Optimization of welding parameters in CMT welding of Al 5083 alloys using VIKOR optimization method

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Abstract. In this paper, an effort is made to examine the cold metal transfer (CMT) welding of Al 5083 sheets having a thickness of 3 mm. The CMT welding was performed based on the L9 Taguchi orthogonal array with welding current (A), welding speed (mm/min) and welding frequency (Hz) as input parameters. The quality of weld was studied by measuring the reinforcement, bead width (BW), depth of penetration (DOP) and heat affected zone width (HAZW). The optimized parameters were found by the VIKOR multi-objective optimization method. The eighth experiment was identified as the optimized parameter from the VIKOR method.

1. Introduction

Al 5083 alloy possesses excellent characteristics such as high strength, good corrosion resistance, and high formability. These properties of Al 5083 alloys make them extremely fit for the automobile sector for developing new vehicles by replacing steel as the structural body [1]. Welding plays an important role in the fabrication of automobile components. Among the various welding processes, Cold metal transfer welding is widely preferred in automobile industries due to its ability to weld with lesser spatter and lower heat input. CMT is a modified metal inert gas (MIG) welding technique that works on the principle of short-circuiting transfer process which was discovered by Fronius in 2004 [2]. CMT provides lower heat input and controlled material deposition by introducing a wire feed technology coupled with high-speed digital control [3]. The wire feed rate is controlled to provide sufficient energy to melt both the base metal and the filler wire. The CMT weld quality mainly relies on parameters such as welding current, welding speed, welding frequency, and feed rate of the filler wire [4].

Beytullah Gungor et al. [5] welded the Aluminum 5083 using the CMT joining process. The base metal showed lesser hardness when compared to the fusion zone (FZ) of the Al 5083 weld. The authors further concluded that the weld was obtained with higher joint efficiency. Lijin Huang et al. [6] examined the mechanical properties of gas metal arc welded (GMAW) Al 5083 thick plates. The authors observed that the uniform distribution of the second phase particles and lesser formation of...
The major challenge faced by any new process in the fabrication of any material is the identification of optimization parameters. To identify the optimized parameter by the method of trial and error is highly laborious and time-consuming. In order to overcome these difficulties, multi-objective techniques such as grey relational analysis (GRA), VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) have been identified. VIKOR is a multi-criteria decision making (MCDM) method which was introduced by Po-Lung Yu in the year 1973. In recent years, the MCDM method is used in various fields of application such as transportation, service quality, economic and sciences [11]. Ajay et al. [12] performed the VIKOR multi-response optimization method in the submerged arc welding of mild steel of thickness 5 mm. Optimised bead width, depth of penetration (DOP), percentage dilution, and reinforcement size were successfully identified by the VIKOR method. From the VIKOR optimization study, the authors were able to optimize the depth of penetration to 4.3080 mm. Analysis of MIG welded AISI 1008 steel by VIKOR based L9 Taguchi method was performed by Aakash et al. [13]. Three responses namely, bending strength of 5.821 KN, a tensile strength of 428 MPa and hardness of 75.266 HRB has been optimized. They found that VIKOR optimization is a straight forward approach and also free from tough computational difficulties as compared to other optimization methods.

From the above literature, it is clear that very few experimental studies have been explored in the CMT welding of Al 5083. Many authors concentrated on optimising weld strength, bead width, depth of penetration but very few concentrated in optimising reinforcement size and HAZ width. Further, VIKOR optimisation is identified as one of the simple and bests optimization methods for finding out the optimized parameter in any of the welding processes. Till now, no literature studies related to the VIKOR optimization technique of CMT welding parameters of Aluminium 5083 alloys are found. Hence in this study, an effort is taken to join Al 5083 using the CMT welding technique and used the VIKOR method for finding out the optimized welding parameters in obtaining proper.

2. Experimental Procedure

Al 5083 plates of thickness 3 mm were joined in a butt joint position using the cold metal transfer (CMT) welding machine. The chemical composition of Al 5083 is depicted in Table 1.

| Elements | Si   | Fe  | Cu  | Mn  | Mg  | Cr  | Ni  | Zn  | Ti  | Al  |
|----------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Weights  | 0.12 | 0.4 | 0.02| 0.94| 4.57| 0.06| 0.01| 0.02| 0.027| Bal.|

Table 1. Chemical composition of Al 5083.
The CMT 6-Axis machine used for the welding Al 5083 plates is shown fig. 1.

Figure 1. 6-Axis CMT welding setup.

Three levels of input parameters namely, welding current, welding frequency, and welding speed were chosen for the experimental study. The input parameters and their levels are shown in table 2.

Table 2. Input parameters and their levels.

| Welding Current (A) | Welding Speed (mm/min) | Welding Frequency (Hz) |
|---------------------|------------------------|------------------------|
| 60                  | 200                    | 0.5                    |
| 65                  | 225                    | 1                      |
| 70                  | 250                    | 1.5                    |

ER 5183 filler wire of diameter 1.2 mm with a wire feed rate of 1600 mm/min was maintained throughout the experiment. The shielding gas is preferred as argon with a flow rate of 14.6 l/min.

Experiments were conducted with the input parameters based on the L9 Taguchi array, shown in table 3.

Table 3. L9 Taguchi array.

| Experiments | Welding Current (A) | Welding Speed (mm/min) | Welding Frequency (Hz) |
|-------------|---------------------|------------------------|------------------------|
| 1           | 60                  | 200                    | 0.5                    |
| 2           | 60                  | 225                    | 1                      |
| 3           | 60                  | 250                    | 1.5                    |
| 4           | 65                  | 200                    | 1                      |
| 5           | 65                  | 225                    | 1.5                    |
| 6           | 65                  | 250                    | 0.5                    |
| 7           | 70                  | 200                    | 1.5                    |
| 8           | 70                  | 225                    | 0.5                    |
| 9           | 70                  | 250                    | 1                      |
3. Results and Discussion

Measured values of reinforcement size, depth of penetration (DOP), bead width (BW), and heat affected zone width (HAZW) of the samples were calculated using machine vision system and tabulated in table 4.

| S.No | Reinforcement (mm) | DOP (mm) | BW (mm) | HAZW (mm) |
|------|--------------------|----------|---------|-----------|
| 1    | 1.895              | 4.295    | 6.474   | 0.884     |
| 2    | 2.41               | 4.239    | 6.427   | 0.889     |
| 3    | 2.52               | 3.815    | 5.858   | 0.915     |
| 4    | 2.552              | 3.672    | 7.69    | 0.799     |
| 5    | 2.293              | 4.387    | 6.877   | 0.679     |
| 6    | 2.017              | 3.63     | 6.983   | 1.255     |
| 7    | 2.139              | 3.991    | 8.156   | 0.835     |
| 8    | 2.071              | 4.248    | 8.442   | 0.826     |
| 9    | 2.165              | 3.861    | 6.809   | 1.017     |

VIKOR optimization is known as the multi-criteria decision-making technique, which is mainly used for the identification of the optimized parameters. This technique helps to derive the integrated eminence measurements of various responses. VIKOR optimization technique comprises the following steps:

Step 1: Calculation of the normalized decision matrix. It can be calculated from equation 1.

\[
A = \left[ P_{ij} \right]_{x \times x}
\]

Where, \( P_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}} \), \( i = 1, 2, \ldots, a; j = 1, 2, \ldots, b \); and \( X_{ij} \) is the execution of the alternative corresponding to the \( i^{th} \) factor. The decision matrix is shown in Table 5.

| Alternatives | Reinforcement (mm) | DOP (mm) | BW (mm) | HAZW (mm) |
|--------------|--------------------|----------|---------|-----------|
| 1            | 1.895              | 4.295    | 6.474   | 0.884     |
| 2            | 2.41               | 4.239    | 6.427   | 0.889     |
| 3            | 2.52               | 3.815    | 5.858   | 0.915     |
| 4            | 2.552              | 3.672    | 7.69    | 0.799     |
| 5            | 2.293              | 4.387    | 6.877   | 0.679     |
| 6            | 2.017              | 3.63     | 6.983   | 1.255     |
| 7            | 2.139              | 3.991    | 8.156   | 0.835     |
| 8            | 2.071              | 4.248    | 8.442   | 0.826     |
| 9            | 2.165              | 3.861    | 6.809   | 1.017     |

The normalized decision matrix is depicted with the minimum and maximum values of each of the factors in Table 6.

| Reinforcement (mm) | DOP (mm) | BW (mm) | HAZ (mm) |
|--------------------|----------|---------|----------|
| 0.282051675        | 0.355752211 | 0.302881727 | 0.322850198 |
| 0.358704241        | 0.351113765 | 0.300682864 | 0.324676273 |
| 0.375076634        | 0.315994106 | 0.274062582 | 0.334171867 |
Step 2: Estimating weights of the relative significance of the output parameters.

\[ N_{axa} = \begin{bmatrix} P_{11} & \cdots & P_{14} \\ \vdots & \ddots & \vdots \\ P_{41} & \cdots & P_{44} \end{bmatrix} \]

Analytic hierarchy process (AHP) is the most significant technique used for the estimation of weights of the relative importance of the parameters. The quality of significance of the output parameters is shown in Table 7.

**Table 7. Quality of Importance.**

| Quality of Significance | Definition       |
|-------------------------|------------------|
| 9                       | Absolute         |
| 2, 4, 6, 8              | Intermediary Values |
| 5                       | Essential/Strong |
| 7                       | Very much strong |
| 1                       | Equal            |
| 3                       | Medium           |

In the matrix, \( P_{ij} = 1 \), where \( i = j \) and \( P_{ij} = \frac{1}{P_{ji}} \).

\( P_{ij} \) denotes the comparative significance of factors of \( i \) corresponding to factors \( j \).

\[ GM_i = \left( \prod_{j=1}^{N} P_{ij} \right)^{\frac{1}{n}} \]

\[ W_j = \frac{GM_i}{\sum_{i=1}^{N} GM_i} \]

The calculated weights of the relative significance of output parameters is shown in Table 8.

**Table 8. Weights of the Relative significance of Parameters.**

| Parameters | Reinforcement(mm) | DOP (mm) | BW (mm) | HAZW (mm) |
|------------|-------------------|----------|---------|------------|
| Weights    | 0.059246          | 0.4828   | 0.31385 | 0.1441     |

Step 3: Determining the utility factor (\( S_i \)) and regret factor (\( R_i \))

The utility factor and the regret factor can be determined by the following equations 2 and 3:

\[ S_i = \sum_{j=1}^{n} W_j (P_j^+ - P_{ij}) / (P_j^+ - P_j^-) \]  \hspace{1cm} (2)

\[ R_i = \max_j \left[ W_j (P_j^+ - P_{ij}) / (P_j^+ - P_j^-) \right] \]  \hspace{1cm} (3)

Where \( W_j \) is the \( j^\text{th} \) factor.

The calculation of \( S_i \) and \( R_i \) values are depicted in Table 9 and Table 10 respectively.
### Table 9. Values of $S_i$

| Reinforcement(mm) | DOP (mm)     | BW (mm)     | HAZW (mm)   | $S_i$ Values |
|-------------------|--------------|-------------|-------------|--------------|
| 0.059246          | 0.058675826  | 0.239031269 | 0.09281441  | 0.449767505  |
| 0.012805072       | 0.094391546  | 0.244739841 | 0.091563542 | 0.4435       |
| 0.00288565         | 0.364810568  | 0.31385     | 0.085059028 | 0.766605246  |
| 0                 | 0.45601321   | 0.091337152 | 0.114079167 | 0.661429528  |
| 0.023355729        | 0            | 0.190083301 | 0.1441      | 0.35753903   |
| 0.04824446         | 0.4828       | 0.177208649 | 0            | 0.708253109  |
| 0.037242919        | 0.252561162  | 0.034737268 | 0.105072917 | 0.429614266  |
| 0.043374925         | 0.088651519  | 0           | 0.107324479 | 0.239350924  |
| 0.034898329         | 0.335472655  | 0.198342512 | 0.059541319 | 0.628254815  |

### Table 10. Values of $R_i$

| $R_i$ Values     |
|-------------------|
| 0.239031269       |
| 0.244739841       |
| 0.364810568       |
| 0.45601321        |
| 0.190083301       |
| 0.4828            |
| 0.252561162       |
| 0.107324479       |
| 0.335472655       |

Step 4: Estimation of the VIKOR index

The VIKOR constant can be calculated by equation 4.

$$Q_i = V \left( \frac{S_i - S_{\min}}{S_{\max} - S_{\min}} \right) + (1 - V) \left( \frac{R_i - R_{\min}}{R_{\max} - R_{\min}} \right)$$  \hspace{1cm} (4)

Where, $i=1, 2, \ldots m$

$V$ is defined as the weight of maximum group utility. The value of $V$ ranges from 0 to 1. Generally, $V$ value is taken as 0.5. Table 11 depicts the $Q_i$ values for each experiment and their corresponding rank.

### Table 11. Rank the order of preference.

| Experiment | $Q_i$ Values | $R_i$ Values | $S_i$ Values | Rank ($Q_i$) | Rank ($R_i$) | Rank ($S_i$) |
|------------|--------------|--------------|--------------|--------------|--------------|--------------|
| 1          | 0.388400049  | 0.239031269  | 0.449767505  | 3            | 3            | 5            |
| 2          | 0.49655051   | 0.244739841  | 0.4435       | 5            | 4            | 4            |
| 3          | 0.869220548  | 0.364810568  | 0.766605246  | 7            | 7            | 9            |
Step 5: The order of preference is ranked
Arrange the alternatives in ascending order according to the value of $Q_i$ and the optimum solution can be determined by the smallest value of $Q_i$, which also satisfied both the conditions as discussed in Rao [14].

Step 6: Proposing the solution
The smallest VIKOR constant ($Q_i$) value corresponds to the optimum solution appropriate for the experiment. Thus, the estimated optimum solution for the experiment is shown in Table 12.

| Current (A) | Welding Speed (mm/min) | Frequency (Hz) |
|------------|------------------------|----------------|
| 70         | 225                    | 0.5            |
| Reinforcement (mm) | DOP (mm) | BW (mm) | HAZW (mm) |
| 2.071      | 4.248                  | 8.442          | 0.826 |

3.1. Metallurgical characteristics of the optimized Al 5083 weld
The macrostructure of the optimized welded specimen is shown in fig. 2.
The microstructure of weld obtained through optimized parameter combination is shown in fig. 3. Optimized weld was free from defects such as cracks and pores. The Microstructure was dominated by the presence of Al(α), Al₃Mg₂ phases. In addition to these phases, Mg₂Si, and [Al₆ (Fe, Mn)] phases were seen in lesser amount. The presence of the phases was confirmed through the XRD analysis and the same is presented in Figure 4.

![Figure 3. The microstructure of the optimized Al 5083 weld.](image)

![Figure 4. XRD graph.](image)
4. Conclusion

Al 5083 sheets were joined successfully using the cold metal transfer welding process and the following conclusions were made.

- From the VIKOR optimization methodology, it was found that the 8th experiment was the optimized parameter combination. The optimized welding input parameter includes: welding current of 70 A, welding speed of 225 mm/min and a frequency of 0.5 Hz and the corresponding output parameters are: Reinforcement is 2.071mm, depth of penetration is 4.248 mm, bead width is 8.442 mm and width of HAZ is 0.826mm.

- The optimized weld was free from defects and the weld was dominated by the presence of Al (α) and Al₃Mg₂ phases.

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