

Optimization of Machining Parameters of EN-27 Material Using Wire Electric Discharge Machining

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Abstract

The optimization of wire electrical discharge machining (WEDM) parameters for EN-27 alloy steel, a high-strength material widely utilized in mechanical and structural applications, is the subject of this study's methodical analysis. Due to its hardness and poor machinability by conventional methods, WEDM is preferred for achieving precise dimensional accuracy and surface integrity. The primary objective of this work is to enhance machining performance by identifying optimal process parameters influencing material removal rate (MRR) and surface roughness (SR). The experimental design was developed using the Taguchi method to minimize the number of experimental runs while ensuring statistical reliability. Four key machining parameters, pulse-on time, pulse-off-time, voltage gap, and wire feed, were selected as control factors. An L16 orthogonal array was employed to conduct the experiments, and the results were analyzed using analysis of variance (ANOVA) to determine the significance of each parameter on the selected responses. The experimental results indicate that pulse-on-time is the most influential parameter affecting MRR, as increased discharge duration leads to higher spark energy and enhanced material erosion. Voltage gap was also found to significantly influence both MRR and SR by regulating discharge stability and energy distribution. Pulse-off-time and wire feed exhibited relatively lower individual contributions; however, they play an important role in maintaining machining stability and surface quality. ANOVA results confirmed the statistical dominance of pulse-on time and voltage gap. The optimized parameter settings resulted in improved machining efficiency and surface finish, demonstrating the suitability of WEDM for machining EN-27 alloy steel in advanced manufacturing applications.

Keywords: WEDM, EN-27 steel, Taguchi method, ANOVA, MRR, surface roughness

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INTRODUCTION

Wire electrical discharge machining (WEDM) is a vital non-traditional machining process capable of manufacturing complex geometries in hard materials. EN-27 steel, known for its high strength and thermal conductivity, presents machining challenges in conventional processes. WEDM offers a feasible solution through the precise control of spark erosion [1–3].

WEDM is a thermo-electrical technique in which unwanted material from the work part is removed by continuous sparking between both the work part and the wire electrode [4–8]. The wire electrode, which is produced from thin copper, brass, or tungsten are used in WEDM. In modern industries, very often, they need to produce high-strength, hardness, toughness, good wear- and

tear-resistance and high-temperature resistance alloys like titanium, Inconel, ceramics, zirconium, stainless steel, etc., applicable in vehicles, aerospace, medical, defense, die and tool manufacturing industries. Machining of advanced materials by using conventional processes is difficult and sometimes impossible [9–12]. Thus, non-conventional methodologies are employed instead of traditional metal cutting methods for machining extremely high-strength, hard, and brittle work parts. Non-conventional machining techniques are distinguished as per the principle used during the processing of materials (Figure 1). WEDM is one such non-conventional process that is widely used for various applications [13–16].

Applications for Wire-Cut Electrical Discharge Machining

The WEDM method can be used to machine all major metals and metal alloys currently in use. It is particularly required for the correct manufacturing of forming tools, model components, small components, and other highly specialized parts. It is a particularly effective and economical method for high-strength alloys and metals that are difficult to machine with conventional metal removal processes. The WEDM method is widely used in modern industries, such as the aerospace industry, precision manufacturing industry, automobile industry, nuclear industry, naval, maintenance and repair work, chemical and petrochemical industries, aircraft and gas turbine plants, medical appliance, and jewelry industries.

Abbreviations and Nomenclature

- WEDM, wire electrical discharge machining
- MRR, material removal rate (mm^3/min)
- SR: surface roughness (μm)
- T_{on} , pulse-on-time (μs)
- T_{off} , pulse-off-time (μs)
- VG, voltage gap (V)
- WF, wire feed (mm/min)

LITERATURE REVIEW

Many researchers have used Taguchi methods and ANOVA to study WEDM. Materials such as Inconel, D2 steel, and EN-series alloys were tested. Studies have shown that input parameters, such as pulse-on-time and voltage, have a significant effect on the output results.

Objectives

- To conduct experiments on EN-27 using WEDM
- To measure MRR and surface roughness (SR)
- To analyze and optimize input parameters using Taguchi and ANOVA

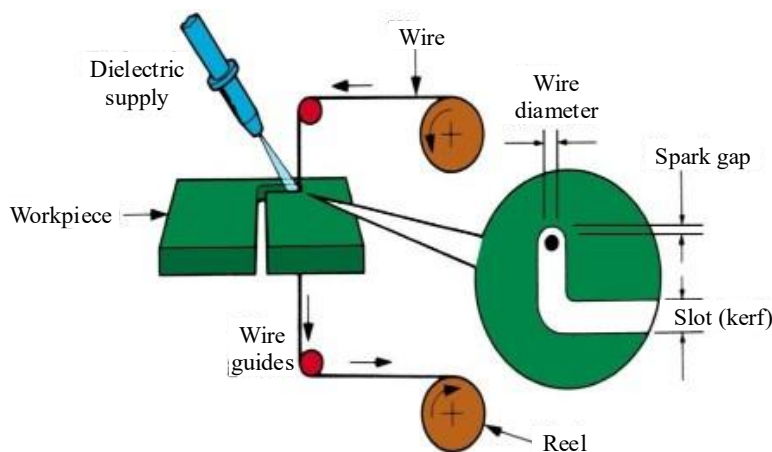


Figure 1. Schematic diagram of wire electrical discharge machining (WEDM) process.

METHODOLOGY

An experimental matrix using the Taguchi L16 orthogonal array was designed. The key input parameters included the pulse-on-time (T_{on}), pulse-off-time (T_{off}), voltage gap, and wire feed rate. The output responses measured were the material removal rate (MRR) and SR. Statistical tools such as ANOVA were used to analyze the influence of parameters.

Material Used

EN-27 steel was selected for its strength and industrial usage (Table 1).

Advantages of EN-27 Material

- High resistance to alkalis
- Good machinability
- High corrosion resistance
- High thermal conductivity

Equipment

- WEDM machine
- Brass wire (0.25 mm diameter)
- *Dielectric fluid*: Water

Experimental Design

The Taguchi L16 orthogonal array was used with four input parameters:

1. Voltage gap (17–20 V)
2. Wire feed (3–6 mm/min)
3. Pulse-on-time (116–123 μ s)
4. Pulse-off-time (50–55 μ s)

Output Responses

- *Material removal rate (MRR)*: Measured in mm^3/min
- *Surface roughness (SR)*: Measured in μm

Analysis Tools

- Taguchi method for optimization
- ANOVA (analysis of variance) using Minitab 16

RESULTS AND DISCUSSION

Taguchi analysis identified the T_{on} and voltage gap as critical parameters influencing the MRR and SR. ANOVA confirmed the statistical significance. Optimal levels resulted in enhanced material removal and a smoother surface finish, indicating process efficiency.

Table 1. Chemical composition of EN-27.

Elements	Weight in %
Carbon	0.40/0.70
Silicon	0.28
Sulphur	0.013
Phosphorus	0.018
Manganese	0.40/0.70
Nickel	3.00/3.75
Chromium	0.50/1.30
Molybdenum	0.20/0.65

- A higher pulse-on time increases the MRR but deteriorates the surface finish.
- Voltage gap and wire feed also influence SR.
- Optimal settings balance productivity and quality.
- ANOVA showed pulse-on-time has the most impact on MRR.

CONCLUSION

WEDM has been demonstrated as an effective and reliable process for machining EN-27 alloy steel when appropriate machining parameters are carefully selected. The present study confirms that systematic parameter optimization significantly improves both machining efficiency and surface quality. The application of statistical tools, such as the Taguchi method and ANOVA, enabled a structured evaluation of the influence of process variables and facilitated the identification of optimal operating conditions with reduced experimental effort.

The results indicate that the pulse-on-time plays a dominant role in governing the MRR owing to its direct influence on the discharge of energy, whereas the wire feed also contributes significantly to the machining stability and surface integrity. The optimized parameter combination resulted in enhanced material removal performance and improved surface finish, thereby reducing the need for secondary finishing operations. The statistical validation provided by ANOVA further strengthens the reliability of the findings and supports their practical application.

Overall, this study established a clear relationship between the WEDM parameters and machining performance for EN-27 steel. The optimized settings identified in this study can be effectively implemented in industrial environments to achieve higher productivity, improved surface quality, and better process control when machining EN-27 alloy steel.

Declaration of Interest

The authors declare no conflict of interest.

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