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Optimization of the P-GMAW Process for Welding Thin AISI 304 Stainless Steel Sheets Using Response Surface Methodology

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Introduction

The welding of thin AISI 304 austenitic stainless steel sheets presents challenges related to heat input control, electric arc stability, and the prevention of defects such as burn-through and thermal distortion [1]. Pulsed Gas Metal Arc Welding (P-GMAW) offers an alternative for these applications, as it provides greater control over metal transfer and welding thermal conditions [2]. However, interactions among operating parameters can significantly influence the electrical characteristics of the process and weld bead geometry. In this context, Response Surface Methodology (RSM), combined with experimental design and statistical analysis, enables the identification of the most influential factors and the establishment of optimized operating conditions for welding thin sheets [3].

Objectives

To optimize the operating parameters of the P-GMAW process for welding thin AISI 304 stainless steel sheets using Response Surface Methodology (RSM) and Analysis of Variance (ANOVA), aiming to identify the most influential factors, develop predictive models, and establish welding conditions that ensure appropriate weld bead geometry and reduced energy consumption.

Methodology

Butt joints in thin AISI 304 stainless steel sheets were welded using the P-GMAW (UltimArc™) process with AWS ER308LSi filler wire. A full \(2^5\) factorial design was employed to evaluate five factors: shielding gas flow rate, wire feed speed, pulse frequency, input voltage, and welding speed. Electrical and geometrical responses were analyzed using Analysis of Variance (ANOVA, $p < 0.05$) and Response Surface Methodology (RSM), followed by multi-objective optimization using a desirability function.

Results and Discussion

Statistical analysis revealed a strong correlation between wire feed speed and welding current ($r = 0.996$), with wire feed speed being the predominant factor in ANOVA (55.21% contribution). The welding current model demonstrated high predictive accuracy (adjusted $R^2 = 0.9976$), with significant interactions among wire feed speed, pulse frequency, and input voltage. The output voltage model showed lower predictive performance (adjusted $R^2 = 0.6299$), with no statistically significant factors ($p > 0.05$), although Random Forest analysis highlighted the influence of input voltage. Multi-objective optimization identified a compromise operating condition balancing electrical responses and weld bead geometry, with a predicted current of 52.2 A and voltage of 16.95 V.

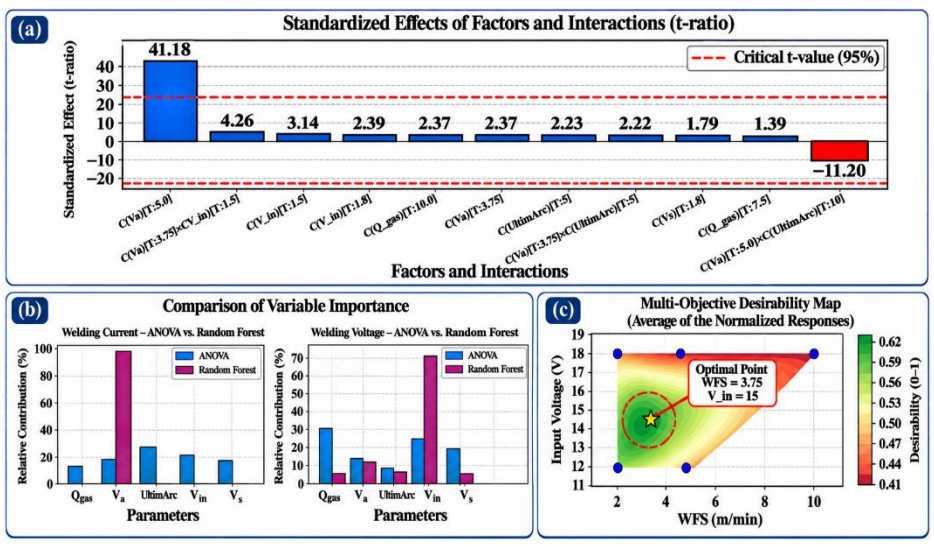


Figure 1. P-GMAW process analysis: (a) Pareto chart of welding current effects; (b) ANOVA and Random Forest variable importance; and (c) multi-objective desirability map.

Conclusions

- Wire feed speed was the most influential factor on welding current, showing a strong correlation ($r = 0.996$) and statistical significance.
- The welding current model showed excellent agreement (adjusted $R^2 = 0.9976$), whereas the voltage model exhibited lower predictive accuracy.
- Multi-objective optimization identified optimal conditions of 15 V, 3.75 m/min (wire feed speed), 5 Hz (pulse frequency), 1.8 m/min (welding speed), and 7.5 L/min (gas flow rate), with a predicted current of 52.2 A.
- RSM proved effective in identifying an optimal operating window for electrical responses, weld bead geometry, and energy consumption.

Reference

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