Proceeding Paper

Cost Estimation and Parametric Optimization for TIG Welding Joints in Dissimilar Metals Using Linear Regression Algorithm †

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Abstract: This study investigated the use of the linear regression algorithm (LRA) for estimating the cost of tungsten inert gas (TIG) welding of dissimilar metals, specifically, stainless steel 304 and aluminum 2024. Various cost analysis parameters, including weld time, power cost rate, labor cost, filler rod cost, and shielding gas cost, were considered. LRA was employed to develop a predictive model for welding costs based on these parameters. The model was then used to optimize welding parameters by identifying the combination that minimized overall welding costs. The results demonstrate that LRA effectively identified a more cost-effective parameter set compared to traditional methods. This highlights the potential of LRA in enhancing the cost-effectiveness of TIG welding processes. The findings have practical implications for field engineers and researchers, enabling the identification of optimal parameters for cost estimation and significant cost savings.

Keywords: linear regression algorithm (LRA); tungsten inert gas (TIG) welding; dissimilar metals; cost estimation of GTAW; linear programming technique (LPT); parametric optimization

1. Introduction

This paper expounds the indispensable use of cost analysis for tungsten inert gas (TIG) welding for dissimilar and erratic metals. Incorporated factors are welding speed, cost of filler rod, labor charges, power cost [1]. Substantially, the usage of tungsten inert gas welding in the fabrication of structural frameworks as a perpetual fastening to generate single-pass, full-penetration welds and root passes of multi-pass welds commenced in the 1940s [2]. In fact, the effectiveness of cost estimation governs the transition of customer to a productive purchase, aids in setting the project budget, planning the required work, evaluating the feasibility of a project, managing new resources and one of the rudimentary imperative of any decision-making for enterprises like choosing material, manufacturing processes and morphological features of production and products [3]. Except for shredding or recycling the integral components of vehicles, this study addresses and guides cost estimation with a pertinent new way to reproduce vehicles assemblages that are comprised of stainless steel and aluminum. By means of TIG welding, using a unique filler metal can overcome this, while the cost estimation of this process is a practical means to determine and evaluate the overall prime expenditures of this course of action to optimize functions [3]. The parametric optimization of TIG welding using linear regression in Python is a significant aspect of this research. Case studies have addressed TIG welding on different
materials, but this study specifically addresses the cost estimation of dissimilar metal welding [4].

2. Methodology

Nomenclature

\( t \) = time in hours, \( V \) = voltage, \( I \) = current, \( \eta \) = efficiency of machine, \( WT \) = weld time, \( PC \) = Power cost, \( P \) = power, \( W \) = filler metal weight (g), \( \rho \) = density (g/cm³), \( L \) = length (cm), \( E \) = deposition efficiency, \( R \) = root gap, \( T \) = thickness of base metal, \( F \) = root face, \( C.G \) = cost of shielding gas (S.G) cylinder, \( S \) = size of cylinder, \( F.G \) = flow rate of gas, \( V \) = volume of S.G, \( DLC \) = direct labor cost, \( AT \) = average time, \( LCOS \) = labor cost (1 Sec), \( NOS \) = number of seconds, \( LC \) = labor cost, \( S \) = speed, \( FRC \) = filler rod cost, \( SHC \) = shielded gas cost, \( U \) = unit cost.

2.1. Physical Experimentation

This experimental work design explains the quantitative analysis by performing experiments to join 100 × 100 mm² square plates of 3 mm thickness through butt joints of dissimilar metals using 17 samples and employing TIG welding in real time to facilitate the mathematical model and optimal parameters to consider multiple dependent and independent variables. As shown in Figure 1a, 17 experiments were performed in the lab while collecting data manually for cost estimation and parametric optimization. The results are as given in Table 1.

Table 1. Experimental readings against parameters.

<table>
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<tr>
<th>Sr no.</th>
<th>I (Amp)</th>
<th>S mm/min</th>
<th>F.G L/min</th>
<th>V Volts</th>
<th>WT min</th>
<th>PC (PKR)</th>
<th>LC (PKR)</th>
<th>FRC (PKR)</th>
<th>SHC (PKR)</th>
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Total 28.57194 11,893.79 1600.15 3594.6
To optimize the total cost of TIG welding, we utilized LP. Linear programming (LP) is a mathematical optimization method that helps identify the best values for decision variables while considering given constraints. The objective function of the LP problem consisted of the coefficients obtained from the linear regression model and the intercept. By minimizing this objective function (Equation (1) below), we aimed to find the optimal values for the welding parameters mentioned in the hope that it would result in the lowest total cost.

\[
PC = \left\{ \frac{V}{\eta} \right\} * t * U, \quad W = A * \rho * L * \frac{1}{E}, \quad A = (R * T) + (T - F)^2 + \tan \left( \theta \right)
\]

\[
SGC = VSG * CGUV, \quad VSG = CSA \left( \frac{mm^2}{m} \right) * LJ * FRG, \quad LCOS = \frac{DLC}{AT}, \quad LC = LCOS * NOS
\]

### 2.2 Experimentation Using Machine Learning

The TIG welding dataset, comprising 17 records with welding parameters and associated costs, underwent preprocessing to prepare it for analysis. To evaluate model performance, the dataset was split into training and testing subsets using the train_test_split.

The training subset contained 70% (11 records) of the data, while the testing subset comprised 30% (6 records), ensuring a representative distribution of data in both subsets. The actual setup and the schematic diagram are shown in Figure 2b.

Figure 2. (a) Total and parametric costs regression lines; (b) paired values comparison.

### 3. Discussion

To optimize the total cost of TIG welding, we utilized LP. Linear programming (LP) is a mathematical optimization method that helps identify the best values for decision variables while considering given constraints. The objective function of the LP problem
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The results are shown the scatter plots of data generated from the model, as shown in Figure 2a. This analysis examines the correlations between cost factors and total cost using scatter plots with regression lines. A positive slope shows positive correlation and a negative slope shows a negative correlation.

Figure 2b compares the estimated optimized cost with the dataset’s cost values, highlighting disparities in feature values using paired bars. The vertical height of each bar indicates the magnitude.

Figure 3 illustrates line plots showing the temporal evolution of cost factors. Each plot represents a specific cost factor, with the y-axis representing corresponding cost values and the x-axis representing chronological order.

![Figure 3. Parametric magnitudes vs. experiments.](image)

Equation (1):

\[
Y = (-2.439591633186284e−14).(I) + (-1.1102230246251565e−16) \cdot (S) + (9.67695975435571e−14) \cdot (FG_- + (-1.25500345930180) - 13).(v) + (0.16190689141474435).(t) + (1.0000000000000047).\text{(PC)} + (0.9730604174018711).\text{(DLC)} + (1.0000000000000047).\text{(FRC)} + (1.0000000000000022).\text{(SGC)} + 1.2505552149377763e−12
\]  

4. Conclusions

This research utilized manual calculations and the Linear Regression Algorithm to estimate and optimize TIG welding costs for dissimilar metals. After analysis, the optimal values for welding parameters that minimize the total cost are current = 70 A, speed = 100.0 mm/min, gas flow rate = 8.0 L/min, voltage = 10.7 V, weld time = 76.0 min, power cost = 1.0149024 KPR, labor cost = 456.76 KPR, filler rod cost = 89.47 KPR, shielded gas cost = 129.0 KPR. These optimized values resulted in a total cost of 676.2449 KPR, reducing it by 169.31 KPR compared to the minimum cost in the original dataset (845.56 KPR).

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References


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