engineering proceedings

Proceeding Paper

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

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† Presented at the Third International Conference on Advances in Mechanical Engineering 2023 (ICAME-23), Islamabad, Pakistan, 24 August 2023.

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

Citation: Mukhtar, G.A.; Shehzadi, S.; Sajid, A.; Laar, J.M.T.; Taqi, S.A.; Usman, R.M.; Hasnain, F.u. Cost Estimation and Parametric Optimization for TIG Welding Joints in Dissimilar Metals Using Linear Regression Algorithm. *Eng. Proc.* **2023**, *45*, 50. https://doi.org/10.3390/engproc2023045050

Academic Editors: Mohammad Javed Hyder, Muhammad Mahabat Khan, Muhammad Irfan and Manzar Masud

Published: 19 September 2023

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

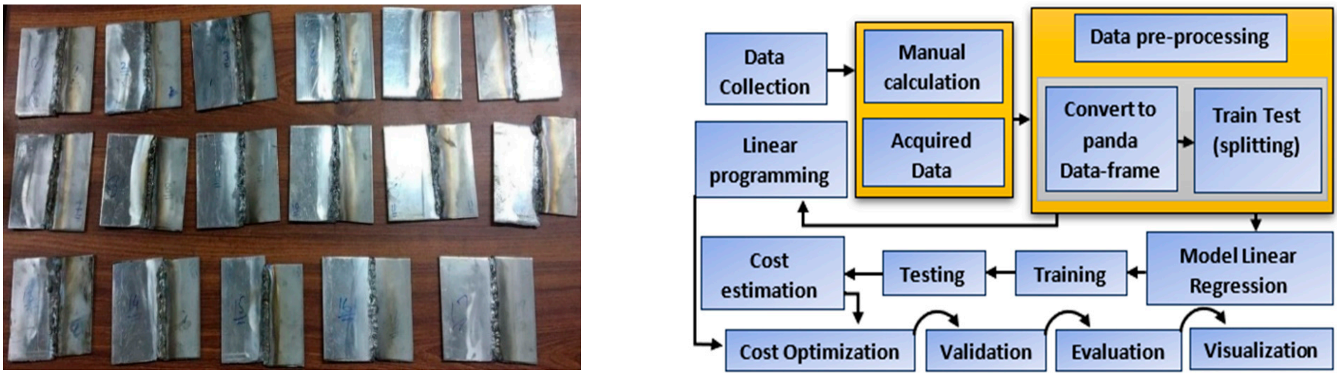
t = time in hours, V = voltage, I = current, η = efficiency of machine, WT = weld time, PC = Power cost, P = power, W = filler metal weight (g), ρ = density (g/cm3), L = length (cm), E = deposition efficiency, R = root gap, T = thickness of base metal, F = root face, C.G = cost of shielding gas (S.G) 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 mm^2 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.

Sr no.	I (Amp)	S mm/min	F.G L/min	V Volts	WT min	PC (PKR)	LC (PKR)	FRC (PKR)	SHC (PKR)
1	80	110	9	12.7	90	1.260587	540.90	96.96	259.2
2	70	110	8	12.2	135	1.601271	811.35	100.62	194.4
3	80	110	9	12.6	136	1.890137	817.36	94.57	172
4	80	100	10	13.1	90	1.300493	540.90	93.51	233
5	70	120	9	12	140	1.621819	841.40	95.64	167
6	80	110	9	12.1	76	1.014902	456.76	91.87	308
7	80	120	10	13.2	105	1.528905	631.05	93.05	200
8	70	110	10	13.3	135	1.732898	811.35	100.40	155
9	80	120	8	12	140	1.853209	841.40	92.19	187
10	90	100	9	11.9	90	1.328933	540.90	90.31	260
11	80	110	9	14.7	98	1.589388	588.98	91.37	238
12	70	100	9	10.7	180	1.858868	1081.8	93.55	129
13	90	110	8	16	140	2.781452	841.40	89.74	187
14	90	110	10	12	84	1.251117	504.84	89.47	250
15	80	110	9	15.8	130	2.26605	781.30	95.50	180
16	80	100	8	13.3	100	1.467082	601.00	95.85	263
17	90	120	9	16.3	110	2.224834	661.10	95.55	212
			Total			28.57194	11,893.79	1600.15	3594.6



(**a**) (**b**)

Figure 1. (**a**) Physical experimentation; (**b**) schematic diagram.

The flow chart in Figure 1b shows the overall framework for performing experiments with collection of raw data and applying mathematical models manually to acquire lucrative data for further processing through a machine learning tool. Data pre-processing and modeling involve using linear regression and linear programming techniques. Acquired datasets are utilized for training with manual calculations. Cost estimation and optimization optimize resource allocation. The following equations show manual calculations for the following parameters:

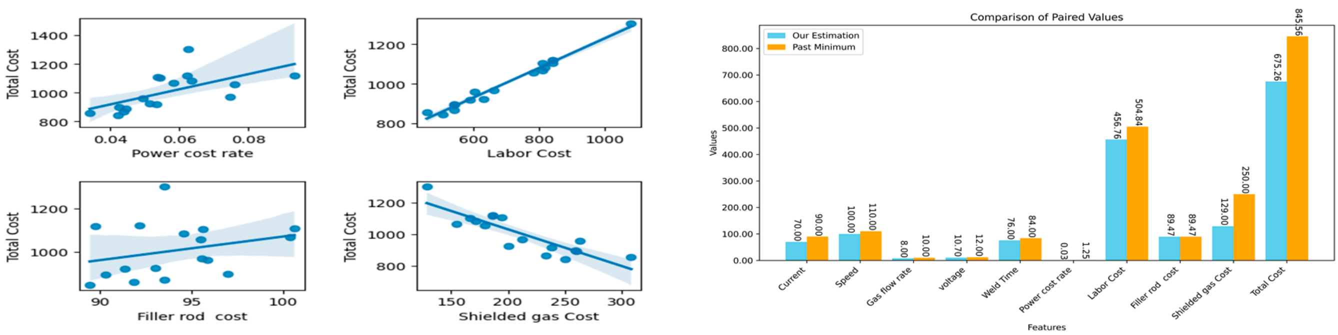
$$\mathrm{PC} = \left\{\mathrm{V} * \frac{\mathrm{I}}{\eta}\right\} * \mathrm{t} * \mathrm{U},\ \ \mathrm{W} = \mathrm{A} * \rho * \mathrm{L} * \frac{1}{\mathrm{E}},\ \mathrm{A} = (\mathrm{R} * \mathrm{T}) + (\mathrm{T} - \mathrm{F})2 + \tan\left(\frac{\theta}{2}\right)$$

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

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.



(**a**) (**b**)

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 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.

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.

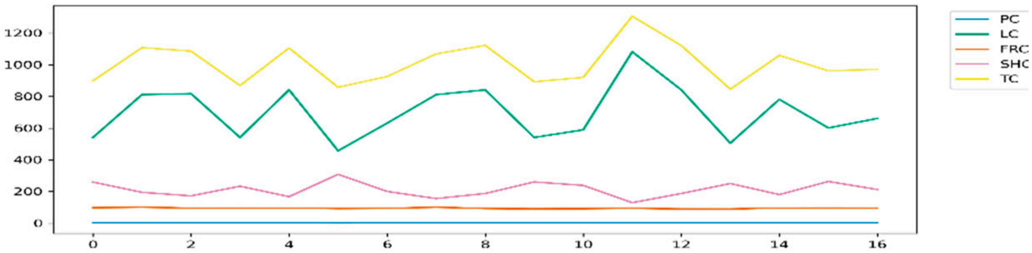


Figure 3. Parametric magnitudes vs. experiments.

The mentioned formula calculates cost as Y. The constants were calculated using Equation (1):

$$\begin{aligned} Y = \; & (-2.4395916331862840e-14).(I) + \; (-1.1102230246251565e-16) \\ & .\,(S) + \; (9.676959754345571e-14).(FG\_ + (-1.255003045930180 \\ & -13).(v) + (0.16190689141474435).(t) \; + \; (1.0000000000009737).\,(PC) \\ & +(0.9730604174018711).(DLC) + (1.0000000000000047).(FRC) \\ & +(1.0000000000000022).\,(SGC) \; + \; 1.2505552149377763e - 12 \end{aligned} \tag{1}$$

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).

Author Contributions: G.A.M.—conceptualization, technical writing, literature, data collection, manual calculations, draft preparation, reviewing, and editing; S.S.—formatting, vector designing, content writing, literature, reviewing, and editing; A.S.—applied ML tool; S.A.T.—applied ML tool; J.M.T.L.—manual calculations; R.M.U.—manual calculations; F.u.H.—final review and supervision. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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