Comparison between PCA analysis and Grey based Taguchi analysis of TIG welding process parameters on Duplex stainless steel

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Abstract: Tungsten inert gas (TIG) welding on Duplex stainless steel (DSS) is more easy, comfortable and useful, if the process is precisely understood and controlled through development of the science & technology. TIG welding on DSS has been performed with the help of specific controlled welding process parameters. Welding quality has been strongly depended on these process parameters. In this study, some valuable welding parameters are chosen. These are welding current, shielding gas flow rate and speed of welding. These process parameters of TIG welding for ASTM/UNS 2205 DSS welds are optimized by using Principal Component Analysis (PCA) method and Grey based Taguchi’s L9 Orthogonal array (OA) experimental plan with the conception of signal to noise ratio (N/S). After that, compression results of above mentioned two analyses of TIG welding process parameters have been calculated. The quality of the TIG welding on DSS has been evaluated in term of ultimate tensile strength, yield strength and percentage of elongation. Compression results of both analyses indicate application feasibility for continuous improvement of welding quality on DSS in different components of chemical, oil and gas industries.

Keywords: TIG welding, UNS DSS2205, Principal Component Analysis (PCA) method, Grey based Taguchi analysis

1. Introduction

The exceptional blend of double phase configuration of ferrite with austenite has been seen in DSS. Austenite structure provides a unique arrangement of strength as well as resistance to corrosion. Ferrite structure provides local corrosion resistance for Duplex stainless steel. Deference type of welding techniques like Gas metal arc welding (GMAW), Manual metal arc welding (MMAW), Submerged arc welding (SAW) can use to coalesce DSS plates. But, TIG welding on DSS is more easy, comfortable and less costly.

Some remarkable researchers have been investigated regarding TIG welding, welding on Duplex stainless steel, or related subject matter. They have been established their opinion authentically. Lakshminarayanan et al. established that the joints welded by GTAW technique shows superior tensile strength values and higher impact strength values [1]. Magudeeswaran et al. investigated on the predominant factor in the electrode gap which affects the characteristic relation of DSS welds welded by a TIG welding method [2]. Badjia et al. observed as in the received metal the textures of both phases are mixtures of recrystallization textures and deformation, which generally establish between the material of single phase BCC and FCC structure [3, 4]. Tarrg and Yang applied Taguchi technique to optimized weld bead geometry in GTAW [5]. Tarrg et al. also investigated on grey-based Taguchi technique to decide optimal procedure factors for SAW in hard facing with concern of several welding characteristics [6, 7]. Different common approaches have been used by various researchers to solve welding related optimization problem in such as response surface methodology, Taguchi technique, multi regression analysis etc [8-11]. TIG welding has been done to get high quality welds in aluminium, stainless steels, nirome alloys (80/20 nickel- chromium) and copper for use in oil and chemical plants [12]. The Taguchi technique is the most accepted method to solve the optimization difficulties within the area of manufacturing technology [6, 10]. The process uses a sensible investigational design said orthogonal array design with signal to noise ratio (S/N ratio). Del Coz Diaz et al. showed the significant role of material characteristics of dissimilar stainless steels.

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using finite element technique with the birth and death procedure [13]. ul-Haq et al. researched on textures and microstructures of duplex stainless steel [14]. They also showed the rolling texture development in the micro-structure of duplex stainless steel. Palani and Murugan investigated the cladding effect on weld bead geometry using different factors, like current, welding speed, nozzle-to-plate distance at the time of welding [15].

In current study, it is planned to decide the most excellent procedure conditions in TIG welding on DSS to get preferred yield strength, percentage of elongation and ultimate tensile strength comparing between different optimization results which comes out from different optimization of TIG welding on DSS process optimization analysis. Process optimization is performed with the help of Grey-based Taguchi method for evaluation of multi-response optimization problem and Principal Component Analysis (PCA) method.

Duplex stainless steel (UNS2205) sheets of dimensions 75 mm × 50 mm × 3 mm are welded by TIG welding process. No filler wire is used for welding. Argon is used as the shielding gas for protection of welding zone, base metal and Tungsten electrode from atmospheric reaction. The effects of TIG welding procedure factors like current, gas flow rate and welding speed on ultimate tensile strengths of butt-welded joints of ASTM/UNS 2205 DSS have been studied. The parameters of TIG welding have been optimized by Grey based Taguchi technique and also by Principal Component Analysis (PCA) method using MINITAB 16. After that both optimized results has been compared to determine the optimum parametric setting. Dimensions of each Duplex stainless steel plate are shown in Figure 1.

2. Experimental work

Duplex Stainless Steel (ASTM/UNS: 2205) material is used as the base metal for experimental work. Welding arrangement has been ready to perform TIG welding process. DSS plates have been welded with suitable welding factors like current, welding speed, gas flow rate. The experiments are completed with a designed investigational way which is L9 orthogonal array design of Taguchi method. Finally both optimized results have been compared to evaluate the optimal TIG welding process parameters. TIG welding on DSS has been completed by 3 levels of welding current, 3 levels of shielding gas flow rate, 3 levels of speed of welding.

Chemical composition of this base metal has been exhibited here by Table 1. Welding process factors with their levels have been listed within Table 2.
Table 2 Welding process factors with their levels

| Factors             | Units     | Notations | Levels |
|---------------------|-----------|-----------|--------|
| Welding Current     | A         | C         | 80     |
|                     |           |           | 85     |
|                     |           |           | 90     |
| Gas Flow Rate       | l/min     | F         | 7      |
|                     |           |           | 7.5    |
|                     |           |           | 8      |
| Speed of Welding    | mm/s      | S         | 2.3    |
|                     |           |           | 2.8    |
|                     |           |           | 3.5    |

Figure 2. Photographic view of TIG welding equipments arrangement

Figure 3. Photographic observation of welding sample no 6 & 7

Figure 4. Photographic view of WEDM

Figure 5. Photographic view of tensile sample no.7
Table 3. Tensile test results

| Sample No. | Yield Strength (MPa) | Ultimate Tensile Strength (MPa) | Percentage of Elongation (%) |
|------------|----------------------|--------------------------------|-----------------------------|
| 1          | 183.3                | 460                            | 10.4530                     |
| 2          | 236.7                | 595                            | 11.6650                     |
| 3          | 253.3                | 635                            | 17.7770                     |
| 4          | 243.3                | 610                            | 14.9470                     |
| 5          | 260                  | 645                            | 14.9070                     |
| 6          | 253.3                | 630                            | 11.9810                     |
| 7          | 256.7                | 640                            | 14.0340                     |
| 8          | 243.3                | 610                            | 10.9380                     |
| 9          | 260                  | 650                            | 14.4790                     |

Table 4. Grey relational grades

| Experiment no. | Grey relational grade |
|----------------|-----------------------|
| 1              | 0.333333              |
| 2              | 0.543353              |
| 3              | 0.905548              |
| 4              | 0.654808              |
| 5              | 0.836875              |
| 6              | 0.68876               |
| 7              | 0.773353              |
| 8              | 0.583024              |
| 9              | 0.84205               |

Figure 6. Photographic view of tensile testing machine after testing
Table 5. Eigen analysis of the correlation matrix

| Variables | Eigen vectors |
|-----------|---------------|
|           | PC1 | PC2 | PC3 |
| S/N-YS    | 0.611| -0.358| 0.706 |
| S/N-UTS   | 0.611| -0.354| -0.708 |
| S/N-PE    | 0.503| 0.864 | 0.003 |

|          | (ξ1) | (ξ2) | (ξ3) |
|----------|------|------|------|
| Eigen value | 0.611| 0.4862| 0.0007 |
| AP        | 0.838| 0.162 | 0.000 |
| CAP       | 0.838| 1.000 | 1.000 |

**Figure 7.** Main effect plot for SN ratios

**Figure 8.** Main effect plot for means
Table 6. Principal component and calculated MPI

| Sl. no. | SN-Yield strength | SN-Ultimate tensile strength | SN- Percentage of elongation | Calculated MPI |
|---------|-------------------|-------------------------------|-----------------------------|----------------|
| 1       | 45.2632           | 53.2552                       | 20.3848                     | 46.5571        |
| 2       | 47.484            | 55.4903                       | 21.3377                     | 48.7810        |
| 3       | 48.0727           | 56.0555                       | 24.9972                     | 49.3659        |
| 4       | 47.7228           | 55.7066                       | 23.4911                     | 49.0162        |
| 5       | 48.2995           | 56.1912                       | 23.4678                     | 49.5780        |
| 6       | 48.0727           | 55.9868                       | 21.5699                     | 49.3548        |
| 7       | 48.1885           | 56.1236                       | 22.9436                     | 49.4740        |
| 8       | 47.7228           | 55.7066                       | 20.7788                     | 49.0162        |
| 9       | 48.2995           | 56.2583                       | 23.2148                     | 49.5888        |

Figure 9. Main Effect plots of the MPI (S/N ratio)

9 butt joint TIG welded samples have been created employing 3 levels of current, 3 level of speed of welding and 3 levels of shielding gas flow rate to determine the effects of ultimate tensile strength, yield strength and percentage of elongation. The photographic view of TIG welding equipments arrangement has been showing by Figure 2.

After completed the TIG welding of DSS plates, the Photographic observation of welded sample no 6 & 7 has been shown in Figure 3.

Tensile testing samples are created from the TIG welding plates, by Electronica Sprintcut-734 WEDM (Input power supply 3 Phase, AC 415 V, 50 Hz, linked load 15 KVA) wire cutting machining. A photographic view of WEDM is exposed by Figure 4. Photographic view of tensile sample of welding specimen no.7 out of nine samples has been shown in Figure 5. Then, these samples have been tested by tensile testing machine.

These tensile samples have been tested with the help of tensile testing machine to determine the tensile strength, percentage of elongation and yield strength. Every tensile testing result is collected properly. Photographic view of tensile testing machine after testing the tensile sample is shown in Figure no.6. And tensile testing results are also plotted in tabular form in Table 3.

2.1. Optimization by Grey Taguchi method

TIG welding process parameters have been optimized using Grey-Taguchi method. Normalized
investigational results have been transferred into grey relational co-efficient of every quality characteristics. Then, grey relational co-efficient for every response have been collected to evaluate Grey relational grade. Larger result of grey relational grade with equivalent to factor arrangement has been understood to be nearer of the optimal. Grey relational grades have been plotted by tabular form in Table 4.

Signal to noise ratio and Main effect plot for means have been shown in Figure 7 & 8 respectively. Using this figures, optimal factor arrangement has been calculated by considering higher the better principle. The optimal parameter setting evaluates C3, F3 and S3 which means current is 90 A, gas flow rate is 8 l/min and speed of welding is 3.5 mm/s.

2.2. Optimization by Principal Component Analysis

The experimental results of yield strength, ultimate tensile strength and percentage of elongation are converted into S/N ratio for analysis using PCA method. After normalization of results, verification is completed whether responses are correlated or not, by Minitab.

Then, the Eigen value, Eigen vector, accountability proportion (AP) and cumulative accountability proportion (CAP) are calculated. Eigen analysis of the correlation matrix is given in Table 5.

The Multi-response Performance Index (MPI) is calculated by the equation \( \text{MPI} = \xi_1*0.838 + \xi_2*0.162 + \xi_3*0.000 \). The MPI results are considered as the single objective function. These are optimised to get the optimum result.

The factorial arrangement so as to maximized MPI has been treated as optimal parametric arrangement ensuring better quality of weld. Principal Components and evaluated MPI have been presented in Table 6. S/N ratio plot of MPI have been presented in Figure 9. S/N ratio has been evaluated with the help of Higher-the-Better (HB) principle. From Main Effect plots of the MPI (S/N ratio), the optimal parameter setting becomes C3, F3, S3 which means current is 90 A, gas flow rate is 8 l/min and speed of welding is 3.5 mm/s. Ultimately quality has developed with the help of this optimal setting.

3. Compression between optimization of Grey Taguchi method and PCA method

The tensile testing results have been optimized with the help of both techniques Grey Taguchi technique and Principal Component Analysis. Signal to noise ratio has been plotted with the help of optimization results which have been evaluated from above stated both techniques. In both cases same result has been observed that is the optimal parameter setting becomes C3, F3, S3 which means current is 90 A, gas flow rate is 8 l / min and speed of welding is 3.5 mm/s.

4. Conclusions

In this current study, complete methodology of Taguchi optimization procedure with Grey relational analysis and Principal Component Analysis has been accepted. It also utilized for calculating optimal parametric arrangement to reach satisfactory value of tensile strength, yield strength and percentage of elongation of TIG welding on Duplex stainless steel. Welding process factors like current, shielding gas flow rate, speed of welding played an important role in mechanical properties of TIG weld like yield strength, ultimate tensile strength and percentage of elongation. Here, both analyzed optimized values are compared. The same result in both cases has been observed. Taguchi’s S/N ratio theory has been employed to establish the optimum situation on behalf of maximum ultimate tensile strength, yield strength and percentage of elongation. The optimal parameter combination becomes C3, F3, S3 i.e. welding current is 90 A, gas flow rate is 8 l/min and speed of welding is 3.5 mm/s.

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Conflict of interest

None of the authors have any conflicts of interest to declare.

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