# Evaluation of Optimal Parametric Combination in Submerged Arc Double Pass Butt Welding

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**ABSTRACT**

In the present paper, application of Taguchi method with grey relational analysis has been highlighted for solving multiple response optimization problem in submerged arc welding (SAW). A grey relational grade evaluated from the grey relational analysis has been adopted to reveal an optimal parameter combination in order to obtain acceptable features of weld quality characteristics in submerged arc butt welding.

*Key words: submerged arc welding, Taguchi method, grey relational analysis, optimization*

## INTRODUCTION

In today's world, quality improvement scheme in process/ product has become the main focus to sustain a manufacturing industry in the market of competition. A good quality product should ensure all functional requirements to suit its area of application, within acceptable limits, that can fetch customer's satisfaction. However, quality of a product is strongly influenced by the process condition, working skill of the personnel involved in the manufacturing process, constraints of funding and also the management strategy how to improve and control quality. One of the most important aspects of quality control is the parametric optimization of process/ product. An optimal parameter setting would provide the features of acceptable quality product with minimum cost. The process should run at optimal process condition, so that, the product becomes unaffected by the causes of variations and insensitive to changes in process condition. Therefore, there exists an increasing need to search for an optimal process condition that is capable of resulting desired yield.
Submerged arc welding is a versatile metal joining process in industry. It is a multi variable, multi-objective metal fabrication process, characterized by the use of granulated fusible flux which cover the molten weld pool during operation. This arrangement facilitates slower cooling rate, prevents atmospheric contamination: nitrogen embitterment into the weld pool and improves both mechanical properties and metallurgical characteristics of the weld bead as well as heat affected zone (HAZ). The acceptable quality characteristics of an weldment include deeper penetration, minimum bead height/ reinforcement, minimum bead width and minimum HAZ width. To reduce weld metal consumption and reduction in fabrication cost, bead volume should be minimum. Moreover, desired mechanical properties of the weldment depend on to some extent the features of bead geometry and HAZ. By parametric optimization of welding phenomena, the desired weld quality characteristics can be achieved easily.

Literature review depicts that much work has been explored on various aspects of modeling and process optimization in submerged arc welding [1-4]. The common approaches to tackle optimization problem include regression analysis, response surface methodology (RSM), Artificial Neural Network (ANN) Modeling and Taguchi Method [5-10]. In most of the cases the optimization has been performed using single objective function. For multi response processes, while applying the optimal setting of control factors, it can be observed that an increase of one response may cause change in another response beyond the acceptable limit. For solving multi response optimization problem, it is required to convert all the objective functions into an equivalent single objective function. This equivalent objective function, which is the representative of all the quality characteristics of the product, is then to be optimized.

In the present research work, an attempt has been made to search for an optimal parametric combination in order to obtain acceptable quality weld bead, produced by submerged arc butt welding on mild steel. Experiments have been conducted using Taguchi's $L_9$ Orthogonal Array (OA) with conventional process parameters: welding current, electrode stick-out and voltage varied at three different levels. The selected bead quality features have been bead width, reinforcement and depth of penetration. A grey relational grade evaluated from grey relational analysis has been adopted to convert multi-objective optimization situation into a single performance index. Based on grey relational analysis followed by Taguchi method optimal welding parameters have been determined. Finally a confirmation experiment has been conducted to verify the optimal parameter setting as predicted by grey relational analysis and Taguchi method.

## BRIEF OVERVIEW OF TAGUCHI METHOD

Taguchi's philosophy is an efficient tool for the design of high quality manufacturing system. Dr. Genichi Taguchi, a Japanese quality management consultant, has developed a method based on orthogonal array experiments which provide much reduced variance for the experiment with optimum setting of process control parameters. Thus the integration of Design Of Experiments (DOE) with parametric optimization of process to obtain desired results is achieved in the Taguchi Method. Orthogonal array (OA) provides a set of well balanced (minimum experimental runs) experiments and Taguchi's signal-to-noise ratios (S/N), which are logarithmic functions of desired output serve as objective functions for optimization. This technique helps in data analysis and prediction of optimum results. In order to evaluate optimal parameter settings, Taguchi Method uses a statistical measure of performance index called signal-to-noise ratio. The S/ N ratio takes both the mean and the variability into account. The S/ N ratio is the ratio of the mean (Signal) to the standard deviation (Noise). The ratio depends on the quality characteristics of the product/ process to be optimized [9]. The standard S/ N ratios generally used are as follows: Nominal is Best (NB), Lower the Better (LB) and Higher the Better (HB). The optimal setting is the parameter combination which has the highest S/ N ratio.

## GREY RELATIONAL ANALYSIS

In the grey relational analysis, as reported in [12], experimental data i.e. measured features of quality characteristics are first normalized ranging from zero to one. This process is known as grey relational generation. Next, based on normalized experimental data, grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Then overall grey relational grade is determined by averaging the grey relational coefficient corresponding to selected responses. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade. This approach converts a multiple response process optimization problem in a single response optimization situation with the objective function of overall grey relational grade. The optimal parametric combination is then evaluated which would result highest grey relational grade.

In grey relational generation, the normalized bead width and reinforcement, corresponding to lower-the-better (LB) criterion can be expressed as

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \quad \text{(i)}$$

Bead penetration should follow larger-the-better criterion can be expressed as

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)} \quad \text{(ii)}$$

where $x_i(k)$ is the value after the grey relational generation, $\min y_i(k)$ is the smallest value of $y_i k$

for the *kth* response, and *max* $y_i(k)$ is the largest value of for the *kth* response, and *max* $y_i(k)$ is the largest value of $y_i(k)$ for the *kth* response. The normalized data after grey relational generation are tabulated in Table 4.1 and 4.2. An ideal sequence is $x_0(k)$ $(k = 1,2,3.......9)$ 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 nine sequences $[x_0(k)$ and $x_i(k)$, $i = 1,2,3......9]$. The grey relational coefficient $\xi_i(k)$ can be calculated as:

$$\xi_i(k) = \frac{\Delta_{\min} + \psi\Delta_{\max}}{\Delta_{0i}(k) + \psi\Delta_{\max}} \qquad \text{(iii)}$$

where $\Delta_{0i} = \|x_0(k) - x_i(k)\|$ = difference of the absolute value $x_0(k)$ and $x_i(k)$; is the distinguishing coefficient $0 \le \psi \le 1$ ;
$\Delta_{\min} = \forall j^{\min} \in i \forall k^{\min} \|x_0(k) - xj(k)\|$ = the smallest value of $\Delta_{0i}$; and
$\Delta_{\max} = \forall j^{\max} \in i \forall k^{\max} \|x_0(k) - xj(k)\|$ = largest value of $\Delta_{0i}$ . The grey relational coefficient for the present case are furnished in Table 5.1 and 5.2.

After averaging the grey relational coefficients, the grey relational grade can be computed as

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k) \qquad \text{(iv)}$$

where $n$ = number of process responses. Table 6.1 and 6.2 represent experimental results for the grey relational grade order by using the colleted experimental data (Table 3.1-3.2). The higher value of grey relational grade corresponds to intense relational degree between the reference sequence $x_0(k)$ and the given sequence $x_i(k)$. The reference sequence $x_0(k)$ represents the best process sequence, therefore, higher grey relational grade means that the corresponding parameter combination is closer to the optimal. Table 7.1 and 7.2 show the mean response for the grey relational grade with its grand mean. The main effect plot of grey relational grade is shown in Fig. 1-2. The figures are very important because optimal process condition can be evaluated from these plots.

## EXPERIMENTATION AND DATA COLLECTION

Based on Taguchi's orthogonal array design, experiments have been conducted with three different levels of process parameters: welding current, electrode stick-out and voltage with electrode of diameter 3.14 mm (AWS A/S 5.17:EH14) to produce butt weld from mild steel plates (100 X 40 X 12) in double pass submerged arc welding. Flux used in this experiment was AWS A5.17/SFA 5.17 with grain size 0.2 to 1.6 mm and basisity index 1.6. Process parameters with their notations, unit and values at different levels are listed in Table 1. Design matrix has been selected based on Taguchi's Orthogonal Array design of L9 ( 3**3) consisting of 9 sets of coded conditions (Table 2). The experiments were performed in Submerged Arc Welding Machine (Maker: IOL Ltd., India).

Table 1. Process Control Parameters and their Levels

| Parameters | Unit | Notation | -1 | 0 | 1 |
|---|---|---|---|---|---|
| | | For Backing Pass | | | |
| Current | Ampere | C | 450 | 465 | 480 |
| Stick out | mm. | T | 22 | 24 | 26 |
| voltage | Volt | V | 30 | 32 | 34 |
| | | For Secondary Pass | | | |
| Current | Ampere | C | 470 | 485 | 500 |
| Stick out | mm. | T | 22 | 24 | 26 |
| voltage | Volt | V | 32 | 34 | 36 |

(Experimental setup is shown in appendix.) For each of the specimens, the dimensions, of the weld bead geometry have been measured (Table 3.1 and 3.2). The bead cross sectional area is also shown in figure (appendix).

Table 2: Taguchi's Orthogonal Array L9 (3**3)

| Sl.No. | Current C | Stick-out T | Voltage V |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 |
| 3 | 1 | 3 | 3 |
| 4 | 2 | 1 | 2 |
| 5 | 2 | 2 | 3 |
| 6 | 2 | 3 | 1 |
| 7 | 3 | 1 | 3 |
| 8 | 3 | 2 | 1 |
| 9 | 3 | 3 | 2 |

Table 3.1: Experimental Data (Backing Pass)

| Sl.No. | Bead Width (mm) | Reinforcement (mm) | Penetration (mm) |
|---|---|---|---|
| 1 | 15.28 | 2.42 | 5.04 |
| 2 | 16.72 | 2.60 | 5.66 |
| 3 | 18.50 | 3.48 | 6.16 |
| 4 | 16.48 | 2.88 | 5.64 |
| 5 | 17.80 | 3.34 | 6.00 |
| 6 | 16.24 | 2.72 | 5.46 |
| 7 | 17.75 | 3.28 | 5.88 |
| 8 | 16.20 | 2.68 | 5.40 |
| 9 | 17.44 | 3.16 | 5.74 |

Table 3.2: Experimental Data (Secondary Pass)

| Sl.No. | Bead Width (mm) | Reinforcement (mm) | Penetration (mm) |
|---|---|---|---|
| 1 | 15.82 | 2.40 | 6.20 |
| 2 | 17.32 | 3.12 | 6.90 |
| 3 | 18.56 | 3.56 | 7.34 |
| 4 | 16.70 | 3.06 | 6.84 |
| 5 | 18.30 | 3.48 | 7.26 |
| 6 | 16.42 | 2.86 | 6.80 |
| 7 | 17.96 | 3.42 | 7.16 |
| 8 | 16.32 | 2.84 | 6.74 |
| 9 | 17.62 | 3.28 | 7.10 |

Table 4.1: Data preprocessing of each performance characteristic (Backing pass) (Grey relational generation)

| Experiment No. | Bead width | Reinforcement | Penetration |
|---|---|---|---|
| Ideal sequence | 1 | 1 | 1 |
| 1 | 1.0000 | 1.0000 | 0.0000 |
| 2 | 0.5528 | 0.8302 | 0.5536 |
| 3 | 0.0000 | 0.0000 | 1.0000 |
| 4 | 0.6273 | 0.5660 | 0.5357 |
| 5 | 0.2174 | 0.1321 | 0.8571 |
| 6 | 0.7019 | 0.7170 | 0.3750 |
| 7 | 0.2329 | 0.1887 | 0.7500 |
| 8 | 0.7143 | 0.7547 | 0.3214 |
| 9 | 0.3292 | 0.3019 | 0.6250 |

Table 4.2: Data preprocessing of each performance characteristic (Secondary Pass) (Grey relational generation)

| Experiment No. | Bead width | Reinforcement | Penetration |
|---|---|---|---|
| Ideal sequence | 1 | 1 | 1 |
| 1 | 1.0000 | 1.0000 | 0.0000 |
| 2 | 0.4526 | 0.3793 | 0.6140 |
| 3 | 0.0000 | 0.0000 | 1.0000 |
| 4 | 0.6788 | 0.4310 | 0.5614 |
| 5 | 0.0949 | 0.0690 | 0.9298 |
| 6 | 0.7810 | 0.6034 | 0.5263 |
| 7 | 0.2190 | 0.1207 | 0.8421 |
| 8 | 0.8175 | 0.6207 | 0.4737 |
| 9 | 0.3431 | 0.2414 | 0.7895 |

Table 5.1: Grey relational coefficient of each performance characteristic (Backing Pass)

| Experiment No. | Bead width | Reinforcement | Penetration |
|---|---|---|---|
| Ideal sequence | 1 | 1 | 1 |
| 1 | 1.0000 | 1.0000 | 0.3333 |
| 2 | 0.5279 | 0.7465 | 0.5283 |
| 3 | 0.3333 | 0.3333 | 1.0000 |
| 4 | 0.5729 | 0.5353 | 0.5185 |
| 5 | 0.3898 | 0.3655 | 0.7777 |
| 6 | 0.6265 | 0.6386 | 0.4444 |
| 7 | 0.3946 | 0.3813 | 0.6667 |
| 8 | 0.6364 | 0.6709 | 0.4242 |
| 9 | 0.4271 | 0.4173 | 0.5714 |

Table 5.2: Grey relational coefficient of each performance characteristic (Secondary Pass)

| Experiment No. | Bead width | Reinforcement | Penetration |
|---|---|---|---|
| Ideal sequence | 1 | 1 | 1 |
| 1 | 1.0000 | 1.0000 | 0.3333 |
| 2 | 0.4774 | 0.4461 | 0.5643 |
| 3 | 0.3333 | 0.3333 | 1.0000 |
| 4 | 0.6089 | 0.4677 | 0.5327 |
| 5 | 0.3558 | 0.3494 | 0.8769 |
| 6 | 0.6954 | 0.5577 | 0.5135 |
| 7 | 0.3903 | 0.3625 | 0.7600 |
| 8 | 0.7326 | 0.5686 | 0.4872 |
| 9 | 0.4322 | 0.3973 | 0.7037 |

Table 6.1: Grey relational grade and its order (Backing pass)

| Experiment No. | Grey relational grade | Order |
|---|---|---|
| 1 | 0.7778 | *1* |
| 2 | 0.6009 | *2* |
| 3 | 0.5555 | *5* |
| 4 | 0.5422 | *6* |
| 5 | 0.5110 | *7* |
| 6 | 0.5698 | *4* |
| 7 | 0.4809 | *8* |
| 8 | 0.5772 | *3* |
| 9 | 0.4719 | *9* |

Table 6.2: Grey relational grade and its order (Secondary pass)

| Experiment No. | Grey relational grade | Order |
|---|---|---|
| 1 | 0.7778 | *1* |
| 2 | 0.4959 | *9* |
| 3 | 0.5555 | *4* |
| 4 | 0.5364 | *5* |
| 5 | 0.5274 | *6* |
| 6 | 0.5889 | *3* |
| 7 | 0.5043 | *8* |
| 8 | 0.5961 | *2* |
| 9 | 0.5111 | *7* |

Table 7.1: Response table (mean) for the grey relational grade (Backing pass)

| Symbol | Factor | Grey relational grade | | | |
|---|---|---|---|---|---|
| | | Level 1 | Level 2 | Level 3 | Delta |
| C | Current | 0.64473 | 0.54100 | 0.51000 | 0.13473 |
| T | Stick-out | 0.60030 | 0.56303 | 0.53240 | 0.06790 |
| V | Voltage | 0.64160 | 0.53833 | 0.51580 | 0.1258 |
| Total mean grey relational grade= 0.565244 | | | | | |

Table 7.2: Response table (mean) for the grey relational grade (Secondary pass)

| Symbol | Factor | Grey relational grade | | | |
|---|---|---|---|---|---|
| | | Level 1 | Level 2 | Level 3 | Delta |
| C | Current | 0.60973 | 0.5509 | 0.53717 | 0.72560 |
| T | Stick-out | 0.60617 | 0.53980 | 0.55183 | 0.06637 |
| V | Voltage | 0.65427 | 0.51447 | 0.52907 | 0.13980 |
| Total mean grey relational grade= 0.565933 | | | | | |

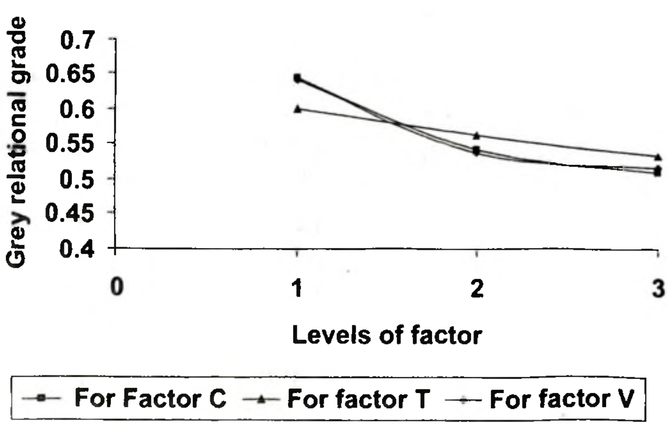


Figure 1: Grey relational grade graph (for backing pass)

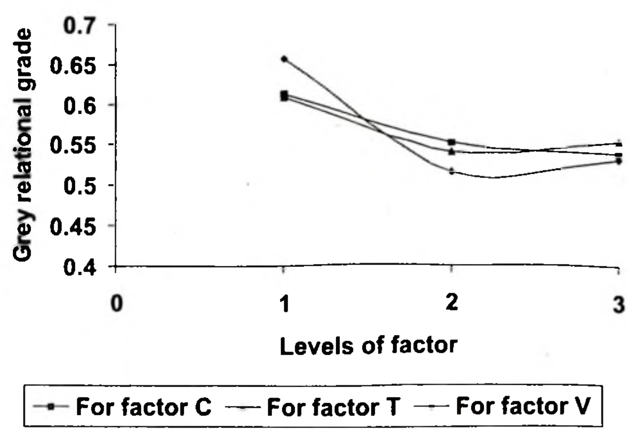


Figure 2: Grey relational grade graph (for secondary pass)

## DATA ANALYSIS AND PARAMETRIC OPTIMIZATION

Experimental data have been normalized first (grey relational generation). The normalized data for each of the parameters of bead geometry have been furnished in Table 4.1 and 4.2. For bead width and reinforcement lower-the-better and for depth of penetration, higher-the-better criteria has been selected. Grey relational coefficients for each performance characteristics have been calculated using equation (iii) (Table 5.1 and 5.2). These grey relational coefficients for each responses have been accumulated to evaluate grey relational grade (equation iv), that is the overall representative of all the features of weld quality (Table 6.1 and 6.2). Thus the multi-criteria optimization problem has been transformed into a single equivalent objective function optimization problem using the combination of Taguchi approach and grey relational analyses. Higher is the value of grey relational grade, the corresponding factor combination is said to be close to the optimal. The mean response table for the grey relational grade are shown in Table 7.1 and 7.2, and are represented graphically in Figures 1 -2. With the help of these figures optimal parametric combination has been determined. The optimal factor setting becomes C1T1V1, both for backing pass and secondary pass.

## CONFIRMATORY EXPERIMENT

After evaluating the optimal parameter settings, the next step is to predict and verify the enhancement of quality characteristics using the optimal parametric combination. The estimated grey relational grade using the optimal level of the design parameters can be calculated as:

(v)

where is the total mean grey relational grade, is the mean grey relational grade at the optimal level, and o is the number of the main design parameters that affect the quality characteristics. Table 8.1and 8.2 represent the comparison of the predicted bead geometry parameters with that of actual by using the optimal welding conditions; good agreement between the two has been observed. It is observed that in both the cases, backing pass and secondary pass, optimal condition improves grey relational grade than that of actual welding condition. This proves the utility of the proposed approach in relation to product/ process optimization, where more than one objectives have to be fulfilled simultaneously. Actually, what happens in a multi-criteria optimization problem, a factor combination (compared to the present condition), may impose improvement of one response but its influence may be adverse on another response. So, in order to make a compromise, an optimal solution is of extreme interest.

Table 8.1 Results of confirmatory experiment (Backing pass)

| | Initial factor setting | Optimal Condition | |
|---|---|---|---|
| | | Prediction | Experiment |
| Level | C2T2V2 | C1T1V1 | C1T1V1 |
| Bead width (mm) | 16.82 | | 15.28 |
| Reinforcement (mm) | 2.90 | | 2.42 |
| Penetration (mm) | 5.68 | | 5.04 |
| Grey relational grade | 0.50276 | 0.76019 | 0.7778 |
| Improvement in grey relational grade= 0.27504 | | | |

Table 8.2 Results of confirmatory experiment (Secondary pass)

| | Initial factor setting | Optimal Condition | |
|---|---|---|---|
| | | Prediction | Experiment |
| Level | C2T2V2 | C1T1V1 | C1T1V1 |
| Bead width (mm) | 17.32 | | 15.82 |
| Reinforcement (mm) | 3.24 | | 2.40 |
| Penetration (mm) | 6.94 | | 6.20 |
| Grey relational grade | 0.49114 | 0.73421 | 0.7778 |
| Improvement in grey relational grade= 0.28666 | | | |

## CONCLUSION

In the present study a detailed methodology of Taguchi optimization technique with grey relational analysis has been reported and applied for evaluating optimal parametric combination to achieve acceptable features of weld bead geometry in submerged arc double pass butt welding. The method is very efficient for solving optimization problem that can be performed in a limited number of experimental runs. The methodology proposed in this reporting can be applied for continuous quality improvement either in the process or in the product.

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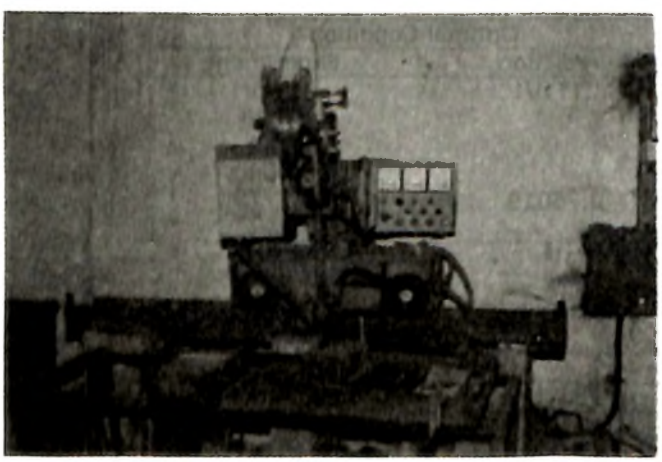
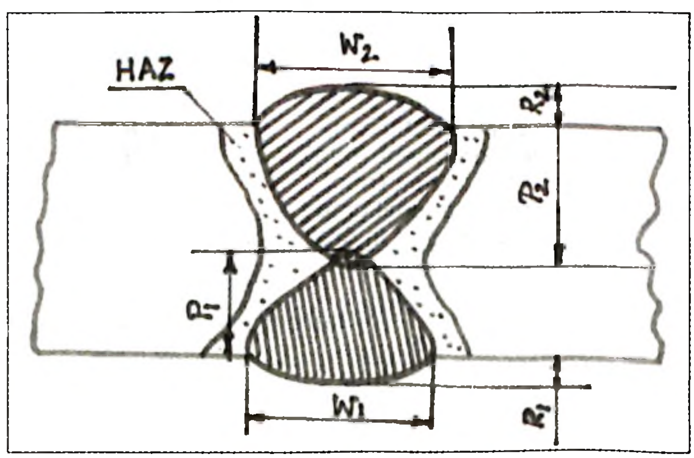
## APPENDIX






Bead cross sectional area for double pass butt welding
*W= Bead width, R= Reinforcement, P= Penetration, Suffix 1 for backing pass and 2 for secondary pass*