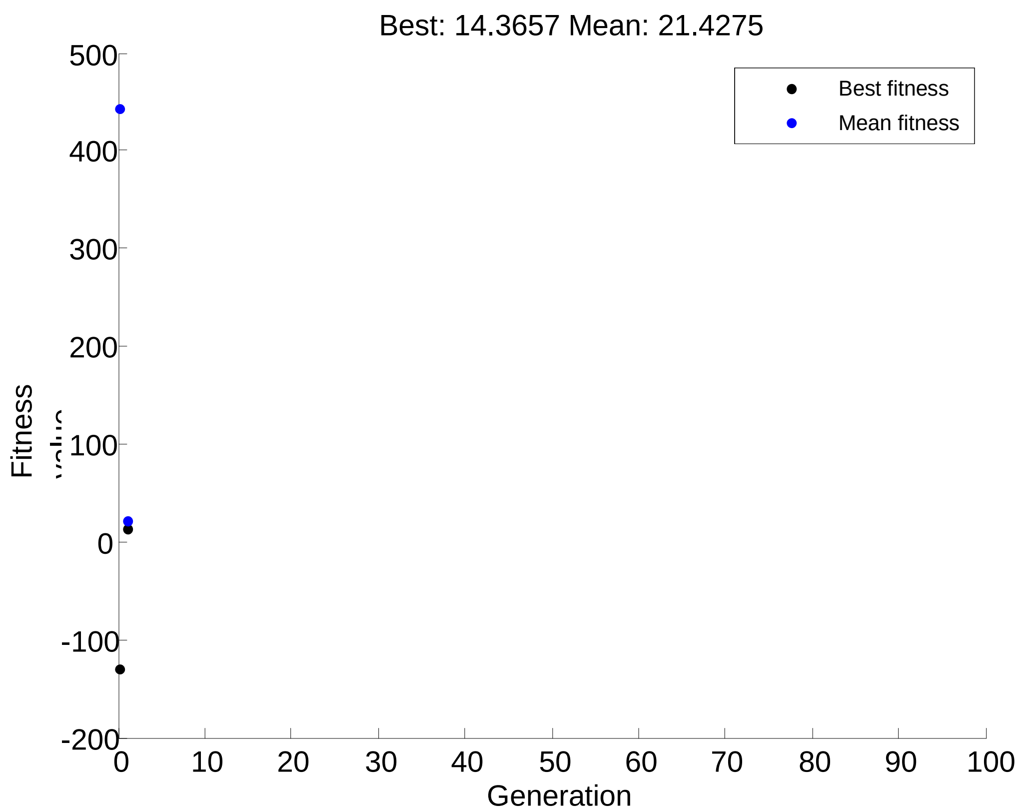

Fig 10. Fitness function for integrates SA-GA Type A

From the fig 4 it is seen that optimal value of dilution is 14.3657. the parameters that lead to minimum dilution is welding current 265 Amps, Welding speed 155 mm/min ,Contact tip to work distance 19.mm,,Welding gun angle 108 and pinch -3.5 respectively. The number of iterations obtained is 52.

Table 12. Limitation constraints bounds of Integrated SA-GA

No:	Condition	Lower limit	Upper limit
1	(OptGA)<(OptSA)	Optga	Optsa
2	(Optga)>(OptSa)	Optsa	Optga
3	(OptGA)=(Optsa)	Nearest lower bound	Nearest upper bound
4		Value of experimental design	Value of experimental design

8. Results and Discussions

The evaluation of results is separated in to three stages. They are evaluation of the minimum percentage of dilution, evaluation of optimal process parameters and evaluation of the number of iteration of the integrated SA-GA.

8.1.1First Objective: Evaluation of the minimum percentage of Dilution.

Fig. 9 and 11 shows minimum percentage of dilution value for both integration systems, Integrated SA-GA Type A, integrated SA-GA Type B are14.3657 and 14.2432 respectively. For fulfilling the first objective of this study the minimum value of percentage of dilution of SA-GA integrated study is compared to the results of experimental data, regression, SA and GA.

8.2 Experimental data vs. integrated SA-GA.

As shown in Table 6 value among all experimental trial i.e. minimum percentage of dilution is15 0978 .It can be concluded that this study have reduced the value.

8.3 GA vs. Integrated SA-GA.

The minimum value of predicted percentage of dilution using GA using MATLAB 7 was 15.0978 .It can be concluded that integrated SA-GA Type A and Integrated SA_GA Type B reduced the value of percentage of dilution to 14.3657 and 14.2432 respectively.

8.4 SA vs. Integrated SA-GA.

The minimum predicted value of percentage of dilution using SA was 14.6342 It can be shown that the Integrated SA-GA Type A and Integrated SA-GA Type B have reduced their value..

8.5 Second objective: Evaluation of the optimal process parameters.

Table 4 shows that minimum and maximum process parameters of experimental design are welding current(I)200-300;Welding speed 150-182;Contact tip to work distance 10-26;Welding angle 70-110; Pinch (Ac) -10-10. Since the optimal solutions of Type A and Type B the process parameters are well within the range of minimum and maximum value of experimented conducted. Thus this study concludes that the second objective is fulfilled.

8.6 Third objective evaluation of number of Iterations.

The number of iterations in GA study for optimization is 68and it was found that number of iterations in Integrated SA-GA Type A is 52 It has been found that number of iterations is reduced by 16Number of iterations in SA optimization is59 and Number of iterations in SA-GA Type B is 57.It has been found that number of iterations reduced by 2.

Since umber of iterations in Type A and Type B is lower than the conventional SA, GA algorithms the study concludes that third objective is fulfilled.

9. Conclusions

An integrated SA-GA model has been developed from the experimental data to achieve desired clad bead geometry. These models are capable of making optimization of clad bead geometry with reasonable accuracy.

In this study the following steps were applied for prediction of stainless steel clad bead geometry using GMAW; (a) Data collection using experimental studies, (b) Analysing and processing of data, (c) Prediction using regression equation, (d) Optimize the data using conventional SA and GA algorithm and (e) Then further optimize with integrated SA-GA algorithm.

The aim of the study was to show the possibility of the use of integrated SA-GA model for calculation of clad bead geometry of stainless steel cladding deposited by GMAW method. The results showed that integrated SA-GA models can be used as an alternative tool according to the present conventional calculation methods.

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