Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/BA08.20250486
Published: December 20, 2025

Parameter Optimization for Reducing Machining Time in Wire-EDM Machining of DanCut 345 Alloy Using Taguchi Method and ANOVA

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Abstract

Wire electrical discharge machining (WEDM) is a non-contact machining process that produces complex shapes with high precision and a good surface finish. However, it can be a time-consuming process, as wire-EDM machining time is significantly affected by various machining parameters and the material properties of both the tool and workpiece. This study identifies and optimizes the most influential process parameters affecting WEDM machining time for the DanCut 345 workpiece. The input factors considered for this study are: pulse-on time (µs), pulse-off time (µs), variable frequency (VF) (mm/min), and MAX speed (mm/min) or cutting speed, while both half-lap and final machining times were measured. The Taguchi optimization method was utilized to analyze the parametric effects with a reduced number of experiments. Analysis of Variance (ANOVA) was performed to determine the statistical significance and percentage contribution of each factor for machining time. The findings reveal that MAX speed is the most influential parameter, accounting for 70.59% and 90.75% of the variation in half-lap machining time and final machining time, respectively, while variable frequency has the least effect. The optimum conditions for minimum final machining time were as follows: maximum wire speed = 200 mm/min, pulse-off time = 7 µs, pulse-on time = 40 µs, and VF = 7 mm/min. The proposed settings reduce the average final machining time by up to 47% compared to the worst experimental conditions. Finally, regression equations were developed, and surface and contour plots revealed the zone of optimal machining conditions for minimizing machining time.

Keywords

Wire-EDM, Machining Time, Taguchi, ANOVA and DanCut 345.

1. Introduction

Wire Electrical Discharge Machining (WEDM) is a precise non-traditional machining process that uses continuously feed wire electrode to erode material through electrical discharges in dielectric fluid. It's ideal for machining complex shapes and hard-to-machine materials, such as superalloys, titanium alloys, and tool steels, making it widely used in aerospace, automotive, and medical devices. Key parameters in WEDM include pulse-on time, voltage, current, and wire feed rate. Optimizing these parameters is crucial for reducing machining time without compromising part quality, enhancing efficiency, and lowering production costs.

Extensive research has been carried out on the optimization of Wire Electrical Discharge Machining (WEDM) for materials such as aluminium alloys, stainless steels, and Inconel. These studies have primarily focused on improving material removal rate (MRR), surface roughness, and dimensional accuracy. However, little to no work has been reported on the optimization of WEDM parameters for the DanCut 345 tool steel alloy. This study seeks to fill that gap by applying the Taguchi L9 orthogonal array and ANOVA methods to optimize machining time for DanCut 345 alloy.

The main objective of this study is to identify and optimize the key process parameters that influence WEDM machining time for the DanCut 345 alloy using the Taguchi L9 orthogonal array and ANOVA techniques. Unlike most previous studies that focused on improving surface quality or material removal rate, this work places special emphasis on reducing machining time, a factor that directly affects productivity and cost efficiency. The novelty of this research lies in modeling and visualizing the relationships between machining parameters and machining time for an alloy that has not been studied yet. These findings aid any untrained user to achieve faster and more energy-efficient WEDM operations for DanCut 345 alloy. By reducing machining time, the research not only enhances WEDM productivity for DanCut 345 alloy but also contributes to environmental sustainability through lower energy use and reduced waste.

1.1 Objectives

- To design and conduct a Taguchi experimental plan to investigate the effects of selected WEDM process parameters on machining time.
- To determine the optimal levels of WEDM process parameters that minimize machining time using the Taguchi method's Signal-to-Noise (S/N) ratio analysis.
- To analyze the statistical significance of the WEDM process parameters on machining time using Analysis of Variance (ANOVA).

2. Literature Review

Wire Electrical Discharge Machining (WEDM) is a precise non-traditional machining process that uses a continuously fed wire electrode to erode material through electrical discharges in dielectric fluid. It's ideal for machining complex shapes and hard-to-machine materials, such as superalloys, titanium alloys, and tool steels (Rafeeq and Parvez 2025), making it widely used in industries like aerospace, automotive, and medical devices. The most significant input parameters in WEDM include pulse-on time, voltage, current, wire feed rate, etc. Optimizing these parameters is crucial for reducing machining time without compromising part quality, enhancing efficiency, and lowering production costs. Sarala et al. (2024) provides a comprehensive review of wire electrical discharge machining (WEDM), focusing on parameter optimization and the factors governing machining efficiency and precision. Additionally, the study discusses the need for adaptive monitoring and real-time control strategies in achieving optimal process performance.

Taguchi is a robust design method for optimizing processes, while ANOVA (Analysis of Variance) is a statistical technique used to analyze differences between group means. Numerous studies have optimized WEDM parameters to enhance material removal rate (MRR), surface finish, and cutting speed using these techniques. Juliyana et al. (2024) applied the Taguchi method for LM5 aluminum alloy. Wasif et al. (2022) used ANOVA for WEDM cutting of Aluminium 5454 to experimentally investigate the effect of various process parameters on machining performance.

Researchers have also tried to study stainless steel, 7075-T651 aluminum, and tough aerospace alloys using Taguchi and ANOVA. For AISI 304 stainless steel, a Taguchi-Grey Relational Analysis (GRA) study showed that pulse-on time and peak current are the most significant factors for MRR, while pulse-on time and pulse-off time had the most profound effect on surface roughness (Azawqari et al. 2024). On Al 7075-T651, a simple Taguchi L9 experiment identified the most favorable parameters to be pulse-on around 100–106 µs, pulse-off at 40 µs, and servo voltage at 15 V, giving a big boost in material removal rate while keeping the surface nice and smooth (Murthy et al. 2019). In aerospace materials, things get even more interesting. For Inconel 625, combining response surface methodology with Taguchi optimized wire feed rate, current and pulse on/off times, delivering higher MRR and lower surface roughness for nickel superalloy (Tejas Ajay et al. 2017). Another group of researchers used Bayesian optimization with neural networks on Inconel 800 and perfectly balanced speed versus energy consumption by optimizing pulse on time (Ton), pulse off time (Toff), current (IP), servo gap voltage (SV), and wire tension (WT) (Choudhuri and Sen 2022).

Classic studies on Inconel 718 repeatedly found that pulse-off time alone explains more than 60% of the variation in MRR—basically the biggest lever for productivity (Sheth et al. 2021). When wire tension was considered as a parameter, GRA-ANOVA revealed that it dominated (91% influence on MRR) and had a profound effect on minimizing kerf width (Karataş 2022). Although for Al 6061, main and interaction effect plots coupled with ANOVA showed that tweaking peak current and pulse-off time can greatly improve MRR (Selva Babu et al. 2021) In particle-reinforced versions of the same alloy, Taguchi analysis revealed that wire feed rate is critical for high MRR and producing better surface finish (Rani et al. 2017). In short, no matter what the alloy is, a handful of parameters, mostly pulse-on/off, current, and wire feed rate, keeps showing up as pertinent to efficient and precise machining.

Recent studies have applied these techniques for machining tool steels. They highlight multi-response optimization, including machining time. Nguyen et al. (2025) used Taguchi and ANOVA in a three-stage WEDM process (roughing, semi-finishing, and finishing) for D2 tool steel. The study shows the trade-offs in multi-stage machining for hard tool steels. They found the best pulse-on time (Ton), pulse-off time (Toff), and servo voltage (SV) to use to reduce surface roughness (SR), dimensional deviation (DD), and machining time (MT). ANOVA revealed that SV was the most important factor (96.9% contribution) for MT in the finish stage, with an optimal MT of 218 seconds. In a similar vein, Saad et al. (2023) optimized the wire EDM (WEDM) settings for AISI 4140 tool steel using the Taguchi L9 design, ANOVA, and signal-to-noise ratio analysis. They found that pulse-on time (Ton) had by far the biggest influence on surface roughness (rank 1), followed by peak current and pulse-off time. The following combination, Ton = 70 µs, Toff = 7 µs, and current = 9 A, gave excellent surface finish and spot-on dimensional accuracy when cutting spur gears.

Shifting the focus to sustainability, Camposeco-Negrete (2021) worked on AISI O1 tool steel and also used the Taguchi method, but this time to balance machining time, electric power consumption, and total energy use, surface roughness and MRR. The key parameters were pulse-on time, servo voltage, and voltage. Interestingly, cranking up the servo voltage cut down energy consumption quite a bit, even though it made the machining take a little longer — a classic trade-off that still supports cleaner, more efficient, and lower-waste manufacturing. Chopde et al. (2014) used Taguchi to fine-tune wire EDM on cryo-treated AISI D2 steel. Pulse-on time (Ton) dominated surface roughness (78% influence), and the smoother finishes they achieved also made the process more stable and indirectly faster. In a broader study, Sana et al. (2025) combined Taguchi with NSGA-II and neural networks to enhance both material removal rate and cutting speed on AISI D2 and DC53 steels. Pulse settings were found to be significant for cutting time, but they noted that current models still don't properly factor in part geometry or deliver precise time predictions for these tough tool steels.

Extensive research has been carried out on the optimization of Wire Electrical Discharge Machining (WEDM) for materials such as aluminium alloys, stainless steels, and Inconel. These studies have primarily focused on improving material removal rate (MRR), surface roughness, and dimensional accuracy. However, research specifically addressing machining time optimization remains limited, despite its critical role in productivity and cost efficiency. Moreover, little to no work has been reported on the optimization of WEDM parameters for the DanCut 345 tool steel alloy. This study seeks to fill that gap by applying the Taguchi L9 orthogonal array and ANOVA methods to optimize machining time for DanCut 345 alloy. The objectives include identifying process parameters—such as pulse-on time, pulse-off time, and wire feed rate—that most strongly affect machining time. Utilizing the "small-is-better" signal-to-noise ratio, the study aims to minimize machining time while maintaining an acceptable surface finish and dimensional accuracy.

The main objective of this study is to identify and optimize the key process parameters that influence WEDM machining time for the DanCut 345 alloy using the Taguchi L9 orthogonal array and ANOVA techniques. Unlike most previous studies that focused on improving surface quality or material removal rate, this work places special emphasis on reducing machining time, a factor that directly affects productivity and cost efficiency. The novelty of this research lies in modeling and visualizing the relationships between machining parameters and machining time for an alloy that has not been studied yet. These findings aid any untrained user to achieve faster and more energy-efficient WEDM operations for DanCut 345 alloy. By reducing machining time, the research not only enhances WEDM productivity for DanCut 345 alloy but also contributes to environmental sustainability through lower energy use and reduced waste.

3. System Components

3.1 WEDM Components

The system has several essential components. Figure 1 illustrates the typical experimental setup for a WEDM machine. The components are listed below:

- Machine: BOMA DK7780D wire EDM machine.
- Moly-Wire: Molybdenum Wire of Dia 0.18mm for Wire EDM Machine.
- Material: DanCut 345 alloy.

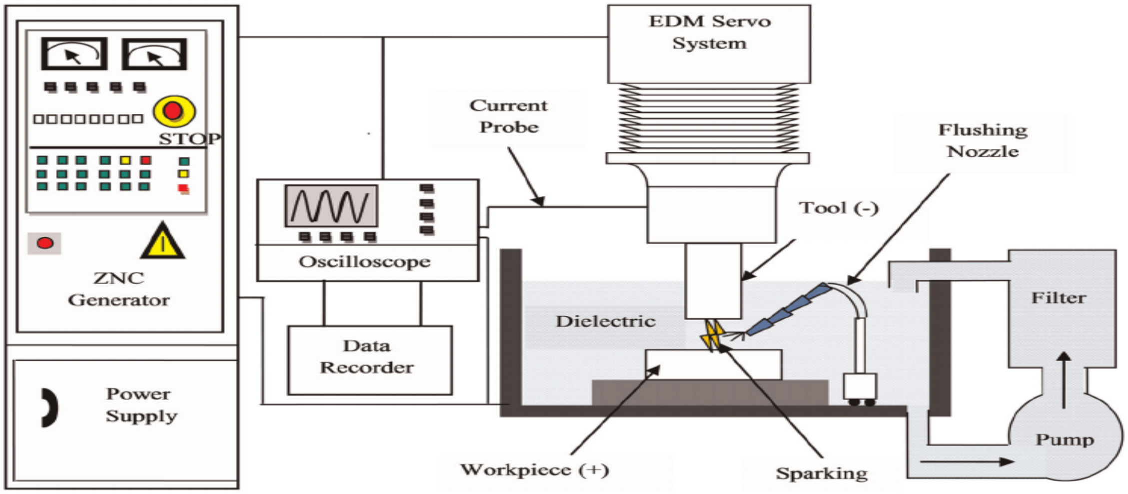


Figure 1. Experimental set up for wire electric discharge machine

3.2 Software Components

- BOMA DK7780D wire EDM machine build software
- AutoCAD
- Minitab

4. Material and Methods

The experimental investigation was conducted using a Wire Electrical Discharge Machining (WEDM) system to study the influence of process parameters on machining performance. WEDM is a thermal erosion process in which material is removed by a series of electrical discharges occurring between a continuously fed wire electrode and the conductive workpiece, submerged in dielectric fluid. The precision, repeatability, and ability to machine hard materials make WEDM an ideal process for advanced manufacturing applications. The experimental setup for the Wire-EDM (WEDM) study on DanCut 345 alloy was designed to systematically evaluate the effect of process parameters on machining time. The setup ensured repeatability, process stability, and accurate time measurement for both half-lap and final cutting operations. Throughout the experimental phase, consistent conditions are maintained regarding the WEDM machine setup and the workpiece material, as these variables can significantly affect machining outcomes. All measurements are conducted with strict attention to accuracy and repeatability to ensure the reliability of the collected data.

4.1 Materials

The study focused on DanCut 345 tool steel, known for its high hardness (54–56 HRC) and toughness (12 KV(J)), achieved by adding 4% nickel. This enhances impact strength without compromising hardness, making it resistant to cracks and deformation. Machining was performed using the BOMA DK7780D wire EDM, which offers high precision with a work travel of 800×1000 mm and cutting accuracy of 0.01 mm. A high-frequency iridium-molybdenum alloy wire (BM-1GPM, 0.18 mm diameter) was used, offering 12% higher tensile strength than standard wires. Its long operational life and low extension ensure precision, ideal for machining DanCut 345.

4.2 WEDM Cutting of Dancut 345 Alloy

In this study, four key process parameters were selected: maximum wire speed, variable frequency (VF), pulse-on time, and pulse-off time, each having three levels. The WEDM machining time was considered as the response factor. Key parameters such as Pulse-On Time (PON), Pulse-Off Time (POFF), Power (IP), and Maximum Speed are adjusted to minimize the machining time. After setting up the workpiece, the earthing was turned on. The wire drum was centered with the workpiece. The cutting operation is started, paused, or reversed as needed, following a specific sequence to ensure smooth processing. After setting and centering, the selected parameters were set by Taguchi L9 half-lap array as shown in Table 1, and the data of half-lap and final machining time were collected.

Table 1. Design scheme of process parameters and their levels

Factors	**Unit**	**Level**		
		1	**2**	**3**
Max Speed	**(mm/min)**	50	150	200
VF	**(mm/min)**	3	5	7
Pulse On	**(µs)**	30	40	50
Pulse Off	**(µs)**	7	9	11

Here, when the tool reaches from the start to the end of the path, it is called "half-lap machining", and when it returns to the starting position, it is called "final machining". The machining time was recorded by counting the travel time with a stopwatch. The process also involves adding lead-in/out lines, selecting the cutting direction (inside or outside the shape), and sending the path to the wire-EDM machine. The machine setup requires selecting the correct card, adjusting the motor, power, wire winding, and water pump settings. Before cutting, ensure the correct alignment of the wire with the workpiece and adjust the machine for stability. Figure 2 illustrates the experimental setup that was used for our research.

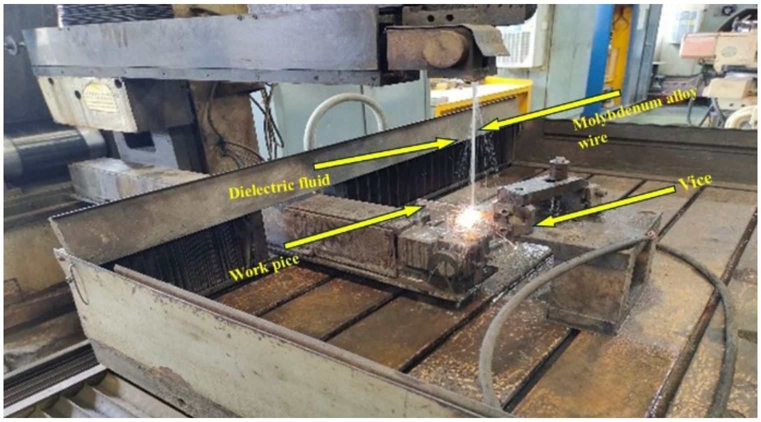
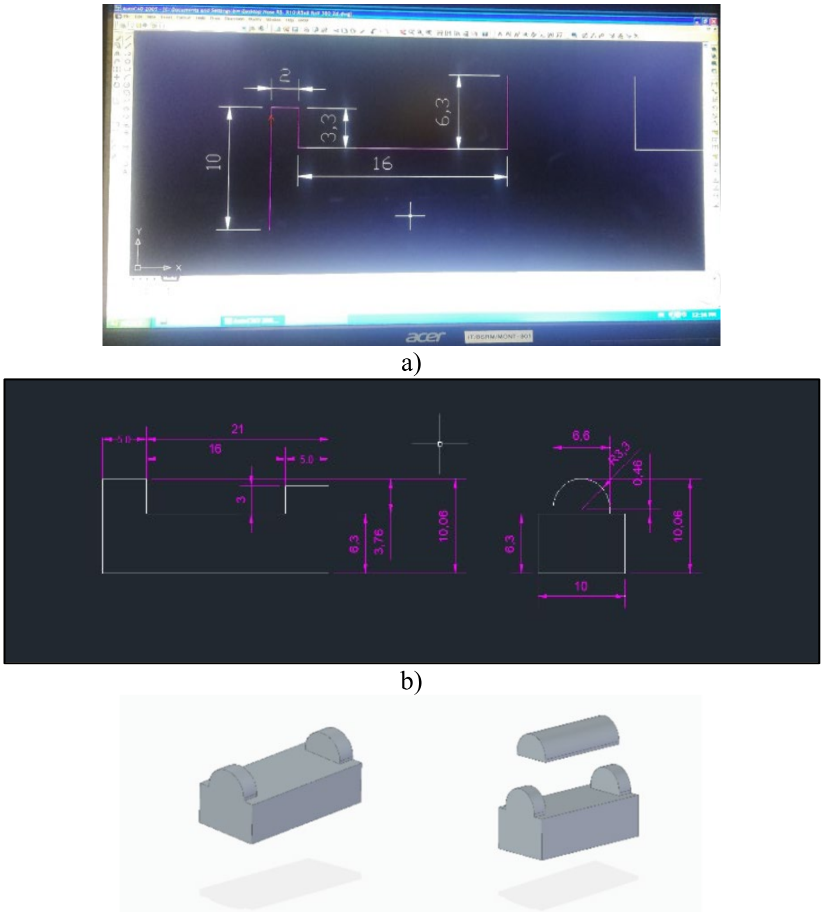


Figure 2. Experimental Setup and machining using BOMA DK7780D wire-EDM

In Figure 3: a) and b), the line path of wire-EDM machining can be seen. This line path was generated from the CAM software. AutoCAD was used to draw the line path for conducting the wire-cut electrical discharge machining process. It operates by selecting the appropriate cutting path, such as Path1 (single cut), Path2 (multi-pass), or Path Taper (for taper cutting).



c)

Figure 3. a) CAD/CAM path b) machining path generated by software and c) isometric view of the workpiece before and after machining

4.3 Data Collection

For each experimental condition, machining time was measured in three repeated runs to ensure reliability and consistency. The data were analysed using the signal-to-noise (S/N) ratio, with the goal of minimizing machining time (smaller-is-better criterion). The Taguchi method is particularly useful because it significantly reduces the number of experiments required to study the effects of several parameters and their interactions, while providing reliable and statistically meaningful results. To assess the influence of each process parameter, an Analysis of Variance (ANOVA) was conducted. ANOVA helps quantify the contribution of each factor to the variation in machining time, identifying the most influential parameters for optimization. Table 2 denotes the L9 orthogonal array that contains the average half lap and final machining time data from our experiments.

Table 2. Taguchi (L9) for Half-Lap and Final machining time

Run No.	**Max Speed (mm/ min)**	**VF (mm/ min)**	**P- On Time (µs)**	**P- Off Time (µs)**	**Avg. Half Lap M/C Time (mins)**	**Avg. Final M/C Time (mins)**
1	50	3	30	7	15.28	30.6
2	50	5	40	9	15.48	31.17
3	50	7	50	11	19.34	34.91
4	150	3	40	11	13.28	22.02
5	150	5	50	7	11.17	20.02
6	150	7	30	9	11.48	18.72
7	200	3	50	9	11.53	20.3
8	200	5	30	11	13.75	23.20
9	200	7	40	7	10.35	18.38

4.4 Theoretical Framework

The Signal-to-Noise (S/N) ratio measures the quality of the process by comparing the mean (signal) to the variability (noise). The specific formula used for S/N ratio calculation depends on the optimization goal, whether it's minimizing or maximizing the response. The formula depends on the goal:

Larger-the-better:

$$\frac{S}{N} = -10\log_{10}\left(\frac{1}{n}\sum\frac{1}{y_i^2}\right) \text{ ………………… (1)}$$

Smaller-the-better:

$$\frac{S}{N} = -10\log_{10}\left(\frac{1}{n}\sum y_i^2\right) \text{………………… (2)}$$

Nominal-the-best:

$$\frac{S}{N} = 10\log_{10}\left(\frac{\bar{y}2}{s2}\right) \text{ ………………………. (3)}$$

Here, y_i are observations, n is sample size, $\bar{y}$ is mean, and s^2 is variance.

ANOVA (Analysis of Variance): ANOVA is used to separate total variation into contributions from different factors and error:

Total Sum of Squares (SST):

$$SST = \sum_{i=1}^{N}(y_i - \bar{y})^2 \text{ ………………..… (4)}$$

Sum of Squares for factor A (SSA):

$$SSA = \sum_{j=1}^{a} n_j\,(\bar{y}_j - \bar{y})^2 \text{ ……………….. (5)}$$

Sum of Squares for Error (SSE):

$$SSE = SST - SSA - \text{otherfactor sums……….} \text{ (6)}$$

Mean Squares (MS) = Sum of Squares / degrees of freedom

F-value = $\frac{MS_{factor}}{MS_{error}}$ (used to test significance of factor effects)

Main effects plots for SN ratios were also generated to visually identify the optimal levels of each parameter. These plots, combined with ANOVA, provide a comprehensive understanding of the process and guide the selection of parameter settings that yield the best machining performance.

5. Result and discussion

This section thoroughly discusses the data obtained from the experimental investigation and analyzes the results using ANOVA.

5.1 Effect of Process Parameters on Half-Lap Machining Time

Taguchi analysis for half-lap machining time showed that MAX speed had the most influence on machining time, followed by pulse-off time, pulse-on time and variable frequency (VF). According to the signal-to-noise (S/N) ratio analysis, MAX speed exhibited the best delta (2.97), confirming its dominant effect, while VF dimension value made the least contribution with a delta of 0.10. Average response analysis further emphasized this finding, as the reduction in machining time was most evident at higher speed levels.

The results of the regression and ANOVA analysis are based on this observation. They have been summarized in Table 3. The regression equation reveals that MAX speed was the most important factor with a negative coefficient (-0.03431, $p = 0.010$), indicating that increasing the wire speed directly reduces the machining time. Pulse-off time also contributes significantly ($p = 0.047$), although at a lower level. VF and pulse-on time are statistically insignificant ($p > 0.6$), which is certain that they play a limited role. The ANOVA reveals that about 63.78% of the variation in the half-lap machining time is attributed to MAX speed alone, while pulse-off time contributes only 23.59%.

Table 3. a) Regression Coefficients, b) Model Summary, and c) ANOVA for half-lap machining time

a)

Term	**Coefficient**	**SE Coefficient**	**T-Value**	**P-Value**	**VIF**
Constant	9.45	3.82	2.48	0.069	-
MAX Speed (mm/min)	-0.034	0.00735	-4.67	0.010	1.00
VF (mm/min)	0.090	0.281	0.32	0.765	1.00
Pulse-on time (µs)	0.0255	0.0562	0.45	0.673	1.00
Pulse-off time (µs)	0.797	0.281	2.84	0.047	1.00

b)

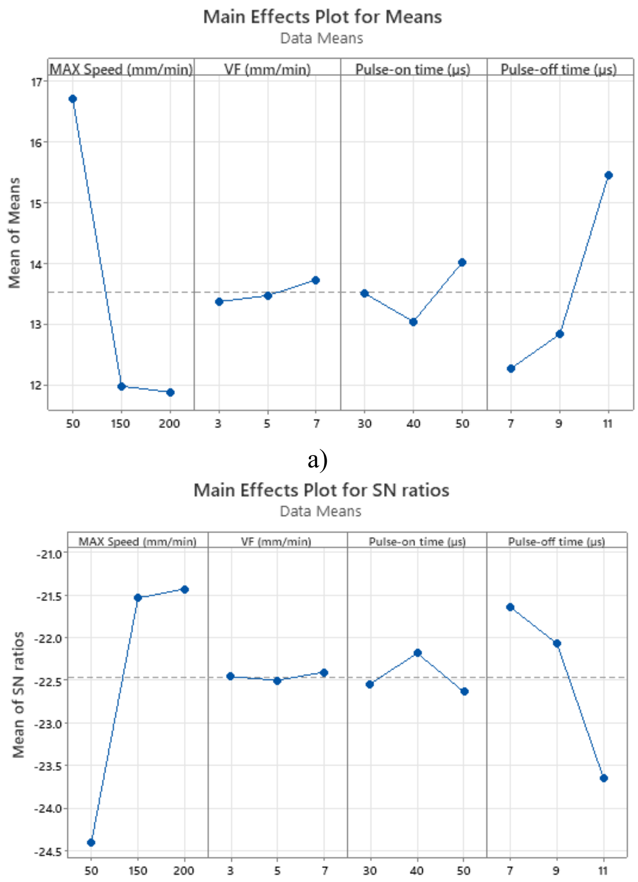
S	**R-sq**	**R-sq(adj)**
1.37594	88.28%	76.56%

c)

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**(% Contribution)**
Regression	4	57.0339	14.2585	7.53	0.038	88.2786151
MAX Speed (mm/min)	1	41.2076	41.2076	21.77	0.010	63.7822393
VF (mm/min)	1	0.1932	0.1932	0.10	0.765	0.29904019
Pulse-on time (µs)	1	0.3902	0.3902	0.21	0.673	0.60396213
Pulse-off time (µs)	1	15.2429	15.2429	8.05	0.047	23.5933734
Error	4	7.5728	1.8932			
Total	8	64.6067				

Together, these two factors account for most of the variability, with a model fit of $R^2 = 88.28\%$. Figure 4 a) illustrates the main effects plot for the mean measurement, while b) illustrates main effects plot for the S/N ratio for the half-lap machining time. Equation 1 indicates the regression equation for the half-lap machining time, which is given below:

$$\begin{aligned}&\text{Half} - \text{Lap Machining Time (mins)}\\ &\quad = 9.45 - 0.03431\ \text{MAX Speed (mm/min)} + 0.090\ \text{VF (mm/min)} + 0.0255\ \text{Pulse}\\ &\quad - \text{on time } (\mu\text{s}) + 0.797\ \text{Pulse} - \text{off time } (\mu\text{s}) \ldots\ldots\ldots\ldots\ldots\ldots.(1)\end{aligned}$$



a)

b)

Figure 4. a) Main effects plot for means, and b) main effects plot for S/N ratios for half-lap machining time

According to the Table 4, the lowest negative S/N value for each factor was chosen because the study used the "smaller-is-better" criterion (minimizing machining time). For the half-lap machining time, the Taguchi S/N analysis favored the highest MAX speed (200 mm/min) and pulse-off time of 7µs, while the pulse-on time and VF favored 40µs and 7 mm/min, respectively. The S/N table focuses on robustness (noise reduction and target achievement).

Table 4. Response Table for Signal to Noise Ratios for Half-Lap Machining Time

***Smaller is better**

Level	**MAX Speed (mm/min)**	**VF (mm/min)**	**Pulse-on time (µs)**	**Pulse-off time (µs)**
1	-24.40	-22.46	-22.55	-21.65
2	-21.54	-22.51	-22.19	-22.08
3	-21.43	-22.41	-22.64	-23.65
Delta	2.97	0.10	0.46	2.00
Rank	1	4	3	2

5.2 Effect of Process Parameters on Final Machining Time

For final machining time, a similar trend was observed as half-lap machining time. The S/N response analysis indicated MAX speed as the most critical factor (delta = 4.04), followed by pulse-off time, VF, and pulse-on time. The mean response analysis also confirmed that higher MAX speed levels substantially minimized machining duration, with a mean reduction of nearly 12 minutes compared to lower speed settings.

The regression model for final instrument time again showed MAX speed as the most critical predictor (coefficient = -0.0834, p = 0.008). Table 5 summarizes the regression coefficients, model summary and ANOVA for final machining time. In contrast to half-lap instrument time, pulse-off time did not reach statistical significance (p = 0.228), although its positive coefficient (0.929) indicates that it may slightly increase instrument time. The ANOVA results show that MAX speed made up 79.44% of the total, while pulse-off time only made up 6.76%.

Table 5. a) Regression Coefficients, b) Model Summary, and c) ANOVA for final machining time

a)

Term	**Coefficient**	**SE Coefficient**	**T-Value**	**P-Value**	**VIF**
Constant	25.70	8.88	2.89	0.044	-
MAX Speed (mm/min)	-0.0834	0.0171	-4.88	0.008	1.00
VF (mm/min)	-0.076	0.653	-0.12	0.913	1.00
Pulse-on time (µs)	0.045	0.131	0.35	0.747	1.00
Pulse-off time (µs)	0.929	0.653	1.42	0.228	1.00

b)

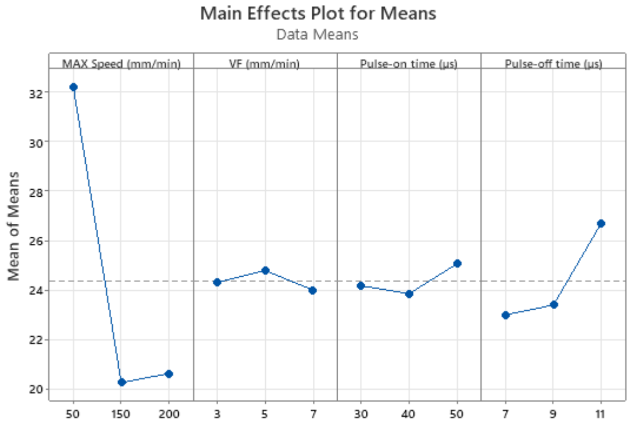
S	**R-sq**	**R-sq(adj)**
3.19919	86.64%	73.28%

c)

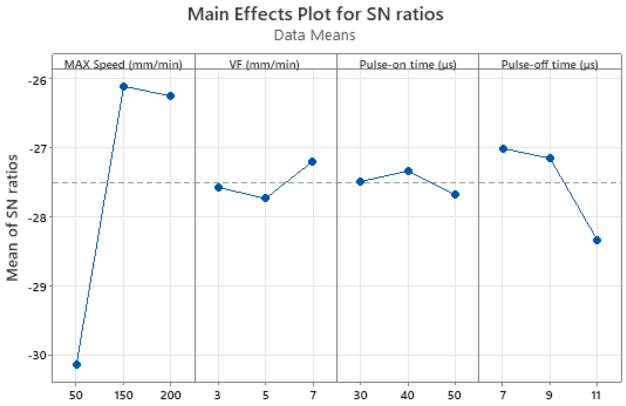
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**(% Contribution)**
Regression	4	265.457	66.364	6.48	0.049	86.6385331
MAX Speed (mm/min)	1	243.389	243.389	23.78	0.008	79.4360892
VF (mm/min)	1	0.139	0.139	0.01	0.913	0.04536613
Pulse-on time (µs)	1	1.221	1.221	0.12	0.747	0.3985039
Pulse-off time (µs)	1	20.708	20.708	2.02	0.228	6.75857387
Error	4	40.939	10.235			
Total	8	306.396				

The model got an R² value of 86.64%. Equation 2 shows the regression equation for the final instrument time, which is given below:

$$\text{Final Machining Time (mins)} = 25.70 - 0.0834\ \text{MAX Speed (mm/min)} - 0.076\ \text{VF (mm/min)} + 0.045\ \text{Pulse} - \text{on time } (\mu\text{s}) + 0.929\ \text{Pulse} - \text{off time } (\mu\text{s}) \ldots\ldots\ldots\ldots\ldots\ldots .(2)$$



a)



b)

Figure 5. a) Main effects plot for means, and b) main effects plot for S/N ratios for half-lap machining time

Figure 5 depicts the main effects plots for final machining time. It shows similar trends as compared to half-lap machining time, with MAX speed having the steepest slope, confirming its dominance. Pulse-off time slightly increases machining time, while VF and pulse-on time remain insignificant. During the final machining, most of the material has been removed by the preceding half-lap. That is why the electrical parameters as well as wire-feed rate do not have a statistically significant effect on the final machining time. Nevertheless, the pulse-off time should be kept the lowest for the most desirable results. The Taguchi S/N analysis favors MAX speed value of 150 mm/min, pulse-off time of 7µs, with pulse-on time and VF favored at 40µs and 7 mm/min respectively. Table 6 contains the S/N ratio values of each level for each factor.

Table 6. Response Table for Signal to Noise Ratios for Final Machining TIme

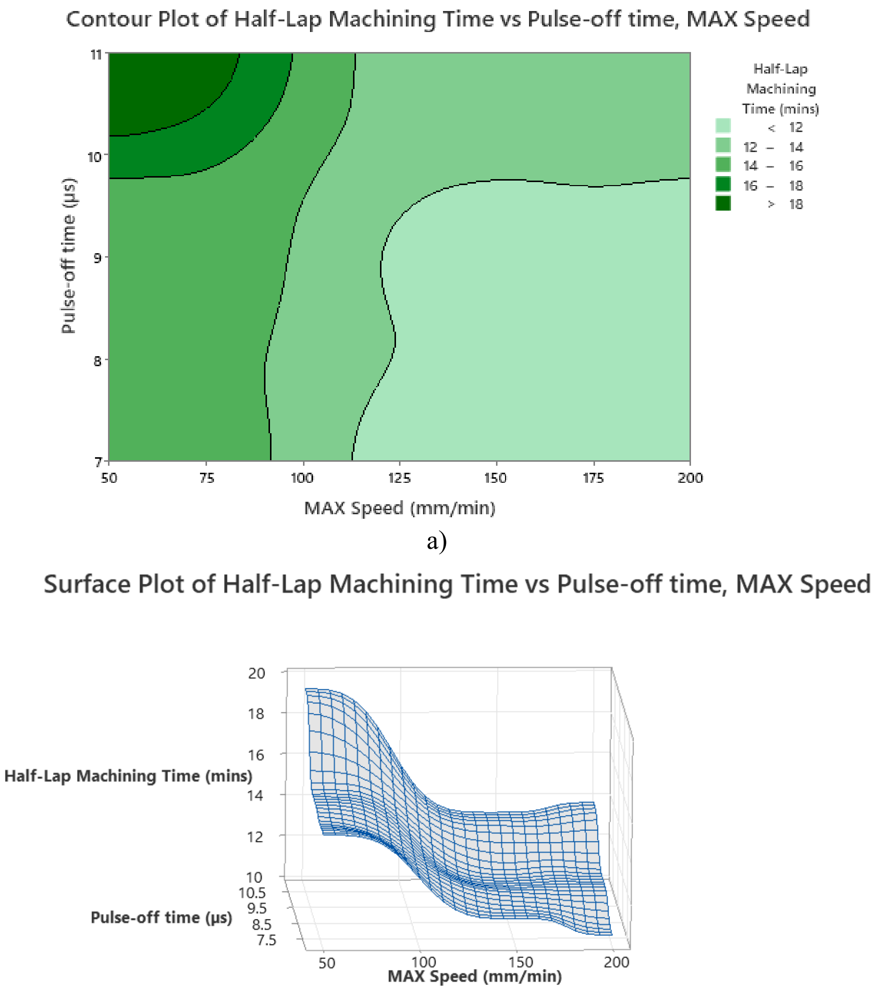
***Smaller is better**

Level	**MAX Speed (mm/min)**	**VF (mm/min)**	**Pulse-on time (µs)**	**Pulse-off time (µs)**
1	-30.15	-27.57	-27.49	-27.01
2	-26.11	-27.74	-27.34	-27.16
3	-26.25	-27.20	-27.68	-28.34
Delta	4.04	0.54	0.34	1.33
Rank	1	3	4	2

5.3 Analysis of combined effect of MAX speed and Pulse-off time on half-lap and final machining time

The contour and surface plots for both half-lap and final machining times provide a visual understanding of the parametric interactions of MAX speed and VF. Our analysis revealed that the effects of pulse-on time and VF are not statistically significant on the machining time of wire-EDM. Furthermore, the combined effect of MAX Speed and pulse-off time has been investigated graphically.

Figure 6 depicts the contour and surface plot for half-lap machining time, while Figure 7 illustrates the same for final machining time. The plots clearly demonstrate that machining time decreases sharply with increasing MAX speed across all levels of other factors.

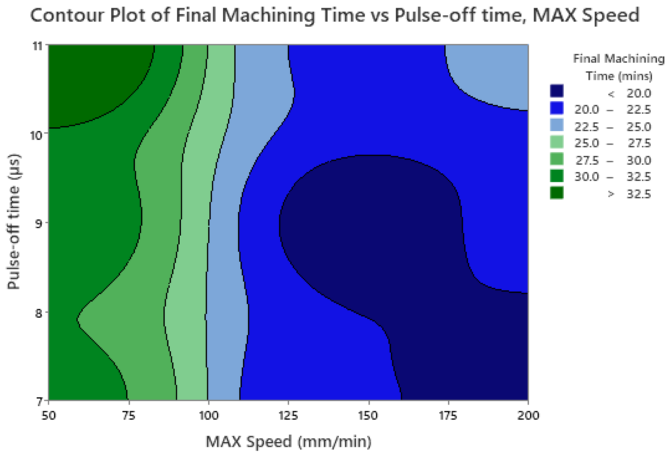


a)

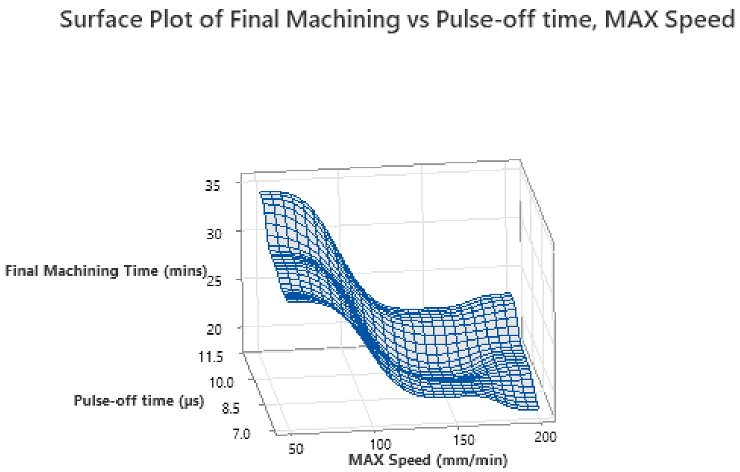
b)

Figure 6. a) Contour plot and b) Surface plot for half-lap machining time vs pulse-off time and MAX speed

The surface plots for half-lap machining show that the curvature gets stronger as the pulse-off time gets longer. This means that cutting speed (MAX Speed) is more important than pulse-off time.



a)



b)

Figure 7. a) Contour plot and b) Surface plot for final machining time vs pulse-off time and MAX speed

The final machining plots, on the other hand, show smoother contours. This suggests that MAX speed is the main factor that controls the process, while the effects of other parameters are almost linear and minimal. Graphical illustrations from Figure 6 and Figure 7 validate the statistical analysis, showing that optimization can be primarily achieved by tuning MAX speed and, to a lesser degree, pulse-off time. The contour responses for VF and pulse-on time are almost flat, showing that they aren't significantly contributed to shorter machining time. The most important factor was always MAX speed, which accounted for more than 70% of the differences in both half-lap and final machining times. This was expected because faster wire travel speeds make cutting more efficient by getting rid of material faster. Even though it wasn't as important, the pulse-off time still had an effect that could be measured, especially in half-lap machining, because it kept the spark discharge steady and stopped the wire from breaking. On the other hand, VF and pulse-on time didn't have much of an effect, which means they didn't really change the amount of time it took to machine. Studied parameter range. The findings align with earlier studies on wire-EDM optimization, where cutting speed has been reported as the primary determinant of machining efficiency. The surface plots for half-lap machining show that the curvature gets stronger as the pulse-off time gets longer. This means that cutting speed (MAX Speed) is again more dominant than pulse-off time. Importantly, the consistency of parametric influence across both machining stages reinforces the robustness of the Taguchi DOE method in capturing true process behavior.

6. Conclusion

In this study on the wire electrical discharge machining of DanCut 345 alloy, it was demonstrated that controlling crucial process parameters can significantly accelerate the machining process. Using a Taguchi design of experiments with an L9 orthogonal array, the analysis can be completed quickly and in fewer trials. Analysis of variance (ANOVA) revealed the parameters that were statistically significant. MAX speed is the most significant factor affecting machining time, contributing to 70.59% and 90.75% of the variation in half-lap and final machining times, respectively. The pulse-off time had a significant effect, although it was not as pronounced as the wire speed. Pulse-on time and variable frequency did not significantly change the machining time. The results show that increasing wire speed reduces both half-lap and final machining times. The regression models demonstrated strong predictive capability, with R^2 values of 88% for half-lap machining time and above 86% for final machining time. This confirmed the robustness of the experimental design. The main effect plots revealed the optimum machining conditions for both half-lap and final machining. They are: 200 mm/min (MAX speed), 7µs (pulse-off time), 40µs (pulse-on time), 7 mm/min (VF) for half-lap machining time, and 150 mm/min (MAX speed), 7µs (pulse-off time), 40µs (pulse-on time), 7 mm/min (VF) for final machining time. The suggested configurations decrease the average final machining duration by as much as 47% relative to the most unfavorable experimental conditions. Surface and contour analyses further validated that machining time decreases sharply with increasing MAX speed, regardless of other parameter levels. The interaction effects between MAX speed and pulse-off time also confirmed that higher wire speeds and lower pulse-off durations result in the shortest machining times. This optimization not only makes the work more efficient but also saves energy and reduces waste, which is beneficial for the environment. Overall, this work fills a gap in machining time studies for DanCut 345 alloy. Future work may extend this study by integrating multi-objective optimization approaches to jointly evaluate machining time, surface finish, and tool wear, enabling a more comprehensive understanding of WEDM performance.

7. Future Work

To enhance the research some future improvements can be made:

I) Implementing and experimentally investigating **multi-pass (rough + semi-finish + finish) WEDM strategies** for DanCut 345 alloy.
II) Identifying the effect of input parameters such as **servo voltage (SV), wire tension, and flushing pressure** on machining performance.
III) Characterization of key response parameters such as **kerf width, corner accuracy, and recast layer**.

References

Altin Karataş, M., Wire EDM cutting of Inconel 718 nickel-based superalloy: kerf and MRR analysis, *Multidiscipline Modeling in Materials and Structures*, vol. 18, no. 4, pp. 653–672, 2022.

Azawqari, A. A., Amrani, M. A., Hezam, L., Baggash, M. and Abidin, Z. Z., Multi-objectives optimization of WEDM parameters on machining of AISI 304 based on Taguchi method, *The International Journal of Advanced Manufacturing Technology*, vol. 134, no. 11, pp. 5493–5510, 2024.

Camposeco-Negrete, C., Analysis and optimization of sustainable machining of AISI O1 tool steel by the wire-EDM process, *Advances in Manufacturing*, vol. 9, no. 2, pp. 304–317, 2021.

Chopde, I. K., Gogte, C. and Milind, D., Modeling and optimization of WEDM parameters for surface finish using design of experiments, *Proceedings of the 4th International Conference on Industrial Engineering and Operations Management,* pp. 1830–1839, Bali, Indonesia, January 7-9, 2014.

Choudhuri, B. and Sen, R., Optimization of WEDM parameters for Machining Inconel 800 by ANN based Bayesian hybrid algorithm, *Materials Today: Proceedings*, vol. 62, pp. 1098–1101, 2022.

Juliyana, S. J., Prakash, J. U., Čep, R., Rubi, C. S., Salunkhe, S., Sadhana, A. D. and Nasr, E. A., Taguchi optimization of Wire EDM process parameters for machining LM5 aluminium alloy, *PLOS ONE*, vol. 19, no. 10, pp. e0308203, 2024.

Murthy, V., Raju, G. S., and Saju, K. K., Optimization of wire EDM machining parameters for optimum material removal rate and surface finish in an aluminum 7075-T651 alloy, *Int J Eng Res Tech*, vol 7, pp. 1–5, 2019.

Nguyen, T. T., Phi, B. P., Tran, V. T., Nguyen, V.-T. and Nguyen, V. T., Three-Stage Optimization of Surface Finish in WEDM of D2 Tool Steel via Taguchi Design and ANOVA Analysis, *Metals*, vol. 15, no. 6, pp. 682, 2025.

Rafeeq, M. and Parvez, S., Wire electrical discharge machining performance during the machining of superalloys: a comprehensive review, *Frontiers in Engineering and Built Environment*, vol. 5, no. 3, pp. 249–260, 2025.

Rani, M. G., Rao, C. V. P. and Kotaiah, K. R., Experimental investigation on optimization of the controlling factors for machining al 6061/mos2 metal matrix composites with wire edm, *Int. J. Appl. Eng. Res*, vol. 12, pp. 12023–12028, 2017.

Saad, K., Javed, M. and Rahman, Z. (2023), Optimization of Wire EDM Process Parameters in the Fabrication of Spur Gear Using Taguchi Technique, *Proceedings of the 6th International Conference on Industrial Engineering and Operations Management,* Dhaka, Bangladesh, December 26 -28 , 2023.

Sana, M., Asad, M., Khan, A., Farooq, M. U., Hassan, S. and Anwar, S., Geometric influence and multi-objective optimization of WEDM for hardened tool steels using ANN and NSGA-II, *Scientific Reports*, vol. 15, no. 1, pp. 41723, 2025.

Sarala Rubi, C., Prakash, J. U., Juliyana, S. J., Čep, R., Salunkhe, S., Kouril, K. and Ramdas Gawade, S., Comprehensive review on wire electrical discharge machining: a non-traditional material removal process, *Frontiers in Mechanical Engineering*, vol. 10-2024, 2024.

Selva Babu, B., Sathiyaraj, S., Ramesh, A. K. P., Afridi, B. A. and Kristo Varghese, K., Investigation of machining characteristics of aluminium 6061 by wire cut EDM process, *Materials Today: Proceedings*, vol. 45, pp. 6247–6252, 2021.

Sheth, M., Gajjar, K., Jain, A., Shah, V., Patel, H., Chaudhari, R. and Vora, J., Multi-objective Optimization of Inconel 718 Using Combined Approach of Taguchi—Grey Relational Analysis, *Proceedings of the 3rd International Conference on Advances in Mechanical Engineering,* pp. 229–235, Chennai, India, February 24 - 29, 2020.

Tejas Ajay, B., Mayur Vitthal, P. and Rajyalakshmi, G., WEDM machining on Aerospace Materials for improving Material Properties, *Materials Today: Proceedings*, vol. 4, no. 8, pp. 9107–9116, 2017.

Wasif, M., Ahmed Khan, Y., Zulqarnain, A. and Amir Iqbal, S., Analysis and optimization of wire Electro-Discharge Machining process parameters for the efficient cutting of Aluminum 5454 alloy, *Alexandria Engineering Journal*, vol. 61, no. 8, pp. 6191–6203, 2022.

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