Optimization of TIG Welding Parameters for Enhanced Weld Strength Using MOORA Method

Shashang G[1,*], Raviram R[1], Ranjith Raj A [1], Shameer Mohamed S[1]
[1]Department of Mechanical Engineering, Sri Venkateswara College of Engineering,
Sriperumbudur, Tamil Nadu, India

*Corresponding author Email: shashang2k23@gmail.com

Abstract

In the present work, application of multi-objective optimization based on ratio analysis (MOORA) method has been applied for solving multiple-criteria (objective) optimization problems in TIG welding for small and medium-sized businesses working with thin steel sheets. Using MOORA, this research examines key welding factors like voltage, current, gas flow, and filler rod usage. Through a systematic approach, including a specialized matrix and analysis techniques, the study identifies the best combination of these factors for optimal welding results. The recommended settings include V=20 V, I=100 A, G=5 litres per minute, and using a filler rod. Combining weight normalization and Shannon entropy strengthened the optimization process, allowing for a comprehensive analysis of the effects of different parameters. This approach ensures a thorough understanding of how changes in settings impact the welding outcome. The findings emphasize the importance of precise welding settings for high-quality sheet metal work and showcase the effectiveness of the optimization method used. By adopting these strategies in metal fabrication, metalworking businesses can improve their efficiency and competitiveness in the industry.

Keywords: TIG welding, Mild steel sheet, Shannon Entrophy, MOORA,

Introduction

Gas Tungsten Arc Welding (GTAW), commonly known as TIG welding, serves as a vital welding technique used extensively in small and medium-sized industries. The process's precision and adaptability in joining different metals with controlled heat input make it highly suitable for sectors that demand accuracy like aerospace, electronics, and medical equipment manufacturing. The neat welds and limited distortion produced by TIG welding are highly appreciated in sectors such as automotive fabrication, where appearance is significant. Furthermore, its capability to join exotic materials proves essential in chemical processing and petrochemical refining operations. TIG welding is also frequently utilized for maintenance and repair tasks due to its adaptability and precision [1]. In TIG welding, the quality of the weld mostly depends on factors such as the current used for welding, the voltage of the arc, the speed of welding, and the application of filler material [2]. In summary, TIG welding holds a crucial role in ensuring the effectiveness, durability, and quality of products in a diverse array of industries. The genetic algorithm does not require the derivatives from objective functions, just the objective values for optimization [3].

In the pursuit of determining the most suitable welding parameters in TIG welding, grappling with various criteria poses a formidable challenge in deriving solutions via mathematical means [4]. The evolution of the process involved working at low current densities and using pulsed direct current, along with expanding its application to various materials and incorporating reactive gases such as CO2 and other gas blends [1]. In TIG welding, the initial welding parameters are generally established using conventional methods like welder experience, process parameter diagrams, and manuals. However, advancements in computer technology have empowered welding engineers to apply sophisticated methods in determining the ideal welding conditions more efficiently [5]. In the end, selecting welding parameters can result in the creation of a welded joint that closely meets the joint requirements, as welds are often produced using very different parameters [6].

At present, a wide spectrum of commercial metals and alloys including carbon steels, stainless steels, high strength low alloy steels, magnesium alloys, copper alloys, aluminium alloys, titanium alloys, and nickel alloys can be welded in any position using this adaptable technique through the selection of suitable process parameters for the specific joint configuration and process variables [7]. The L16 orthogonal array is utilized to adjust the input factors of TIG welding, such as voltage, current, gas flow rate, and the utilization of filler rod. This adjustment aims to enhance the outcome characteristics like Penetration, Reinforcement, Bead Width, and dilution percentage [8,9].

The settings used in welding are really important for making a good weld. They affect how the weld turns out. Welding involves lots of factors like heat, speed, and pressure that all play a part. But getting everything just right can be complicated [10]. We need simple and well-organized approaches or mathematical instruments to aid decision-makers in evaluating different selection criteria and their interconnections [11]. It takes a lot of trial and error to figure out the best settings for each new welding job. Engineers or machine operators have to guess at the right settings, and then test the welds to see if they meet the standards. [10]

The primary objective of any selection process is to identify the criteria and select the optimal combination that aligns with the specific requirements. Therefore, it is essential to identify the factors influencing the selection of alternatives for a given issue using simple techniques. This ensures eliminating unsuitable choices and selecting the most suitable one to enhance existing selection procedures. Numerous approaches exist for decision-making with multiple objectives, this article delves into a novel technique known as Multi-Objective Optimization based on Ratio Analysis (MOORA) [10,12,13]. This strategy is straightforward to use and does not require complicated computations, thus assisting decision-makers in ignoring alternatives and selecting the best one, thereby enhancing the selection process. MOORA method has been utilized to optimize the TIG welding parameters in this research.

Experiment and Methods

The TIG welding process utilized a Toshon TIG/ARC 200 DC inverter source and a Zirconiated Tungsten Electrodes (EWZr-2; ISO = WZ3) Color-Coded Brown. The gas cylinder was fitted with a gas flow meter. For the experiment, mild steel sheet metal (IS 2062 GR E250) of 2 mm thickness was cut to the desired dimensions of 28×150mm using a punching machine. Plate surfaces were cleaned using wire brushes and emery paper to eliminate any rust. A single bead was then applied to two clean plates using a 1.2 mm diameter tungsten electrode while maintaining a pure Argon gas flow rate and negative electrode polarity to form a butt joint. All experimental analyses were conducted utilizing Minitab software (version 22.1.0) and Microsoft Excel. Figure 1 shows the sample specimen.

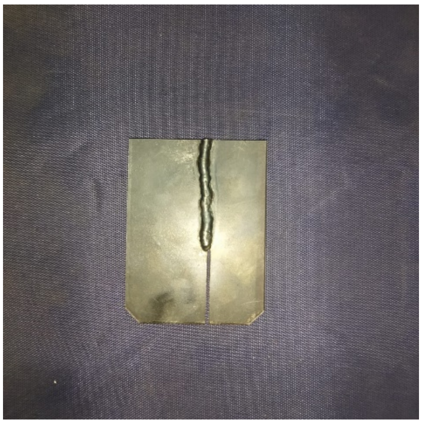
C	**Mn**	**Si**	**P**	**S**

0.2	1.5	0.04	0.04	0.04

Table 1 Chemical composition of E250

C	Si	Mn	S	Cu	Ni	Cr
0.07	0.55	1.15	0.035	0.5	0.15	0.15

Table 2 Chemical composition of Filler rod



1 Sample specimen

Parameter selection

In testing various combinations of voltage, welding current, gas flow rate, and the usage of filler, we experimented to determine the optimal parameters for the welding process. An analysis of trial welds and results was recorded. The settings employed and their respective levels are detailed,

The data was gathered from sixteen welding experiments using the L16 orthogonal array design. These experiments were done randomly to avoid any mistakes that could happen from a patterned approach. After each welding session, sections are cut out from the middle of the welded pieces. The weld beads are then analyzed using the visual inspection method, and measurements are taken. Using ImageJ software, the dilution percentage is calculated by examining the areas of melted base metal and metal used for reinforcement. The results are presented in Tables 5 and 6.

Parameters	Level 1	Level 2	Level 3	Level 4
Voltage (V), V	20	22	24	26
Current (I), A	100	110	120	130
Gas flow rate (G), L x sec^{-1}	5	7	9	11
Filler (f)	yes	no		

Table 5 Process parameters based on their levels

No.	Voltage	Current	Gas flow rate	Filler	Penetration, mm	Reinforcement, mm	Bead Width, mm	Dilution Percentage
1	20	100	5	y	3.243	1.209	8.458	27.552
2	20	110	7	y	1.978	1.622	10.996	17.749
3	20	120	9	n	0.979	0.705	4.526	19.427
4	20	130	11	n	0.855	0.921	4.862	20.599
5	22	100	7	n	0.808	1.04	5.324	23.205
6	22	110	5	n	0.855	1.244	6.022	13.356
7	22	120	11	y	0.872	2.325	7.422	11.065
8	22	130	9	y	1.576	2.564	6.84	10.030
9	24	100	9	y	2.058	1.684	5.174	30.308
10	24	110	11	y	0.872	1.576	7.188	24.083
11	24	120	5	n	1.04	1.209	4.328	22.449
12	24	130	7	n	1.538	1.41	5.481	18.803
13	26	100	11	n	1.368	1.026	6.846	13.828
14	26	110	9	n	0.872	0.541	6.857	19.015
15	26	120	7	y	0.705	3.082	9.237	12.815
16	26	130	5	y	0.764	3.266	9.75	10.160

Table 6 The arrangement of the L16 orthogonal array along with values of individual experiment

Shannon Entropy Method

The usage of entropy spans across social and physical sciences, with applications in various fields like economics, spectral analysis, and language modelling [14]. Shannon introduced a communication theory incorporating entropy to evaluate the expected informational content of messages. In information theory, entropy acts as a measure of the inherent uncertainty within a discrete probability distribution. Additionally, entropy is beneficial in decision-making by highlighting differences in data sets and revealing the average information conveyed to decision-makers. To determine the objective weight using Shannon entropy, individuals must follow the recommended steps provided by Hwang and Yoon in 1981 [15]. The normalization of the rays of the decision matrix (performance indices) to get the desired outcomes P_{ij} is done by the usage of the following formula.

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \qquad (1)$$

To calculate the entropy for different matrices by utilizing the subsequent formula where it represents k = 1/ln(m).

$$E_j = -k \sum_{i=1}^{m} p_{ij} \ln p_{ij} \qquad (2)$$

Here the target weight for individual matrices is determined using the entropy concept, as below.

$$w_j = \frac{1-E_j}{\sum_{j=1}^{n}(1-E_j)} \qquad (3)$$

Exp. No.	**Normalization matrix Pij**			
	Penetration	**Reinforcement**	**Bead Width**	**Dilusion Percentage**
1	0.159103	0.047553	0.077376	0.093573
2	0.097042	0.063798	0.100594	0.060279
3	0.04803	0.02773	0.041405	0.06598
4	0.041947	0.036226	0.044479	0.069959
5	0.039641	0.040906	0.048705	0.07881
6	0.041947	0.04893	0.055091	0.045358
7	0.042781	0.091449	0.067898	0.037579
8	0.077319	0.10085	0.062574	0.034065
9	0.100966	0.066237	0.047333	0.102931
10	0.042781	0.061989	0.065757	0.081791
11	0.051023	0.047553	0.039593	0.076241
12	0.075455	0.055459	0.050141	0.06386
13	0.067115	0.040356	0.062629	0.046964
14	0.042781	0.021279	0.062729	0.064579
15	0.034588	0.121224	0.084502	0.043522
16	0.037482	0.128461	0.089195	0.034507

Table 3 Normalized matrices for individual attributes

Sum	-2.66014	-2.65683	-2.73514	-2.71928
Eij	0.957651	0.95646	0.984651	0.978939
1-Eij	0.042349	0.04354	0.015349	0.021061
Wij	**0.346277**	**0.356016**	**0.125503**	**0.172205**

Table 4 Entropy and Subjective Attribute Weighting attributes

MOORA Method

Multi-Objective Optimization Based on Ratio Analysis (MOORA) method is a robust strategy for addressing complex optimization challenges, especially in the field of welding technology where achieving high-quality welds is crucial for industrial advancement. MOORA provides a systematic to handle multi-criteria optimization issues, and the discovery of optimal parameter combinations to improve weld quality [16]. Researchers have successfully identified the most favourable welding parameter combination through the careful application of MOORA. This geometry covers key aspects like penetration depth, reinforcement height, bead width, and dilution percentage, guaranteeing top-notch weld quality [17].

The MOORA technique [18-24] begins with a decision matrix that illustrates the performance of different options in relation to various attributes (objectives).

$$X = \begin{bmatrix} X_{11} & X_{12} & \dots & \dots & \dots & \dots & X_{1n} \\ X_{21} & X_{22} & \dots & \dots & \dots & \dots & X_{2n} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ X_{m1} & X_{m2} & \dots & \dots & \dots & \dots & X_{mn} \end{bmatrix} \qquad (4)$$

In this method, normalization plays a crucial role in standardizing the elements within the matrix, ensuring consistent values across all options. This procedure involves comparing every option of performance on a specific attribute to a reference that represents all options for that attribute.

In this multi-objective optimization, standardized performances are combined for favourable attributes and deducted for less favourable ones. This standardization process expresses the way for structuring an optimization difficulty where attribute weights, determined through the analytic hierarchy process or entropy method, play a crucial role in precisely reflecting attribute significance. Brauer and colleagues [25] examined various ratio systems like total ratio and reached the consent that the most optimal selection for this standard is the square root of the sum of squares of each option per attribute. This ratio can be mathematically articulated as follows:

$$\overset{a}{X}_{ij} = X_{ij}/\sqrt{\textstyle\sum_{i=1}^{m} X_{ij}^2}(j = 1,2,\dots,n) \qquad (5)$$

Where x_{ij}, represents a dimensionless number within the interval [0,1] that belongs to the normalized performance of alternative ith on the attribute j [26]. For optimization with multiple objectives, these normalized performances are added for maximization (beneficial attributes) and subtracted for minimization (non-beneficial attributes). The optimization problem then is generated.

The methodology MOORA begins with a decision matrix that shows the performance of various alternatives over different attributes. This matrix supports the comparison of alternative performances in relation to a representative denominator for each specific attribute [27]. Remarkably, Brauer et al. delved into various ratio systems and elevated the square root of the sum of squares for each alternative per attribute as the most optimal denominator selection.

$$y_i = \textstyle\sum_{j=1}^{g} \overset{a}{X}_{ij} - \sum_{j=g+1}^{n} \overset{a}{X}_{ij} \qquad (6)$$

Where g is of attributes to be maximized the number, (n−g) is of attributes to be minimized in some cases, and y_i is the normalized assessment value of ith alternative for all attributes. In some cases, it is often observed that some more attributes are important than others. To give more importance to an attribute, it could be multiplied by its corresponding weight (significance coefficient) [28]. These attribute weights are taken into consideration, w_i refers to the weight of the ith attribute, and x_i is the normalized value of the ith attribute for the existing alternative. We can calculate the final value y_i, for an alternative by using the equation given below:

$$y_i = \sum_{j=1}^{g} W_j \cdot \overset{a}{X}_{ij} - \sum_{j=g+1}^{n} W_j \cdot \overset{a}{X}_{ij} (j = 1,2, \ldots., n) \qquad (7)$$

The analytical hierarchy processor entropy method is used to determine the weights (W_j) of all input parameters. The value y_i may be positive or negative based on the combination of its maxima (beneficial attributes) and minima (non-beneficial attributes) in the decision matrix. An ordinal arrangement of y_i establishes the final preference, with the highest y_i indicating the best choice and the lowest signifying the worst alternative. The MOORA methodology generates normalized evaluation values for each alternative, facilitating ordinal ranking for ascertaining preferences. The alternative with the highest normalized assessment value signifies the optimal decision, highlighting the efficiency of MOORA in simplifying decision-making processes and boosting industrial outcomes.

The weights of attributes are displayed in Table 7 which outlines the various weightings that have been assigned to the different variables. Table 8 shows the values for each alternative, which have been normalized across various attributes, and calculated using Equation (5). Following that, Equation (7) was employed to calculate the normalized values (y_i) for each alternative based on these attributes. The outcome of the MOORA method is displayed in the table, listing the alternatives in a random order of the assessment of their value. Experiment number 16 emerges as the top-ranked option, noted by the process parameters set at Voltage=26 V, Current=130 A, Gas flow rate=5 mm/min, and the decision to use filler rod material.

Parameters	Penetration, mm	Reinforcement, mm	Bead Width, mm	Dilution Percentage
Weights	0.346277	0.356016	0.125503	0.172205

Table 7 Weights of responses

No.	Weight Normalized matrix				C	Rank
1	0.0341	0.0086	0.0013	0.0008	-0.025	16
2	0.0208	0.0115	0.0017	0.0005	-0.008	14
3	0.0103	0.0050	0.0007	0.0006	-0.005	11
4	0.0090	0.0065	0.0008	0.0006	-0.002	8
5	0.0085	0.0074	0.0008	0.0007	-0.001	7
6	0.0090	0.0088	0.0009	0.0004	0.000	6
7	0.0092	0.0164	0.0012	0.0003	0.008	3
8	0.0166	0.0181	0.0011	0.0003	0.002	5
9	0.0217	0.0119	0.0008	0.0009	-0.010	15
10	0.0092	0.0111	0.0011	0.0007	0.002	4
11	0.0109	0.0086	0.0007	0.0006	-0.002	9
12	0.0162	0.0100	0.0009	0.0005	-0.006	12
13	0.0144	0.0073	0.0011	0.0004	-0.006	13
14	0.0092	0.0038	0.0011	0.0005	-0.005	10
15	0.0074	0.0218	0.0014	0.0004	0.015	2
16	0.0080	0.0231	0.0015	0.0003	0.016	1

Table 8 Moora Method Ranking

Conclusion

The employment of entropy and the Multi-Objective Optimization by Ratio Analysis (MOORA) technique offers a promising approach to boost the efficiency and quality of TIG welding on mild steel sheets. Derived from Shannon's research on uncertainty in information systems, entropy plays a fundamental role in establishing objective weights for various welding parameters. This concept enables decision-makers to consider probabilities and uncertainties linked to crucial factors like voltage, welding current, wire feed speed, and gas flow volume. An entropy-based weight system allows stakeholders to make well-informed choices when determining optimal parameter values, leading to enhanced welding results. The adoption of MOORA method decided that a voltage of 26 V, welding current of 130 A, gas flow rate of 5 L/min, including the application of filler would result in the finest welding bead figuration with penetration of 0.0080 mm, reinforcement of 0.0231 mm, bead width of 0.0015 mm, and dilution percentage of 0.0003%. The Yi value is attained by summarizing the beneficial and non-beneficial attributes which is 0.016 which gains rank 1. By utilizing these objective weights, the MOORA method prioritizes and identifies the most effective parameter combinations, balancing quantitative inputs such as electrical and material properties with qualitative aspects like bead quality and structural integrity. The simplicity and adaptability of the MOORA method make it highly beneficial for fine-tuning welding parameters, especially in small and medium-sized industries. However, challenges may arise in addressing qualitative elements within dynamic manufacturing environments, requiring continuous adjustments to fully encompass the complexities of welding processes. By merging Shannon's entropy with the MOORA method, stakeholders can institute a systematic strategy to improve TIG welding on mild steel sheets, facilitating the attainment of high-quality welds. Nonetheless, ongoing research and development endeavours are crucial to refine these methodologies and ensure their efficacy in evolving manufacturing settings. Furthermore, the utilization of the L16 orthogonal array has proven pivotal in identifying optimized parameters customized for the requirements of small and medium-scale industries, highlighting the practical significance of these methodologies in real-world scenarios.

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