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# Optimization of Welding Parameters for Weld Dilution in GMAW using Genetic Algorithm

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***Abstract:*** *Hardfacing is a technique in which deposition of material on the surface of similar/dissimilar material is done to improve its wear resistant properties. The benefits also include the minimization of downtime needed to replace worn components and reduction of spare part inventory and finally saves money. So, it is essential to select welding process parameters carefully, to achieve a quality bead which is defect free. In order to achieve the above objective, a set of mathematical models has been developed for the prediction of weld bead dilution using 5-factor, 2 – levels Factorial design for 140MXC Nano structured wire with IS2062 substrate. The developed model was checked for its adequacy. The main and the interaction effects of the process parameters on weld bead dilution are presented in graphical form. Moreover, Genetic Algorithm computational model was used for the optimization of welding parameters to achieve desired optimum weld dilution.*

***Keywords:*** *Harfacing, Gas Metal Arc Welding; Factorial Design Approach, Genetic Algorithm.*

## 1. INTRODUCTION

The welding process, due to its complexity, has relied on empirical and experimental data to determine its welding conditions. However, trial-and-error methods to determine optimal conditions incur considerable time and cost,as stated by Kim et al. [1]. In order to overcome these problems optimization of welding input parameters, for making high quality weldment can be envisaged as a vital area of research. Weld bead shape plays an important role in determining the quality and mechanical strength of the weldment. Weld bead geometry is dependent on number of input parameters such as wire feed rate, welding speed, voltage, nozzle to plate distance, gas flow rate etc. as stated by Kim et al. [2].To predict the effect of various welding parameters on weld bead geometry various researchers used variety of techniques. (Benyounis et al. [3]; Kannan and Yoganandh, [4]; Singla et al. [5];Sudhakaran et al.[6]).Statistical approach is one way to increase the amount of information-rich data gathered. Numerous studies validated that efficient use of statistical design of experiment techniques, works as an excellent tool for the development of a mathematical model for the prediction of weld bead geometry, (Murugan and Parmer[7], Subramaniam[8], Allen et al.[9], Kim et al.[10].

So, to achieve the above mentioned objective statistical designing technique was employed to depict weld bead geometry of surfaced steel. Experiments were conducted based on fractional factorial designing i.e., 2 level 5 factors. Process control variables considered were wire feed rate, welding speed, welding voltage, nozzle to plate distance and torch angle.

To ascertain the acceptability of weldment, control of dilution is very important in hardfacing, where low dilution is typically desirable. For the present research, it was planned to use GA computational technique for the optimization of welding parameters to minimize dilution, as it owns high reliability, robustness and accuracy, Palaniswamy et al. [12].

## 2. MATERIALS AND METHODS

### 2.1 MATERIALS

The experiments were carried out by the deposition of 140MXC Nano-structured wire of 1.6 mm diameter using Miller Migmatic 273 welding machine onIS2062 substrate. The chemical composition of substrate and filler wire are given in table 1. Shielding gas used was pure Argon with flow rate kept constant at 25 l/min. Bead- on – plate technique was used to make the weld runs.

**TABLE 1: Chemical composition of base plate and filler wire**

| IS 2062 | | | | | | |
|---|---|---|---|---|---|---|
| Element | C | Si | Mn | S | P | Fe |
| % | 0.227 | 0.161 | 0.50 | 0.05 | 0.023 | Balance |

| TAFA 140MXC Nano-structured wire | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Element | Cr | C | Mo | B | W | Si | Nb | Fe |
| % | 20.8 | 2.84 | 12.1 | 0.64 | 9.79 | 0.54 | 0.8 | Balance |

## 2.2 EXPERIMENTAL DESIGN

Factorial design can be written in the form of a design matrix where the rows correspond to different trials and the columns correspond to the levels of the process parameters. The design matrix developed to conduct the sixteen trials of $2^n$ fractional factorial design is given in table-2. To determine the two levels of each control variables, pilot study was carried out by varying the control variables in all possible combination. The experiments so carried, gave the limits, which is shown in table- 3.

Welding parameters were coded as (+1) and (-1), corresponding to the high and low levels for the ease of recording and processing of the data using equation (1).

$$X_j = (X_{jn}-X_{jo}) \ / J_j \qquad (1)$$

Where, $X_j$is the coded value of the parameter, $X_{jn}$is the natural value of the parameter, $X_{jo}$ is the natural value of the basic level, $J_j$is the variation interval and j is the number of parameter.

**TABLE 2: Design matrix**

| Experiment No. | W 1 | S 2 | V 3 | N 4 | T 5= -(1234) |
|---|---|---|---|---|---|
| 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 |

**TABLE 3: Levels of the welding parameters**

| Parameters | Units | Symbols | Lower Limit -1 | Upper Limit +1 |
|---|---|---|---|---|
| WireFeed Rate | m/min | W | 7.62 | 9.04 |
| Welding Speed | cm/min | S | 27 | 36 |
| Voltage | Volts | V | 26 | 32 |
| Nozzle to Plate Distance | mm | N | 15 | 20 |
| Torch Angle | Degree | T | 80 | 100 |

## 2.3 WELDING PROCEDURE AND DILUTION MEASUREMENT

Fromdesignof experiments, it was clear that 16 trials were needed toconduct the experiments, keeping the values set in the design matrix. The weld runs were then performed on each of these strips throughout the length of the strip using bead- on – plate technique.

To get the dimensions of the bead geometry all the samples were cut and scanned. The scanned images were then transferred to Corel Draw X5, using the ruler tool in the software. Calculated values of %dilution are tabulated in Table 4.

**TABLE 4: %Dilution**

| Experiment No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Dilution, %D | 40.01 | 33.34 | 34.7 | 36.95 | 44.25 | 33.9 | 38.25 | 50.86 |
| Experiment No. | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| Dilution, %D | 24.5 | 39.61 | 32.6 | 42.29 | 52.56 | 41.6 | 53.46 | 36.69 |

## 3. SELECTION AND DEVELOPMENT OF MATHEMATICAL MODEL

The response function representing % dilution, can be represented as:

$$\%Dilution = f(W, S, V, N, T) \qquad (2)$$

Where, W, S, V, N and T represent the wire feed rate, welding speed, welding voltage, nozzle to plate distance and torch angle respectively.

The above expression, being a second degree response surface can be expressed as:

$$y = b_0+b_1W+b_2S+b_3V+b_4N+b_5T+ b_6 WS+b_7 WV+b_8 WN+b_9 WT+b_{10} SV+b_{11} SN+b_{12} ST+b_{13} VN+b_{14} VT+b_{15} \qquad (3)$$

Where, $b_0, b_1, b_2, \ldots\ldots b_{15}$are the coefficients of the polynomial equation

The value of regression coefficients was calculated using equation 4,

$$bij = \frac{\sum_{i=1}^{M} X_{ji} Y_i}{M}, j = 0,1,2,3......,k \qquad (4)$$

Where, $X_{ji}$ is the value of a parameter or interaction in coded form, $Y_i$ is the average value of the response parameters, is the number of observations and $k$ is the number of coefficients of the model. These models for predicting different responses mentioned above are given below:

%D= 39.72 - 0.32W + 1.0S + 4.22V + 0.69N + 0.9T + 1.29WS -2.87WV- 0.05WN +1.72WT - 0.13SV - 0.16SN + 3.7ST + 1.44VN+ 2.69VT - 0.85NT (5)

## 4. CHECKING THE ADEQUACY OF THE MODELS

The adequacy of the model was tested using Analysis of Variance (ANOVA) as explained byKumariet. al. [13] and Singla et al.[14].The scatter diagram for observed vs. estimated values of % dilution for different rows of the design matrix is given in figure 1.

**TABLE 5: Analysis of variance (ANOVA)**

| Resp-onse | DOF | | Var. response | Std. dev. | Var. adeq. | 'F' model | 'F' table | $F_m<F_t$ |
|---|---|---|---|---|---|---|---|---|
| | $S^2_Y$ | $S^2_{ad}$ | $S^2_Y$ | $S_{bj}$ | $S^2_{ad}$ | $S^2_{ad}/S^2_Y$ | (10,16,0.05) | |
| %D | 16 | 10 | 0.594 | 0.192 | 0.059 | 0.10 | 2.49 | Yes |

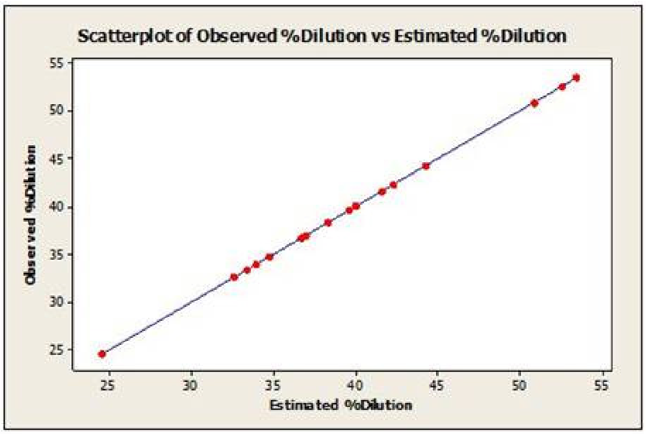


**Fig. 1.Scatter plot for weld bead dilution model**

The proposed model developed for %dilution after dropping insignificant coefficients is given in equation 6. Based on these models, graphs have been drawn for interpretation of the direct and interaction effects of the process parameters on %dilution.

%D= 39.72 -0.32W + 1.0 S + 4.22V -2.87 WV +1.72 WT - 0.13 SV + 2.69 VT (6)

## 5. OPTIMIZATION

Minimization of dilution was the main purpose of the present study while keeping in mind other important bead parameters with their constraints in the equation form. GA search ranges for delivering the optimal responses are given in Table 6. The experiments were carried out with the conditions as mentioned in Table 7.

Direct, indirect and response parameters for the selected set of problem are mentioned in Table 8.

**TABLE 6: GA search ranges**

| Parameters | Units | Range |
|---|---|---|
| WireFeed Rate | m/min | 7.62 - 9.04 |
| Welding Speed | cm/min | 27 - 36 |
| Voltage | Volts | 26 - 32 |
| Nozzle to Plate Distance | mm | 15 - 20 |
| Torch Angle | Degree | 80 - 100 |

**TABLE 7.Experimental condition**

| | |
|---|---|
| Base Metal | IS 2062 steel of 10mm thickness |
| Deposited Alloy | TAFA 140MXC Nano-structured wire of 1.6 mm dia. |
| Welding conditions | Flat |
| Technique | Bead on plate |
| Process | Semiautomatic GMAW |

**TABLE 8. Direct, indirect and response parameters for the selected set of problem**

| Direct parameters | Indirect parameters | | Response parameters |
|---|---|---|---|
| WireFeed Rate | Shielding gas | Argon | Penetration, p |
| Welding Speed | Power source | Constant potential | Width, w |
| Voltage | Welding current | D.C | Reinforcement height, h |
| Nozzle to Plate Distance | VI characteristic | Flat | %Dilution, D |
| Torch Angle | Electrode polarity | Positive | |

GA optimization tool available in MATLAB R2009a, was employed for fulfilling the purpose of optimization. M-file was created which is shown below:

```
function [f,g]=fp(x)
```

f(1)= 39.72-0.3872*x(1)+1.0*x(2)+4.22*x(3)-2.87*x(1)*x(3)+1.72*x(1)*x(5)-0.13*x(2)*x(3)+2.69*x(3)*x(5);
g(1)= 8.51 + 0.62*x(1)-1.01*x(2)+1.54*x(3)+0.33*x(1)*x(2)+0.59*x(1)*x(5)-0.54*x(2)*x(3)+0.54*x(3)*x(5)-0.24*x(4)*x(5);
g(2)= 5.5-8.51 + 0.62*x(1)-1.01*x(2)+1.54*x(3)+0.33*x(1)*x(2)+0.59*x(1)*x(5)-0.54*x(2)*x(3)+0.54*x(3)*x(5)-0.24*x(4)*x(5);
g(3)= 4.01-0.32*x(2)-0.39*x(3);
g(4)= 3.0-4.01-0.32*x(2)-0.39*x(3);
g(5)= 3.91 + 0.18*x(1)-0.34*x(2)+0.19*x(3)-0.35*x(1)*x(3)+ 0.38*x(2)*x(5)+0.21*x(3)*x(4)+0.30*x(3)*x(5);
g(6)= 2.4-3.91 + 0.18*x(1)-0.34*x(2)+0.19*x(3)-0.35*x(1)*x(3)+ 0.38*x(2)*x(5)+0.21*x(3)*x(4)+0.30*x(3)*x(5);
g(7)= f-53.46;
g(8)= 24.5-f;
end

Parameters for GA computation and setting of GA graphical interface are given in table 9 and figure 2 respectively, Yoganandhet al.[15].

**TABLE 9: Parameters for GA computation**

| Population type | Double vector | Crossover function | Intermediate |
|---|---|---|---|
| Population size | 100 | Migration | Forward |
| Number of generations | 52 | Lower boundary limits | -1, -1, -1, -1, -1. |
| Reproduction elite count | 2 | Upper boundary limits | 1, 1, 1, 1, 1. |

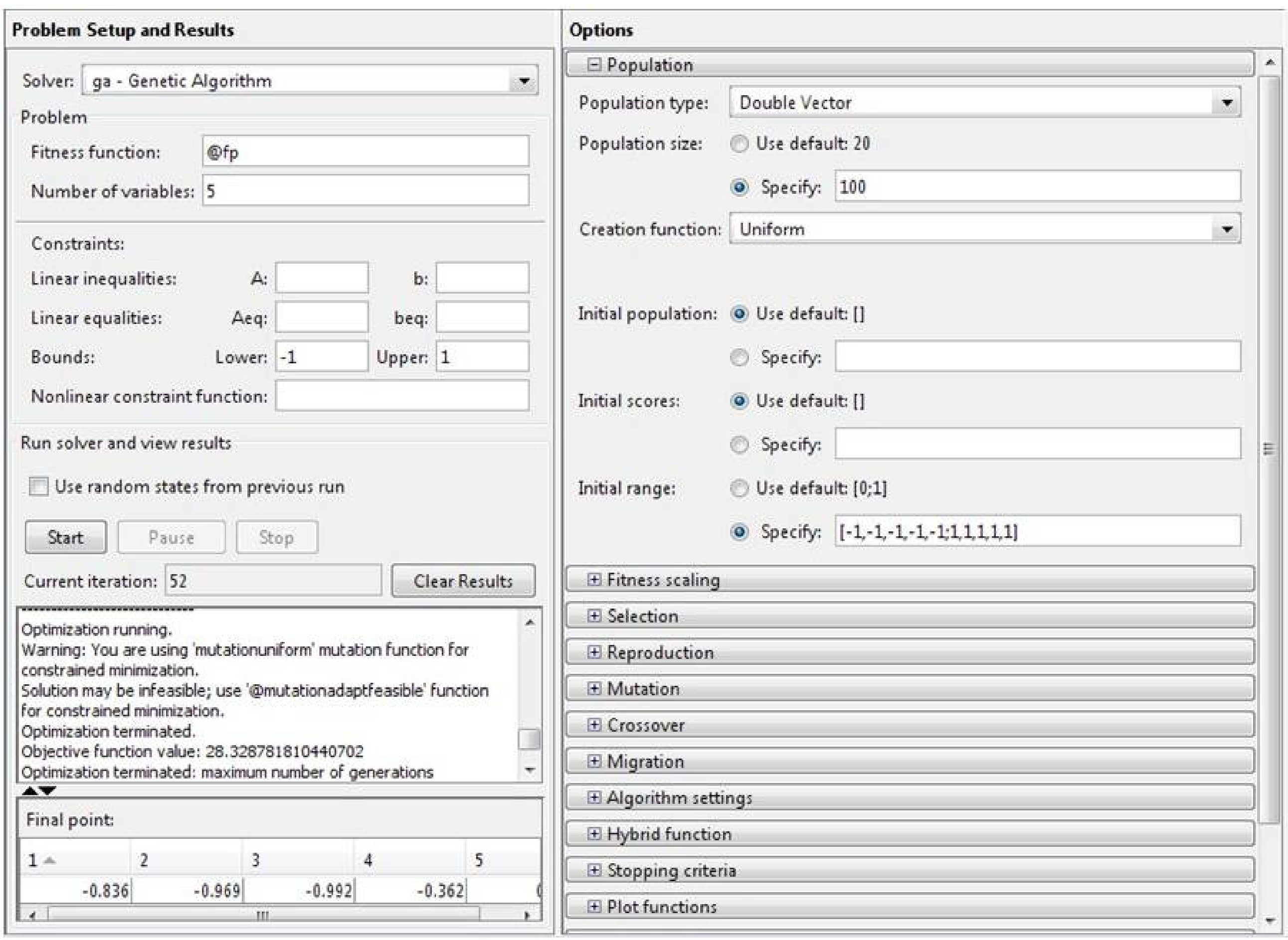


**Fig. 2.GA algorithm tool**

## 6. RESULT AND DISCUSSION

1. Increase in voltage, speed and torch angle increases the % dilution from 34.3 to 49.94,43.42 to 46.9and 32.8 to 50.44 respectively.
2. Increase in wire feed rate decreases the % dilution from 50.44 to 44.56.
3. % dilution remains constant at 46.03 with increase in nozzle to plate distance
4. Different coded values obtained after running the M-file are:

x(1) = Wire feed rate (W) = -0.836

x(2) = Welding speed (S) =-0.969

x(3) = Voltage(V) = -0.992

x(4) = Nozzle to plate distance (N) = -0.362

x(5) = Torch angle (T) = 0.866

Different plots for the developed code are shown in figure 3.The values of the direct parameter for the coded results and optimized response parameters of the hardfacedweldment are given in table 10.

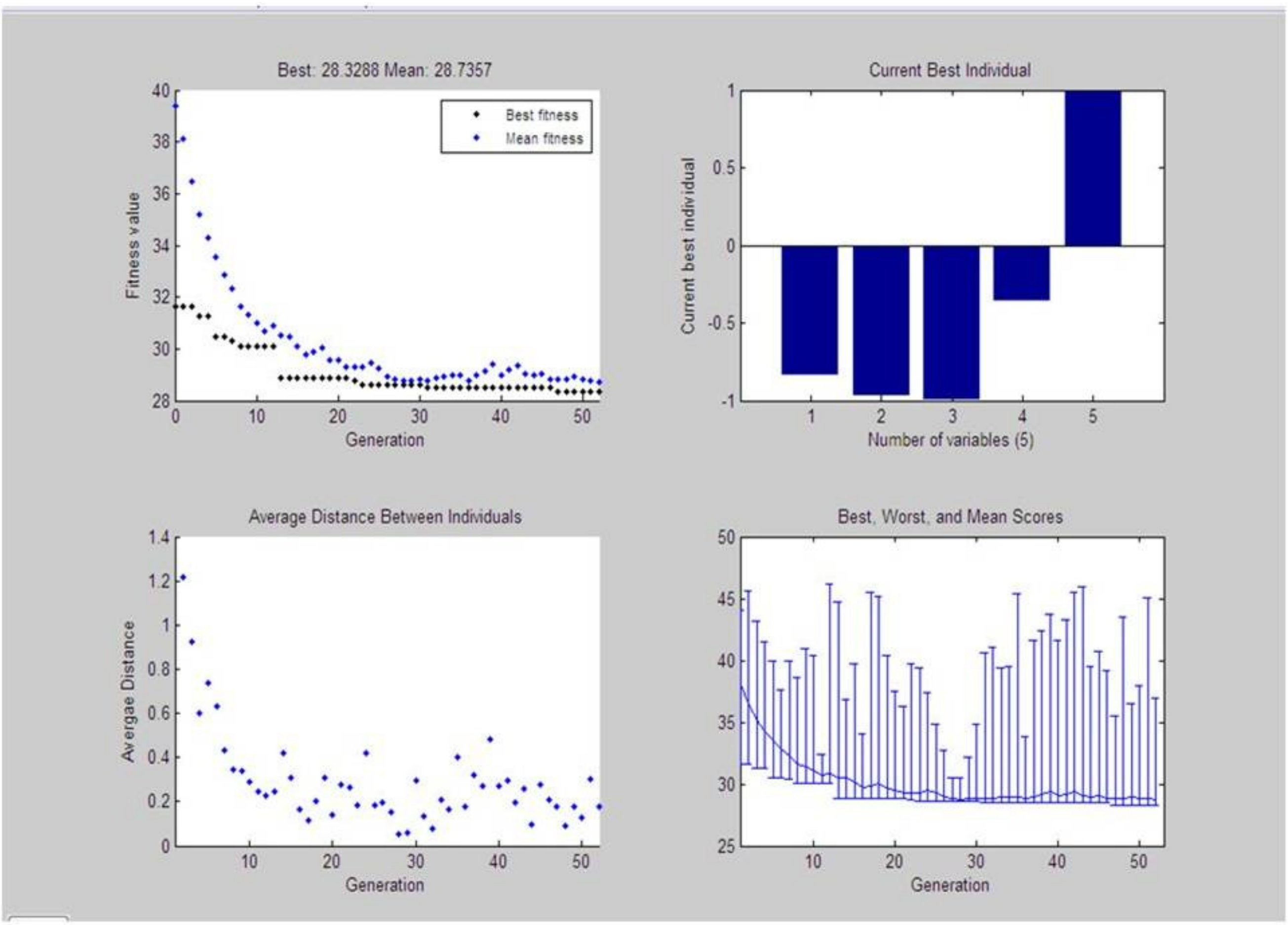


**Fig. 3. GA output plots**

**TABLE 10. Values of optimized parameters**

| Direct parameter | Value | Response parameters | Value |
|---|---|---|---|
| WireFeed Rate | 8.03322 m/min | %Dilution, D | 28.3288 |
| Welding Speed | 29.31976 cm/min | | |
| Voltage | 27.512 V | | |
| Nozzle to Plate Distance | 17.0475 mm | | |
| Torch Angle | 94.33 ° | | |

## 7. CONCLUSIONS

1. Response Surface Methodology (RSM) approach is an excellent and effective tool, for the development of mathematical model for the prediction of response.
2. Scatter diagram ensures the accuracy of the model.
3. Genetic Algorithm was found to be very effective and powerful technique for optimization of welding parameters.
4. Genetic Algorithm graphical user interface toolbox of MATLAB was used for minimization of dilution.
5. The optimum dilution obtained was 28.3288.
6. GMAW optimal process parameters were determined:

Wire Feed Rate = 8.03322 m/min; Welding Speed = 29.31976 cm/min; Voltage = 27.512V; Nozzle to Plate Distance = 17.0475 mm; Torch Angle = 94.33˚.

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