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The Influence of Angled Electrodes on Various Characteristics in EDM Process - Review Article

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Abstract: Electric discharge machining (EDM) is considered one of the most energy-efficient production methods for the highly accurate processing of any electrically conductive materials, regardless of mechanical characteristics. EDM is a non-contact method used in a diverse range of industries, including aerospace, industrial, instruments, molds and dies, and medical tools, particularly for hard materials with simple or intricate geometries and shapes. This review investigated EDM research in process, material, operational parameter selection, the influence on outputs, numerous process varieties, and innovative strategies to improve performance. The present study presented an overview of the EDM process with different angled electrode geometry, optimization, and modeling of method parameters, and the effect of parameters such as material removal rate (MRR), pulse shape, and surface roughness. This review (1) organized the published literature in a specific way, with an emphasis on both theoretical and experimental findings investigations to enhance the process performance, such as the rate of material removal and quality of surface, among others, and tool wear; (2) investigated assessment methods and procedures used to evaluate process circumstances; and (3) examined the EDM improvements and predicted future trends study. The article's conclusion section extracts specific points and gaps in each part. As a result, the article is straightforward to comprehend and incredibly beneficial to the scientific community.

Keywords:

EDM; Electrode Geometry; MRR; Optimization; Surface Roughness

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تأثير الالكترودات المائلة بزاوية في مكائن القطع بالشرارة الكهربائية على بعض الخصائص أثناء عملية التشغيل

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الخلاصة
تعتبر عملية القطع بالشرارة الكهربائية (EDM) واحدة من أكثر طرق التشغيل كفاءة في استخدام الطاقة لتشغيل الأشكال الدقيقة للغاية لأي مادة موصلة للكهرباء وبغض النظر عن الخصائص الميكانيكية لها. هذه الطريقة في القطع والتي تكون بعدم التماس بين المشغولة وعدة القطع تستخدم في العديد من الصناعات، مثل أجزاء الطائرات، الأدوات، القوالب، والأدوات الطبية، خاصة للمواد عالية الصلادة ذات الأشكال الهندسية المعقدة. تقدم هذه المراجعة تحقيقًا في الأبحاث المتعلقة بعملية EDM من حيث كيفية التشغيل، مادة المشغولة، المتغيرات التشغيلية، والتأثير على المخرجات، والاستراتيجيات المبتكرة المستخدمة لتحسين الأداء. قدمت الدراسة الحالية نظرة عامة حول عملية EDM مع استخدام الكترودات ذات زوايا مختلفة، وتحسين ونمذجة متغيرات هذه الطريقة، وتأثيرها على معدل إزالة المعدن (MRR)، وشكل الموجة، وخشونة السطح. تنظم هذه المراجعة الأدبيات المنشورة بطريقة محددة، مع التركيز على كل من تحقيقات النتائج النظرية والتجريبية لتحسين أداء العملية، مثل معدل إزالة المواد وجودة السطح وتآكل الألكترودات، كذلك التحقيق في الأساليب والإجراءات المستخدمة لتقييم ظروف العملية، وأيضا" عرض اقتراحات لتحسين عملية EDM والتنبأ بدراسة الاتجاهات المستقبلية لهذه العملية.

الكلمات الدالة: EDM، هندسة الإلكترود، MRR، التحسين، خشونة السطح.

1.INTRODUCTION

Electric discharging machining (EDM) is one of the unconventional cutting methods that produce geometries with high accuracy, and surface integrity, which is classified as one of the most common thermal methods as the metal can be removed easily, despite its hardness. Without contact between the workpiece and the cathode (electrode), the removal of metals occurs due to discharging between two electrodes through a dielectric, as shown in Fig. 1 [1].

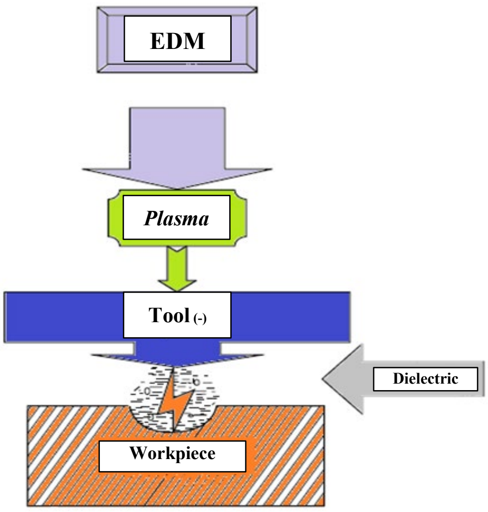

Fig. 1 EDM Scheme [1].

A material is removed from the workpiece by erosion action between a cathode, which usually is the electrode, and a work material which usually is the anode, due to high temperature, through discharging in a dielectric fluid, that acts as flush the debris from machining region and to focus discharge energy in a small zone. This method has become widespread due to the possibility of using high temperatures to cut conductive materials. Despite numerous review papers, the conventional machining process is not recommended to cut shapes with sharps and accurate corners as in (EDM)[2] Despite the existence of numerous review papers. Angled tool is utilized in diverse uses and with molds hard to cut with traditional production techniques. Non-traditional machining technology, EDM, has become more widespread. One electrical discharge machining (EDM) technique is typically utilized in manufacturing tools, dies, and molds. This review paper summarizes current studies conducted in all EDM variants for machining various tool geometries. The paper starts with a brief description of EDM and its variations, followed by an explanation of how it works. It continues to discuss the EDM process conditions and performance indicators as shown in Fig. 2. The main text begins with a review of major areas of EDM research involving various shapes of tools. The paper concludes with conclusions and trends from the reviewed research bodies[3].

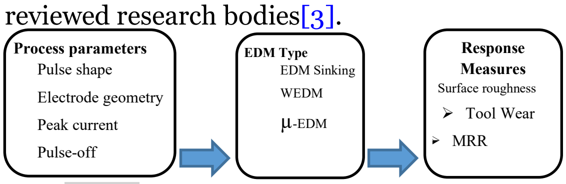

Fig. 2 Methods of Electric Discharge Machining (EDM) and their Parameters with Response Measures.

2.EFFECT OF PULSE SHAPE ON MACHINING PERFORMANCE.

The pulse-on time is the duration of the discharge. The MRR is directly influenced by the energy generated during pulse-on time. The MRR increased by increasing the discharge energy via an extended pulse-on time. The pulse-on time is the duration at which there is no discharge. Throughout this period, the particles from sparking and erosion are removed from the space between the work material and electrode. Flushing enhances the ionization situations and prevents the growth of an insulating layer; consequently, appropriate choice of pulse-on time allows for steadier machining [4, 5]. Moreover, a pulse wave can take several forms, including sine and rectangular waves and hybrid trapezoidal shapes or waves. The literature demonstrates, along with other things, that the trapezoidal wave type reduces electrode wear in contrast to standard shapes. The electrode taper angle increased with the pulse-on-time duration in a range of (90 - 150) µs. In addition, the angle of electrode taper decreased at the minimum pulse-on-time value [6]. It was found that there was an insignificant impact when the current increased with three different pulse-on-time duration values in different electrode shapes [7]. From experimental work, the pulse-on-time was the highest influential "second" variable impacting the machining performance in the case of a hexagonal electrode, whereas the pulse-on-time unaffected on MRR[8]. Generally, MRR increased with the pulse-on time and pulse-off time, as shown in Table 1 [3].

Table 1 The General Effect of Significant Parameters on Key Performance Measures [3].

	Discharge Current	Pulse-On Time	Pulse-Off Time	Voltage	Electrode Rotation Speed
MRR ↑	↑	↑	↓	↗↘	↑
EWR ↓	↓	↓	↓	↓	↓
SR ↓	↓	↓	↑	↓	↑

The pulse-on time negligibly impacts over-cut using a U-geometry electrode, whereas peak current had the most significant influence[9]. Abdulkareem et. al (2010) [10] attempted to reduce electrode wear (EW) by applying liquid nitrogen as dielectric; increasing pulse-on and pulse-off reduces the EW at peak values of 6 µ and 24 V. The pulse-off current could produce a better surface finish than the conventional generators. It has been claimed that the pulse-on time had the highest impact on surface roughness in case of copper electrode cooling [11].

3.EFFECT OF ELECTRODE GEOMETRY ON (MRR)

This section discusses how electrode shape configuration and EDM input parameters, such as current, voltage, pulse-on-time, and duty cycle, affect machining properties, such as MRR, SR, TWR, and microstructure. It has been shown that the MRR increased rapidly with rake angle when using a tool designed for various terrain types and relief angles[12]. The conical and spherical geometries were investigated; however, it was found that a flat tool had the highest MRR compared to the other shapes of electrode tools [13]. The impact of the Cu tool's tip angle and tip radius was discussed. It was found that the highest metal removal can be obtained when using a conical electrode with a radius of 1 mm [14]. The graphite electrodes were clustered together in this experiment. The orthogonal method experimental results showed an increase in MRR by 11.24 %[15]. Manu Goiogana investigated the affectivity of flushing within the (EDM) for electrodes during various cross-sections. The electrodes with rounded corners electrodes showed the highest MRR compared to other sharp corners[16]. It was stated that (MRR) increased with the distinctive electrodes fabricated from brass, with helical flutes alongside the shank[17]. Tawfiq and Abbas (2018) [7]. studied five shapes of electrodes (a triangle, square, circular, cylindrical solid, and eventually polygon) for different current values. They concluded that the highest value of MRR was for the square geometry of the electrode[7]. An experimental study investigated three different electrodes shape (single-channel, multi-channel, and solid). The material removal rate was the most efficient for the same electrode. The most significant parameter was capacitance, and MRR increased with the capacitance. The solid channel was better in MRR than others[18]. The conventional electrode tool and step-cylindrical electrode tool increased with electrode diameter, as shown in Fig. 3 [19, 20]. Dewangan [9] found that the current significantly affected the material removal rate in the U-shaped electrode in the internal flushing method. As a result, MRR raised with increasing current. Dave and Patel[21] described the application of four copper electrodes (rectangular, square, triangle, and round). The contribution rate of the electrode shape was approximately (10-20) % through ANOVA and S/N ratio modelling, the surface roughness quality showed more significant. MRR was enhanced at PON=22 and POFF =22. The impact of tilt electrode angle ranged between (5 ° -30 °), on MRR, MRR is decreased with tilt angle raised. In this research MRR had a linear relative positive correlation with mass flow rate between a mixture of kerosene and air media[22, 23] .

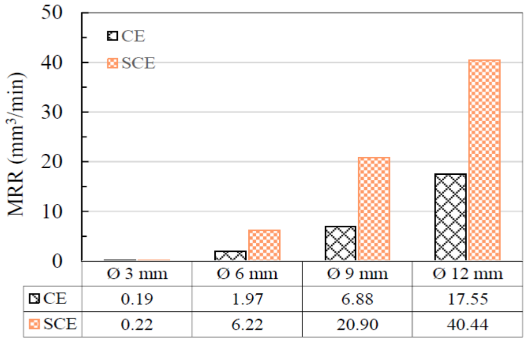

Fig 3. MRR for CE (Conventional Electrode) and SCE (Stepped Cylindrical Electrode) [19].

4.SURFACE ROUGHNESS

Current time fabrications require to achieve preferable surface finishing. Studies and conclusions assessed the EDM parameters' influence in finishing the surface machined during EDM. Nearly most studies have focused on improving the quality of the machined surface. Ahmed-Mufti, et al. [24] found that the suggested electrode designs produced less surface roughness (Ra) than traditional ones. The minimum surface roughness value obtained was 4.42µm by the electrode having a 10° of relief angle. Surface roughness Ra ≤ 3.2 µm was obtained during the machined surface finishing. Optimization of the experimental method have been studied using the distributed electrode variables in the finishing process [15, 25]. Jitendra Kumar et al. [15] concluded that the graphite electrode's lowest surface roughness was obtained with positive polarity. Surface roughness (SR) with a minimum value means a much smoother surface[26]. Rahul[27] concluded that cryogenically Cu showed a high degree of surface finishing with minimized tool wear. The tungsten electrode tool also showed a rough surface machined for the EDM process. It has been found that the effect of electrode geometry was insignificant on surface roughness. The electrode geometries were square, diamond, triangle, and round. The round shape electrode showed the lowest surface roughness value [14]. Fig. 4 shows the influence of electrode shape on surface roughness. R_a sharply raised with current. Stronger discharging was produced by a high current that caused a deep crater. The diamond shape generated high roughness[28]. A stepped cylindrical copper tool used Jamkamon K,and Janmanee P [19]. The experimental results revealed that machined surface roughness was larger than traditional electrodes. The authors concluded that the conical electrode tool had less roughness, comprised of hollow electrodes due to particle removal in the case of conical electrodes, and could machine larger crates for hybrid metal matrix in drilling workpiece composites[29, 30].

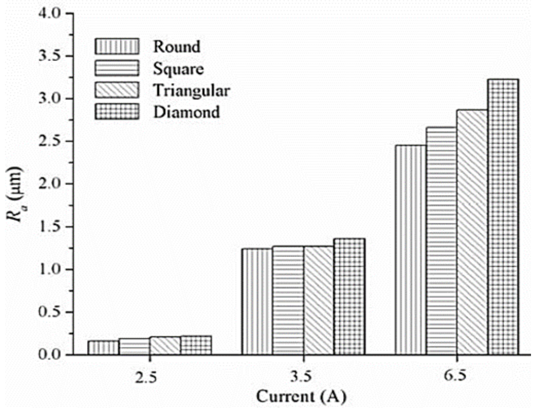

Fig. 4 Electrode Geometry vs. Surface Roughness (Ra) [28].

5.EDM PROCESS OPTIMIZATION AND SIMULATION MODELS

Investigations were conducted to improve the electrical process variables in EDM techniques. Several simulation methodologies and modeling were offered to identify the ideal parameters for the EDM process. For example, Kumar et al. investigated the "GRA" and VIKOR" optimization techniques. The VIKOR approach was more applicable than other investigated optimization approaches[31]. The optimization of the EDM variables was presented with the help of the Taguchi approach for three parameters used in this experiment with three stages using Minitab software[32]. Dewangan [9] studied a hollow U-shaped electrode tool with an internal flushing method. Taguchi analyzing method was used to optimize pulse-on duration, electrode diameter, and current. Micro-machining EDM was presented using the Taguchi method to gain experimental results including three parameters, i.e., Capacitance, Voltage, and Spindle speed. MRR and tool wear were analyzed using the Taguchi method optimization[33]. Experimental results confirmed that the Taguchi Orthogonal was selected with representative data to reach an optimal solution of parameters with the minimum achievement variance[34, 35]. The discharging process through electrical discharging machining was presented using the finite element method. It was reported that validating simulation models using temperature readings taken during experiments was impossible because the EDM process is complicated [36]. Afzaal Ahmed [37] presented an experimental study and numerical analysis by CFD, i.e., the fluent software. The result of the proposed electrode was proved by CFD simulation and analytical solution. The dielectric flow rate, fluid speed, kerosene, and volume percentage were calculated. Comparison based on (CFD) software package with experimental results by the EDM process was achieved[22, 35]. A novel method was studied to improve the flushing system by FEM simulation. There was a coincidence of mathematical results offered in the same study. The best electrode geometry was obtained through the simulation. Also, the ability to flush flow through the gap was achieved [38]. The circle shape geometry was the best in the simulation of contours, followed by square and triangle geometries. Verification between experimental works and simulation was checked using the ANSYS package[35, 39]. Although many researchers have studied EDM simulation, a few papers still use simulation software. Table 2 summarizes the most related EDM processes used by researchers using different simulation methods[22]. Electrode material was corroded through EDM due to discharging at high temperatures. This phenomenon has been called "Tool Wear." TWR is measured by the weighting of the electrode before and after the machining by the time consumed. Also, tool wear represents the most critical factor in electrode manufacturing and design because it influences the production's efficiency and cost. Nadeem Ahmad Mufti et al.[24] presented a new tool design with longitudinal wear, showing a minimum value less than the traditional one. It was observed that 10° of the relief angle in the new electrode design "recorded" less wear rate value than the traditional technique. Tool wear and MRR are enhanced with electrodes had a different pathway tool. The higher depth in the drilling process was obtained in this electrode. Electrode within an angle of 66° achieved good corner radius quality [45, 46]. The skin effect on the electrode tool was investigated. It was concluded that the tool wear rate increased with the tool diameter because of the high frequency in the discharge process due to the current increase in large diameter[47]. Obtaining dimensional groove shape accuracy is still a critical challenge in electrode wear phenomena. The rectangle and square electrodes had better EWR besides high machining performance[48, 49]. Ravinder Kumar and Inderdeep Singh[50] concluded that an electrode tool with slotted grooves enhanced the conditions' results, i.e., TWR. The studied electrode was also set to eliminate clusters of particles in the machining area. Ali Abbar Khleif and Osama S. Sabbar[51] studied different variables in the EDM process. The essential aims of this investigation were to increase the MRR by analyzing and levelling parameters and minimized TWR in same Taguchi method, EWR is decreased by increasing of pulseoon time.

Table 2 Various Process Simulations and Most Related Results.

No	Year	researchers	Process simulation	Results
1 [40]	2014	Ramy Nastasi, Philip Koshy	CFD analysis	Improved gap flushing, enhanced removal rate, decreased the tool sectional area
2 [41]	2014	Jin Wang, FuzhuHan	Fluent software	The bubble's ability to exclude the debris from machining gap became strong as the current and pulse-on time increased.
3[42]	2017	Tanjilul, Afzaal Ahmed	CFD analysis	Improved surface roughness was observed. Particles size increased with machining current.
4[43]	2018	Kliuev. Baumgart and Wegener	CFD analysis	Simple cylindrical flushing channel provided the best performance of the flow.
5[44]	2018	Yu Liu, Hao Chang, Wenchao Zhang	Fluent analysis	Increasing the vibration parameters obviously improved the removal of debris in the machining gap

Table 3 Outlines the Parameters in the Literature Survey for Enhancing EDM Performance [52].

Ref.	No	Year	Electrode/ W.P materials	Process type	Geometry of Electrode	Parameters	Optimization and Simulation
[53]	1	2019	Not specified	EDM	flat-end cutter	With and without CAD tool	Tool-path CAD simulation
[54]	2	2013	POCO EDM-C3 copper infiltrated graphite	5-axis EDM	integral shrouded blisks	Electrode polarity, Pulse duration Pulse pauses Current	dynamic programming
[55]	3	2018	Superfine graphite/ structural steel.	Sinking EDM	Shrouded blisks and worn electrode	Current, voltage, pulse on, pulse off	CAD software
[56]	4	2018	Theoretical design	EDM	CAD model	Split and re built faces	CATIA v5 R21
[57]	5	2020	SS-304/borosilicate glass	ECDM	Circular	Voltage, pulse on, electrolyte concentration	———
[58]	6	2018	Cu/steel	EDM-milling	Cylindrical geometry	Gap distance, tool path steepness (simulation)	Tool-path strategy
[59]	7	2021	W/Ti6Al4V	EDD	Solid shape. Single slotted. Double slotted	Electrode diameter, Tool speed, Voltage, Capacitance, Feed Polarity	———
[60]	8	2009	CAD design simulation	oscillating EDM,	rectangular, discretionary and circular	———	CAD software
[61]	9	2014	Cu/Inconel 718	EDM	Convex, Concave, Flat	Current Pulse-on time, pulse-off time	———
[49]	10	2014	———	Micro-EDM milling	Cone-shaped	Length, Height of work material	Compensation method. 2D

6.CONCLUSIONS

The present study presented a contribution survey of electrical discharging variables acting on EDM in various aspects, such as pulse shape, MRR, surface roughness, and optimization and simulation of the EDM process parameters. The main factors impacting the MRR were: current, pulse-on-time, and various tool geometries in EDM. The MRR was also affected by pressure and electrode speed of rotation. The MRR can also be enhanced by implementing an electrode material with good electrical conductivity. The following observations could be fundamentally dependent on the survey of the literature.

1. Studies concentrated on performance, simulation, design, and optimization in electric discharging machining.
2. It has been shown that pulse-on duration increased with the electrode taper and decreased with the lowest electrode taper. Increasing pulse-on and pulse-off reduced EW at peak values of electrode taper.
3. It was found that there was no extreme relationship between increasing current with different pulse-on values, beside that it is no significant relation between increasing of current and change of electrode geometry.
4. Pulse-on-time significantly impacted roughness in the case of cryogenic copper electrode cooling.
5. MRR increased with the rake angle. The flat shape electrode tool had the largest MRR, whereas MRR decreased as the tilt angle raised
6. The electrodes with rounded corners electrodes showed a higher MRR
7. Current significantly affected the material removal rate in U-electrode shaped
8. The lower value for surface roughness was found in the round shape electrode, and it was much less with positive polarity.
9. The Taguchi method was a practical optimization analysis, and it was characterized as an optimal solution achieved with the minimum results variance.
10. A verification was achieved using ANSYS.

7.SUGGESTED STUDIES

After studying the processes and procedures used in designing and manufacturing the electrodes' shape, it is novel to deploy electrodes tilted at different angles with a side hole other than the standard vertical hole, as shown in Fig. 5 below.

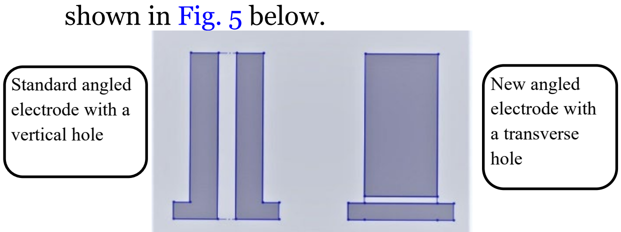

Fig. 5 Comparison Between Common Electrodes with New Angled Electrodes [62].

It is recommended that researchers in this area pay special attention to simulation software such as Abaques and Ansys.

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