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MULTI CHARACTERISTIC OPTIMIZATION OF FLUX CORED ARC WELDING PROCESS PARAMETERS USING GREY BASED GA APPROACH

P. SREERAJ

Department of Mechanical Engineering
Younus College of Engineering and Technology
Kerala, India-691010

ABSTRACT

This paper presents the application of Taguchi method coupled with grey based GA approach for multiple output optimization of flux cored arc welding (FCAW) to obtain optimal weld bead geometry in mild steel plates IS 2062.This approach converts complex multiple objectives into a single grey reasoning grade which is the objective function for genetic algorithm (GA) approach. The welding parameters such as voltage, current, stick out and wire feed are optimized with multiple considerations such as bead width, penetration, reinforcement and dilution. Taguchi's concepts of orthogonal array signal to noise (S/N) ratio has been used to optimize FCAW through a single comprehensive output measure (COM) which is the objective function. The significant contributions of parameters are estimated using analysis of variance (ANOVA) test. Confirmation test is conducted and reported. It is found that welding current is the most significant factor affecting bead geometry. Results indicate feasibility of grey based GA analysis in continuous improvement of welding industry.

Keywords: *Flux cored arc welding, analysis of variance, taguchi method, grey based genetic algorithm*

1.0 INTRODUCTION

Flux cored arc welding is a multi-factor, multi-objective manufacturing process. Because of easy control of process variables, high quality, deep penetration and smooth surface finish, it is widely preferred in fabrication industry [1]. In the present work, the effect of voltage, current, wire speed and stick out on bead geometry has been studied. Mechanical and chemical properties of good weld depend on bead geometry. Bead geometry has a direct effect on process parameters. Thus, it is necessary to study the relationship between process parameters and weld bead geometry.

Figure 1 shows the weld bead geometry. Mechanical strength of weld metal is highly influenced by the composition of metal but also by weld bead shape. This is an indication of bead geometry. It mainly depends on wire feed rate, welding current, arc voltage etc. [2]. Therefore, it is necessary to study the relationship between in process parameters and bead parameters to study weld bead geometry. This paper highlights the study carried out to develop mathematical models to optimize weld bead geometry, on bead on plate welding by FCAW.

*Corresponding author: pathiyasseril@yahoo.com

Taguchi method is a powerful tool for the design of high quality welding operations. It provides a systematic approach for optimization problems. The methodology is valuable when the process parameters are qualitative and discrete. Taguchi method uses a special type of design of orthogonal arrays (OA) to study the entire parameter space with smaller number of experiments. The experimental results are then transferred to signal-to-noise (S/N) ratio. This ratio can be used to measure the quality characteristics deviating from desired values. Usually there are three categories of in the analysis of the signal-to-noise ratio, that is the lower- the- better (LB), higher-the- better (HB) and nominal-the- best (NB). Regardless of category of quality characteristics, larger signal-to-noise ratio corresponds to the better quality characteristics. The optimal process parameters are the levels with highest signal-to-noise ratio. Once the experimental data is normalized using NB/LB/HB criteria; normalized value lies between zero and one. Zero represented worst quality and one represented most satisfactory quality. Since S/N ratio is expressed as mean (signal) to the noise (deviation from the target); maximising S/N ratio ensures minimum deviation and hence it is S/N ratio to be maximized.

S/N ratio for NB, $\eta = 10 \log \frac{1}{n}\sum_{i=1}^{n}\frac{\mu^2}{\sigma^2}$ (1)

S/N ratio for LB, $\eta = 10 \log \frac{1}{n}\sum_{i=1}^{n} y_i^2$ (2)

S/N ratio for HB, $\eta = 10 \log \frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}$ (3)

y_i = Value of the quality characteristic at i^{th} setting.
n = Total number of trial runs at i^{th} setting.
Σ = Standard deviation of value of quality characteristic.
μ = Mean of quality characteristic.

Percentage dilution, D = [B/(A+B)] × 100 %, where A is the reinforcement area and B is the penetration area.

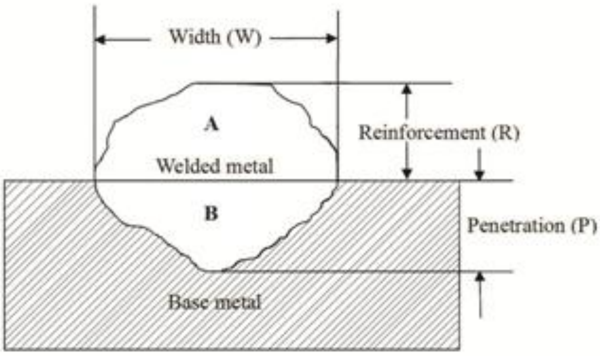


Figure 1: Weld bead geometry

2.0 GREY RELATIONAL ANALYSIS

In grey relational analysis, experimental data are first normalised from zero to one. This process is known as grey relational generation. Based on the normalised data, grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Overall grey relational grade is determined by averaging the grey relational coefficient corresponding to selected responses. The overall performance characteristics of the multiple responses process depends on the calculated grey relational grade. This process converts a multiple response process optimization problem with objective function as grey relational grade. The optimal parametric combination is then evaluated which would result highest grey relational grade [3].

In grey relational generation, normalized bead width and reinforcement corresponding to LB criterion can be termed as:

$$x_i\,(k) = \frac{\max y i(k) - y i(k)}{\max y i(k) - \min y i(k)} \tag{4}$$

Bead penetration and percentage of dilution should be the larger the better and is expressed as

$$x_i\,(k) = \frac{y i\,(k) - \min y i\,(k)}{\max y i(k) - \min y i(k)} \tag{5}$$

where $x_i(k)$ is the value after the grey relation generation, min $y_i(k)$ is the smallest value of $y_i(k)$ for k^{th} response, and max $y_i(k)$ is the largest value of $y_i(k)$ for k^{th} response. The normalized data after grey relational generation are tabulated in Table 5.An ideal sequence is $x_0(k)$ where k=1, 2, 3....16, for the responses. The definition of grey relational grade in the course of grey relational analysis is to reveal the degree of relation between the 16 sequences [$x_0(k)$ and $x_i(k)$,i=1,2,3....16]. The grey relational coefficient shown:

$$\epsilon_i\,(k) = \frac{\Delta\min + \psi\Delta\max}{\Delta 0i(k) + \psi\Delta\max} \tag{6}$$

where $\Delta_{0i} = \|x_0(k) - x_i\,(k)\|$ is the difference of the absolute value $x_0(k)$ and $x_i(k)$;ψ is the diminishing coefficient $0 \leq \psi \leq$i;$\nabla_{min}=\forall j^{min}\ \epsilon i \forall k^{min} \|x_0(k) - x_i\,(k)\|$ is the smallest value of Δ_{0i}; and $\Delta_{max}=\forall j^{max}\ \epsilon i\ \forall k^{max} \|x_0(k) - x_i\,(k)\|$ = largest value of Δ_{0i}. After averaging the Grey relational coefficients, the grey relational grade γ_i can be calculated as:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i\,(k) \tag{7}$$

where n is the number of process responses. The higher value of grey relational grade corresponds to intense relational degree between sequence $x_0(k)$ and the given sequence $x_i(k)$. It means that higher grey relational grade it is closer to the optimal point.

3.0 EXPERIMENTATION

Test plates of size 300 × 200 × 6 mm were cut from steel plate of grade IS – 2062 and one of the surfaces is cleaned to remove oxide and dirt before cladding. E7 IT-1C wire of 1.2 mm diameter was used for depositing bead on plate welding [4]. The properties of base metal and filler wire are shown in Table 1.

The selection of the welding electrode wire is based on the matching the mechanical properties and physical characteristics of the base metal, weld size and existing electrode inventory.

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	-	-	-
E7 IT-1C	0.12	0.90	1.75	0.030	0.030	-		0.30	0.50

4.0 PLAN OF INVESTIGATION

The research work is carried out in the following steps [5].

- Identify the quality characteristics and process parameters to be studied
- Determine the number of levels for the process parameters and possible
- Orthogonal array
- Select appropriate orthogonal array and assign process parameters
- Conduct experiment as per arrangement of orthogonal array
- Analyze the experiments through grey based GA approach
- Select the optimum level of process parameters
- Conduction of confirmation experiment

4.1 Identification of factors and responses

The percentage of dilution has got a very dominating effect in welding. The properties of the welding is the significantly influenced by dilution obtained. Hence control of dilution is important in welding where a high dilution is highly desirable [6]. When dilution is quite low, the final deposit composition will be closer to that of filler material and hence corrosion resistant properties of welding will be greatly improved. The chosen factors have been selected on the basis to get optimal dilution and optimal weld bead geometry [1]. These are wire speed (T), welding voltage (V), welding current (I) and stick out (N). The responses chosen were 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.

4.2 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 [7]. Working range of each process parameters was decided upon by inspecting the bead for smooth appearance without any visible defects. The chosen level of the parameters with their units and notation are given in Table 2.

Table 2: Welding parameters and their levels

Parameter	Unit	Factor Level			
		1	2	3	4
Welding Voltage (V)	V	20	22	24	25
Welding Current (I)	A	87	123	138	155
Stick out (N)	mm	15	20	25	30
Wire feed (T)	mm/min	25	40	50	53

4.3 Development of Orthogonal Array

Design matrix chosen to conduct the experiments was Taguchi's robust design. The design matrix comprises of $L_{16}\,(4^4)$ designs. This is shown in Table 3.

Table 3: Design matrix

Experimental Run	Design Matrix			
	V	I	N	T
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

V - Welding voltage; I - Welding current; N –Stick out; T – Wire speed

4.4 Conducting Experiments as Per Orthogonal Array

In this work, sixteen experimental runs were allowed for the estimation of each treatment combination of parameters on bead geometry as shown in Table 3. 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 Younus College of Engineering and Technology (YCET), Kollam, 649010, India.

4.5 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 bead profiles were traced using a reflective type optical profile projector at a magnification of X10, in YCET Kollam [8]. Then the bead dimensions such as depth of penetration height of reinforcement and clad bead width were measured [6]. The profiles traced using AUTO CAD software. The welded specimen is shown in Figure 2. The measured weld bead dimensions and percentage of dilution is shown in Table 4.

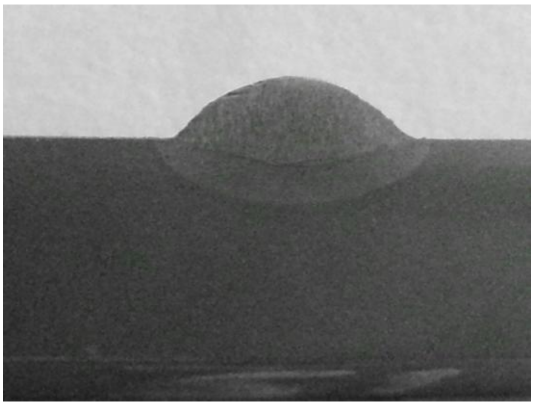


Figure 2: Scanned specimen

Table 4: Design matrix and observed values of weld bead geometry

Experimental Run	Design Matrix				Bead Parameters			
	V	I	N	T	W (mm)	P (mm)	R (mm)	D (%)
1	1	1	1	1	8.306	1.235	2.815	17.623
2	1	2	2	2	8.243	1.347	2.543	17.462
3	1	3	3	3	8.731	1.388	2.675	17.842
4	1	4	4	4	8.925	1.425	2.931	17.442
5	2	1	2	3	9.792	1.657	2.449	18.332
6	2	2	1	4	10.415	1.586	2.779	16.692
7	2	3	4	1	8.869	1.456	2.863	17.823
8	2	4	3	2	8.614	1.738	2.597	20.424
9	3	1	3	4	8.908	1.416	2.538	17.912
10	3	2	4	3	9.371	1.537	2.397	18.182
11	3	3	1	2	9.087	1.465	2.432	18.218
12	3	4	2	1	8.853	1.368	2.672	17.512
13	4	1	4	2	9.125	1.487	2.423	18.221
14	4	2	3	1	8.753	1.398	2.567	17.943

15	4	3	2	4	8.971	1.457	2.697	17.841
16	4	4	1	3	9.807	1.868	2.243	21.512

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

4.6 Calculation of Grey Relational Grade

From Table 4, the experimental data are normalized using equations (4) and (5). For penetration and dilution higher the better and for reinforcement and bead width lower the better is used as criteria. Rey relational coefficient for each performance characteristics obtained using equation (6) [9]. Here Ψ is taken as 0.5 [9]. The overall grey is calculated using equation (7). These are shown in Table 5 and Table 6.

Table 5: Grey relational coefficient of each performance characteristics (with ψ = 0.5)

Bead Parameters			
W	P	R	D
1	1	1	1
1	0.333333	1	0.382601
0.851644	0.37791	0.738552	0.373065
0.631154	0.397363	0.674036	0.396382
0.572279	0.416722	0.624922	0.371914
0.403812	0.6	0.428559	0.431127
0.333333	0.528822	0.474113	0.333333
0.588097	0.434454	0.588789	0.395147
0.672948	0.708847	0.38619	0.688965
0.576435	0.411841	0.636132	0.400998
0.412371	0.488803	0.511718	0.419861
0.530898	0.439889	0.573855	0.422511
0.592768	0.38763	0.704027	0.375975
0.52203	0.453763	0.556669	0.422733
0.623908	0.402416	0.660415	0.403078
0.559848	0.435052	0.583363	0.396316
0.41666	1	0.3333	1

Table 6: Overall grey relational grade.

Experiment Run	Overall Grey Relational Grade
1	0.678984
2	0.585293
3	0.524734
4	0.496459
5	0.465875
6	0.4174

7	0.501622
8	0.614238
9	0.506352
10	0.458188
11	0.491788
12	0.5151
13	0.488799
14	0.522454
15	0.493645
16	0.68749

5.0 RESULTS AND DISCUSSION

Methodology applied optimization of flux cored arc welding process parameter is based on grey relational analysis and GA approach. Using the observed experimental data, initially four models were developed by multiple regression models to correlate the welding process parameters and responses. These models were incorporated in GA model through grey relational analysis, and hence the GA code was developed to optimize the welding parameters to achieve desired properties.

5.1 Development of Regression Models

The statistical method multiple regression analysis (MRA) was used to develop the mathematical models using experimental data listed in Table 2. In this study voltage, welding current wire feed rate and stick out are independent parameters while dilution, penetration; reinforcement and bead width are dependent parameters. Regression equations of three responses are given in equations (8) to (11) and related ANOVA has been presented in Table 7. From the ANOVA analysis it is shown that welding current is the most significant factor affecting bead geometry.

Regression equations

$$W = 6.48 + 0.0918\ V - 0.00056\ I - 0.0241\ N + 0.0259\ T \quad (8)$$

$$P = 0.500 + 0.0261\ V + 0.00170\ I - 0.00318\ N + 0.00600\ T \quad (9)$$

$$R = 3.756 - 0.0555\ V + 0.00116\ I + 0.00525\ N - 0.00370\ T \quad (10)$$

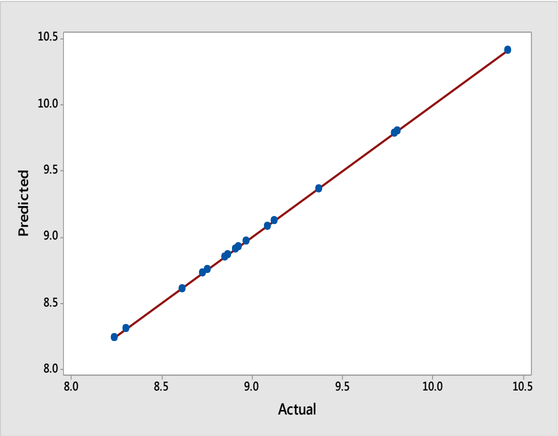
$$D = 12.09 + 0.190\ V + 0.0140\ I - 0.0208\ N + 0.0114\ T \quad (11)$$

Table 6: ANOVA Table

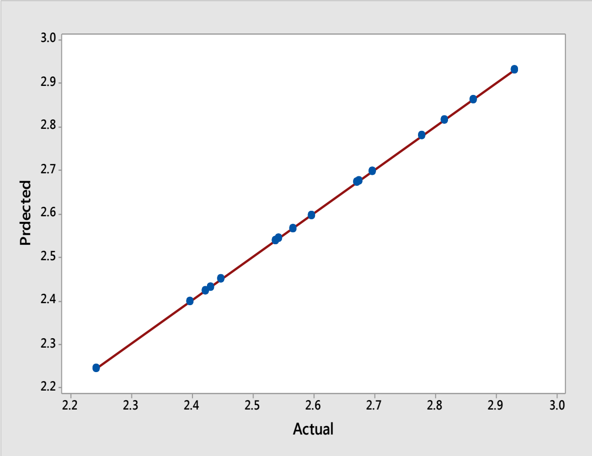
Source	DF	Adj SS	AdjMS	F-Value	P-Value
Regression	4	0.021905	0.005476	0.94	0.479
V	1	0.002542	0.002542	0.43	0.524
I	1	0.001534	0.001534	0.26	0.619
N	1	0.009766	0.009766	1.67	0.223
T	1	0.008062	0.008062	1.38	0.265
Error	11	0.064409	0.005855		
Total	15	0.086314			

From Table 6, regression equation (12) is derived using software MINITAB 7. This equation is used for further calculations.

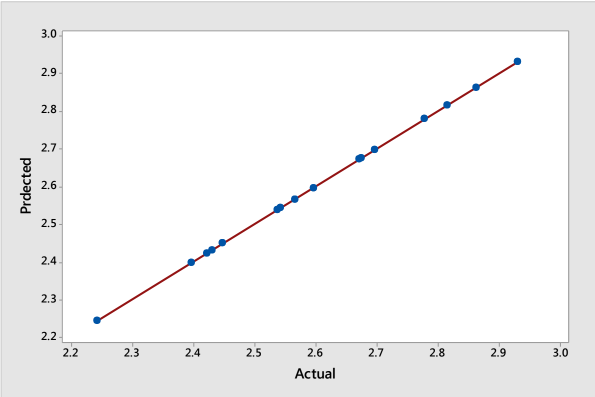
$$GRG=0.814-0.00656\times(1)+0.000391\times(2)-0.00442\times(3)-0.00205\times(4) \quad (12)$$



(a)



(b)



(c)

Figure 3: Plot between predicted and actual values of response parameters, (a) Bead width; (b) Penetration; and (c) Reinforcement

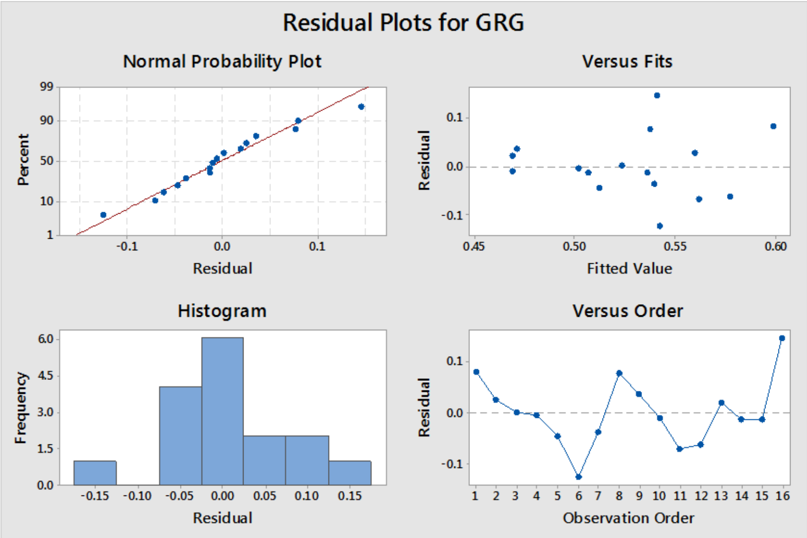


Figure 4: Residual plot for GRG

From the ANOVA table it was found that calculated F-ratio were greater than Tabulated value at a 95% confidence level which means that models are significant. The validity of regression model tested by scatter diagrams .The predicted and observed values of the responses are scattered close to 45^0 lines, indicate the perfect fit of developed models.

5.2. Development of GA code

The code for the GA was developed in MATLAB version 7.9.0 for optimizing the FCAW process parameters.

5.2.1 Development of objective function through grey relational analysis.

To obtain optimal setting for FCAW process, GA code should be made to converge for solutions [10]. To ease multi the multi objective function and to converge the solutions with less iteration grey relational analysis is used as the objective function .The objective function to maximize is Equation (12). By doing so the process parameters are calculated in such a way that welding parameters obtained is desired optimal values. The best welding parameters for GA is shown in Table 8.

5.2.2 Selection of GA parameters

Several parameters are involved in a GA like population science, number of generation type of selection, crossover type, crossover rate and mutation rate. The best combination of GA parameter leads to faster convergence to solution. In GA procedure, population size crossover rate and mutation rate are important factors which determine the performance of the algorithm. Large population size or higher crossover rate allows exploration of solutions space and reduces the chances of setting poor solution. The range of each welding parameters were specified. The initial population is randomly fixed for the iteration process. Each individual in the initial population represents each welding parameters .Genetic operators such as selection, crossover and mutation are employed to produce next generation of the new population.

5.2.3 Selection

To select the best chromosomes from the population roulette wheel selection is used .in this method, the parents are selected based on their fitness values .The better chromosomes have more chances to select The individual being selected from the roulette wheel selection process are stored in a mating pool and algorithm will until it has generated the entire population for the next generations.

5.2.4 Crossover

After selection, multipoint crossover was carried out in these selected chromosomes. This method takes two parent string from the mating pool and performs an exchange at some positions between them to form a new string First ,two parent string are selected randomly from the mating pool .Second an arbitrarily location in both strings is chosen randomly. Finally a portion of the strings following the crossover site are exchanged between two parent strings to form an off spring strings. This crossover does not occur with all strings, but limited by crossover rate. In this research, it is fixed as 0.80.

5.2.5 Mutation

Mutation probability rate is set as low as 0.01 in order to avoid good strings. Mutation was carried out on the offspring's in which one allele of the gene is randomly replaced by other to produce a new genetic structure. The off spring then decoded in to real values then objective function is evaluated for this new set of chromosomes. And they may be ranked based on their fitness values. From this mix of parent and offspring's, the 100 best chromosomes are selected based on their fitness ranking. Then theses newly selected chromosomes were reinserted for next iteration. Similar iterations continue until no more changes take place in the value of the optimized process parameters.

5.3. Multi Objective Optimization

In this section, GA procedure is employed to iterate the optimal welding parameters set in multi objective model. In the optimal process the purpose is to maximize the objective function. By doing so the process parameters are calculated ain such a way that flux cored arc welding parameters approach the desired values. The best parameters are shown in Table 8.

Table 8: The best tuning parameters for GA procedure

Number of generation	Population size	Crossover rate	Crossover mechanism	Mutation rate
800	30	80%	scatter	1%

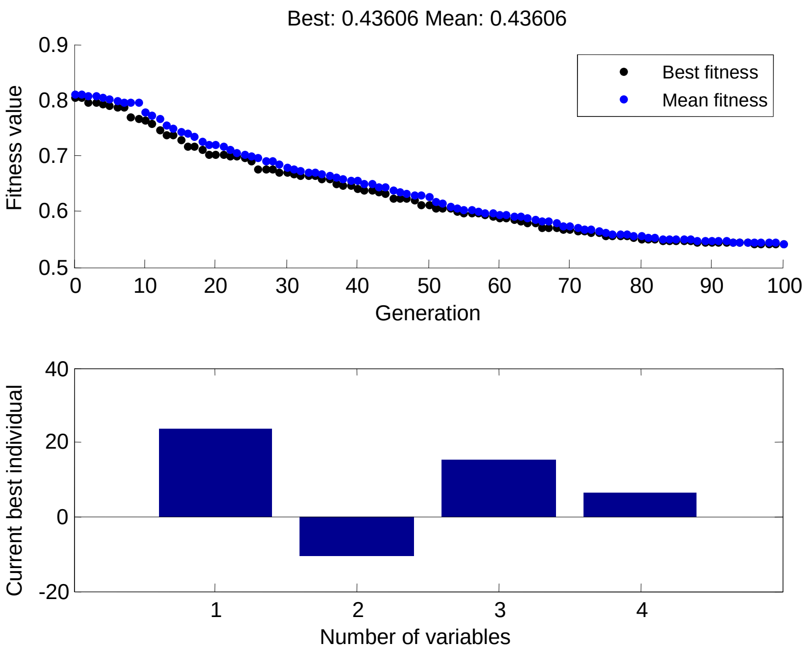


Figure 5: Convergence of GA model

Convergence of the developed model is shown in Figure 5. From the figure, it is clear that the maximum dilution is obtained at 80^{th} iteration. The optimal process parameters obtained is from GRG model is voltage 22.63 V, welding current 123.74 A, stick out 15 mm and wire feed rate 53.88 mm/min.

6.0 CONFORMITY TEST

In the present work, to validate the computational model based on GA code a confirmatory test is conducted. Using the optimal process combination process parameters welding has been done. Table 9 shows comparison of results predicted by GA model with the experimental results.

Table 9 Comparison of predicted and experimental value

	Voltage	Current	Stick out	Wire feed	W	p	R	D
Solution by GA	2.63	123.74	15	53.8	9.51 9	1.3871	2.4545	16.4181
Experimental Value	22	123	15	53	10.415	1.586	2.779	16.192

From the result for GRG given in Table 9, the optimal welding parameters setting is to maintain voltage 22 V, stick out 15mm, current 123 A and wire speed 53 mm/min and calculated values shown in Table 9. The predicted and experimental values validate the experiment.

7.0 CONCLUSIONS

From the above discussions following conclusions are made. Regression modelling correlating bead geometry viz bead width, penetration dilution and reinforcement with FCAW process parameters wire feed rate, voltage, current and stick out have been developed to individual objective function in GA. This is in close agreement with predicted and observed values. Grey relational analysis is found to be useful to solve multi objective problem. Overall, grey relational grade has been used as objective function to maximize percentage of dilution. In this experiment, optimal process parameters are obtained by GA approach combined with grey relational analysis and conformity test validate the experimental results.

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