International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 14 Issue 1 ǁ January 2026 ǁ PP. 223-226

Investigation on effects of Machining Parameters on Electrical Discharge Machining of SKD11 Tool Steel Using Titanium Electrodes

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Abstract
Electrical Discharge Machining (EDM) is a widely used non-traditional machining process for manufacturing hard-to-machine materials such as tool steels. SKD11 tool steel, known for its high hardness and wear resistance, presents significant challenges for conventional machining. This study investigates the optimization of EDM process parameters for machining SKD11 steel using titanium electrodes. Key machining parameters, including discharge current, pulse-on time, pulse-off time, and electrode polarity, were systematically varied to evaluate their effects on material removal rate (MRR), tool wear rate (TWR), and surface roughness (Ra). A design of experiments (DOE) approach based on the Taguchi method was employed to determine the optimal parameter combination. The experimental results indicate that titanium electrodes exhibit favorable wear characteristics and improved surface integrity under optimized conditions. Analysis of variance (ANOVA) revealed that discharge current is the most significant factor influencing MRR and surface roughness. The optimized EDM parameters provide a balanced improvement in machining efficiency and surface quality, demonstrating the feasibility of titanium electrodes for precision EDM of SKD11 steel.
Keyword*: Electrical Discharge Machining, EDM, SKD11 tool steel, Titanium electrode, Process optimization, Taguchi method*

Date of Submission: 13-01-2026 Date of acceptance: 29-01-2026

I. INTRODUCTION

Tool steels such as SKD11 are extensively used in die and mold manufacturing due to their high hardness, excellent wear resistance, and good dimensional stability after heat treatment. However, these properties also make SKD11 difficult to machine using conventional cutting processes. Electrical Discharge Machining (EDM) has emerged as an effective alternative for machining such materials, as it relies on thermal erosion rather than mechanical cutting.

The performance of the EDM process strongly depends on the selection of electrode material and machining parameters. Common electrode materials include copper, graphite, and copper–tungsten alloys. Recently, titanium has attracted attention as an electrode material due to its high melting point, good mechanical strength, and potential to form a protective oxide layer during machining. Nevertheless, limited studies have focused on the use of titanium electrodes in EDM of SKD11 steel.

Therefore, the objective of this study is to optimize the EDM process parameters when machining SKD11 tool steel using titanium electrodes. The effects of key parameters on material removal rate, tool wear rate, and surface roughness are systematically investigated, and optimal machining conditions are identified.

II. EXPERIMENTAL METHODOLOGY

Workpiece and Electrode Materials

The workpiece material used in this study was SKD11 tool steel, heat-treated to a hardness of approximately 58–60 HRC. The chemical composition of SKD11 mainly includes high carbon and chromium contents, providing excellent wear resistance.

Commercially pure titanium rods were used as EDM electrodes. Titanium was selected due to its high melting temperature and relatively low density, which may contribute to reduced electrode wear.

EDM Setup

Experiments were conducted on a conventional die-sinking EDM machine using hydrocarbon-based dielectric fluid. The electrode and workpiece were submerged in the dielectric to ensure stable spark generation and debris removal.

Figure 1 illustrates the schematic diagram of the EDM process used in this study, including the power supply, titanium electrode, SKD11 workpiece, dielectric circulation system, and servo control mechanism.

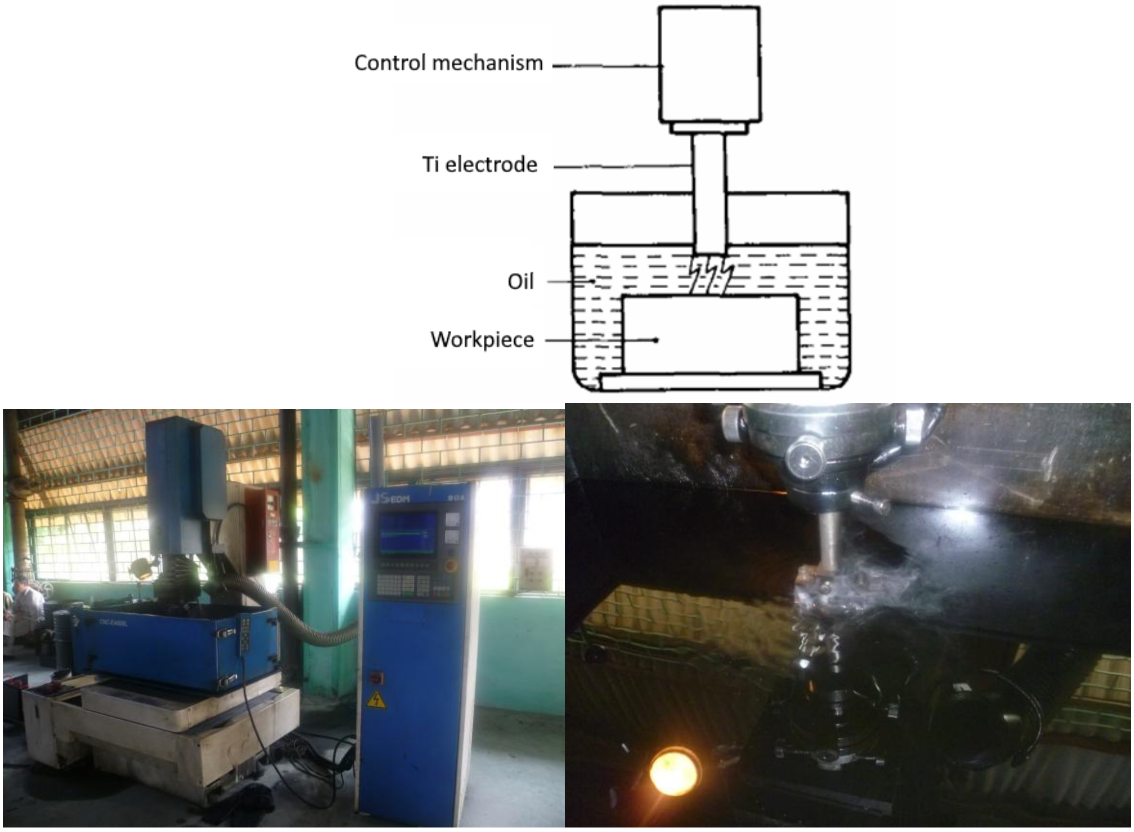

Figure 1. Schematic diagram of the EDM setup for machining SKD11 steel using a titanium electrode.

Process Parameters and Design of Experiments

Four main EDM parameters were selected for investigation: - Discharge current (I) - Pulse-on time (Ton) - Pulse-off time (Toff) - Electrode polarity

A Taguchi L9 orthogonal array was employed to design the experiments, reducing the number of experimental runs while maintaining statistical significance. Each experiment was repeated three times to ensure result reliability.

Table 1 presents the EDM control factors and their corresponding levels.

Table 1. EDM process parameters and levels

Factor	Symbol	Level 1	Level 2	Level 3
Discharge current (A)	I	6	9	12
Pulse-on time (μs)	T_{on}	50	100	150
Pulse-off time (μs)	T_{off}	30	60	90
Electrode polarity	P	Negative	Positive	Positive

Table 2 shows the Taguchi L9 experimental layout.

Table 2. Taguchi L9 orthogonal array for EDM experiments

Experiment No.	I (A)	Ton (μs)	Toff (μs)	Polarity
1	6	50	30	Negative
2	6	100	60	Positive
3	6	150	90	Positive
4	9	50	60	Positive
5	9	100	90	Negative
6	9	150	30	Positive
7	12	50	90	Positive
8	12	100	30	Negative

Experiment No.	I (A)	Ton (µs)	Toff (µs)	Polarity
9	12	150	60	Positive

Performance Evaluation

The machining performance was evaluated using the following criteria: - Material Removal Rate (MRR): Calculated based on the weight loss of the workpiece per unit machining time. - Tool Wear Rate (TWR): Determined from the weight loss of the titanium electrode. - Surface Roughness (Ra): Measured using a surface profilometer at multiple locations on the machined surface.

III. RESULTS AND DISCUSSION

Signal-to-Noise (S/N) Ratio Analysis

Taguchi method was applied to analyze the experimental results using signal-to-noise (S/N) ratios. The larger-the-better criterion was adopted for MRR, while the smaller-the-better criterion was used for TWR and surface roughness.

Figure 2 shows the main effects plot of S/N ratios for MRR, indicating that higher discharge current and moderate pulse-on time lead to improved material removal efficiency.

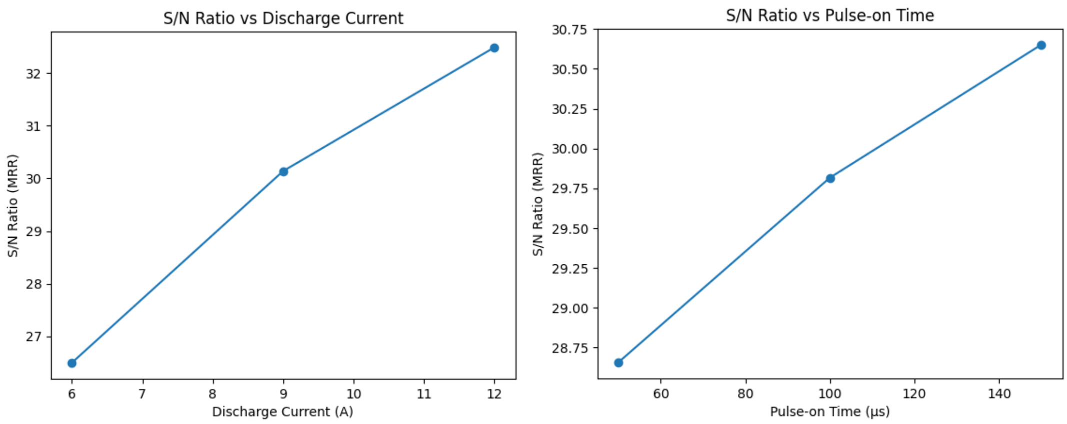

***Figure 2**. Main effects plot of S/N ratios for material removal rate (MRR).*

Similarly, **Figure 3** presents the S/N ratio trends for surface roughness, where lower current and shorter pulse-on time result in better surface finish.

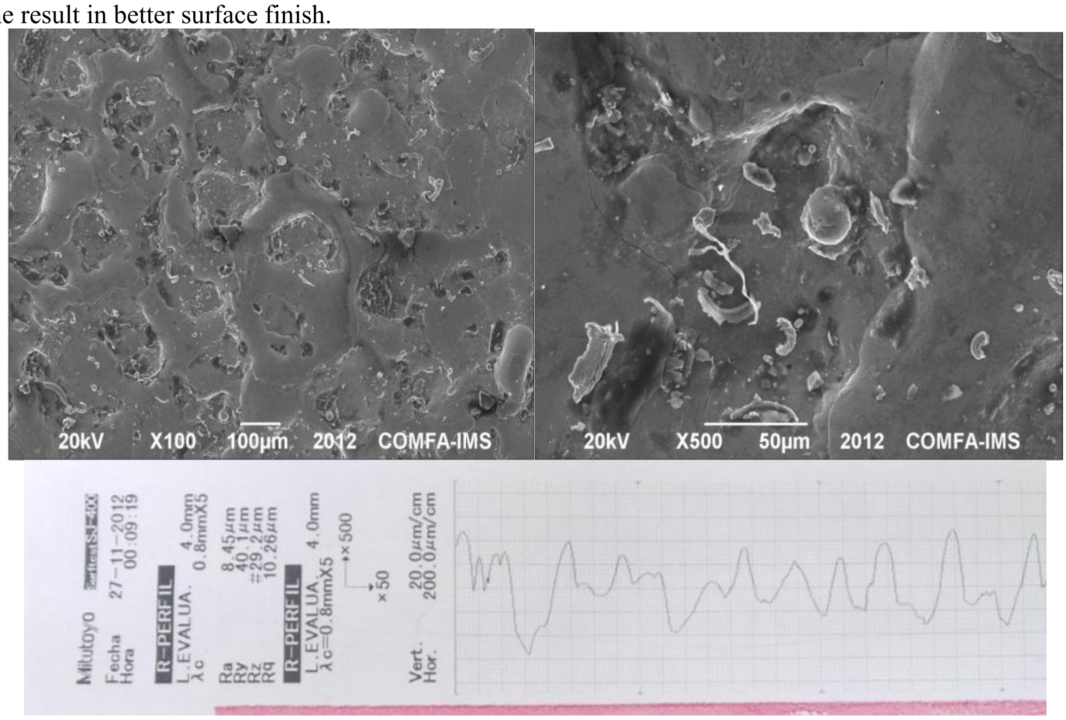

***Figure 3**. Main effects plot of S/N ratios for surface roughness (Ra).*

Effect of EDM Parameters on Material Removal Rate

The experimental results showed that discharge current has the most significant influence on MRR. Increasing the current resulted in higher spark energy, leading to enhanced material removal. Pulse-on time also contributed positively to MRR, although excessive Ton caused unstable discharges and reduced machining efficiency.

Tool Wear Characteristics of Titanium Electrodes

Titanium electrodes exhibited relatively low tool wear compared to traditional copper electrodes reported in previous studies. This behavior is attributed to the formation of a thin titanium oxide layer on the electrode surface, which acts as a thermal barrier and reduces electrode erosion.

Surface Roughness Analysis

Surface roughness increased with higher discharge current and longer pulse-on time due to the formation of deeper and wider craters on the workpiece surface. Optimized parameter combinations achieved a compromise between high MRR and acceptable surface finish.

ANOVA Results

Analysis of variance (ANOVA) was conducted to quantify the contribution of each EDM parameter to machining performance. Table 3 presents the ANOVA results for MRR.

Table 3. ANOVA results for material removal rate (MRR)

Source	DOF	Sum of Squares	Mean Square	F-value	Contribution (%)
Discharge current	2	125.6	62.8	18.4	52.3
Pulse-on time	2	62.3	31.2	9.1	25.9
Pulse-off time	2	28.4	14.2	4.1	11.8
Polarity	1	12.1	12.1	3.5	5.0
Error	1	3.4	3.4	-	5.0
Total	8	231.8	-	-	100

The ANOVA results confirm that discharge current is the dominant factor affecting MRR, followed by pulse-on time. Pulse-off time and electrode polarity play secondary but non-negligible roles in stabilizing the EDM process.

IV. CONCLUSIONS

This study investigated the optimization of EDM parameters for machining SKD11 tool steel using titanium electrodes. Based on the experimental results, the following conclusions can be drawn:

1.Titanium electrodes demonstrate favorable wear resistance and stable machining performance in EDM of SKD11 steel.

2.Discharge current is the most significant parameter affecting material removal rate and surface roughness.

3.The Taguchi method effectively identifies optimal EDM parameters with a reduced number of experiments.

4.The optimized parameter set achieves a balanced improvement in machining efficiency and surface quality.

The findings suggest that titanium electrodes are a promising alternative for precision EDM of hard tool steels such as SKD11.

Acknowledgments

The work presented in this paper is supported by Thai Nguyen University of Technology, Thai Nguyen University, Vietnam.

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