






Category: STEM (Science, Technology, Engineering and Mathematics)

REVIEW

## WEDM Process Parameters Analysis and Optimization: A Review

### Análisis y optimización de los parámetros del proceso WEDM: Una Revisión

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#### ABSTRACT

Wire Electrical Discharge Machining (WEDM) represents a non-conventional machining approach that harnesses thermal electrical energy for the fabrication of intricate structures. WEDM machines excel in achieving precise dimensions and a polished surface finish. It finds frequent application in the machining of robust materials that pose challenges for conventional manufacturing methods due to issues like vibrations. Within this machining method, numerous process parameters and performance indicators come into play, prompting various studies and investigations into its intricacies. This paper presents a comprehensive overview of current research trends in WEDM, particularly focusing on parameters for enhancing performance, such as surface roughness (SR), material removal rate (MRR), and Kerf width (KW). Notably, several process parameters, including pulse-off-time ( $T_{OFF}$ ), servo voltage (SV), pulse-on-time ( $T_{ON}$ ), peak current (I), and wire tension (WT), contribute to the WEDM process. Additionally, various optimization techniques like the Taguchi method, Grey Relation Analysis (GRA), and analysis of variance (ANOVA) are employed across diverse materials, encompassing alloys, superalloys, and composites. The findings of this study suggest the importance of considering various process parameters, such as pulse-off-time ( $T_{OFF}$ ), servo voltage (SV), pulse-on-time ( $T_{ON}$ ), peak current (I), and wire tension (WT), in the WEDM process. Moreover, the application of optimization techniques like the Taguchi method, Grey Relation Analysis (GRA), and analysis of variance (ANOVA) is recommended. These recommendations aim to improve the understanding and optimization of WEDM processes, especially when applied to diverse materials, including alloys, superalloys, and composites.

**Keywords:** WEDM; Parameters for Enhancing Performance; Various Optimization Techniques; Analysis of Variance (ANOVA).

#### RESUMEN

El mecanizado por descarga eléctrica de hilo (WEDM) representa un método de mecanizado no convencional que aprovecha la energía eléctrica térmica para la fabricación de estructuras complejas. Las máquinas WEDM destacan en la obtención de dimensiones precisas y un acabado superficial pulido. Su aplicación es frecuente en el mecanizado de materiales robustos que plantean problemas a los métodos de fabricación convencionales debido a problemas como las vibraciones. En este método de mecanizado entran en juego numerosos parámetros de proceso e indicadores de rendimiento, lo que ha dado lugar a diversos estudios e investigaciones sobre sus entresijos. Este artículo presenta una visión general de las tendencias actuales de la investigación en WEDM, centrándose especialmente en los parámetros para mejorar el rendimiento, como la rugosidad superficial (SR), la tasa de arranque de material (MRR) y la anchura Kerf (KW). En particular, varios parámetros del proceso, como el tiempo de apagado del pulso (TOFF), el servo voltaje (SV),

el tiempo de encendido del pulso (TON), la corriente pico (I) y la tensión del hilo (WT), contribuyen al proceso de WEDM. Además, se emplean varias técnicas de optimización, como el método Taguchi, el análisis de relaciones grises (GRA) y el análisis de la varianza (ANOVA) en diversos materiales, que abarcan aleaciones, superaleaciones y materiales compuestos. Los resultados de este estudio sugieren la importancia de tener en cuenta varios parámetros del proceso, como el tiempo de apagado del pulso (TOFF), el servo voltaje (SV), el tiempo de encendido del pulso (TON), la corriente pico (I) y la tensión del hilo (WT), en el proceso WEDM. Además, se recomienda la aplicación de técnicas de optimización como el método Taguchi, el análisis de relaciones grises (GRA) y el análisis de la varianza (ANOVA). Estas recomendaciones pretenden mejorar la comprensión y optimización de los procesos de WEDM, especialmente cuando se aplican a diversos materiales, incluyendo aleaciones, superaleaciones y materiales compuestos.

**Palabras clave:** WEDM; Parámetros para Mejorar el Rendimiento; Diversas Técnicas de Optimización; Análisis de Varianza (ANOVA).

## INTRODUCTION

The electrical discharge machining (EDM) technique emerges as the superior solution for the machining of a growing array of materials renowned for their elevated strength, exceptional resistance to corrosion, and remarkable wear resistance. This method proves particularly effective in addressing the challenges posed by an expanding diversity of materials with such high-performance characteristics. Wire Electrical Discharge Machining (WEDM) is a non-traditional type of machining that employs thermal electrical energy to manufacture complicated structures.<sup>(1,2)</sup>

### The WEDM process

WEDM is a procedure where the material is removed via a sparks sequence from a work-piece. Particularly, a moving wire electrode that goes through the work-piece is used in the WEDM. A Computer-Numerically Controlled (CNC) machine is carefully monitored.<sup>(3)</sup> WEDM, like any other machining tool, removes the material; however, WEDM eliminates the material electrically by spark erosion. As a result, WEDM materials must be electrically conductive. As a Direct Current (DC) between the work-piece and the wire electrode, electrical pulses are generated. And, the dielectric is a deionized water shield sitting between the work-piece and the wire. In this regard, the pure water is an insulator; however, the tap water sometimes comprises minerals making it too conductive for WEDM.<sup>(4)</sup> Specifically, the conductivity of water is controlled via passing it throughout a resin tank, which removes many of its conductive elements, and this is known as deionized water. The conductivity of the water tends to grow as the machine cuts, and when the conductivity of the water becomes too high, a pump automatically pumps the water through the resin tank.<sup>(5,6)</sup> The schematic of the WEDM process is depicted in figure 1.

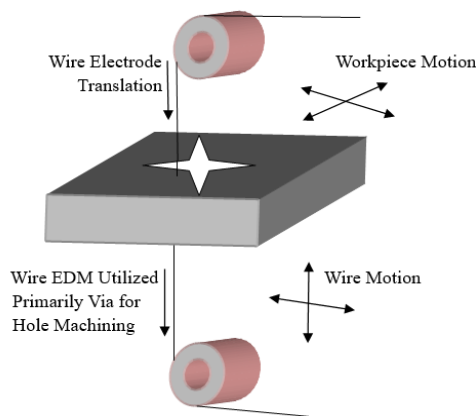


Figure 1. Schematic of the WEDM process

### Components of WEDM

- Workpiece: all conductive materials can be machined via the process of WEDM.
- Tool Electrode: the electrode of WEDM is an instrument used to define the form of the cavity to be manufactured. A wire is a tool electrode of the WEDM.
- Dielectric Fluid: the WEDM setup comprises a tank filled with dielectric fluid. Also, the work-piece and the wire electrode are immersed into the dielectric fluid.

- Servo System: signs from the power supply's gap voltage sensor system direct the servo system, which controls the feeding of the work-piece and the electrode for perfectly matching the MRR.
- Power Supply: the power supply converts the Alternating Current (AC) from the chief usefulness supply into Direct Current (DC) pulses necessary for creating the discharge of spark at the gap of machining and the DC pulse generator is in charge of providing pulses at a definite current and voltage for a set period of time.<sup>(7)</sup>
- The purpose of such article is to examine the parameters of WEDM process, like ( $T_{OFF}$ ), ( $T_{ON}$ ), ( $I$ ), tension of wire, and feed of wire, upon various materials in relation to different responses of process, like Electrode Wear (EW), integrity of surface, Kerf width, and MRR.<sup>(8,9)</sup>

### WEDM Process Parameters

WEDM process parameters are utilized to regulate the machining process's performance measurements. The process parameters are typically controlled machining input elements that govern how machining is performed. These machining parameters will have an impact on the process performance results, which are measured using a variety of performance metrics.<sup>(10)</sup>

- Pulse on Time ( $T_{ON}$ ): the actual electrical discharge takes place between the work-piece and the gap of wire at this period, and the electric potential is also applied along. A big value of on time must be chosen to Peak current is the power expended when the current gradually increases during the pulse-on time until it reaches a determined level. Higher peak current values are used in roughing operations or when working on large surface areas obtain a lengthy discharge. It's written as TON. However, an elevated value of electric discharge may induce the breaking of wire.<sup>(11)</sup>
- Pulse-off-Time ( $T_{OFF}$ ): the time between discharges, referred to as the pulse interval or pulse off time, is measured in microseconds. This duration signifies the interval between successive discharges. It's important to note that the discharge energy remains constant regardless of the off time. During the off time, which is the period between discharges, debris solidifies and is cleared away by the dielectric before the subsequent discharge.<sup>(12)</sup>
- Peak Current ( $I$ ): the peak current is critical in WEDM. It is measured in amperage units. During the  $T_{OFF}$  period, the current grows till it attains a certain degree, which is signified by the Peak Current ( $I$ ). And, in this regard, more amperage is employed in roughing procedures.<sup>(13)</sup>
- Speed of Wire: this is also a significant parameter in the process of WEDM. The wire dissipation and machining costs grow as wire speed increases. On the other hand, wire breaking happens at low wire speeds.
- Wire Tension: if the wire tension is high enough, the wire will keep straight; otherwise, the wire will drag behind. Within a certain range, increasing wire tension enhances cutting speed and accuracy dramatically. Higher tension reduces the wire vibration amplitude and hence the cut width, resulting in a faster speed for the same discharge energy.<sup>(14)</sup> The process parameters ( $T_{ON}$ ,  $T_{OFF}$  and  $I$ ) are revealed in figure 2.

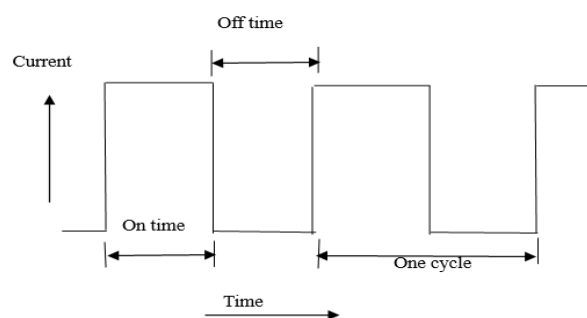


Figure 2. Process parameters (pulse on time, pulse off time, peak current)

### WEDM Process Response (Output)

Many elements influence the WEDM process, such as surface roughness, kerf width, micro-hardness, and microstructure, which are all critical factors in evaluating machining precision and play an essential role in many fields. To maintain a high production rate while maintaining an acceptable quality level, it is critical to choose the best combination of the parameters of WEDM procedure, like the current, the ( $T_{ON}$ ), the ( $T_{OFF}$ ), and the rate of feed.<sup>(15)</sup>

## Survey and discussion of the research work of WEDM process based upon performance metrics

Regarding WEDM (Wire Electrical Discharge Machining), the existing body of literature can be divided into three primary sections, each focusing on research related to SR (Surface Roughness), KW (Kerf Width), and MMR (Material Removal Rate). This categorization aims to facilitate a better understanding of the various configurations of WEDM parameters, their intricate interplay, and their connections to potential avenues for study and research. The purpose of this classification is to offer a structured framework for researchers and practitioners, aiding them in navigating the complexities of WEDM. This, in turn, promotes a deeper comprehension of the implications of WEDM parameter settings for future investigations in the field.<sup>(16)</sup>

### Surface Roughness

Surface roughness (SR) is an important factor whose value influences the surface integrity. Khan et al.<sup>(17)</sup> examined the influence of the parameters of the WEDM method upon the stainless-steel SR. In particular, GRA was employed for determining the optimum combination of the parameters of WEDM method, as well as it was found that the SR was effectively affected via TON. Additionally, the outcomes of ANOVA revealed that the TON was the highly important factor. In another study, Bobbili et al.<sup>(18)</sup> revealed that the TON, I, and voltage of spark significantly affect the surface roughness. Moreover, Shunmuga et al.<sup>(19)</sup> carried out SR experiments considering variables, such as TON, TOFF, and SV, as well as the Grey relational analysis was used to determine the optimal parameter settings. Particularly, it was discovered that the ideal process parameters for the SR are TON at level 3 (10  $\mu$ s), TOFF time at level 3 (4  $\mu$ s), and SV at level 2 (60 V). Hong et al.<sup>(20)</sup> studied the influences of the parameters of WEDM procedure upon the SR, where the impacts of these parameters on SR were examined using the variance analysis. The study results showed that the cutting voltage, TON, TOFF, and SV are all important parameters that influence the SR. In addition, ElBahloul et al.<sup>(21)</sup> improved the WEDM operating settings to achieve a low SR for an AISI 304 stainless steel, and the findings demonstrated that increasing I and TON and reducing TOFF result in a rougher workpiece surface. Furthermore, Hema et al.<sup>(22)</sup> investigated the optimum set of input factors, like TON, WT, and TOFF in WEDM. Specifically, the experiment described the variation in SR and KW when (3) process factors are changed. The Taguchi approach depending upon the GRA was employed, and the findings showed that the TON possesses a substantial influence upon (3) output factors. More precisely, the ninth experiment revealed that a TON of (150  $\mu$ s), a TOFF of (40  $\mu$ s), and a (14 kgf) tension of wire are the ideal process parameters. Murali et al.<sup>(23)</sup> considered three WEDM process factors, including TON, TOFF, and WF. The WEDM's output response, namely the SR, was measured and its parameters were optimized to reduce the major influence on productivity and component quality. It was discovered that when TON increased, the SR values dropped. With an increase in TON, Rao et al.<sup>(24)</sup> determined the ideal combinations from the results of calculating multi-performance, and they revealed that the SV and TOFF have the greatest effect on multiple-response. Sapit Azwan et al.<sup>(25)</sup> utilized the statistical analysis (ANOVA) to conclude that the intensity of the pressure of process dielectric fluid with nano powder has a significant effect upon the enhanced SR. More specifically, the best value determined in the SR was (2,87  $\mu$ m), which is regarded a (95 %) rate of enhancement. Mukulanand Jha et al.<sup>(26)</sup> examined the SR measurable output response characteristic, taking into consideration the machine input control factors (TON, TOFF, I and rate of WF). Taguchi L16 orthogonal arrays were used to build the experiments, and the Taguchi-based GRA was employed for optimizing the governing settings. According to the ANOVA, the factors (TON, TOFF, I, and WF) had the contributions of (85,67 %, 4,38 %, 8,47 % and 0,26 %), correspondingly. Kandala et al.<sup>(27)</sup> conducted a comparison of the Taguchi design with the Response Surface Methodology (RSM) to predict the optimal conditions set to obtain the best SR of the traditionally unalloyed Ti powder metallurgy part utilizing the WEDM process. With SR as a response as well as the TON, TOFF, and temperature of sintering as the influencing parameters, the optimal circumstances for the SR of material were forecast and analyzed. The ANOVA was employed for discovering the important components influencing the regime. It was concluded that the Taguchi design needs fewer experimentations than those required by the response surface methodology, as well as that the forecast SR of the parts with the Taguchi design (was 2,4  $\mu$ m), while it was within the range (2,41-3,04  $\mu$ m) with the RSM. More precisely, the parameter TON has a substantial influence on the system's reaction. Moreover, the effect of the parameters of process upon the achievable SR of the SS (304) was investigated by Noha Naeim et al.<sup>(28)</sup>, including the applied voltage, traverse feed, TON, TOFF, and intensity of current. And, the process factors influences were as follows: The intensity of current was (p-value =  $1,89 \times 10^{-7}$ ), TON was ( $1,602 \times 10^{-5}$ ), and TOFF was (0,0204), which are the highly important factors influencing the SR. R. Rawat et al.<sup>(29)</sup> Explored WEDM for AA6061 to optimize process parameters for minimizing Surface Roughness (SR). Used Taguchi's L18 OA matrix, Signal-to-Noise ratio, ANOVA, and GRA. ANOVA revealed TON and peak current (I) as crucial factors, contributing 13,33 % and 16,25 %, respectively. GRA identified optimal settings for SR: TON (50  $\mu$ s), TOFF (13  $\mu$ s), and I (4 A). Hammami et al.<sup>(30)</sup> examined a qualitative evaluation of the Wire Electrical Discharge Machining (WEDM) process applied to 2017T451 and 7075T651 aluminum alloys, emphasizing surface finish. The study utilizes three-factor, three-level WEDM trials and employs an L9 Taguchi's orthogonal array to investigate the influence of various process parameters. The analysis identifies pulse-on time (TON) and pulse-off time (TOFF) as

pivotal cutting parameters that significantly impact surface roughness (SR), as determined through the signal-to-noise (S/N) ratio and analysis of variance (ANOVA) results. Vinod Kumar et al.<sup>(31)</sup> investigated experimental data on Nimonic-90 machining with wire electrical discharge machining (WEDM). Four input parameters ( $I_p$ ,  $T_{ON}$ ,  $T_{OFF}$ , SV) were analyzed using Response Surface Methodology. A quadratic model is suggested for cutting speed (CS), surface roughness (SR). ANOVA shows the significance of  $I_p$ ,  $T_{ON}$ ,  $T_{OFF}$ , and SV for CS and SR. A desirability function was used to optimize multiple performance characteristics. Devarasiddappa et al.<sup>(32)</sup> employed the Taguchi L16 experimental plan to optimize surface roughness in Ti6Al4V alloy using WEDM. The study varied pulse on time, pulse off time, current, and wire speed at four levels, aiming to minimize roughness. Optimal settings ( $T_{ON} = 13 \mu\text{s}$ ,  $T_{OFF} = 10 \mu\text{s}$ ,  $I = 1 \text{ A}$ ,  $WS = 850 \text{ rpm}$ ) led to a 2,65 % reduction, achieving a global optimum at 3,749  $\mu\text{m}$ . Pulse on time (44,06 %) and current (28,69 %) were identified as the most influential factors, followed by pulse off time (15,80 %) and wire speed (7,47 %).

#### Material Removal Rate

Protim et al.<sup>(33)</sup> found that the  $T_{ON}$  was 115  $\mu\text{s}$ , the  $T_{OFF}$  was 35  $\mu\text{s}$ , the SV was 40 V, and the WT was 5 kgf, with a tendency for maximizing the MRR. Pramanika et al.<sup>(34)</sup> studied the impacts of wire tension,  $T_{ON}$ , and  $T_{OFF}$  on the MRR. It was revealed that due to faster machining, longer  $T_{ON}$  increased MRR, which was raised more by reducing the wire tension as well as decreasing the  $T_{OFF}$  compared to the case of using greater wire tension and  $T_{OFF}$ . Priyadarshini et al.<sup>(35)</sup> considered the influence of the factors ( $T_{ON}$ ,  $T_{OFF}$ , and SV) upon the low-carbon mold steel's MRR. Specifically, it was concluded that MRR grows indefinitely as  $T_{ON}$  increases. The best setting for the maximal MRR was ( $T_{ON} = 120 \text{ s}$ ), ( $T_{OFF} = 23 \mu\text{s}$ ), and ( $SV = 40 \text{ V}$ ). In addition, Chaudhary et al.<sup>(36)</sup> studied the WEDM, which was used to manufacture nimonic alloy tiny gears. The effects of wire tension,  $T_{ON}$ , and dielectric fluid on the variables of response were also investigated. The material removal rate was the key response element evaluated. The results showed that, as a result of multi-response optimization, dielectric fluid is an important consideration, followed by  $T_{OFF}$ , wire tension, peak current, and  $T_{ON}$ . In addition, Basavaraju et al.<sup>(37)</sup> studied a correlation between Wire Electrical Discharge Machining (WEDM) parameters (Pulse-on, Pulse-off, and Indicated Power) and machining outcomes, specifically Material Removal Rate (MRR). The research focuses on optimizing zinc-coated brass electrodes in the WEDM process of Titanium Grade-7 alloy using statistical techniques. ANOVA analysis is employed to assess MRR, and the results are validated through regression. The key findings highlight that Pulse-on time ( $T_{ON}$ ) is the most statistically significant factor, followed by Pulse-off time ( $T_{OFF}$ ) and Indicated Power (IP), influencing on MRR. The study identifies the optimal parameter combination for achieving high MRR (8,5682 mm<sup>3</sup>/min) as higher Indicated Power (6 A), longer Pulse-on time (60  $\mu\text{s}$ ), and shorter Pulse-off time (12  $\mu\text{s}$ ). In another study, Pawan Kumar et al.<sup>(38)</sup> examined input parameters such as pulse-on time, pulse-off time, peak current, spark gap voltage, wire tension, wire feed, and assessed performance in terms of material removal rate. The study revealed that, at a machine unit of 110 for TON, 35 machine units for Toff, 46 volts for spark gap voltage (SV), 120 amperes for peak current (IP), the corresponding values for material removal rate (MRR), was 27,691 mm<sup>2</sup>/min. Kalyanakumar et al.<sup>(39)</sup> investigated the WEDM parameters on SS304 stainless steel, including pulse on time, pulse off time, peak current, and wire feed, with a focus on Material Removal Rate (MRR). Grey Relation Analysis assessed MRR, and optimal conditions were identified as  $T_{ON}$  1 at 105  $\mu\text{s}$ ,  $T_{OFF}$  3 at 63  $\mu\text{s}$ , IP 3 at 210 Volts, and WF at 24 m/min. These conditions were confirmed as the most optimum for achieving the desired results.

#### Kerf Width

Suresh et al.<sup>(40)</sup> investigated the application of Wire Electrical Discharge Machining (WEDM) for cutting AleSiCeB4C hybrid metal matrix composites under various machining conditions. The study analyzes parameters like current, pulse on time, and wire feed rate to assess their impact on kerf width. Multi-objective optimization using Response Surface Methodology (RSM) reveals that the minimum kerf width, measuring 0,271 mm, is achieved at a wire feed rate of 10 mm/min and a current of 12 A. The optimal machining conditions, as determined by RSM, include a current of 20 A, pulse on time of 108,6 ms, and a wire feed rate of 10 mm/min. Sridhar et al.<sup>(41)</sup> studied, various parameters, including discharge current, pulse duration, pulse frequency, wire speed, wire tension, and flushing pressure of the dielectric medium, are analyzed for their impact on kerf width (KW) in (WEDM). The study involves experimental investigation and the utilization of the Grey Taguchi approach to optimize these parameters, aiming for minimal kerf. These optimal parameters can be adjusted to enhance the overall performance of WEDM. Babasaheb Shinde et al.<sup>(42)</sup> investigated the variation of servo reference voltage to examine changes in kerf width, which determines the accuracy of the component. The optimal graphite concentration was identified within the range of 3 to 5 g/liter. Within this range, ceramic erosion was found to be most stable, resulting in an optimum kerf width. A consistent increase in kerf width was observed with the rise in gap voltage for each graphite concentration. Ishfaq et al.<sup>(43)</sup> found that the most significant variable on the KW was the current. In another study, the WEDM method limitations influence upon the KW of SS (304) grade was investigated by Bagal et al.<sup>(44)</sup>. According to the ANOVA findings, the most

significant factor for the KW was  $T_{ON}$ . 39. Muniappan et al.<sup>(45)</sup> endeavored to enhance the kerf width in wire electrical discharge machining (WEDM) for Aluminum hybrid composite utilizing Zinc-coated brass wire. The Taguchi orthogonal method was applied to design the experiment. The obtained results indicate that the Pulse on Time has the most significant influence on the kerf width, surpassing even the impact of peak current. Ablyaz et al.<sup>(46)</sup> examined the wire-cut electro-discharge machining (W-EDM) of the polymer composite material (PCM). The parameters of the input process were a variable  $T_{ON}$  in the range (5-15  $\mu$ s), a voltage of (50-100 V), and a  $T_{OFF}$  of (10-50  $\mu$ s). While kerf width was acknowledged as an output parameter. The results showed that the voltage and  $T_{ON}$  had a substantial impact on cut-width accuracy. Additionally, a theoretical machining model was built, which displays the efficacy within an acceptable range. Pujara et al.<sup>(47)</sup> conducted an investigation focused on optimizing process parameters to enhance the kerf width in WEDM operations. The experiments involved varying  $T_{ON}$ ,  $T_{OFF}$ , peak current, and wire feed using a Taguchi L9 orthogonal array. The Grey Relational Analysis (GRA) optimization technique was applied to determine the optimal selection of process parameters for improving WEDM performance. The study revealed that pulse on time and peak current are significant factors influencing the kerf width, while pulse off time, peak current, and wire feed also exert substantial influence. In another work, Yasir Nawaz et al.<sup>(48)</sup> applied the Taguchi method to study the influence of different factors in wire electric discharge machining (WEDM) on the kerf width of DC53 die steel. It was observed that current intensity had a significant impact, and pulse on time was crucial in determining the kerf width. The optimal values for achieving a small kerf width involved setting factors to 4- $\mu$ s Pon, 9- $\mu$ s Poff, 1-A C, and 7-m/s WS. Ramesh et al.<sup>(49)</sup> analyzed the kerf width in wire electrical discharge machining (WEDM) of Die Steel D3. An orthogonal array was formed, incorporating peak current, pulse on time, and pulse off time as machining parameters. The investigation indicated a substantial impact on the kerf width due to all three selected electrical parameters, with peak current identified as the most critical factor for kerf width.

Ashish Goyal et al.<sup>(50)</sup> conducted experiments on a wire electrical discharge machine (WEDM) for NiTi, varying current, pulse on time, pulse off time, wire tension, and wire feed as input parameters. The study observed the influence of these parameters on kerf width, with results highlighting that pulse on time is the most critical process parameter affecting the outcome.

## CONCLUSIONS

Following a comprehensive review of the existing literature, several conclusions have been drawn. The survey distinctly highlights the frequent exploration of WEDM processes on superalloys and composites within the literature. Specifically, experimental findings indicate that increasing parameters such as pulse on time ( $T_{ON}$ ), servo voltage (SV), and peak current (I) contribute to an enhancement in surface quality. Conversely, pulse on time, wire tension, and wire feed do not exert a significant impact on material removal rate (MMR) or surface roughness (SR). Moreover, it has been observed that the majority of research endeavors have been directed towards the improvement and optimization of common performance measures like MMR, SR, and kerf width (KW) across various materials. However, certain crucial performance metrics, such as dimensional deviation, hardness, gap current, and others, have either not received sufficient attention or have not yet been considered in the existing body of research. Consequently, there exists a need for further exploration and investigation in this specific area to broaden the understanding of the effects of WEDM parameters on these unexplored or underexplored performance aspects. In summary, the literature review underscores the importance of expanding the scope of investigation to encompass a more comprehensive range of performance metrics in the realm of WEDM processes.

## REFERENCES

1. Kapoor, Jatinder, Sehijpal Singh, and Jaimal Singh Khamba. "High-performance wire electrodes for wire electrical-discharge machining-a review." Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 226.11 (2012): 1757-1773.
2. Sharma, Neeraj, Rajesh Khanna, and Rahuldev Gupta. "Multi quality characteristics of WEDM process parameters with RSM." Procedia Engineering 64 (2013): 710-719.
3. Sahoo, Sarat Kumar, Sunita Singh Naik, and Jaydev Rana. "Optimisation of WEDM process parameters during machining of HCHCr steel using TOPSIS method." International Journal of Process Management and Benchmarking 9.2 (2019): 216-231.
4. Singh, Harvinder, Vinod Kumar, and Jatinder Kapoor. "Multi-response optimization of WEDM process parameters during the fabrication of microchannels for industrial applications." Materials Today: Proceedings 46 (2021): 81-88.

5. Singh, Hari, and R. Garg. "Effects of process parameters on material removal rate in WEDM." *Journal of achievements in materials and manufacturing engineering* 32.1 (2009): 70-74.□
6. Mahapatra, S. S., and Amar Patnaik. "Optimization of wire electrical discharge machining (WEDM) process parameters using Taguchi method." *The International Journal of Advanced Manufacturing Technology* 34 (2007): 911-925.
7. Kumar, Rajender, Puneet Kalyal, and Shiwani Mandhania. "Grey relational analysis based multiresponse optimization for WEDM of ZE41A magnesium alloy." *International Journal of Lightweight Materials and Manufacture* 5.4 (2022): 543-554.
8. Ehsan Asgar, M., & Singh Singholi, A. K. (2018, September). Parameter study and optimization of WEDM process: A Review. In *Iop conference series: Materials science and engineering* (Vol. 404, p. 012007). IOP Publishing.
9. Boujelbene, M., Ezzdini, S., Elboughdiri, N., Salem, W. B., & Youssef, W. (2017). Investigation on the surface roughness of the high steel material after wire electrical discharge machining process. *International Journal of Advanced and Applied Sciences*, 4(5), 130-136.
10. Shather, Saad Kariem, Abbas Fadhil Ibrahim, and Diana Abed al kareem Noori. "Experimental investigation to predict metal removal and surface roughness in wire cut process." *Diyala Journal of Engineering Sciences* (2016): 49-58
11. Rathod, L., N. S. Poonawala, and R. Rudrapati. "Multi response optimization in WEDM of H13 steel using hybrid optimization approach." *IOP Conference Series: Materials Science and Engineering*. Vol. 814. No. 1. IOP Publishing, 2020.
12. Patel, Vijay D., and Rajeev V. Vaghmare. "A review of recent work in wire electrical discharge machining (WEDM)." *International Journal of Engineering Research and Applications* 3.3 (2013): 805-816.
13. Complete EDM handbook compliments of [www.reliable EDM. Com](http://www.reliable EDM. Com)
14. Aidil, A. R. M., M. Minhat, and N. I. S. Hussein. "Current research trends in wire electrical discharge machining (WEDM): a review." *Journal of Advanced Manufacturing Technology (JAMT)* 12.1 (1) (2018): 11-24
15. Ali, Muayad M., and Abbas F. Ibrahim. "Effect of machining parameters on surface roughness and metal removal rate for AISI 310 L stainless steel in WEDM." *Engineering and Technology Journal* 40.01 (2022): 181-188.
16. Kumar, Anish, Dr Vinod Kumar, and Dr Jatinder Kumar. "A review on the state of the art in wire electric discharge machining (WEDM) process." *International Journal of Mechanical Engineering Research and Development (IJMERD)* 1.1 (2011).
17. Khan, Z. A., Siddiquee, A. N., Khan, N. Z., Khan, U., & Quadir, G. A. (2014). Multi response optimization of wire electrical discharge machining process parameters using Taguchi based grey relational analysis. *Procedia Materials Science*, 6, 1683-1695.
18. Bobbili, R., Madhu, V., & Gogia, A. K. (2015). Multi response optimization of wire-EDM process parameters of ballistic grade aluminium alloy. *Engineering science and technology, an international journal*, 18(4), 720-726
19. Priyan, M. Shunmuga, et al., "Investigation of surface roughness and MRR on stainless steel machined by wire EDM." *International Journal of Engineering Research and Technology* 5.3 (2016).
20. Thi Hong, T., Do Tam, T., Nguyen, M. C., Anh Tung, L., Ngoc Pi, V., Le Ky, H., & Tien Dung, H. (2019). Effects of process parameters on surface roughness in wire-cut EDM of 9CRSI tool steel. *International Journal of Mechanical Engineering and Technology*, 10(3).
21. El-Bahloul, S. A. (2020). Optimization of wire electrical discharge machining using statistical methods coupled with artificial intelligence techniques and soft computing. *SN Applied Sciences*, 2, 1-8.

22. Hema, P., & Aparna, K. (2021, April). Process parameter optimization of wire EDM on weldment of Monel 400 and AISI 316 grade steel. In IOP Conference Series: Materials Science and Engineering (Vol. 1132, No. 1, p. 012027). IOP Publishing.
23. Murali, G., Murugan, M., Arunkumar, K., Elumalai, P. V., Mohanraj, D., & Prabhakar, S. (2022). Investigation and Process Parameter Optimization on Wire Electric Discharge Machining of Aluminium 6082 Alloy. *Advances in Materials Science and Engineering*, 2022.
24. Rao, C. M., & Subbaiah, K. V. Optimization of Wire EDM Process Parameters in Machining SS316 Using DEAR Method (.2021)
25. Sapit, Azwan, Shather, Saad, & Nehad, Farook. (2021). Parameters analysis in wire electric discharge machine process of titanium alloys with dielectric alumina. *Journal of Materials Today: Proceedings*, 10.1016/J.matpr.2020.12.216
26. Jha, Mukulanand, Rajiv Kumar Garg, & Shekhar Shrivastava. "Experimental investigation and optimization of WEDM process for AISI 420 stainless steel." IOP Conference Series: Materials Science and Engineering. Vol. 1259. No. 1. IOP Publishing, 2022.
27. Uday Kiran Kandala, A. V., Solomon, D. G., & Arulraj, J. J. (2022). Advantages of taguchi method compared to response surface methodology for achieving the best surface finish in wire electrical discharge machining (WEDM). *Journal of Mechanical Engineering (JMechE)*, 19(1), 185-200.
28. Naeim, N., AbouEleaz, M. A., & Elkaseer, A. (2023). Experimental Investigation of Surface Roughness and Material Removal Rate in Wire EDM of Stainless Steel 304. *Materials*, 16(3), 1022
29. SAIF, M., & Rawat, R. K. (2023). Investigation of aluminum alloy 6061 in Wire-EDM regarding surface roughness and material removal rate by adopting optimization techniques. *Journal of Mechanical Engineering and Sciences*, 9410-9420.
30. Hammami, D., Louati, S., Masmoudi, N., & Bradai, C. (2023). Influence of WEDM process parameters on aluminum alloy's surface finish. *The International Journal of Advanced Manufacturing Technology*, 126(1-2), 453-469.
31. Devarasiddappa, D., M. Chandrasekaran, and R. Arunachalam. "Experimental investigation and parametric optimization for minimizing surface roughness during WEDM of Ti6Al4V alloy using modified TLBO algorithm." *Journal of the Brazilian Society of Mechanical Sciences and Engineering* 42 (2020): 1-18.
32. Kumar, Anish, Vinod Kumar, and Jatinder Kumar. "Multi-response optimization of process parameters based on response surface methodology for pure titanium using WEDM process." *The International Journal of Advanced Manufacturing Technology* 68 (2013): 2645-2668.
33. Das, P. P., Diyaley, S., Chakraborty, S., & Ghadai, R. K. (2019). Multi-objective optimization of wire electro discharge machining (WEDM) process parameters using grey-fuzzy approach. *Periodica Polytechnica Mechanical Engineering*, 63(1), 16-25.
34. Priyadarshini, M., Biswas, C. K., & Behera, A. (2019, February). Grey-Taguchi optimization of Wire-EDM parameters for P20 tool steel. In *Proceedings of the 5th International Conference on Mechatronics and Robotics Engineering* (pp. 5-8).
35. Pramanik, A., Basak, A. K., Dixit, A. R., & Chattopadhyaya, S. (2018). Processing of duplex stainless steel by WEDM. *Materials and Manufacturing Processes*, 33(14), 1559-1567
36. Chaudhary, Tina, et al., "multi-response optimization for Nimonic alloy miniature gear fabrication using wire electrical discharge machining." *Advances in Mechanical Engineering* 12.10 (2020): 1687814020967580
37. Kalyanakumar, S., Prabhu, L., Saravanan, M., & Imthiyas, A. (2020, December). Experimental investigation of MRR, RA of 304 stainless steel using WEDM. In IOP Conference Series: Materials Science and Engineering (Vol. 993, No. 1, p. 012035). IOP Publishing.



38. Basavaraju, H. R., S. S. Manjunatha, and R. Suresh. "Investigation on Surface Roughness and MRR in WEDM of Titanium Grade 7 (Ti-0.15 Pd) Alloy using Statistical Techniques." *Journal of Mechanical Engineering (1823-5514)* 20.2 (2023).
39. Kumar, Pawan, Meenu Gupta, and Vineet Kumar. "Microstructural analysis and multi response optimization of WEDM of Inconel 825 using RSM based desirability approach." *Journal of the Mechanical Behavior of Materials* 28.1 (2019): 39-61.
40. Kumar, S. Suresh, Erdemir, F., Varol, Temel, Kumaran, S. Thirumalai, Uthayakumar, M., Canakci, Aykut (2020) Investigation of WEDM process parameters of Al-SiC-B4C composites using response surface methodology. *International Journal of Lightweight Materials and Manufacture-3-2-127-135-2020*.
41. Sridhar, Kandukuri, and G. Gopinath. "OPTIMIZATION OF PROCESS PARAMETERS FOR WIRE CUT EDM OF H-13 HOT DIE TOOL STEEL BY GREY RELATIONAL ANALYSIS."
42. Shinde, Babasaheb, and Raju Pawade. "Study on analysis of kerf width variation in WEDM of insulating zirconia." *Materials and Manufacturing Processes* 36.9 (2021): 1010-1018.
43. Ishfaq, K., Ahmad, N., Jawad, M., Ali, M. A., & M. Al-Ahmari, A. (2019). Evaluating material's interaction in wire electrical discharge machining of stainless steel (304) for simultaneous optimization of conflicting responses. *Materials*, 12(12), 1940.
44. Bagal, D. K., Barua, A., Jeet, S., Satapathy, P., & Patnaik, D. (2019). MCDM optimization of parameters for wire-EDM machined stainless steel using hybrid RSM-TOPSIS, genetic algorithm and simulated annealing. *Int J Eng Adv Technol*, 9(1), 366-371.
45. Muniappan, A., C. Thiagarajan, and S. Somasundaram. "Optimization of kerf width obtained in WEDM of aluminum hybrid composite using Taguchi method." *ARPN J. Eng. Appl. Sci* 12 (2017): 382-388.
46. Ablyaz, T. R., Shlykov, E. S., Muratov, K. R., & Sidhu, S. S. (2021). Analysis of wire-cut electro discharge machining of polymer composite materials. *Micromachines*, 12(5), 571.
47. Pujara, J. M., K. D. Kothari, and A. V. Gohil. "An investigation of material removal rate and kerf on WEDM through grey relational analysis." *Journal of Mechanical Engineering and Sciences* 12.2 (2018): 3633-3644.
48. Nawaz, Y., Maqsood, S., Naeem, K., Nawaz, R., Omair, M., & Habib, T. (2020). Parametric optimization of material removal rate, surface roughness, and kerf width in high-speed wire electric discharge machining (HS-WEDM) of DC53 die steel. *The International Journal of Advanced Manufacturing Technology*, 107, 3231-3245.
49. Goyal, Ashish, and H. U. Z. E. F. Ur Rahman. "Experimental studies on Wire EDM for surface roughness and kerf width for shape memory alloy." *Sādhanā* 46.3 (2021): 160
50. Verma, Ramesh Kumar, Rajeev Kumar Upadhyay, and Syed Asghar Husain Rizvi. "Modeling of kerf width during WEDM of die steel D3." *Materials Today: Proceedings* 54 (2022): 832-838.

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