**Multi Objective Optimization of Weld Bead Geometry in Double Pulsed Gas Metal Arc Welding using Grey Relational Analysis**

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**Abstract.** In Manufacturing Industry, there is a need to estimate/predict values for performance measures for a set of input parameters and vice versa, for various machining operations which consume lot of operational time and money. This present paper discusses on grey relational analysis method using full factorial devise of experiments conducted on double-pulsed GMAW of AA5083 H111, for multi output optimization. The welding parameters namely, wire feed rate, wire feed rate/travel speed, amplitude (variation of wire feed rate) and double pulse frequency are measured each at three levels for the multiple performance measures of bead geometry considered to be bead penetration, bead reinforcement, bead width and convexity index. Grey relational grade is used to correlate multi counteracts to a single response known as all-inclusive component output measure which is otherwise called the grey relational grade. Here the analysis of variance technique ANOVA is applied in order to get the most influential multi response DP-GMAW parameter. The results conclude that the wire feed rate of 5.5 m/min, wire feed rate/travel speed of 30, amplitude of 0.4 Amp and frequency of 2 Hz are the most favorable welding parameters for double-pulsed GMAW of AA5083 H111.

Keywords: Gas Metal Arc Welding (GMAW), fractional factorial method, S/N ratio, Grey relational grade

1. **Introduction**

Welding is considered as one of the most widely used mechanized process in the industries. This study of welding process mainly concentrates on weld bead geometry, mechanical properties and welding parameters that persuades the efficiency and quality of the process. An expansion in process effectiveness can be got by optimizing the process parameters which are identified and determined using regions of critical process control resulting in output responses with acceptable variations. The simplest set can be modeled using single response optimization. However, welding process is considered too complex to be categorized into individual response. [1] This problem can be solved by the grey system theory introduced by Deng. [10]. Chen et al. [11] anticipated the assimilation of grey relational analysis and the Taguchi Method to resolve multiple quality characteristics. This technique transforms multiple quality characteristics into single grey relational grades. When compared the computed grey relational grades, the collection of respective quality characteristics are obtained in accordance with response grades to select an optimal set of process parameters. Optimal process parameters can then be resolute by the Taguchi method using the grey relational grade as its performance index.

This present study works on the application of Taguchi-GRA a Multi output optimization which is used as a well-organized approach to resolve the optimal welding parameters in double-pulsed GMAW of AA5083 H111 In this method the using fractional factorial design of experiments. In this process, Taguchi models of signal for noise (S/N) ratio, ANOVA are processed. The grey relational analysis used to optimize the double-pulsed GMAW process parameters for a single comprehensive output measure is called grey relational grade. As a final point, the analysis of variance is used to find out the most influential welding parameter for optimization problems of single and multiple responses.

1. **Experimental data Generation**

Welding of AA5083 H111 is considered for experimental work. A plate of 6mm thickness is used as foundation material. Wire feed rate, travel speed, amplitude i.e variation in wire feed rate and double pulse frequency are considered to be the input parameters. Depth of penetration, reinforcement, bead width and convexity index are considered as performance measures. Table 1 shows the level of the input parameters. The full factorial design of experiments comprising of 81 experiments is chosen to predict the process parameters that effect on bead geometry and thus the experiments are conducted accordingly.

**2.1** **Experimental set-up**

The experiment work is carried out on PROMIG welding machine as shown in the Figure 1. It comprises of gas metal arc welding machine, automatic feeding weld bed, DC motor, and a rheostat. The weld bed is then connected to a lead screw which is connected to a DC motor to obtain movement, when a DC Motor is powered. The weld bed automatically feeds in opposite direction when the lead screw moves forward. The amount of current passage to the DC Motor is monitored by varying rheostat such that the speed of the DC motor varies.

The travel speed of the weld bed facilitates to calculate wire feed rate. Welding is done on the weld plate by keeping welding torch fixed at a position and giving movement to the weld bed by varying the position of pointer on rheostat and the wire feed rate. After welding the weld plate, it is cut to metallurgical finish and then the depth of penetration, reinforcement, bead width and convexity index are then calculated.

## **2.2 Fractional factorial design of experiments**

One-third of the fractional factorial design is considered for carrying out the experiments. The fraction is selected to make use of the sparity-of-effects principle, to interpret information about the significant features of the problem. In the present work 27 such experiments are considered by taking generator as I=ABCD, out of suggested 81 experiments as shown in Table 2.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **TABLE 1.** Welding parameters at different levels   |  |  |  |  |  | | --- | --- | --- | --- | --- | | **Parameter** | **Symbol** | **Level 1** | **Level 2** | **Level 3** | | Wire feed rate (m/min) | A | 4.0 | 5.5 | 7.0 | | Wire feed rate/  Travel speed | B | 20 | 25 | 30 | | Amplitude (Amp) | C | 0.4 | 1.2 | 2.0 | | Frequency (Hz) | D | 1.5 | 2.0 | 2.5 | | IMG_20150224_104732.jpg  Figure 1. PROMIG3200 welding machine |

TABLE 2: Fractional factorial design of experiments

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Expt. No.** | **A** | **B** | **C** | **D** | **Expt.**  **No.** | **A** | **B** | **C** | **D** | **Expt. No.** | **A** | **B** | **C** | **D** |
| 1 | 4 | 20 | 0.4 | 1.5 | 10 | 5.5 | 20 | 0.4 | 2 | 19 | 7 | 20 | 0.4 | 2.5 |
| 2 | 4 | 20 | 1.2 | 2 | 11 | 5.5 | 20 | 1.2 | 2.5 | 20 | 7 | 20 | 1.2 | 1.5 |
| 3 | 4 | 20 | 2 | 2.5 | 12 | 5.5 | 20 | 2 | 1.5 | 21 | 7 | 20 | 2 | 2 |
| 4 | 4 | 25 | 0.4 | 2 | 13 | 5.5 | 25 | 0.4 | 2.5 | 22 | 7 | 25 | 0.4 | 1.5 |
| 5 | 4 | 25 | 1.2 | 2.5 | 14 | 5.5 | 25 | 1.2 | 1.5 | 23 | 7 | 25 | 1.2 | 2 |
| 6 | 4 | 25 | 2 | 1.5 | 15 | 5.5 | 25 | 2 | 2 | 24 | 7 | 25 | 2 | 2.5 |
| 7 | 4 | 30 | 0.4 | 2.5 | 16 | 5.5 | 30 | 0.4 | 1.5 | 25 | 7 | 30 | 0.4 | 2 |
| 8 | 4 | 30 | 1.2 | 1.5 | 17 | 5.5 | 30 | 1.2 | 2 | 26 | 7 | 30 | 1.2 | 2.5 |
| 9 | 4 | 30 | 2 | 2 | 18 | 5.5 | 30 | 2 | 2.5 | 27 | 7 | 30 | 2 | 1.5 |

1. **Experimental results**

The experimental results shown in Figure 2(a) to 2(d) show the ranges of depth of penetration PD (0.31 mm to 5.67 mm), reinforcement RH(2.65 mm to 4.62 mm), bead width BW (5.193 mm to13.408 mm) and convexity index CI (0.242 to 0.68) respectively .

|  |  |
| --- | --- |
|  |  |
| (a) | (b) |
|  |  |
| (c ) | (d) |

## Figure 2. Experimental results for the response variables

1. **Optimization of DP-GMAW parameters**

Taguchi method is used in combination with Grey relational analysis for the optimal welding parameters in Double-Pulsed GMAW process [1].The deviation between experimental value and desired value are approximated by Taguchi’s loss function. The characteristics of performance by signal-to-noise ratio is analyzed under three classes namely-‘lower-the-better’, ‘higher-the-better’ and ‘nominal-the-best’.[1] “Lower-the-better” is preferred in obtaining optimal welding performance with the minimum reinforcement and convexity index. “Higher-the-better” characteristic is preferred for achieving optimal welding performance maximum depth of penetration and bead width.

S/N ratio values are tabulated in Table 3 for each experimental parameter combinations for depth of penetration, reinforcement, bead width and convexity index and are used for single and multi characteristic optimizations.

1. **Single output parameter optimization**

In a single-response problem the Taguchi method is used. The largest S/N ratio is used for the quality characteristic. Besides, the influence of every factor is estimated through ANOVA. In GMAW, a smaller value of reinforcement and convexity index is normally essential. Consequently, the smaller-the-better approach of S/N ratio is applied to obtain the above mentioned responses. The higher-the-better approach of S/N ratio is used in calculating the depth of penetration and bead width.

## **5.1 Optimization for Depth of penetration**

As per ANOVA response table of S/N ratios of depth of penetration the factor combination A3B3C1D2 is recommended as shown in Table 3. It is observed that the contribution factor A to the depth of penetration is the largest (36.9%) followed by factor D (20.03%). Thus, wire feed rate is the most important factor followed by frequency to the extent that depth of penetration is concerned

## **5.2 Optimization for Reinforcement**

As per S/N ratios of reinforcement Factor combination A2B1C2D2 is recommended as shown in Table 4. Also it is observed that the contribution of factor D to the reinforcement is the largest (29.183%) followed by factor B (12.893%). As far as reinforcement is concerned, frequency is the most important factor followed by wire feed rate/travel speed.

## **5.3 Optimization for Bead width**

From the ANOVA response table of S/N ratios of bead width as shown in Table 5, factor combination A2B3C1D2 is recommended. Also it is detected that the contribution of factor A to the bead width is the largest (38.548%) followed by factor B (17.321%). As far as bead width is concerned, wire feed rate is the most important factor followed by wire feed rate/travel speed.

TABLE 3. ANOVA analysis of S/N ratios of depth of penetration

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Variable** | **Average level** | | | **DOF** | **SS** | **MS** | **F** | **Contribution (%)** |
| **1** | **2** | **3** |
| A  B  C  D  Error  Total | 0.697  4.32  **7.788**  6.868 | 7.384  5.995  5.641  **8.511** | **9.368**  **7.134**  4.02  2.07 | 2  2  2  2  3  11 | 371.516  36.065  64.306  201.621  333.103  1006.611 | 185.76  18.033  32.153  100.81  111.035 | 1.673  0.163  0.29  0.908 | **36.908**  3.583  6.389  20.03  33.092  100 |

TABLE 4. ANOVA analysis of S/N ratios of reinforcement

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Variable** | **Average level** | | | **DOF** | **SS** | **MS** | **F** | **Contribution (%)** |
| **1** | **2** | **3** |
| A  B  C  D  Error  Total | -10.631  **-9.864**  -10.508  -11.211 | **-9.935**  -10.706  **-10.354**  **-9.598** | -10.884  -10.881  -10.589  -10.642 | 2  2  2  2  3  11 | 4.348  5.322  0.257  12.047  19.307  41.281 | 2.174  2.661  0.129  6.024  6.436 | 0.338  0.414  0.021  0.936 | 10.533  12.893  0.623  **29.183**  46.77  100 |

**TABLE 5.** ANOVA analysis of S/N ratios of bead width

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Variable** | **Average level** | | | **DOF** | **SS** | **MS** | **F** | **Contribution (%)** |
| **1** | **2** | **3** |
| A  B  C  D  Error  Total | 17.174  18.081  **19.062**  19.168 | **19.77**  18.602  18.755  **19.52** | 19.758  **20.018**  18.884  18.014 | 2  2  2  2  3  11 | 40.25  18.086  0.428  11.171  34.482  104.417 | 20.125  9.043  0.214  5.586  11.494 | 1.751  0.787  0.019  0.486 | **38.548**  17.321  0.41  10.699  33.024  100 |

**TABLE 6.** ANOVA analysis of S/N ratios of convexity index

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Variable** | **Average level** | | | **DOF** | **SS** | **MS** | **F** | **Contribution (%)** |
| **1** | **2** | **3** |
| A  B  C  D  Error  Total | 6.547  8.223  **8.556**  7.958 | **9.836**  7.899  8.406  **9.927** | 8.875  **9.136**  8.296  7.374 | 2  2  2  2  3  11 | 51.482  7.407  0.307  32.208  82.983  174.387 | 25.741  3.704  0.154  16.104  27.661 | 0.931  0.134  0.006  0.583 | **29.522**  4.248  0.177  18.47  47.586  100 |

## **5.4 Optimization for Convexity index**

Factor combination A2B3C1D2 is recommended from the ANOVA response table of S/N ratios of convexity as shown in Table 6. It is also observed that the contribution of factor A to the convexity index is the largest (29.522%) followed by factor D (18.47%). Thus, wire feed rate is the most important factor followed by frequency as far as convexity index is concerned. We can thus conclude that a study of all the four ANOVAs reveal the optimal factor/level combination, or the most significant factor. It also reveals that one quality is generally different from another.

1. **Multi characteristic optimization by Grey Relational Analysis method**

To obtain the optimal level/factor combination of DP-GMAW process, Grey relational analysis is performed when a multi-response problem is considered. This transforms the four correlated responses to a single response called comprehensive output measure. The following are the steps followed for performing grey relational analysis.

**6.1 Normalizing Signal to Noise (S/N) ratio**

In this first step, pre-processing of the data is performed for normalizing the raw data for analysis. Signal to noise ratio responses obtained are used for finding normalized signal to noise ratio

=(higher better);= (lower better)

**6.2 Calculating Grey Relational Coefficient and Grey Relational Grade**

The grey relational coefficient is calculated to express the relationship between the ideal (best) and actual normalized experimental results. Earlier to that, the deviation sequence for the reference and comparability sequence are found out.

**Deviation Sequences: Grey Relational Coefficient:**

 

Where,  is the deviation sequence of the reference sequences

is distinguishing or identified coefficient. The value of is the smaller and the distinguished ability is larger. = 0.5 is generally used. Grey Relational Grade is determined by averaging the Grey Relational Coefficient corresponding to each performance characteristic. The overall performance characteristic of the multiple response process depends on the calculated Grey Relational Grade, can be expressed as

**6.3 Determining of the optimal factors**

From the graph shown in figure3, experiment No.26 has the highest grade to obtain the best multi-response characteristics of minimum bead height, maximum depth of penetration, maximum bead width and minimum convexity index. Thus, the multi response optimal parameters obtained at A3B3C1D2 represent the best multi-performance characteristics amongst the 27 experimental run conditions. In addition, the mean response which refers to the average value of the grey relational grade on each parameter at different levels are calculated as shown in Table 7. The optimal welding parameters are the wire feed rate at level 2 (5.5 m/min), wire feed rate/travel speed at level 3 (30), amplitude at level 1 (0.4 Amp) and frequency at level 2 (2 Hz) i.e. A2B3C1D2 are the most favorable welding parameters for double-pulsed GMAW of AA5083 H111.

**6.4 Confirmation Experiments**

Confirmation experiments are conducted and the observed output characteristics obtained at the optimal setting of the process parameters are compared with the characteristic values obtained at the initial setting of the process parameters. It can be observed from Table 8, that there is significant improvement in all the performance characteristics at the specified optimal levels of welding parameters for double-pulsed GMAW of AA5083 H111parameters obtained by application of Taguchi grey relational analysis (TGRA).

1. **Conclusions**

In this study, to optimize the DP-GMAW of AA5083 H111 the Taguchi is used with grey relational analysis approach. In contradiction to full factorial design, the welding parameters optimization is activated through experiments with minimum number of trials using Fractional factorial design of experiments. The results are as follows:

(i) The factor/level combination A3B3C1D2 for depth of penetration, A2B1C2D2 for reinforcement, A2B3C1D2 for bead width and A2B3C1D2 for convexity index are the suggested optimum parameters, for DP-GMAW when all four responses are considered independently. (ii) In the multi-response problem, all the four depth of penetration, reinforcement, bead width and convexity index are simultaneously considered and A2B3C1D2 is the suggested optimum condition with reference to the Taguchi-GRA approach. (iii) It can be seen that middle level of wire feed rate (5.5 mm) and frequency (2 Hz), lower level of amplitude (0.4 amp) and higher level of wire feed rate/travel speed (30) yield the optimal result. (iv)Both the single response and multi-response optimization analysis prove that middle level of frequency (D2) is favorable in increasing depth of penetration, bead width and reducing reinforcement, convexity index when compared to higher (D3) and lower (D1) levels of frequency.

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| Figure 3. Grey relational grade for the response variables | Table 7 Response table for grey relational grades   |  |  |  |  |  | | --- | --- | --- | --- | --- | | Para  meter | Level 1 | Level 2 | Level 3 | Max-Min | | A | 0.500419 | **0.575417** | 0.5432 | 0.074998 | | B | 0.544292 | 0.519077 | **0.555666** | 0.036589 | | C | **0.561398** | 0.551482 | 0.506156 | 0.055242 | | D | 0.527976 | **0.597812** | 0.493248 | 0.104564 | |
| |  |  |  | | --- | --- | --- | | Condition description | 26th Expt. Result | Grey theory prediction results | | Levels | A3B2C1D2 | A2B3C1D2 | | Penetration depth | 5.67 | 4.7 | | Bead height | 3.39 | 2.92 | | Bead width | 13.24 | 14.11 | | Convexity index | 0.257 | 0.207 | | Grey relational grade | 0.7989 | 0.8656 | | Improvement in grey relational grade=0.067 | | |   Table 8 - Improvements in grey relational grade with optimized DP-GMAWelding parameters | |

This present paper acquaints the use of fractional factorial method with Grey relational analysis to Taguchi method in optimization of the DP-GMAW with multiple performance uniqueness and a four performance characteristics namely depth of penetration, reinforcement, bead width and convexity index can be enhanced. Hence, it can be concluded that the optimization methodology extended in this present study is useful in enriching the multi performance characteristics in DP-GMAW.

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