Chapter 5
Adaptive Optimization of Wire EDM Process for Ti6Al4V Alloy Using ANFIS and AI Technique

V. Senthilkumar
https://orcid.org/0000-0003-1673-3180
SRM TRP Engineering College, Trichy, India

A. Nagadeepan
https://orcid.org/0000-0002-7442-2658
SRM TRP Engineering College, Trichy, India

ABSTRACT

Wire Electrical Discharge Machining (WEDM) is a non-traditional machining process widely used for machining difficult-to-cut materials such as titanium alloys. This study proposes an intelligent optimization approach using Adaptive Neuro-Fuzzy Inference System (ANFIS) to optimize WEDM parameters for machining titanium alloy (Ti6Al4V) with coated wires. The key parameters investigated include pulse-on time, pulse-off time, peak current, and wire tension. The results demonstrate that the ANFIS model accurately predicts the optimal parameters, achieving a material removal rate (MRR) of up to 5.22 mm^3/min (increased by 15%) and a surface roughness (Ra) as low as 3.60 μm (reduced by 12%). The proposed approach significantly improves machining efficiency and surface quality, reducing the need for costly experimental trials. This study highlights the potential of ANFIS in optimizing WEDM processes for industrial applications, particularly in aerospace and biomedical industries where titanium alloys are extensively used.

INTRODUCTION

Wire cut electrical discharge machining (WEDM) is a vital non-traditional machining technique employed in industries such as aerospace, automotive, and biomedical engineering. It offers precision machining with minimal tool wear, making it suitable for difficult-to-machine materials like Ti6Al4V. Titanium alloys are extensively used in aircraft structural components, medical implants, and automotive

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parts due to their high strength-to-weight ratio, corrosion resistance, and biocompatibility. However, their poor machinability necessitates WEDM, which enables superior surface finish and intricate geometries.

The selection of Ti6Al4V for this study is based on its critical applications in aerospace and biomedical fields, where high precision and excellent surface integrity are required. EDM is preferred over conventional machining due to its ability to machine hard materials without inducing residual stresses.

Despite extensive research on optimizing WEDM parameters, gaps remain in understanding the impact of AI-driven optimization techniques. This study fills this gap by leveraging ANFIS to predict and optimize machining parameters, improving performance metrics like MRR and Ra. The novelty of this study lies in integrating ANFIS for real-time prediction and optimization, providing a more adaptive and accurate approach to WEDM parameter selection.

BACKGROUND

The researchers investigated Wire cut Electrical Discharge Machining (WEDM) of titanium alloys and examined the effect of pulse duration, wire feed rate, and wire tension. The second optimizes the machining parameters of Ti-6Al-4V using response surface methodology and artificial neural network. The third studies the impact of pulse-on time, pulse-off time, peak current, and wire tension on surface quality and material removal rate of Ti-6Al-4V. The fourth optimizes the process parameters for WEDM of Ti-6Al-4V. These studies offer insights into optimizing WEDM process parameters for better machining performance (Rajurkar et al., 1996), (Jha et al., 2016), (Liu et al., 2017), (Rahim et al., 2013). The four reviewed papers provide valuable insights into the optimization of WEDM process parameters for machining titanium alloys, particularly Ti-6Al-4V. Both Taguchi-based grey relational analysis and response surface methodology are effective methods for optimizing multiple objectives, including surface roughness, kerf width, and material removal rate. The pulse-on time, pulse-off time, peak current, and wire tension are identified as critical process parameters affecting the machining performance of titanium alloys. These studies provide a useful framework for achieving better machining performance and can guide future research in this field (Choudhury & Bhattacharyya, 2021), (Kansal et al., 2017), (Rajmohan et al., 2018), (Ravi et al., 2019). These papers all focus on the optimization of Wire Electrical Discharge Machining (WEDM) process parameters for Inconel 718 using Response Surface Methodology (RSM) and/or other optimization techniques. The process parameters considered include pulse-on time, pulse-off time, wire feed rate, wire tension, spark gap voltage, and servo voltage. The objective is to improve machining performance by optimizing the surface roughness, material removal rate, kerf width, and roundness. Some papers also use a desirability function-based approach or a genetic algorithm-based approach for multi-objective optimization. Overall, the results suggest that RSM-based optimization can improve the machining performance of Inconel 718 using WEDM (Joshi et al., 2016), (Pawade et al., 2014), (Sapkal et al., 2013), (Azam et al., 2014), (Patil & Joshi, 2016). The studies by Singh et al (2021), Kulkarni et al (2021), Gholami et al (2021), Mahapatra and Routara (2021), and Borah and Kalita (2021) have demonstrated the effectiveness of using artificial neural network (ANN) (Sana et al., 2024), (Hurairah et al., 2024), (Hassan et al., 2024), (Ghosh & Debnath, 2022), (Dhanalakshmi et al., 2022) in combination with optimization algorithms for optimizing the WEDM process parameters and improving the surface roughness of the machined part. The optimization algorithms used in these studies, such as genetic algorithm (GA), teaching-learning-based optimization (TLBO), and particle swarm optimization (PSO), have been shown to significantly improve the accuracy of predictions and optimization results.