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Recent advances in electrical discharge machine techniques and machining: A review

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Abstract

E.D.M has played an essential role in the machining industry, but as technology has advanced, advanced alternative methods of machining have emerged. In terms of performance characteristics such as higher material removal rate (M.R.R.) and improved surface characteristics of the machined surface with high tolerance quality products, this technology has been proven to be more efficient than traditional E.D.M. Electric discharge machining is a sophisticated method of machining rigid conductive materials with complex geometries that are difficult to machine using standard methods. In this study, Die Sink E.D.M, Wire E.D.M, Green E.D.M, Dry E.D.M, and Hybrid E.D.M were analyzed, and experiments were conducted on Die sink E.D.M to achieve better material removal and lower tool wear rates.

Keywords: E.D.M; Dry-E.D.M; Green E.D.M; Taguchi; ANOVA

1. Introduction

Six decades ago, doctors B. R. and N. I. Lazarenko developed the electrical discharge machining (EDM) process as a die-sinking method that could be used to remove stock material [1]. Subsequently, the EDM is becoming more and more important, and it is used in the aerospace, biomedical, mould and die preparation industries. The EDM process is very good at forming complicated shapes and cutting materials that are challenging to cut. It also eliminates vibration and mechanical stresses. Because it can machine any type of conductive material, regardless of its mechanical properties, it is one of the most popular non-conventional machining techniques [3]. The principles of electrical corrosion and thermoelectric energy are the basis of EDM [4-5]. Melting is the mechanism of metal removal in the EDM process, and work material vaporization occurs in a specific area afterward. A specific type of additional discharge raises the temperature to 8,000–12,000 C, melting and vaporizing the work material and tool. The dielectric medium that is pumped into the machining region flushes away the material that has been removed in the form of powders. The shape and accuracy of the tool geometry, along with electrical and non-electrical parameters, determine the final shape of the machined surface.

Surface roughness (SR), tool wear rate (TWR), and material removal rate (MRR) are the main metrics used to assess machinability in the EDM process. The majority of researchers have used various tool materials, such as copper, graphite, brass, copper tungsten, steel, silver tungsten, tungsten, copper graphite, etc., to conduct experimental research in EDM [7-13]. Afterwards, because of the electrode material's migration to the workpiece, researchers concentrate their attention on the EDM electrode made using the powder metallurgy process [14]. However, the choice of tool material is crucial for the machining results; during the EDM process, the work material and its surface are also significantly altered, which requires consideration. Heat-affected layers, also known as re-solidified material, form on the machined region as a result of the electrical spark during the EDM process releasing a large amount of heat energy between the electrodes. In contrast to their parent material, these layers have a different nature [15].

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Advanced materials have been used in modern industrial applications because of advantages such as high stiffness, high strength, better damping capacity, lower fatigue, and low thermal expansion. Because of the advantageous properties of advanced materials, they are in high demand in today's manufacturing industries.

With regard to these advanced materials, the modern manufacturing industries faced a number of challenges. The main challenges were machining difficulty and low precision with high machining costs Sanjay Sundrayal et al. [16]. Because of their improved mechanical, chemical, and thermal properties, conventional machining processes were unable to machine advanced materials. Drilling, turning, and milling were ineffective in machining these advanced materials because they resulted in improper removal, poor surface finish, and high tool wear Farshid Jafarian et al. [17]. To cope with this issue, an advanced methodology was developed. Electric Discharge Machining (E.D.M) uses thermal energy to solve this trivial problem and was established in the manufacturing industry for purposes such as forming dies, tools, and Molds made of advanced materials. It was regarded as a non-traditional method for accurate and precise material machining. Many researchers have been conducted to improve E.D.M.

2. Principle working of Electric discharge machine.

The removal of material in E.D.M. is complicated and not defined easily. Still, the conversion of electric energy into thermal by means of electric discharge is most effortlessly understood and accepted by researchers around the world. There is the movement of fast-moving electrons from the tool cathode to the anode workpiece when the required voltage is applied across the tool and workpiece. The discharged electrons collide on the dielectric medium, dividing into electrons and ions. A discrete column of dielectric molecules is established between the tool and the workpiece, which leads to the creation of sparks. A wave is created with a high-temperature range of 8000 to 12000 degrees Celsius. This high temperature causes the melting of the workpiece and tool. Lastly, the tiny chips are removed from the workpiece to form craters. Tiny debris is removed by flushing the dielectric fluid. The accuracy of machining is highly dependent on the flushing.

Components of E.D.M.

- Workpiece. Can deal with any conductive material using E.D.M.
- Tool Electrode. E.D.M electrode is of the shape required to be embossed on the workpiece. In wire cut E.D.M., a wire will shorten the workpiece.
- Dielectric fluid. E.D.M. is made up of a tank that holds a dielectric fluid. The tool, along with the workpiece, is submerged in the dielectric liquid.
- Servo driving system. Guided by signals from the gap voltage sensor system of the power supply. It controls the feed of the electrode and workpiece to match the material removal rate.
- Power management. Power management is an essential part of any EDM system. In order to create the spark at the machining gap, it transforms the alternating current from the main supply into pulse direct current (DC).
- D.C. pulse generator supplies pulses at a required voltage and current for a set period.

3. Types of E.D.M

Die Sink E.D.M. E.D.M is known to everyone as a non-conventional machining process frequently used for Mold-making and automobile industries. E.D.M is a thermoelectric process that can machine any material irrespective of its hardness. A dielectric fluid, generally oil is used between the tool and the workpiece, which works as an insulator and conductor of the heat. It is used for cooling and flushing of the debris. this type of E.D.M, tools, and workpieces should be conducted. The tool can be copper, graphite, S.S. 304,[1] or tungsten carbide material. When a 3-phase dielectric inlet is provided, electrons are emitted from the tool to the workpiece. The workpiece is removed in small portions in the form of debris. This debris is removed from the workpiece by providing flushing of dielectric fluid.

Wire cut E.D.M. Wire cut E.D.M. uses a rotating wire tool electrode for cutting the workpiece. An upper and lower guide are used to cut the workpiece in small portions. This type of E.D.M is generally used to cut complex shapes. The wire can be copper or brass, while deionized water, which works as a dielectric fluid, removes the debris. Wire-cut EDM can cut any hard material. The process is computer-controlled, which can produce any complex parts.

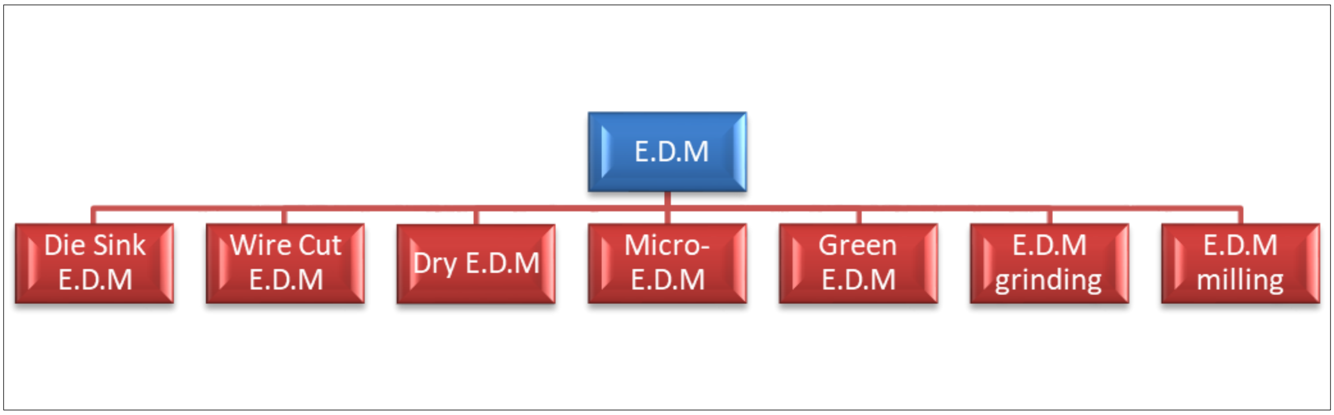
Dry E.D.M: In this type, machining occurs without using a liquid medium. In usual E.D.M. processes, dielectric fluid removes debris and conducts electricity between the electrode and workpiece. However, in Dry E.D.M., the liquid is removed with a gas, usually compressed nitrogen or air.

Micro E.D.M: This type of machining is a unique form of E.D.M designed for machining extremely minute and delicate features with high precision. It uses an electrode designed with extreme precision, with diameters ranging from tens to hundreds of micrometers. Similar to traditional E.D.M., electrical discharges create sparks between the microelectrode and the workpiece. Micro E.D.M is a specialized and advanced technique used by industries that require high accuracy, in the production of micro-Molds, micro-fluidic devices, micro-optics, and miniature parts.

Green E.D.M: Green E.D.M makes use of environment-friendly and sustainable materials. This technique aims to reduce waste creation, energy efficiency, alternative dielectric fluids, recycling, and reusing materials with process optimization.

E.D.M Grinding: In E.D.M grinding, a conductive grinding wheel rotates continuously as it comes into contact with the workpiece. The abrasive grains on the wheel remove the workpiece surface. The combination of electrical discharges and mechanical grinding creates heat, vaporization, and melting of the material. It can machine any hard or brittle material like ceramics, carbides, and steels. It has the advantage of fine surface finishes, precise shaping of complex shapes, and delicate machining features.

E.D.M Milling: E.D.M milling is a type of Electric Discharge machine used for shaping, drilling, and milling operations on conductive materials. In E.D.M milling, the tool electrode moves on programmed contours or paths, which removes materials. This process creates precise geometries, cavities, and shapes on the workpiece. However, it is pretty slow to conventional milling operation and it creates thermal damage to workpiece due to creation of heat. This type milling finds application in automotive, aerospace and tool-die making industries.



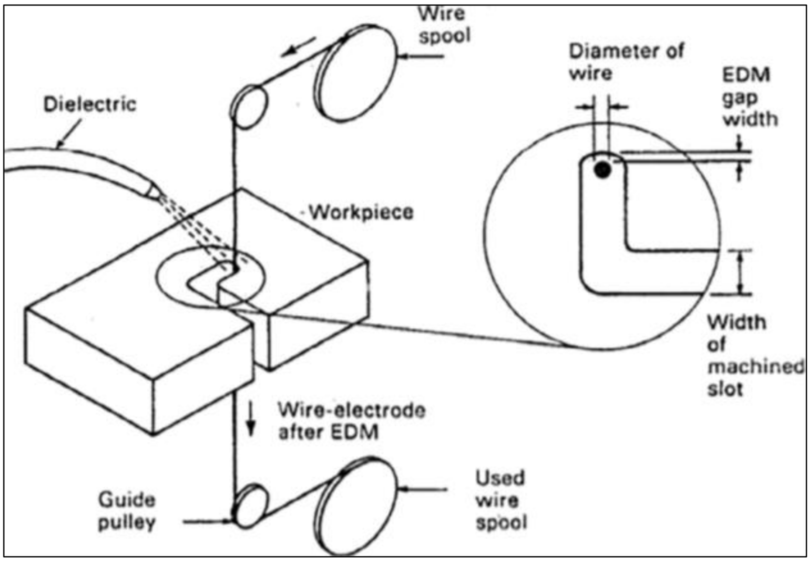


Figure 1 Wire-Electric Discharge Machine [31]

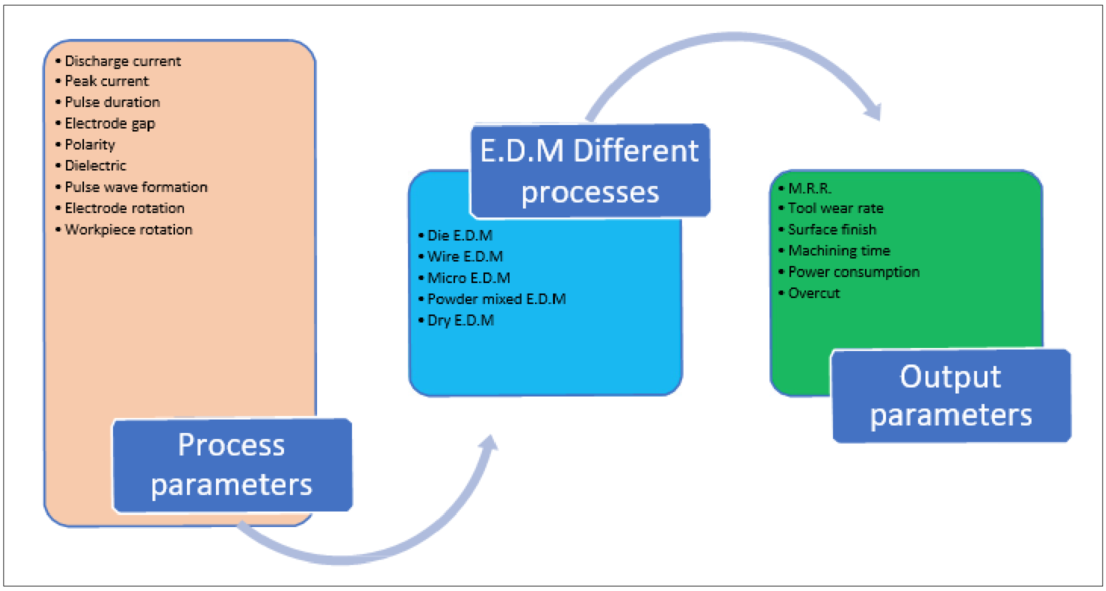


Figure 2 EDM and process parameters

4. Major areas of EDM research

4.1. Mechanism for removing materials

The material removal mechanism (MRM) has been described in various research frameworks as the migration of material elements between the electrode and workpiece. Considerable amounts of elements were observed to diffuse from the electrode to the workpiece and vice versa by Soni and Chakraverti [18]. By going through a solid, molten, or gaseous-phase reaction, these elements are transported in a solid, liquid, or gaseous state and alloyed with the contacting surface [19].

The MRM pertaining to the three phases of sparking—breakdown, discharge, and erosion—is greatly impacted by the kinds of eroded electrode and workpiece elements as well as the broken-down dielectric fluid products [20]. Furthermore, the material removal phenomenon is changed when the polarity of the sparking is reversed, with a noticeable amount of electrode material depositing on the workpiece surface [21].

4.2. Techniques to increase the rate of material removal

The utilization of CNC in EDM has aided in investigating the potential for enhancing the MRR through the use of different kinds of tools. For the sparking process, EDM frequently uses 3D profile electrodes, which are expensive and time-consuming to make. Nonetheless, studies have been conducted using a frame electrode to create swept surfaces that are both circular and linear by adjusting the electrode's axial motion [22]. The time required to machine a cubic cavity using a 3D solid electrode was compared using a similar machining technique with a wire frame electrode [23].

Recently, a different approach to improving MRR has also shown promise: altering the fundamental idea of EDM, which only produces one discharge for every electrical pulse. A multi-electrode discharging system that delivers additional discharge simultaneously from a corresponding electrode connected serially was experimented with by Kunieda and Muto [24]. The idea of splitting an electrode into several electrically insulated electrodes, as proposed by Mohri et al. [25], served as the foundation for the electrode's design.

It was stated that the conventional EDM was inferior in terms of TWR and energy efficiency, but there was no appreciable change in surface roughness (SR). Additionally, an oxygen-assisted EDM system that significantly increases the MRR was tested by injecting oxygen into the discharge gap [26].

4.3. Process of tool wear

Because the tool and workpiece are viewed as a single set of electrodes in EDM, the tool wear process (TWP) and the MRM are fairly similar. According to Mohri et al. [27], during sparking, carbon from the hydrocarbon dielectric precipitates onto the electrode surface, causing tool wear. Additionally, they contended that the quick wear on the electrode edge resulted from carbon's inability to precipitate at the electrode's harder-to-reach areas.

Based on this basic comprehension of TWP, several practical applications that take advantage of electrode wear's benefits and drawbacks have been created. By changing the process parameter settings before the electrode surface became normal EDM conditions, Marafona and Wykes [28] were able to introduce a wear inhibitor carbon layer. Using this basic comprehension of TWP, a few practical applications that The TWR was significantly improved by the thickness of the carbon inhibitor layer,

but the MRR is not much affected by it. Conversely, a high pulse current is recommended to enhance electrode wear in applications that call for material accretion by implanting electrode material onto the workpiece [29].

5. Summary of various optimization technique used by literature survey

Table 1 Literature Survey of optimization technique.

Paper No.	Paper Title	Year of Publication	Author Name	Material Used	Technique Used	Findings
1	Optimization by Grey relational analysis of EDM parameters on machining Al–10%SiCP composites [30]	2004	P. Narender Singha, K. Raghukandana, B.C. Paib	Al–10%SiCP composites	Taguchi and GRA Analysis	The experimental result for the optimal setting for MRR is 0.0511 g/min, TWR is 0.0651 g/min and Taper its 84 min.
2	Multi-objective optimization of wire-electro discharge machining process by Non-Dominated Sorting Genetic Algorithm [31]	2005	Shajan Kuriakose, M.S. Shunmugam	Hard material	Non-Dominated Sorting Genetic Algorithm (NSGA)	On a Pentium IV PC, the NSGA algorithm was implemented using Turbo C.
3	Development of hybrid model and optimization of surface roughness in electric discharge machining using artificial neural networks and genetic algorithm [32]	2009	G. Krishna Mohana Rao, G. Rangajanardha, D. Hanumantha Rao, M. Sreenivasa Rao	Ti6Al4V, HE15, 15CDV6 and M-250.	Artificial neural networks and genetic algorithm	Based on the experimental findings, it can be said that 15CDV6 And M250 have good surface finishes at 50V and 12A.
4	Optimization of machining parameters in magnetic force assisted EDM based on Taguchi method [33]	2009	Yan-Cherng Lina, Yuan-Feng Chena, Der-An Wanga, Ho-Shiun Lee	SKD 61 steel	ANOVA and Taguchi	In comparison to standard EDM, the experiments l results indicate that the magnetic force assisted EDM has a smaller SR, a lower relative electrode wear

						ratio (REWR), and a higher MRR.
5	Intelligent process modelling and optimization of die-sinking electric discharge machining [34]	2011	S.N. Joshia, S.S. Pande	AISI P20 mold steel	FEM– ANN– GA	The BPNN Network with SCG training algorithm reduced a more accurate process model and has greater potential for modelling complex manufacturing processes like EDM, even though the RBFN is quick and simple to set up.
6	The Optimization of the Electro-Discharge Machining Process Using Response Surface methodology and Genetic Algorithms [35]	2012	R. Rajesh and M. Dev Anand	Al Alloy with Grade HE9	Response Surface Methodology and Genetic Algorithms	The ideal parameters identified by GA were: flow rate at 1, voltage at 78 V, gap at 0.35, current at 3 A, pulse ON at 1 and pulse OFF at 8, in order to simultaneously Maximise MRR and minimise surface roughness among the experimental data.
7	Statistical modelling and optimization of process parameters in electro- discharge machining of cobalt-bonded tungsten carbide composite (WC/6%Co)[36]	2013	S. Assarzadeh, M. Ghoreishi	Cobalt-bonded Tungsten Carbide	ANOVA and Regression Analysis	Discharge Current, duty cycle had significant impact on MRR.
8	Optimization of Electric Discharge Machining Process Using the Response Surface methodology and Genetic Algorithm Approach [37]	2013	Chorng-Jyh Tzeng and Rui- Yang Chen	JIS SKD 61	Response Surface and Genetic Algorithm	In contrast, the RSM method yields inferior prediction and confirmation results compared to the suggested BPNN/GA approach.
9	Application of Taguchi-grey multi responses optimization on process	2014	T. Muthuramalingama, B. Mohan	AISI 202 Stainless steel.	Taguchi- grey multi responses optimization	The factor That most influences response characteristics is

	parameters in electro erosion [38]					tool electrical conductivity
10	Optimization of WEDM parameters using Taguchi technique and Response Surface Methodology in machining of AISI D2 Steel [39]	2014	Vikram Singha, S.K. Pradhan	AISI D2 Steel	Taguchi and Response Surface	To maximise MRR and cutting while minimising SR, the ideal combination setting parameters are as follows: pulse on time of 112.99 µs, pulse off time of 45µs, servo voltage of 20 volts, and wire feed rate of 4.85mm/min.
11	Optimization of surface roughness and cutting force during AA7039/Al2O3 Metal matrix composites milling using neural networks and Taguchi method [40]	2015	Sener Karabulut	AA7039/Al2 O3 metal matrix composites	Neural networks and Taguchi method	The cutting force and surface roughness were predicted by ANN with mean squared errors of 6.66% and 2.25%, respectively.
12	Multi-attribute optimization of machining process parameters in powder mixed electro- discharge machining using TOPSIS and grey relational analysis [41]	2016	S. Tripathy, D.K. Tripathy	H-11 die steel	TOPSIS and grey relational analysis	It is determined that the suggested process parameter settings are as follows: from TOPSIS, Cp = 6g/l, Ip = 6 Amp, Tonne = 100 µs, DC = 90%, and Vg = 50V; from GRA, Cp =6g/l, Ip = 3 Amp, Tonne = 150µs, DC = 70%, and Vg = 30V.
13	Multi Objective Optimization of Wire EDM Machining Parameters for AA7075-PAC Composite Using Grey - Fuzzy Technique [42]	2018	G Ramanan, J Edwin Raja Dhas	Aluminium 7075	ANOVA and Grey Fuzzy Model	ANOVA analysis indicates that the most important factor in achieving superior outcomes is servo speed.
14	Multi-objective optimization design Of die-sinking electric discharge	2019	Kuwar Mausam, Kamal Sharma, Gaurav Bharadwaj, Ravindra P. Sing h	carbon nanotube-reinforced carbon fibre	GRA	Duty cycle (η), which is ranked first by GRG, is the most important factor for the

	machine (EDM) machining parameter for CNT-reinforced carbon fibre nanocomposite using grey relational analysis [43]			nano composite		chosen work material, a 10-layered carbon fibre nanocomposite reinforced with carbon nanotubes (CNTs).
15	Multi-objective optimization of process variables for MWCNT-added electro- discharge machining of 316L steel [44]	2021	Md Al-Amin & Ahmad Majdi Abdul-Rani & Rasel Ahmed & Muhammad Umair Shahid & Fatema Tuj Zohura & Muhammad Danial Bin Abd Rani	316L steel	Non-dominated sorting genetic algorithm- II (NSGA- II)	The maximum material removal rate (MRR) was 42.25 mg/min, which is equivalent to a peak current of 10 A, a pulse- on time of 16 µs, an amount of 1 g/l of MWCNT, and a duty cycle of 45%.

6. Discussion

Dry E.D.M is an environmentally friendly method of machining. The use of gas instead of oil-based dielectric reduces pollution. During machining, no harmful or toxic fumes are generated. Dry E.D.M improves the material removal rate (M.R.R.) and electrode wear ratio (E.W.R.). Somebody should support such techniques; more research must be conducted because it helps save the environment. The primary benefit of dry E.D.M (D.E.D.M).

Very little work has been reported on improving the Material Removal Rate (M.R.R.). Also, no materials such as water-hardened die steel and high-speed molybdenum steel (H.S.S.) have been tried as work materials in near-dry E.D.M and powder-mixed E.D.M (P.M.E.D.M). The same approach can be used in future works.

Because of improved flushing conditions, hollow tube and eccentric drilled hole electrodes have been shown to impact M.R.R. positively. Such designs necessitate further research into additional work materials.

After reviewing the literature on tool steel machining using the E.D.M process, it was discovered that most studies investigated the effect of operating parameters on the performance parameters of M.R.R., E.W.R., and surface quality. Other studies were carried out to explore other issues to be resolved or studied, including the electrode shape and movement, the effect of the E.D.M process on the tool steel properties and machined surface, combined and hybrid processes, and the impact of various dielectric fluids used in the process, among others. Researchers focused more on sinking E.D.M and micro-E.D.M processes to obtain optimal and near-optimal operating parameters, which could be attributed to their popularity.

7. Conclusion

This paper discusses the various advances in Electric Discharge Machine. Most of the output parameters optimized by various researchers are MRR, TWR and Surface Roughness. The input parameters used are Pulse On, Pulse Off, Current, Discharge Voltage, Flushing pressure, Powder concentration. This study will provide an insight into the input and output parameters selection, various materials that be machined on Electric Discharge Machine.

Compliance with ethical standards

Disclosure of conflict of interest

The Authors proclaim no conflict of interest.

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