A REVIEW OF THE RECENT RESEARCH ACTIVITIES IN THE FILD OF ELECTRICAL DISCHARGE MACHINING

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Abstract: Electrical discharge machining (EDM) is one of the earliest non-traditional machining processes being considered one of the most popular machining methods today. The EDM process basis on thermoelectric energy between the workpiece and an electrode, so that the discharge energy generated during the operation characterizes the productivity of the process. Due to the well-established machining options utilized in the industry of aerospace, automotive industry and surgical components for precision machining and making complex geometrical shapes in hard-to-cut materials, a significant amount of research interests has been created in this field. This paper provides a review of numerous academic research activities carried out in the previous years, as well as numerous developments in the field of EDM related to increased machining rates, improved performance, materials and dielectrics used, electrode design and manufacture.

Keywords: electrical discharge machining, electrode, dielectric, machining rates

1. INTRODUCTION

In recent years, advanced manufacturing technologies have been developed to attempt to solve a number of problems where traditional techniques have proved ineffective [1-5]. The electric discharge machine (EDM) process is a non-traditional process, which can cut materials with a high melting point, high hardness, high strength, and low brittleness [6]. Electric discharge machining is a metalworking technique that uses an electric erosion effect in conjunction with an electrosparking spark. A current discharge takes place in a narrow space between the work piece and the electrode, melting and vaporizing the unwanted material and separating it from the parent metal in the process [7].

This gap is filled with isolating fluid such as (hydrocarbon oil or deionized water). Both the electrode and the workpiece connect to the power supply. Dielectric fluids can maintain their insulating properties except at the nearest contact points between the electrode and workpiece. At these points where sparking voltage triggers the dielectric fluid, the dielectric fluid behaves as a conductor, resulting in a spark. Once the spark ceases, the dielectric fluid reverts to being an isolating state [8], cools the heated electrodes, and produces the melted materials as particles called debris, which are mixed with the dielectric fluid [9].

In the EDM process, the quality of the machined surface is affected by many parameters such as the electrical parameters (peak current, gap voltage, pulse on time, pulse off time, duty factor), the material of the electrode, electrode shape, electrode wear, the type of the dielectric fluid, and flushing type in the EDM process [10-12].

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This paper provides a review on the various academic research activities carried out in the last few years and various developments in the field of EDM related to improvement in performance, materials and dielectrics used, improvements in machining rates, and electrode design and manufacture.

2. REVIEW OF THE CURRENT RESEARCH

2.1. Dielectric fluid and pressure

Dielectric fluid is one of the main drivers of EDM technologies. The type and the quality of the dielectric fluid have a major effect on the performance and efficiency of the EDM process. There are three basic functions of dielectric fluid in the EDM process [13]:

- It acts as an insulating medium though the flow of currents occurs after breaking down upon application of suitable voltage;
- It acts as a medium to carry away the heat from the electrodes;
- Debris is washed away from the inter-electrode gap, thus clearing the machined area.

The dielectric fluid and pressure are essential parameters in EDM as they assist in spark generation, heat dissipation, and material flushing. Recent research has investigated the effects of different dielectric fluids, such as kerosene, deionized water, and vegetal dielectric oils, on the EDM process and optimized their use for specific materials and machining conditions. Moreover, studies have also explored the impact of dielectric fluid pressure on the EDM performance, including material removal rate, surface roughness, and tool wear, and have proposed optimal pressure settings [14].

2.1.1. Powder mixed electrical discharge machining (PMEDM)

The principle of powder mixed EDM (PMEDM) depends on the behaviour of the conductive powders in the electrical field generated by the voltage. This charges the powder particles and makes them behave in the dielectric fluid. These charge powders accelerate and move near each other in zigzag movement in the sparking area. They form a chain and bridge the gap between the electrode and the workpiece surface, which decrease the insulation intensity of dielectric fluid [15].

The breakdown of the dielectric fluid and the mechanism of the particle movement to form the bridge between the electrode and the workpiece have been explained [16]. The bridge of the powder particles results in implementing a simple short circuit, and that results in an early explosion from a long distance, as a result, it enlarges the discharge gap area that improves the flushing of the debris. When the charged powder particle collides with dielectric molecules, it generates more electric charges and enlarges the discharge column, which result in large shallow gravity, as shown in Figure 1 [15, 17]. The rapid zigzag movement of the powder particles results in uniform distribution of the heat in the workpiece surface that generates many craters from only one pulse.

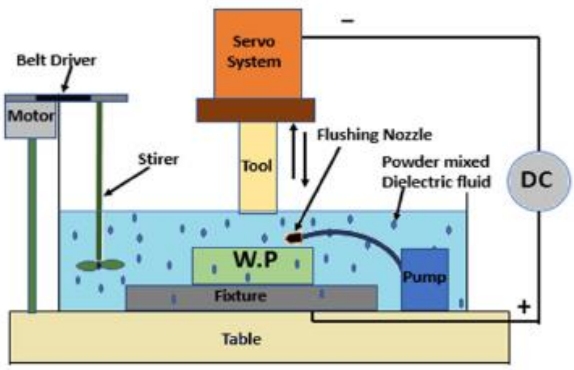

Fig. 1. Schematic diagram of PMEDM setup [18].

The intrinsic issues of low machining rate (MRR), dimensional overcuts and surface roughness (SR) limit its application and results revealed that the addition of nano-alumina powder has proved to be a better choice in contrast to SiC for achieving high MRR [19].

The machined surface features and the possible elemental compositions of the machined surfaces were analysed using field emission scanning electron microscopy (FE-SEM), energy dispersive spectroscopy (EDS) and X-ray diffraction (XRD) [20]. The SEM investigations elucidate that the samples machined with Titanium powder mixed with EDM have fewer surface defects, cracks, microholes and layer deposition compared to the sample machined with graphite powder [21].

A highly carbonated liquid has been utilized as a dielectric medium in the EDM process. The effect of the dielectric medium has been investigated and then, finally, compared with EDM oil. The outcomes have demonstrated that discharge energy density has escalated to fierce-extent, thus, removing a voluminous amount of material from the workpiece. The highly carbonated liquid dielectric has been considered the most suitable dielectric medium for high discharge energy. Micro-crack density and size have increased with MRR because of highly concentrated discharge energy. The recast layer thickness has increased with the dielectric medium's viscosity because of improper molten metal flushing, and the molten metal re-solidifies on the same surface [22].

Incorporation of alumina nanoparticles with deionized water may improve machining performance, with no prior research on machining characteristics of Inconel 718 using alumina nanofluid in EDM. The machinability of Inconel 718 via the electrical discharge machining process, as well as the performance of alumina nanofluid as a dielectric medium, have been evaluated using deionized water with a concentration of 0.5% [23]. Carbon nano tube combined as dielectric fluid improved surface roughness by an average of 30% while improving MRR by an average of 19% while decreasing TWR by 8.51 percent [24].

A percent improvement of 12.75% in MRR was found in comparison to the published work in EDM of IN600 using kerosene dielectric. It has also been revealed that the addition of Cu powder in the concentration of 1.5 g/100 mL has raised the MRR to 25.53% [25]. ANOVA is used to identify the most influential input parameter that has the greatest impact on the final outcome. Using design expert software, the characteristics of EN-31 steel were improved and regression equations with and without MWCNT were compared using an electro-destructive method (EDM) [26].

Further, surface morphology, recast layer thickness (RLT) analysis, and microhardness analysis reveals that multi-wall carbon nanotube mixed rotary EDM using JCO shows small micro holes, no micro crack, smaller size debris deposition, lower RLT, and smaller microhardness of recast layer as compared to EDM oil [27]. Overall, the use of alumina nanofluid can improve machining performance in EDM, due to the reduction of abnormalities such as crack formation and molten metal debris in the machined surface of Inconel 718 [28].

2.1.2. Dielectric gases

The dielectric is formed by dispersing oxygen into deionized water, reducing the shortcomings of traditional water-based dielectric and introducing the advantages of gas-based one. The feasibility of the proposed method is systematically studied compared to the method that uses deionized water. Compared with using deionized water, the proposed method shows better processing characteristics, including larger material removal rate (MRR), smaller relative electrode wear rate (REWR), and thinner recast layers [28].

Surface finish of the product refers to quality of machining operation, while production rate refers to machining performance. Analysis through ANOVA revealed that the discharge current is the dominant factor in affecting the material removal, while O2 pressure is the dominant factor on surface roughness. Validation result has confirmed that the prediction results are within the allowable limit [29].

The performance of three dielectric gases, air, argon, and oxygen, has been evaluated. To predict the parametric relationship, investigations have been performed by altering pulse current along with pulse-on/off times by utilizing the response-surface-methodology. Optimization results showed that oxygen rendered a maximum MRR, which is almost three times that of argon. Splat-like surface features were observed on the machined surface for oxygen [30].

2.1.3. Vegetable oil (biodiesel) green dielectric fluid

Natural vegetable oil is one of the alternative approaches in dielectric liquid. The findings depicted in the specialty literature reveal the technical feasibility and qualitative performance of vegetable oils as substitutes for hydrocarbon-based and synthetic dielectrics oils in EDM processing [31]. Vegetable oil (sunflower and canola oils) is tried as dielectric liquid for machining of die steel and performance comparison of vegetable oil with conventional dielectric liquid is made. Three different levels of input parameters were used, material removal rate

(MRR), tool wear rate (TWR) and surface roughness (SR). The results showed that better MRR is obtained when using sunflower oil as a dielectric fluid, as well as higher TWR and SR than when using a conventional dielectric [32]. The feasibility of jatropha bio-oil is already judged technically as a green and sustainable dielectric of EDM in terms of material removal, surface roughness and surface hardness. A suitable range of flushing pressure and velocity have been recommended to ensure desirable surface characteristics and responses with jatropha, so that the issues of sustainability can be entertained [33], based on the test results of dissolved gas analysis, Jatropha oil and Rice Bran oil have been introduced as sustainable and biodegradable dielectrics [34]. Neem biodiesel follows more closely with EDM oil than Sunflower biodiesel for all considered response measures. The contact angle of the machined surface with biodiesels is smaller than EDM oil attributed to the presence of broader craters in the surface. The recast layer thickness is increased by 92% and 44% with Neem biodiesel than EDM oil [35]. Biodiesel could be a real alternative to hydrocarbon oil for micro-ED milling in terms of performance and safer environment. Minimum hardness was achieved when the biodiesels were used as the flushing media at considered discharge energy range due to lesser carbon deposition. MRR was decreased by 55% with palm biodiesels as compared to EDM oil dielectric fluid. Microhardness was increased by 10% with EDM oil as compared to Karanja biodiesel under considered discharge energy [36].

Through the combination of experimental and theoretical modelling and analysis, it can be concluded that liquid dielectric water has the functions of endothermic cooling, inducing an intermittent gas supply environment between electrodes, efficient etching product removal, improving oxygen utilization efficiency, controlling oxygen diffusion speed, and increasing the discharge gap between electrodes, which can significantly improve the inter-electrode discharge state and material removal rate [37].

2.2. Electrodes

Electrodes play a crucial role in the EDM process as they act as the tool for material removal. We provide an overview of the different types of electrodes used in EDM and their properties.

2.2.1. Types of electrodes

Copper, brass and tungsten carbide electrodes were utilized with iso energy pulse generator. It was observed that the use of copper electrode could enhance material removal mechanism due to its higher electrical conductivity. The better surface topography with tiny craters could be observed on machined specimen with tungsten carbide electrode owing to its high melting point, tungsten carbide tool electrode can create lower surface roughness than other electrodes.

Brass electrode can create larger craters on the machined surface of titanium alloy specimens due to its low melting point. Hence it could create higher surface roughness and electrode wear [38]. Nevertheless, the surface qualities such as hardness and wear resistance, of aluminium alloy are insufficient to meet the needs of a wide range of applications. As a result, some researchers looked into the electrical discharge coating (EDC) of aluminium alloy utilizing a green compact WS2/Cu electrode to alter the surface properties. Energy-dispersive spectroscopy measurements were taken to validate the successful deposition of several elements on the workpiece surface [39].

The selection of proper electrode material plays an important role in defining the machining performance. In order to select a suitable electrode material for the newly developed process, several experimental investigations have been conducted with three different electrode materials, namely brass, copper (Cu) and copper tungsten (CuW). The results have shown that, for all the current settings, brass electrode provides the highest material removal rate (MRR), followed by Cu and CuW electrodes. However, CuW exhibited the lowest electrode wear rate (EWR). Moreover, the average surface roughness and surface characteristics of the electrodes after machining were investigated as well. Based on all the performance parameters, CuW appears to be the best choice for the hybrid process to machine Inconel 718 [40].

2.2.2. Optimizations of electrodes

It has been clearly evident that the tool electrodes prepared by powder metallurgy by mixing silver nanoparticles by weight percentage yielded great results. The reason for the improvement in MRR is due to the noticeably substantial action of the spark for a longer duration, which made more high energy electrons impinging on the work material [41]. Also, reduced graphene oxide (RGO) nanoparticles have been synthesised by modified Hummer's technique. Substantial improvement in material removal rate at current of 20 amperes, pulse on time of 90 microseconds and pulse off time of 1 microsecond. It was also found that current and pulse off were significant factors that influenced the material removal rate [42].

Compared with conventional milling (CM), the high-frequency electrical discharge assisted milling (HF-EDAM) greatly reduced the cutting force, and the machined surface quality after HF-EDAM also effectively improved. Subsequently, the excellent machinability achievable based on copper-beryllium bundle electrodes was verified by a combination of experiments and theory in this research, demonstrating HF-EDAM as an effective method for high-quality and efficient machining of Inconel 718 [43].

It was developed an ultrasonic assisted micro-EDM (UA-MEDM) setup, in which tool is rotating and workpiece is vibrating and the machining characteristics have been studied when ultrasonic vibration and rotation of tool are switched-off. Surface quality of microholes and micro-tools has also been observed by using scanning electron microscopy (SEM). Experimental results show that rotating tool and vibrating workpiece give microholes of better quality with higher MRR [44]. In order to uplift the machining efficiency and accuracy of micro electrical discharge machining (micro-EDM) milling, it was studied the prediction and compensation method of electrode loss and established a fixed length compensation model for micro-EDM milling with spiral electrodes. It was verified through experiments that the model can successfully predict the electrode loss of micro-EDM milling with spiral electrodes [45].

A novel approach is proposed to eliminate the uneven tool electrode wear by reversing pulse polarity in a repetitive manner. Using this method, uneven tool electrode wear can be avoided and high accuracy micro-holes without the features of a cone and/or conical concavity can be obtained [46]. Experimental results when rough machining a complex semi-closed cavity show that the porous electrode can greatly shorten the machining time by 47 %, which demonstrates that a porous electrode improves the machining of a complex cavity in a titanium alloy [47]. Electrode thickness is the most influential parameter (85.4%) affecting width deviation of microchannel(s). Width deviation experiences a drop when a thicker electrode is engaged. The thinnest electrode (0.2 mm) has provided the highest value of arc radius which translates to flatter base of channel [48].

The performance of fabricated composite electrodes has also been compared with conventional copper electrode. Results show that optimum microhardness has been observed at high peak current value when surface is machined with copper conventional electrode while pulse on time has been found to the major contributor when surface is machined by composite material electrode. XRD analysis indicates the formation of tungsten-carbide, iron-carbide, chromium-nickel and copper on the machined surface of the workpiece [49]. Compared with the straight electrode, the maximum effective cutting depth of curved electrodes and long-curved electrodes increased, and the MRR of stepped electrodes was significantly higher. The surface roughness was identical for holes machined by all types of electrodes. However, obvious carbon adhesion can be observed at lower cutting depth for straight electrode, followed by curved and long-curved electrodes [50].

2.3. Process optimization

Process optimization is a key area of research in the field of Electrical Discharge Machining (EDM) to achieve better machining performance with reduced costs and environmental impacts. The optimization of various process parameters such as discharge current, pulse duration, electrode material, and dielectric fluid properties can lead to improved machining efficiency, precision, and process stability.

2.3.1 Advanced modelling and simulation techniques

Multi-criteria decision-making (MCDM) technique known as a Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is used to optimize the response performance variables of material removal rate (MRR) and surface roughness (SR). TOPSIS combines multiple objectives into a single objective and provides the optimum set of parameters. Confirmatory experiments show a satisfactory improvement of preference values utilizing TOPSIS in the EDM experimental and initial settings [51]. The best effectiveness of the TOPSIS algorithm is compared with the genetic algorithm (GA). It is found that the TOPSIS algorithm behaves better compared to GA with esteem to best possible process response values [52]. The best parameter setting (I = 10 A, V = 30 V, ton = 100 μs and toff = 20 μs) is identified using the TOPSIS method for the performance measures machining rate (MR), tool wear rate (TWR), overcut (OC), and taper overcut (TOC). Further tool wear behaviour is also studied through scanning electron microscope (SEM) images by varying the voltage [53].

Four popular multi-criteria decision making (MCDM) techniques, in the form of weighted aggregated sum product assessment, technique for order of preference by similarity to ideal solution, combinative distance-based assessment and complex proportional assessment are separately hybridized with teaching-learning-based optimization (TLBO) algorithm to solve the parametric optimization problems of a micro-EDM process. The polynomial regression (PR) models are considered here as the inputs to these hybrid optimizers. Their optimization performance is subsequently validated against the conventionally adopted weighted sum multi-objective optimization (WSMO) approach at four different weight scenarios. It is revealed that for the micro-EDM process, all the MCDM-PR-TLBO approaches provide better solutions as compared to PR-WSMO-TLBO method for the considered weight scenarios [54].

The EDM is combined with Solid Isotropic Material with Penalization (SIMP) method to solve 2–3D topological optimization problems under different conditions. The key to derive the objective function of second-order EDM element, which is suitable for the SIMP-based topology optimization process. And the sensitivity is solved by Optimality Criteria (OC) method. The results show that the method has good accuracy, efficiency and robustness in topology optimization of 2D and 3D minimum compatibility problems [55].

The identification accuracy and generalization ability of the kurtosis-based stage identification method (KBSI) have been verified in various machining conditions. To improve the overall machining efficiency, the influence of servo control parameters on machining efficiency of each machining stage was analysed experimentally, and a new stage-wise adaptive control strategy was then proposed to dynamically adjust the servo control parameters according to the online identification results. The performance of the new strategy is evaluated by drilling film cooling holes at different hole orientations. Experimental results show that with the new control strategy, machining efficiency and the machining quality can be significantly improved [56].

An artificial neural network (ANN) together with a heuristic algorithm, called particle swarm optimization (PSO), was used to set up a methodology for selecting the optimal process parameters for the micro-EDM process. The developed methodology is characterized by a double direction functionality responding to different industry needs. Usually, in the industrial scenario, the operators are bound by the project specifications or by the limited availability of time. For this reason, a methodology tested only on a specific workpiece material, that involves limited input parameters or developed for the optimization of a single performance is limiting. The developed 2-steps model leaves operators free to establish which factors to impose for the optimization and allows to define the best solution for the production of a part. The validation of the model shows a good fit between predicted and experimental results [57]. Artificial Neural Network (ANN), together with a Particle Swarm Optimization (PSO) and Finite Element Model (FEM), was used to forecast the process performances for the Micro Electrical Discharge Machining (micro-EDM) drilling process [58].

The energy distribution in EDM drilling is the factor that has to be analysed and optimized in order to achieve high-performance machining, reduce costs and increase the quality of the machined parts. A finite element analysis (FEA) of a single discharge is performed to calculate the energy fraction flowing into the anode. Computational fluid dynamics (CFD) simulations with Marangoni effect and considering the temperature dependent material properties are performed. Inverse FEA is performed in order to calculate the fraction of the energy distributed into the workpiece using a measured crater shape as an input parameter of the model. The model considers as an input the measured current, voltage and final shape of a single crater [59].

The multi-objective optimization on the basis of ratio analysis (MOORA) method coupled with principal component analysis (PCA) in order to achieve the optimal combination of EDM parameters. Proposed MOORA-PCA hybrid results and conventional MOORA results were compared, and it is found that proposed methods are accurate for predicting the responses [60].

2.3.2. Parameters optimization

Analysis of variance (ANOVA) has been performed to find significant process parameters affecting responses and the validity of the derived modal in the present work. The grey relational analysis method has been used to find the optimum weightage for all responses. The comparison found that the butterfly optimisation algorithm (BOA) gives very close results to the Genetic Algorithm so that BOA can be applied for real-world optimisation problems [61]. An improvement in performance indicators was achieved thanks to the Taguchi-grey relational analysis (TGRA) multiresponse optimization [62]. Impact of parameters on material removal rate (MRR) and surface roughness (SR) were examined via signal-to-noise ratio (S/N ratio, expressed in decibel, dB) as well as analysis-of-variance (ANOVA). Outcomes disclose that every selected response explicitly surface roughness (SR) and material removal rate was significantly influenced by parameters [63]. Using copper electrode, the impacts on performance indicators of discharge current, pulse time and pulse interval were investigated with 3D surface topography images. It was determined that the peaks and craters formed on the machined surface expanded with the increase of pulse time, and the decreased with the increase in the pulse interval.

The EDM procedure is used to study the MRR, TWR, and SR of the MWCNT combined with dielectric fluids. EDM process output parameters were predicted using regression models. Predictive models were built using the peak current, pulse on time, and pulse off time parameters of machining. In order to collect data, it was used a full factorial design. ANOVA is used to identify the most influential input parameter that has the greatest impact on the final outcome. Using design expert software, the characteristics of EN-31 steel were improved and regression equations with and without MWCNT were compared using an electro-destructive method (EDM). Carbon nano tube combined as dielectric fluid improved surface roughness by an average of 30% while improving MRR by an average of 19% while decreasing TWR by 8.51 percent [64].

Experiments are performed based on DOE, the study effect of the individual parameters (compaction load, current and pulse on time) on the responses such as micro hardness and surface roughness. The experimental results are verified and justified using ANOVA and revealed that pulse on time has most significant parameter followed by current and compaction load. However, the coating performance are conflict in nature hence there is a need to identify the optimal coating parameters to achieve the desired coating characteristics. Finally, RSM method is adopted for optimization of electrical discharge coating (EDC) to identify the optimal coating parameters. Confirmation tests are performed on at predicted optimum process parameters and results are verified. Further, SEM was used to determine the surface morphology and EDS is used to validate the alloying of electrode materials on the surface of Al alloy [65].

Due to dynamic changes in the machine's parameters and production environmental changes, using an uncertain model is inevitable. To investigate the machining data under uncertainty, a mathematical modelling approach based on the fuzzy possibility regression integrated (FPRI) model is developed. The findings confirm the accuracy and reliability of the proposed method for prediction and optimisation of the EDM's parameters and encourage further tests for other production and supply chain applications [66]. The hybrid multiobjective optimisation technique of grey relational analysis (GRA) combined with principal component analysis (PCA) was used to determine the optimal process input parameters [67].

It was aimed to attempt the machine learning (ML) algorithms-based optimization of the different process inputs in electrical discharge machining of Cu-based shape memory alloy. The considered process input factors are namely as; pulse on time (Ton), pulse off time (Toff), peak current (Ip), and gap voltage (GV) and their effects were studied on dimensional deviation (DD) and tool wear rate (TWR). The central composite design matrix has been employed for planning the main runs. The 2-D and 3-D graphs represents the behaviour of the response parameters along with variations in the machining inputs. The novelty of the work is machining of Cu-based Shape Memory Alloy (SMA) in EDM operations and optimization of parameters using Machine Learning techniques. Furthermore, machine learning based, single and multi-objective optimization of investigated responses were conducted using the desirability approach, Genetic Algorithm (GA) and Teacher Learning based Optimization (TLBO) techniques [68].

The products processed by Electrical Discharge Machining (EDM) leave some undesirable effects, the most prominent of which is Residual Stress (RS). These RS affect fatigue behaviour, dimensional stability, and stress corrosion. The latter is the cause of failure of processed products. It has been observed that products obtained by Powder Mixing Near Dry Electric Discharge Machining (PMND-EDM) have relatively low RS values. The purpose is to minimize the RS caused in the machined workpiece (EN-31) by optimizing the process parameters that significantly affect the machining characteristics. The selected parameters were tool diameter, mist flow rate, metal powder concentration, and mist pressure, and the selected workpiece was EN-31 because it has ideal mechanical properties and is widely used in manufacturing. The minimum value of RS at optimized values of process parameters was found to be 106.32 MPa [69].

An application of an integrated approach for parametric optimization of a green PMEDM process is proposed, thereby minimizing its effect on the environment while maintaining the desired quality of the machined components/parts. Influences of different preference functions in the preference ranking organization method for enrichment of evaluation (PROMETHEE) on the derived parametric intermixes and the predicted response values are also studied. Analysis of variance results and the developed surface plots further illustrate the effects of PMEDM process parameters on its machining ability. It is observed that this approach can attain better response values as compared to other popular mathematical tools and is also quite efficient in achieving green machining environment for the considered PMEDM process with enhanced performance [70].

RSM was proven to be an effective statistical tool for reducing the experimental runs, and also establishes the relation between multiple inputs and single output. The neuro-fuzzy system combined with PSO results a suitable model to convert multiple response into an equivalent single response. The approach can be a practical method for situations where multiple conflicting objectives are needed to be optimized at the same time [71]. Rotating ultrasonic vibration assisted EDM is a composite machining method that uses EDM to etch a metal surface and adds rotating and ultrasonic vibration. It has high efficiency and a wide range of workpiece materials. Aiming at the structural characteristics of rotary ultrasonic vibration assisted EDM machine tool, the errors caused by the main moving parts of the machine tool were analysed [72]. The implementation of three smart hybrid predictive models based on the adaptive neuro-fuzzy inference system (ANFIS), ANFIS and genetic algorithm (GA), and ANFIS and particle swarm optimization (PSO). All such strategies have been used to determine and compare machining key elements including material removal rate (MRR) and surface roughness (SR) during the gas-assisted electrical discharge (GAEDM) process [73]. Multi-response, optimization techniques is being taken into considerations and reveals the investigation of process parameters on Current, Pulse on time, duty cycle, voltage, spark gap and flushing pressure for Metal removal rate (MRR) and Surface Roughness (SR). The maximum effect on Utility is shown by the pulse on time, then flushing pressure, current, spark gap and voltage have their effect but duty cycle proved to be an insignificant factor as shown by the experimental results [74].

The process optimization is a critical area of research in EDM, and various techniques such as DOE, RSM, and evolutionary algorithms can be used to determine the optimal process parameters. By optimizing the process parameters, the machining performance of EDM can be significantly improved, leading to better efficiency, precision, and surface quality.

3. CONCLUSIONS

These are some of the latest research trends in EDM process optimization. Further advancements in modelling and simulation techniques, AI and ML, optimization algorithms, electrode materials, in-situ process monitoring, adaptive control, and intelligent process planning are expected to drive future research in this field, leading to further improvements in the EDM process and its applications in various industries. Optimizing the EDM process involves finding the optimal combination of process parameters to achieve improved machining performance, higher productivity, and a better surface finish. Over the years, researchers have developed various approaches and methods for optimizing the EDM process.

In conclusion, EDM has emerged as a promising technology for machining difficult-to-machine materials with high precision and accuracy. Recent research activities have focused on improving the process capabilities of EDM, developing new materials and techniques, and exploring its potential applications in various industries. As a result, EDM is poised to play an increasingly important role in modern manufacturing and engineering applications.

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