

Modeling and Multi-objective Optimization of the Wire Electric Discharge Machining Process of 7075 Aluminum

A. Foorginejad^{1,*}, J. Sanaei Moghadam², H. Afshari³, A. Ghazanfari Hesari⁴, A. Bazrafshan Tanha³

¹ Assoc. Prof., Department of Mechanical Engineering, Birjand University of Technology, Birjand, Iran.

² Department of Mechanical Engineering, Shahid Montazeri Faculty, Technical and Vocational University, Mashhad, Iran.

³ PhD Student, Department of Mechanical Engineering, University of Birjand, Birjand, Iran.

⁴ B.Sc. Student, Department of Mechanical Engineering, Birjand University of Technology, Birjand, Iran.

*Corresponding author: foorginejad@birjandut.ac.ir

Received: 02/19/2026 Revised: 05/09/2026 Accepted: 06/25/2026

Abstract

With increasing industrial competition, limited resources, and the need to simultaneously achieve high quality, higher productivity, and reduced manufacturing costs, process optimization has become a key pillar in the development of advanced manufacturing technologies. In this study, multi-objective modeling and optimization of the wire electrical discharge machining (WEDM) process for 7075 aluminum alloy were investigated. Four control parameters, including voltage, current, pulse-on time, and pulse-off time, were examined using a Box–Behnken response surface design, and their effects on surface roughness, material removal rate, and kerf width were evaluated. To model the nonlinear behavior of the process, Gaussian process regression with a Matérn covariance function was employed, and model performance was assessed using five-fold cross-validation. The results indicated satisfactory predictive accuracy, particularly for surface roughness. Subsequently, the problem was formulated as a multi-objective optimization task with the objectives of minimizing surface roughness and kerf width while maximizing material removal rate, and the non-dominated sorting genetic algorithm was used to obtain the Pareto front. The findings revealed an inherent trade-off between surface quality and machining productivity, and an experimental validation test at the selected optimal point confirmed a relative error of less than 7%.

Keywords: Wire electrical discharge machining; Gaussian process regression; Multi-objective optimization; Non-dominated sorting genetic algorithm; Aluminum 7075.

1. Introduction

Wire Electrical Discharge Machining (WEDM), introduced to industry in the late 1960s, is a non-traditional material removal process that has become widely used for producing complex shapes in electrically conductive materials [1–3]. In this process, a thin wire—typically brass or copper—acts as a continuously moving electrode under controlled mechanical tension. Electrical discharges occur between the wire and the workpiece in deionized water as the dielectric medium. Because there is no direct mechanical contact, cutting forces and machining stresses are largely eliminated, while high precision and good dimensional control can be achieved. However, process performance is strongly affected by parameters such as voltage, current, pulse on-time and off-time, as well as wire tension and wire feed rate, all of which directly influence material removal rate (MRR), surface roughness, and kerf width [4].

Due to the nonlinear and highly interactive nature of WEDM, identifying optimal operating conditions is challenging. Previous studies have shown that peak

current and pulse on-time are among the most influential factors governing both MRR and surface quality. For instance, research on aluminum alloys such as 6061 and 5083 using Taguchi design and analysis of variance has indicated that proper adjustment of pulse on-time and current can significantly improve productivity while maintaining a better surface finish [2,3]. In addition, studies on aluminum 7075 and other advanced alloys suggest that combining statistical methods with intelligent modeling techniques can enhance prediction accuracy and support more reliable optimization [1].

Given these complexities, the present work investigates the effects of four key control parameters—voltage, discharge current, pulse on-time, and pulse off-time—on three main performance indicators: surface roughness, material removal rate, and kerf width. The experimental design is developed using response surface methodology, and Gaussian Process Regression is employed to capture the nonlinear behavior of the process. Finally, the problem is formulated as a multi-objective optimization task,

and a non-dominated sorting genetic algorithm is used to generate the Pareto front, enabling a balanced trade-off between surface quality and machining efficiency.

2. Experimental Procedure

In this study, WEDM was applied to aluminum alloy 7075, which is widely used due to its high strength, good electrical and thermal conductivity, corrosion resistance, and low weight [5]. Machining experiments were conducted using a PW500a WEDM machine with a 0.18 mm molybdenum-coated tungsten wire. The main experimental procedure is illustrated in (Figure 1).

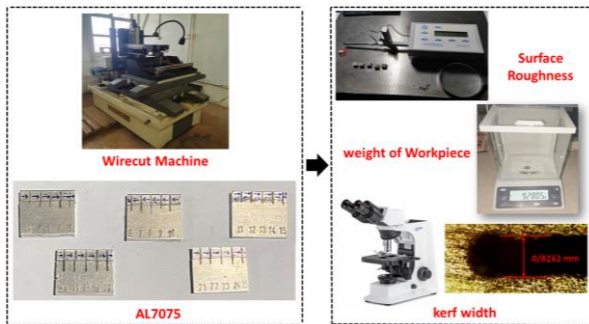


Figure 1. Experimental setup, machined specimens, and measurement equipment.

To ensure consistency, parameters such as dielectric fluid (deionized water), flushing pressure, wire tension, and polarity were kept constant throughout the experiments.

Three performance indicators were evaluated: material removal rate, surface roughness, and kerf width. MRR was calculated based on the weight difference of the workpiece before and after machining divided by machining time. Surface roughness was measured using a surface profilometer with three repetitions per sample, and the average value was recorded. Kerf width was measured using an optical microscope at three different locations, and the mean value was reported.

A Response Surface Methodology based on the Box–Behnken design was employed to systematically investigate the effects of four key process parameters: voltage, discharge current, pulse on-time, and pulse off-time. This approach enabled the evaluation of linear, quadratic, and interaction effects with a limited number of experiments. The parameter levels are listed in Table 1.

Table 1. Levels of the experimental design parameters

Parameter	Level 1	Level 2	Level 3
V (v)	80	100	120
T _{on} (μs)	16	32	48
T _{off} (μs)	8	16	24
I (A)	0.5	1.0	1.5

To model the nonlinear behavior of the process, Gaussian Process Regression (GPR) was adopted. GPR

is a non-parametric probabilistic method capable of capturing complex relationships while providing uncertainty estimation. Separate models were developed for each output response. Prior to training, the data were normalized using the Min–Max scaling method, and model performance was assessed through five-fold cross-validation to evaluate generalization capability.

Since minimizing surface roughness and kerf width often conflicts with maximizing MRR, the problem was formulated as a multi-objective optimization task. The NSGA-II algorithm was employed to obtain the Pareto front. The trained GPR models were used as surrogate models within the optimization process, reducing computational and experimental cost. The final optimal solution was selected as the point closest to the ideal condition, providing a balanced trade-off between machining quality and productivity.

3. Results and Discussion

In this study, Gaussian Process Regression (GPR) models were employed to predict the main responses of the Wire EDM process, namely surface roughness, material removal rate, and kerf width. Because the responses have different scales, all outputs were first mapped to the range [0,1] using Min–Max normalization to stabilize training and prevent one response from dominating the others. Then, an independent GPR model was developed for each response. A Matern 3/2 kernel was used for surface roughness and kerf width, while a Matern 5/2 kernel was selected for MRR. Model performance was evaluated using five-fold cross-validation, and the results showed that the surface roughness model achieved higher accuracy than the other two responses. Residual analysis indicated that prediction errors were generally centered around zero, suggesting no strong systematic bias, although larger dispersion was observed for MRR and kerf width.

A one-factor-at-a-time sensitivity analysis revealed that discharge current and pulse on-time have the strongest influence on surface roughness. In contrast, voltage and pulse off-time play a more dominant role in controlling MRR. Kerf width was found to depend on both electrical and timing parameters and exhibited a clearly nonlinear behavior.

The outcomes of the multi-objective optimization are summarized by the Pareto front shown in (Figure 2), which highlights the trade-off among minimizing surface roughness and kerf width while maximizing MRR. The results indicate that higher MRR is typically associated with increased surface roughness and a wider kerf. The selected optimal point lies in the middle region of the Pareto front, providing a practical balance between machining quality and productivity. Finally, an experimental validation test showed a small deviation between predicted and measured values, confirming the acceptable accuracy and practical reliability of the proposed framework.

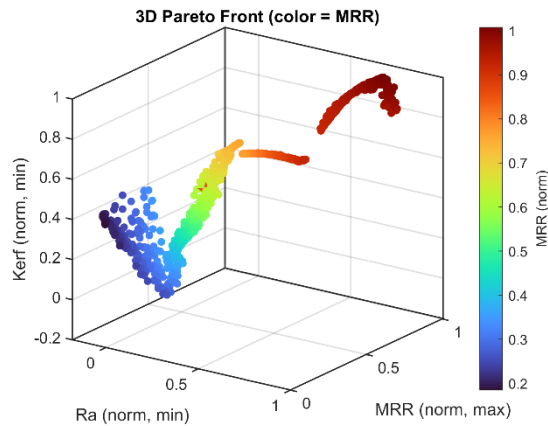


Figure 2. Three-dimensional Pareto front of the output responses

4. Conclusions

In this study, a Gaussian Process Regression-based framework was developed for modeling, sensitivity analysis, and multi-objective optimization of Wire EDM for aluminum 7075. The results showed good predictive accuracy, and the Pareto front was obtained using NSGA-II. Experimental validation also confirmed the effectiveness and reliability of the proposed approach.

5. References

- [1] Deepak, D., Yathindra, K. V., Vijayan, V., Sachidananda, H. K., & Bhat, S. K. (2025). Surface Integrity and Kerf Characteristics in Wire-EDM of WAAM-Fabricated Hybrid ER70S-308L Steel: A Taguchi-Based Parametric Analysis. *Results in Surfaces and Interfaces*, 100627.
- [2] Abouhawa, M., Elshinawi, A., Eisa, A., & Fattouh, M. (2025). A hybrid machine learning approach to optimize kerf quality in AWJM of Ti-6Al-4V/CFRP/Al7075 stacks. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, 19(11), 7413-7435.
- [3] Afridi, S. A., Younas, M., Khan, Z., & Khan, A. M. (2025). Investigating wire electric-discharge machining (wedm) parameters for improved machining of D2 Steel: a multi-objective optimization study. *International Journal of Precision Engineering and Manufacturing*, 26(4), 817-835.
- [4] Saha, S., Arunkumar, T., Debnath, K., & Chaurasia, S. (2025). Optimization of Kerf width in WEDM of sandwich woven CFRP-an ensemble machine learning based approach. *Arabian Journal for Science and Engineering*, 50(17), 13713-13724.
- [5] Ranjbar, S., Foorginejad, A., Emam, S. M., Ebadi, M., & Shiri, K. (2026). Effects of cryogenic cooling on cutting temperature and surface roughness in turning of AA7075 aluminum alloy. *Scientific Reports*, 16(1), 7914.