International Journal of
Emerging Research in Management &Technology
ISSN: 2278-9359 (Volume-4, Issue-12)

Research Article **December 2015**

Various Research Trends of Electrical Discharge Machining (EDM)– A Review

BSV Ramarao*
Associate Professor, Dept of Mech,
ASTI, Hyderabad, India

Dr. P Shailesh
Professor, Dept of Mech,
MCE, Hyderabad, India

Dr. M Sreenivasarao
Professor & Head, Dept of Mech
JNTUH, Hyderabad, India

Abstract—

Electrical discharge machining (EDM) is one of the oldest non-traditional machining processes. EDM process is basically done through the thermoelectric energy between the work piece and an electrode. In electrical discharge machining (EDM), a process utilizing the removal phenomenon of electrical discharge in dielectric, the working fluid plays an important role affecting the material removal rate and the properties of the machined surface. Selection of the right dielectric fluid is important for successful operations. This paper presents a literature survey on the various concepts with current research trends and also their effects in electrical discharge machining characteristics.

Keywords— DOE, RSM, GFRG, GRA, ANFIS, CACO, DEA, WLT, SCD, WG, EW & OC

I. INTRODUCTION

Electrical discharge machining

The electrical discharge machining (EDM) is one of the popular manufacturing processes widely used in die and mold making industry to generate deep complex cavities in various classes of materials under roughing and finishing operations

The EDM process is most widely used by many of the industries like mold-making tool and die industries, but is becoming a general method of making prototype and production parts, especially in the aerospace, auto-mobile and electronics industries in which production quantities are relatively low. It is also used for coinage die making, metal disintegration machining, etc. There are few types of EDM available which is discussed below.

Sinking EDM: In the sinking EDM process, a mirror image of tool shape occurs on the surface of work piece. In this process, copper or graphite is generally used as electrode material. The numerical control monitors the gap conditions (voltage and current) and synchronously controls the different axes and the pulse generator. The dielectric liquid is filtrated to remove debris particles and decomposition products. In this process electrical energy turns into thermal energy through a series of discrete electrical discharges occurring between the electrode and work piece immersed in a dielectric fluid. The thermal energy generates a channel of plasma between the cathode and anode. When the pulsating direct current supply is turned off, the plasma channel breaks down. This causes a sudden reduction in the temperature allowing the circulating dielectric fluid to implore the plasma channel and flush the molten material from the workpiece surface.

Wire EDM: Wire-cut EDM (WEDM) is one of the most favorable variants owing to its ability to machine conductive, exotic and high strength and temperature resistive (HSTR) materials with the scope of generating intricate shapes and profiles. It uses a thin continuously traveling wire feeding through the work piece by a micro-processor eliminating the need for elaborate reshaped electrodes, which are required in the EDM. The wire-cut EDM process uses a thin copper wire of diameter about 0.1–0.3 mm as the electrode and the workpiece is mounted on a controlled worktable, enabling complex two dimensional shapes can be cut on the work piece by controlled the movement of the X–Y worktable. Wire EDM process is widely applied not only in tool and die-making industry, but also in the fields of medicine, electronics and the automotive industry.

Micro EDM: The recent trend in reducing the size of products has given micro-EDM a significant amount of research attention. Micro-EDM is capable of machining not only micro-holes and micro-shafts as small as 5 _m in diameter but also complex three-dimensional (3D)micro cavities. Micro EDM process is basically of four types: micro-wire EDM, die-sinking micro-EDM, micro EDM drilling and micro-EDM milling. In micro-wire EDM, a wire which has a diameter down to 0.02 mm is used to cut through a work piece. Indie-sinking micro-EDM, an electrode is used containing micro-features to cut its mirror image in the work piece. In micro EDM drilling, micro-electrodes (of diameters down to 5–10 _m) are used to 'drill' micro-holes in the work piece. In Micro-EDM milling, micro-electrodes (of diameters down to 5–10 _m) are employed to produce 3D cavities by adopting a movement strategy similar to that in conventional milling.

Powder mixed EDM (PMEDM) : The mechanism of PMEDM is totally different from the conventional EDM. A suitable material in the powder form is mixed into the dielectric fluid of EDM. When a suitable voltage is applied, the spark gap filled up with additive particles and the gap distance setup between tool and the work piece increased from 25–50 to50–150 mm. The powder particles get energized and behave in a zigzag fashion. These charged particles are accelerated by the electric field and act as conductors. The powder particles arrange themselves under the sparking area and gather in clusters. The chain formation helps in bridging the gap between both the electrodes, which causes the early explosion. Faster sparking within discharge takes place causes faster erosion from the workpiece surface.

Dry EDM: In this process a thin walled pipe is used as tool electrode through which high-pressure gas or air is supplied. The role of the gas is to remove the debris from the gap and cooling of the inter electrode gap. The technique was developed to decrease the pollution caused by the use of liquid dielectric which leads to production of vapors during machining and the cost to manage the waste

II. LITERATURE

Gostimirovic et al. (1) investigated the effects of electrical process parameters on the performances of die-sinking electrical discharge machining process with RC pulse generator while machining manganese-vanadium tool steel workpiece using graphite tool electrode. They found that the discharge current and pulse duration have highly influenced the material removal rate of the EDM process.

Puertas et al. (2) carried out a study on the influence of the factors of current intensity, pulse time and duty cycle over the material removal rate, surface quality and electrode wear rate. They modeled the relationship between the input parameters and response parameters in the die-sinking EDM process using response surface methodology. It has been concluded that the lower values of the current intensity and the machining time have to be used in order to obtain a good surface finish.

Patel et al. (3) presented a detailed experimental investigation of machining characteristics such as surface integrity and material removal mechanisms of advanced ceramic composite Al2O3–SiCw–TiC with EDM process. It has been concluded that the surface roughness and material removal rate have been increased with pulse duration in EDM process.

A Yahya et al. (4) explained the use of the dimensional analysis for investigating the effects of the electrical and the physical parameters on the material removal rate of a die-sinking EDM process has been described by Yahya and Manning. From the experimental results, it has been found that the material removal rate has been increased with discharge current, gap voltage and pulse on time.

Patel et al. (5) investigated the feasibility of fabricating micro holes in SiCp–Al composites using electrical discharge machining with a rotary tube electrode [31]. They have investigated the material removal rate, electrode wear rate and hole tapper as the responses for the study. The experimental results have revealed that pulse on duration has significantly affected the response characteristics involved in EDM process.

Pelicer et al. (6) focused on investigating the influence of EDM process parameters and electrode geometry on feature micro accuracy on tool steel for mold fabrication purposes. A set of designed experiments with varying process parameters such as pulse current, open voltage and pulse duration have been carried out in H13 steel using different shaped copper electrodes. It has been concluded that the triangular shaped electrode would produce highly inefficient output, since the fast wearing nature of the electrode edges.

Kuppan et al. (7) reported about the experimental investigation of small deep hole drilling of Inconel 718 with electrolytic copper tool electrode using the electrical discharge machining process [30]. The experimental results have shown that the material removal rate has been increased with the increase in the peak current and duty factor.

Wang et al. (8) carried out a series of experiments to investigate the impacts of machining polarity, electrode rotation speed and nominal capacitance on the material removal rate and tool wear rate with poly crystalline diamond. It has been demonstrated that favorable machining performance of EDM process on the workpiece could be achieved in tool with negative polarity as compared to the positive polarity.

Batish et al. (9) investigated the effect of process parameters and mechanism of material deposition in electric discharge machining on surface properties of EN31, H11 and high carbon high chromium die steel materials [38]. It has been discussed about material transfer mechanism involved in EDM process. It has been found that die steels have been machined effectively with copper tool electrode using EDM process.

Jahan et al. (10) conducted an experimental investigation with the view of obtaining fine surface finish in die-sinking EDM process of tungsten carbide using different tool electrodes such as tungsten, copper tungsten and silver tungsten. It has been found that the surface finish has been influenced by the discharge energy during machining process. It has been realized that the lower discharge energy has produced good surface finish.

Yeo et al. (11) discussed about the machining of zirconium based bulk metallic glass by EDM process with different tool electrodes such as copper, brass and tungsten rod electrode. The experimental results have shown that the usage of lower input energy has produced the lower surface roughness and electrode tool wear.

Khanra et al. (12) investigated the influence of energy input on the workpiece surface during the machining in the EDM process. In this experimental investigation, a well-polished mild steel (C – 0.18%) plate has been used for machining by EDM. It has been observed that the energy input has influenced the debris particle size in the EDM process.

Popa et al. (13) showed the importance of optimizing the process parameters that could influence the quality of the EDM process. They formulated the equation of crater depth in terms of discharge energy in EDM process. From the relation, it has been observed that the crater depth has been increased with the discharge current flowing through the work piece and tool electrode.

Kojima et al. (14) described about the spectroscopic measurement of arc plasma diameter in EDM. They found that the arc plasma has been increased with increasing discharge current. It has been verified that crater diameter and depth decrease with increasing gap width due to the increased plasma diameter. The arc plasma diameter has been increased with increasing spark gap and thus clarified the reason for lower material removal rate and smoother surface finish with longer spark gap.

Wong et al. (15) developed a single spark pulse generator using resistance–capacitance arrangement to study the erosion characteristics in the EDM process from the crater size. The volume and size of the craters have been found to be more consistent at lower energy discharge sparks than the higher energy discharge sparks. The higher energy pulse leads to the micro surface crack on the work surface.

Guu et al. (16) aimed to investigate the machining characteristics of manganese–zinc ferrite magnetic materials using electrical discharge machining process. The experimental results have indicated that the morphology of debris revealed the mechanism of material removal. It has been observed that the better machined surface has been obtained by setting process parameters at low pulse energy.

H Singh et al. (17) The theoretical modeling of the EDM process based upon the heat transfer equations has been established by Singh. In the study, the input energy equation has been developed as a function of pulse duration, current, polarity of electrode and properties of the work piece and tool electrodes. This model has been helpful to calculate the optimal process parameters for obtaining optimum discharge energy.

Fenggou et al. (18) presented a method to automatically determine and optimize the process parameters on the EDM sinking process with the application of artificial neural network [58]. The experimental results have proved that automatic determination of current value would be the efficient method on improving EDM performance.

Caydas et al. (19) developed an adaptive neuro-fuzzy inference system model for the prediction of the surface roughness of machined surface using wire EDM process as a function of process parameters such as open circuit voltage, pulse duration and wire feed rate. From the experimental results, it has been found that the proposed control system has improved the surface quality in EDM process.

Zhou et al. (20) developed an adaptive control system which directly and automatically has regulated the tool down time for improving the process performance in EDM process. It has been observed that this adaptive system would improve the machining rate, due to the automatic adjustment of spark gap.

Yilmaz et al. (21) introduced a used friendly intelligent system based on the knowledge of the skilled operators for the selection of the EDM process parameters for machining AISI 4340 stainless steel. The system has been provided with a compact selection tool based on expert rules and enabled an unskilled user to select necessary parameters which lead to lower electrode wear rate and better surface quality.

Behrens et al. (22) proposed a neuro-fuzzy based gap width controller for a highly efficient removal mechanism in EDM process. The experimental results have indicated that the proposed controller has enhanced EDM process to achieve the better surface finish of workpiece.

Kao et al. (23) monitored the discharge current in electrical discharge machining using high speed data acquisition with high frequency response. From the experimental results, it has been found that decrease in air gap between tool and workpiece has improved the material removal rate in EDM process.

Chang et al. (24) designed a proportional derivative controller of the spark gap between an electrode and a workpiece to analyze the non-linearity involved in EDM process. They concluded that this non-linearity has reduced the effective discharge in electrical discharge machining process.

Tong et al. (25) designed an experimental system with a macro/ micro dual feed spindle to improve the machining performance of servo scanning micro EDM process, which utilized an ultrasonic linear motor as the macro drive and a piezoelectric actuator as micro feeding mechanism. Based on LabVIEW software package, a real time control system has been developed to control coordinately the dual-feed spindle to drive the tool electrode.

Spadlo et al. (26) developed a thermo model for brush electrical discharge alloying process. It has been realized that material removal depends on the discharge current pulse flowing through the dielectric medium.

Salonitis et al. (27) developed the thermal based model for the determination of the material removal rate and average surface roughness achieved as a function of the process parameters in the EDM process.

Liu et al. (28) constructed a plate capacitor model for electrical discharge machining process. The correlation actions of process parameters and energy distribution have been discussed based on the field electron emission theory. It has been observed that machining time plays a major role to improve the process efficiency.

Matoorian et al. (29) presented the application of the Taguchi robust design methods to optimize the precision and accuracy of the EDM process for machining of precise cylindrical forms on hard and difficult-to-machine materials. They found that the current intensity of the EDM process affects the material removal rate greatly.

Muthuramalingam et al. (30) and Mohan developed Taguchi-DEAR methodology based optimization of electrical process parameters.

Tzeng et al. (31) described about the application of the fuzzy logic analysis coupled with Taguchi methods to optimize the precision and accuracy of the high speed electrical discharge machining process. The most important factors affecting the precision and accuracy of the high speed EDM process have been identified as duty cycle and peak current.

Most number of research works have been carried out to optimize the electrical process parameters in EDM process. Marafona et al. (32) described an investigation into the optimization of material removal rate in the electric discharge machining process with copper tungsten tool electrode. From the experimental results, it has been proved that large current intensity would result in higher material removal rate.

R. Landfried et al. (33) conducted an experiment to find the influence of TiC particle size on the material properties and also on electrical discharge machining. They have focused the same of ZTA-TiC ceramics with 24% TiC, 17% ZrO_2 and 59% Al_2O_3. It was shown that reducing the size of electrical conductive grains strongly increases the electrical conductivity and slightly decreases mechanical properties and also it have considerable impact on the machinability by EDM and at the end concluded that the size of the particle should not be reduced below a threshold.

K. Palanikumar et al. (34) studied machining characteristics of WC/Co composites on Electrical Discharge Machining. They have performed experiments on a newly designed experimental set up developed in their own lab using response surface methodology to identify the most influenctial parameters for maximizing metal removal rate and to minimize the surface roughness. Their experiments were carried out using a Box–Behnken experimental strategy. At the end they have concluded that the effect of machining parameters such as flushing pressure, pulse on-time, peak current and electrode rotation on MRR and surface quality of the WC/Co composites was analyzed using 3-D response graphs

M. Merkleina et al. (35) presented a research on influence of machining process on residual stresses in surface of cemented carbides for the purpose of investigation and description of correlation between manufacturing process and surface properties in a quantitative way. During their study they have found that grinding is accompanied by compressive stresses as it achieves higher removal rates and lower surface roughness and also tool geometries of low complexity should be machined by grinding. They have concluded that, both machining methods reveal that hard machined surfaces are not sufficient for application in cold forging. Consequently a final polishing step is required. After fine machining both surface types reveal compressive stresses in the top layer.

Jambeswar Sahu et al (36) applied a approach called DEA for optimization of multiple responses in EDM of AISI D2 steel to select a best process parameters in multi response situation. They have conducted experiments on DSEDM under different conditions of process parameters. During their study, A response surface methodology (RSM) is adopted to establish effect of various process parameters such as discharge current (Ip), Pulse on time (Ton), Duty factor and flushing pressure on four important responses like material removal rate (MRR), tool wear rate (TWR), surface roughness (Ra) and circularity (r1/r2) of machined componentThus, DEA method has the ability to hold the multiplicity of inputs and outputs and an easy optimization technique to find the best alternatives.

Abdus Sabur et al. (37) investigated of MR characteristics in EDM of non conductive ceramics. Electro discharge machining (EDM) technique, a noncontact machining process, is applied for processing nonconductive ceramic ZrO2 using assisting electrode. in this technique, pyrolytic carbon layer on the ceramic surface formed by the cracked carbon from the carbonic dielectric, plays the key role for continuous EDM. In this study, experiments were done to investigate the effect of input power on the material removal rate (MRR) and to explore the material removal mechanism. At the end, the experimental results show that the material is removed in EDM of nonconductive ZrO2 ceramic mostly by spalling and it increases with the increase of input power. They have concluded that, using adhesive copper foil as assisting electrode and copper tool electrode with –ve polarity in kerosene dielectric, EDM of nonconductive ZrO2 ceramic is done effectively and also The material removal can be increased by increasing the input power keeping other parameters constant

Sengottuvel.Pa et al. (38) presented a research paper on optimization of multiple characteristics of EDM parameters for the super alloy Inconel 718 based on desirability approach and fuzzy modeling. They have investigated the effects of various EDM input parameters as well as the influence of different tool geometry on Material Removal Rate(MRR), Tool Wear Rate(TWR) and Surface Roughness(SR) on machining of Inconel 718 material by using copper electrode. Five EDM parameters, namely pulse on time (TON), pulse off time (TOFF), peak current (A), flushing pressure (P) and electrode tool geometry (Geo), were considered here. Tool geometry of the electrodes was circle (C), square (S), rectangle (R) and triangle (T). They have concluded that, higher current (15A) and flushing pressure was preferred. Medium pulse on time was suitable for copper electrode. Rectangular tool geometry was best for copper electrode. The contribution of peak current was high followed by pulse on time. At the end they have concluded that the tool geometry was not the most significant factor to affect the performance measures.

Chinmaya P Mohanty et al. (39) conducted experiments to determine the machinability of Inconel 718 in EDM using a multi objective particle swarm optimization (MOPSO) algorithm. A Box-Behnkin design of response surface methodology has been used to collect data for the study. The machining performances of the process are evaluated in terms of material removal rate (MRR) and surface quality.Their proposed model shows the interactive and complex effects of various important process variables viz. open circuit voltage (V), discharge current (Ip), pulse-on-time (Ton) and tool material on responses justified through experimentation and analysis.

Milan Kumar Dasa et al. (40) applied ABV algorithm for optimization MRR and surface roughness in EDM of EN31 tool steel. For experimentation, they have considered machining parameters viz., pulse on time, pulse off time, discharge current and voltage are varied based on central composite design (CCD). Second order response equations for MRR and surface roughness are found out using response surface methodology (RSM). Empirical equations for MRR and Ra in terms of four important EDM parameters viz. pulse on time, pulse off time, current and voltage are obtained. The optimum values obtained from the analysis show good agreement with that of experimental values. It is seen that MRR and Ra are proportional to pulse on time and discharge current in the experimental regime. Finally, surface morphology is studied using SEM images.

V. Muthukumara et al. (41) presented a Mathematical Modeling for Radial Overcut on Electrical Discharge Machining of Incoloy 800 by Response Surface Methodology. The experiments were planned as per central composite design (CCD) method. After conducting 30 experiments, a mathematical model was developed to correlate the influences of these machining parameters and ROC. The significant coefficients were obtained by performing ANOVA at 5% level of significance. From the obtained results, It was found that current and voltage have significant effect on the radial overcut. The predicted results based on developed models are found to be in good agreement with the predicted values match the experimental results reasonably well with the coefficient of determination 0.9699 for ROC.

M. Munza et al. (42) conducted experiments to find Machinability of ZTA-TiC ceramics by electrical discharge drilling. During their study electrically conductive ceramic ZTATiC composites were machined by EDM drilling with variation of pulse shape, discharge current, discharge time and flushing conditions. Their results show the strong influence of machining parameters on the machining quality, the economical performance and the accuracy of the EDM process. They have concluded that the triangular pulses with a discharge current of 20 A or lower are more suitable for EDM drilling of ZTA-TiC than rectangular pulses, since rectangular pulses do not allow a broad variation of parameters to adjust the parameters fine enough. And also, the drill oversize and the feed rate during machining mainly depend on the correct flushing conditions controlled by the volumetric flow rate.

F. Klockea et al. (43) done Experimental research on the electrochemical machining of modern titanium- and nickel-based alloys for aero engine components. In their paper modern hard to machine alloys for aero engine components were analyzed in terms of their electrochemical machinability. Therefore at first the basic research platform at WZL with the associated ECM-tool has been presented. With the help of this platform the feed rate - current density curves for several titanium and nickel-based alloys have been examined. Experimental results were compared to theory according to Faraday's law and among each other by effective material removal rates. For all analyzed titanium materials the effective material removal rates were almost equal to Veff,Ti ≈ 1.78 $mm^3/(Amin)$. They have concluded that, in case of nickel-based alloys it turned out that the more fine grained the microstructure of the material the better its electrochemical machinability.

M. Iwai et al. (44) examined EDM properties of newly developed PCD made up of electrically conductive diamond particles. They have studied material properties and electrical discharge machinability of EC-PCD. Their result shows that the EC-PCD is superior in heat resistance to conventional PCD by a factor of about 200°C. And the EC-PCD shows low frictional wear at high temperature in a sliding test against a stainless steel disk. They have concluded that the processing speed of EC-PCD is more than 7 times higher than that of conventional PCD in EDM.

M. Iwai et al. (45) presented a research paper on Improvement of EDM properties of PCD with electrode vibrated by ultrasonic transducer. During their series of EDM experiments, three types of ultrasonic vibration modes were selected (axial vibration, flexural vibration and complex vibration). From the experimental results, it was found that EDM efficiency became 3 times higher than the ordinary EDM (no vibration given to the electrode) under the two specific vibration modes, namely, 1) the axial vibration (large) mode and 2) the complex vibration (axial vibration: large + flexural vibration: small) mode. At the end it was shown that the effects resulted from not only the cavitation effect of the working fluid but also the vibrational action of the electrode itself.

Shailesh Dewangan et al. (46) obtained Multi-response optimization of surface integrity characteristics of EDM process using grey-fuzzy logic-based hybrid approach. During their study, grey-fuzzy logic-based hybrid optimization technique is utilized to determine the optimal settings of EDM process parameters with an aim to improve surface integrity aspects after EDM of AISI P20 tool steel. The experiment is designed using response surface methodology (RSM) considering discharge current (Ip), pulse-on time (Ton), tool-work time (Tw) and tool-lift time (Tup) as process parameters. Various surface integrity characteristics such as white layer thickness (WLT), surface crack density (SCD) and surface roughness (SR) are considered during the current research work. Grey relational analysis (GRA) combined with fuzzy-logic is used to determine grey fuzzy reasoning grade (GFRG). They have concluded that the optimal solution based on this analysis is found to be Ip ¼ 1 A, Ton ¼ 10 ms, Tw ¼ 0.2 s, and Tup ¼ 0.0 s. Analysis of variance (ANOVA) results clearly indicate that Ton is the most contributing parameter followed by Ip, for multiple performance characteristics of surface integrity.

R. Teimouri et al. (47) performed Optimization of magnetic field assisted EDM using the continuous ACO algorithm. During their study, a rotary tool with rotary magnetic field has been used to better flushing of the debris from the machining zone in electrical discharge machining (EDM) process. Two adaptive neuro-fuzzy inference system (ANFIS) models have been designed to correlate the EDM parameters to material removal rate (MRR) and surface roughness (SR) using the data generated based on experimental observations. And then continuous ant colony optimization (CACO) technique has been used to select the best process parameters for maximum MRR and specified SR. Experimental trials divided into three main regimes of low energy, the middle energy and the high energy. At the end, results show that the proposed ANSIS models have an acceptable performance to prediction of the MRR and SR in terms of three input parameters.

L. Li et al. (48) presented a paper on Surface Integrity Evolution and Machining Efficiency Analysis of WEDM of Nickel-based Alloy. Their study focused on the evolution process of surface integrity and machining efficiency of W-EDM in machining IN718 by one rough cut (RC) mode followed by three trim cut (TC) modes. Material removal efficiency, surface roughness, surface topography, surface alloying, and micro hard ness have been characterized. Their results show that high material removal efficiency can be achieved in W-EDM. Six-sigma distribution of Ra in RC mode is different from that of TC modes. The high toughness of IN 718 would be the major contributing factor to the absence of micro cracks in the TC modes. Thick white layers (6-8μm) with micro cracks in RC mode and very thin white layers (0-2μm) free of those defects in TC2 mode can be observed, while white layer is nearly invisible in TC3 mode. They have concluded that the micro hardness of white layer in TC mode is higher than that in MC mode.

M. Kunieda et al. (49) preseted a paper on Advancing EDM through Fundamental Insight into the Process. According to them, these EDM phenomena are not in thermal equilibrium, but include transitions between solid, liquid, gas, and plasma, chemical reactions, mass transfer, and displacement of boundaries. they have concluded that, compared to other discharge phenomena such as glow discharge in dry etching processes and arc discharge in welding processes, physics involved in EDM processes are obviously most complicated, rendering observation and theoretical analysis extremely difficult.

Harminder Singh (50) have conducted an Experimental study of distribution of energy during EDM process for utilization in thermal models. During their study they have experimentally calculated the distribution of input discharge energy during electric discharge machining, using heat transfer equations. The results obtained especially of fraction of energy transferred to the workpiece (Fcw) for different machining parameters are in good concurrence with the results obtained by other authors for the effect of Fcw, i.e., MRR, for same combination of electrodes.

Vineet Srivastava et al. (51) conducted Study of ultrasonic assisted cryogenically cooled EDM process using sintered (Cu–TiC) tooltip. During their research, the process performance of sintered copper (Cu)–titanium carbide (TiC) electrode tip in ultrasonic assisted cryogenically cooled electrical discharge machining (UACEDM) has been studied. The performance parameters studied are electrode wear ratio (EWR), material removal rate (MRR), surface roughness (SR), out of roundness and surface integrity. During their work, cermet electrode tip of sintered copper (Cu)- titanium carbide (TiC) was successfully fabricated and brazed with copper rods to perform as electrodes. At the end the electrodes with modified tooltip were tested for UACEDM process and compared with electrodes having Cu tooltip.

M.P. Jahan et al (52) presented a paper on a study on the fine-finish die-sinking micro-EDM of tungsten carbide using different electrode materials. During their study, investigations have been conducted with view of obtaining fine surface finish in the micro-EDM of WC using tungsten (W), copper tungsten (CuW) and silver tungsten (AgW) electrodes and it was found that the surface characteristics are dependent mostly on the discharge energy during machining. The fine-finish micro-EDM requires minimization of the pulse energy supplied into the gap. In addition, the surface finish was found to be influenced greatly by the electrical and thermal properties of the electrode material. And also the performance of the electrodes for the finishing micro-EDM was evaluated based on the achieved surface roughness and surface characteristics with respect to material removal rate (MRR) and electrode wear ratio (EWR) and it was found that AgW electrode produces smoother and defect-free nano surface with the lowest Ra and Rmax among the three electrodes. They have concluded that a minimum amount of material migrates from the AgW electrode to the WC work piece during the finishing micro-EDM.

J. Murray et al. (53) presented a paper on Work piece debris deposition on tool electrodes and secondary discharge phenomena in micro-EDM. Their work furthers the understanding of the little understood discharge gap phenomena by investigating the attachment of machined material back onto the tool electrode surface and explains the mechanism of this attachment. After the machining of high-aspect ratio slots, SEM and EDS techniques along with single discharge and cross-sectional analysis were used to explain that debris reattachment onto the tool electrode does not occur randomly but is dependent on its re-melting in the dielectric by the secondary discharge process. They have concluded that the bonded material is present mainly in the centre of the discharge crater, with no attachment occurring outside of discharge affected regions.

Yin Qingfeng et al.(54) conducted a Research of lower tool electrode wear in simultaneous EDM and ECM. In their manuscript, a new method to reduce the electrode wear and suppress excessive electrolytic-erosion is investigated. Electrolyte with a much higher conductivity than deionized water is utilized as machining fluid in the method, while electro-deposition is used to compensate for tool electrode wear in the processing. Besides, nanosecond voltage pulse and tool electrode with side-insulation are adopted to suppress excessive electrolytic-erosion. Experiment results show that this new method can reduce electrode wear and suppress excessive electrolytic-erosion effectively. And concluded that Excessive electrolytic-erosion can be suppressed in SEDCM by using tool electrode with side-insulation.

S. Dewangan et al. (55) presented a paper on Study of Surface Integrity and Dimensional accuracy in EDM using Fuzzy TOPSIS and Sensitivity Analysis. Their work aims at investigating the influence of various EDM process parameters like pulse current (Ip), pulse-on time (Ton), tool work time (Tw) and tool lift time (Tup) on various aspects of surface integrity like white layer thickness (WLT), surface crack density (SCD) and surface roughness (SR). The dimensional accuracy, characterized by over cut (OC), has also been studied in the similar way. A response surface methodology (RSM) - based design of experiment has been considered for this purpose. Their study also recommends an optimal setting of EDM process parameters with an aim to improve surface integrity aspects after EDM of AISI P20 tool steel. That was achieved by simultaneous optimization of multiple attributes (i.e. WLT, SCD, SR and OC) using Fuzzy-TOPSIS-based multi-criteria decision making (MCDM) approach. The optimal solution was obtained based on five decision makers' preferences on the four responses (i.e. WLT, SCD, SR, and OC. Furthermore, sensitivity analysis is also carried out to study the sensitivity or robustness of five decision makers' preference of optimal machining parameters. Form their study, decision makers' preference for surface crack density has been found to be the most sensitive response and therefore should be chosen first and analyzed very carefully.

M Manohara et al. (56) conducted an Experimental study to assess the effect of Electrode bottom profiles while machining Inconel 718 through EDM Process. During their study, it was observed that the bottom surface profile of the electrode was contributing towards many aspects like Material Removal Rate (MRR), Electrode Wear Rate (EWR), surface roughness and surface integrity. Certainly such process improvements would contribute a lot in the shop-floor in terms of productivity and product-quality, while machining Inconel 718 alloy. It was concluded that the adverse effects caused due to the erosion of flat profile electrodes on the machined surfaces could be overcome by employing convex profile electrodes; concave profile electrodes almost simulate the condition of eroded flat-profile electrode; convex profile electrodes produce machined surfaces of better quality in terms of higher surface finish, thinner recast-layer and closer geometry, in addition to higher MRR compared to flat profile or concave profile electrodes.

Mao-yong LIN et al. (57) presented a research paper on Optimization of electrical discharge machining of Inconel 718 by Grey-Taguchi method. The optimization of electrical discharge machining (EDM) process parameters of Inconel 718 alloy was done to achieve multiple performance characteristics such as low electrode wear, high material removal rate and low working gap was investigated by the Grey-Taguchi method. The influences of peak current, pulse on-time, pulse off-time and spark gap on electrode wear (EW), material removal rate (MRR) and working gap (WG) in the electrical discharge machining of Inconel 718 were analyzed.

Peng-fei BAI et al (58) presented a paper on Solid-phase sintering process and forced convective heat transfer performance of porous-structured micro-channels. According to them, a solid-phase sintering process for the low-cost fabrication of composite micro-channels was developed. Three kinds of composite micro-channels with metallic porous structures were designed. The sintering process was studied and optimized to obtain porous-structured micro-channels with high porosity. The flow resistance and heat transfer performance in the composite micro-channels were investigated. At the end, the composite micro-channels show acceptable flow resistance, significant enhancement of heat transfer and dramatic improvement of flow boiling stability, which indicates a promising prospect for the application in forced convective heat transfer.

III. CONCLUSION

Good number of researchers have worked on the study of various concepts of EDM process. The review of the research trends in EDM in different concepts and research trends of EDM along with the various methods of optimization is presented. The remarkable machining rates have been achieved mostly with the tap water. Machining with water acting as dielectric has the possibility to achieve zero electrode wear while using copper tool is connected to the negative polarity. Surface roughness of the Work piece is also dependent on the type of dielectric fluid. It produced with deionised water is generally lower than that with hydrocarbon oils. Various methods have been used for optimization like DOE, RSM, ANOVA, GFRG, GRA, ANFIS, CACO and DEA with input parameters like pulse current (Ip), pulse-on time (Ton), tool work time (Tw) and tool lift time (Tup) on various aspects for the output parameters like Material Removal Rate (MRR), white layer thickness (WLT), surface crack density (SCD), working gap (WG), Electrode wear (EW) , overcut (OC) and surface roughness (SR).

REFERENCES

[1] M. Gostimirovic, P. Kovac, B. Skoric, M. Sekulic, Effect of electrical process parameters on the machining performance in EDM, Indian Journal of Engineering and Materials Sciences 18 (2012) 411–415.
[2] I. Puertas, C.J. Luis, L. Alvarez, Analysis of the influence of EDM parameters on surface quality, MRR and EW of WC-Co, Journal of Materials Processing Technology 153/154 (2004) 1026–1032.
[3] K.M. Patel, P.M. Pandey, P.V. Rao, Surface integrity and material removal mechanisms associated with the EDM of Al2O3 ceramic composite, International Journal of Refractory Metals and Hard Materials 27 (2009) 892–899.
[4] A. Yahya, C.D. Manning, Determination of material removal rate of an electro discharge machine using dimensional analysis, Journal of Physics D: Applied Physics 37 (2004) 1467–1471.
[5] K.M. Patel, P.M. Pandey, P.V. Rao, Understanding the role of weight percentage and size of silicon carbide particulate reinforcement on electro-discharge machining of aluminium based composites, Materials and Manufacturing Processes 23 (2008) 665–673.
[6] N. Pelicer, J. Ciurana, T. Ozel, Influence of process parameters and electrode geometry on feature micro-accuracy in electro discharge machining of tool steel, Materials and Manufacturing Processes 24 (2009) 1282–1289.
[7] P. Kuppan, A. Rajadurai, S. Narayanan, Influence of EDM process parameters in deep hole drilling of Inconel 718, International Journal of Advanced Manufacturing Technology 38 (2008) 74–84.
[8] D. Wang, W.S. Zhao, L. Gu, X.M. Kang, A study on micro hole machining of poly crystalline diamond by micro- electrical discharge machining, Journal of Materials Processing Technology 211 (2011) 3–11.
[9] A. Batish, A. Bhattacharya, V.K. Singla, G. Singh, Study of material transfer mechanism in die steels using powder mixed electric discharge machining, Materials and Manufacturing Processes 27 (2012) 449–456.
[10] M.P. Jahan, Y.S. Wong, M. Rahman, A study on the quality micro-hole machining of tungsten carbide by micro-EDM process using transistor and RC-type pulse generator, Journal of Materials Processing Technology 209 (2009) 1706–1716.
[11] S.H. Yeo, P.C. Tan, E. Aligiri, S.B. Tor, N.H. Loh, Processing of zirconium based bulk metallic glass using micro electrical discharge machining, Materials and Manufacturing Processes 24 (2009) 1242–1248.
[12] A.K. Khanra, L.C. Pathak, M.M. Godkhindi, Micro analysis of debris formed during electrical discharge machining, Journal of Materials Science 42 (2007) 872–877.
[13] M.S. Popa, G. Contiu, G. Pop, P. Dan, New technologies and applications of EDM process, The International Journal of Material Forming 2 (2009) 633–636.
[14] A. Kojima, W. Natsu, M. Kunieda, Spectroscopic measurement of arc plasma diameter in EDM, CIRP Annals – Manufacturing Technology 57 (2008) 203–207.
[15] Y.S. Wong, M. Rahman, H.S. Lim, H. Han, N. Ravi, Investigation of micro-EDM material removal characteristics using single RC-pulse discharges, Journal of Materials Processing Technology 140 (2003) 303–307.
[16] Y.H. Guu, K.L. Tsai, L.K. Chen, An experimental study on electrical discharge machining of manganese–zinc ferrite magnetic material, Materials and Manufacturing Processes 22 (2007) 66–70.
[17] H. Singh, Experimental study of distribution of energy during EDM process for utilization in thermal models, International Journal of Heat and Mass Transfer 55 (2012) 5053–5064.
[18] C. Fenggou, Y. Dayong, The study of high efficiency and intelligent optimization system in EDM sinking process, Journal of Materials Processing Technology 149 (2004) 83–87.

[19] U. Caydas, A. Hascalik, Modeling and analysis of electrode wear and white layer thickness in die-sinking EDM process through response surface methodology, International Journal of Advanced Manufacturing Technology 38 (2008) 1148–1156.
[20] M. Zhou, F. Han, Adaptive control for EDM process with a self tuning regulator, International Journal of Machine Tools and Manufacture 49 (2009) 462–469.
[21] O. Yilmaz, O. Eyercioglu, N.N.Z. Gindy, A user friendly fuzzy based system for the selection of electro discharge machining process parameters, Journal of Materials Processing Technology 172 (2006) 363–371.
[22] A. Behrens, J. Ginzel, Neuro-fuzzy processes control system for sinking EDM, Journal of Manufacturing Processes 5 (2003) 33–39.
[23] C.C. Kao, A.J. Shih, Sub-nano second monitoring of micro-hole electrical discharge machining pulses and modeling of discharge ringing, International Journal of Machine Tools and Manufacture 46 (2006) 1996–2008.
[24] X.F. Chang, Mixed H2/H1 optimization approach to gap control on EDM, Control Engineering Practice 13 (2005) 95–104.
[25] H. Tong, Y. Li, Y. Wang, D. Yu, Servo scanning 3D micro-EDM based on macro/micro dual feed machine, International Journal of Machine Tools and Manufacture 48 (2008) 858–869.
[26] S. Spadlo, J. Kozak, P. Mlynarczyk, Mathematical modelling of the electrical discharge mechanical alloying process, Procedia CIRP 6 (2013) 423–427.
[27] K. Salonitis, A. Stournaras, P. Stavropoulos, G. Chryssolouris, Thermal modeling of the material removal rate and surface roughness for die-sinking EDM, International Journal of Advanced Manufacturing Technology 40 (2009) 316–323.
[28] S. Liu, Y. Huang, Y. Li, A plate capacitor model of the EDM process based on the field emission theory, International Journal of Machine Tools and Manufacture 51 (2011) 653–659.
[29] P. Matoorian, S. Sulaiman, M.M.H.M. Ahmed, An experimental study for optimization of electrical discharge turning process, Journal of Materials Processing Technology 204 (2008) 350–356
[30] T. Muthuramalingam, B. Mohan, Multi response optimization of electrical process parameters on machining characteristics in EDM using Taguchi-DEAR methodology, Journal of Engineering Technology 3 (2013) 57–60.
[31] Y.F. Tzeng, F.C. Chen, Multi objective optimisation of high speed electrical discharge machining process using Taguchi fuzzy based approach, Materials and Design 28 (2007) 1159–1168.
[32] J. Marafona, C. Wykes, A new method of optimizing material removal rate using EDM with copper–tungsten electrodes, International Journal of Machine Tools and Manufacture 40 (2000) 153–164.
[33] R. Landfried □, F. Kern, R. Gadow, Electrically conductive ZTA–TiC ceramics: Influence of TiC particle size on material properties and electrical discharge machining, Institut für Fertigungstechnologie keramischer Bauteile, Universität Stuttgart, Allmandring 7b, D-70569 Stuttgart, Germany
[34] K. Palanikumar and J. Paulo Davim, Electrical discharge machining: study on machining characteristics of WC/Co composites , Published by Woodhead Publishing Limited, 2013
[35] M. Merkleina & K. Andreasa, Influence of machining process on residual stresses in the surface of cemented carbides, 1st CIRP Conference on Surface Integrity (CSI), 2012 Published by Elsevier Ltd.
[36] Jambeswar Sahu, Chinmaya P. Mohanty & S.S. Mahapatra, A DEA approach for optimization of multiple responses in Electrical Discharge Machining of AISI D2 steel, Chemical, Civil and Mechanical Engineering Tracks of 3rd Nirma University International Conference on Engineering (NUiCONE 2012), Procedia Engineering 51 (2013) 585 – 591
[37] Abdus Sabur,* Mohammad Yeakub Ali, Md. Abdul Maleque, Ahsan Ali Khan, Investigation of material removal characteristics in EDM of nonconductive ZrO2 ceramic, 5th BSME International Conference on Thermal Engineering, © 2012 The authors, Published by Elsevier Ltd.
[38] Sengottuvel.Pa*, Satishkumar.Sb, Dinakaran.Dc, Optimization Of Multiple Characteristics Of EDM Parameters Based On Desirability Approach And Fuzzy Modeling, International Conference On DESIGN AND MANUFACTURING, IConDM 2013, Procedia Engineering 64 (2013) 1069 – 1078, © 2013 The Authors. Published by Elsevier Ltd.
[39] Chinmaya P Mohanty*, Siba Shankar Mahapatra, Manas Ranjan Singh, An Experimental Investigation of Machinability of Inconel 718 in Electrical Discharge Machining, 3rd International Conference on Materials Processing and Characterisation (ICMPC 2014), Procedia Materials Science 6 (2014) 605 – 611
[40] Milan Kumar Dasa, Kaushik Kumarb, Tapan Kr. Barmana*and Prasanta Sahooa, Application of Artificial bee Colony Algorithm for Optimization of MRR and Surface Roughness in EDM of EN31 tool steel, 3rd International Conference on Materials Processing and Characterization (ICMPC 2014), Procedia Materials Science 6 (2014) 741 – 751
[41] V. Muthukumara*, N. Rajesha, R. Venkatasamya, A. Sureshbabub , N. Senthilkumarc, "Mathematical Modeling for Radial Overcut on Electrical Discharge Machining of Incoloy 800 by Response Surface Methodology, 3rd International Conference on Materials Processing and Characterization (ICMPC 2014), Procedia Materials Science 6 (2014) 1674 – 1682
[42] M. Munza, M. Ristoa, R. Haasa, R. Landfriedb*, F. Kernb, R. Gadowb, "Machinability of ZTA-TiC ceramics by electrical discharge drilling", The Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM), Procedia CIRP 6 (2013) 77 – 82

[43] F. Klockea, M. Zeisa,*, A. Klinka, D. Veselovaca, " Experimental research on the electrochemical machining of modern titanium- and nickel-based alloys for aero engine components", The Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM), Procedia CIRP 6 (2013) 368 – 372

[44] M. Iwaia*, S. Ninomiyab, K. Suzukib, "EDM properties of newly developed PCD made up of electrically conductive diamond particles", The Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM), Procedia CIRP 6 (2013) 140 – 145

[45] M. Iwai, S. Ninomiya, K. Suzuki, " Improvement of EDM properties of PCD with electrode vibrated by ultrasonic transducer", The Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM), Procedia CIRP 6 (2013) 146 – 150

[46] Shailesh Dewangan, Soumya Gangopadhyay*, Chandan Kumar Biswas 1, Multi-response optimization of surface integrity characteristics of EDM process using grey-fuzzy logic-based hybrid approach ,Engineering Science and Technology, an International Journal xxx (2015) 1e8

[47] R. Teimouri & H. Baseri, Optimization of magnetic field assisted EDM using the continuous ACO algorithm, Applied Soft Computing 14 (2014) 381–389

[48] L. Li*, X.T. Wei, Z.Y. Li, Surface Integrity Evolution and Machining Efficiency Analysis of WEDM of Nickel-based Alloy

[49] M. Kunieda, B. Lauwers, K. P. Rajurkar, B. M. Schumacher, Advancing EDM through Fundamental Insight into the Process.

[50] Harminder Singh, Experimental study of distribution of energy during EDM process for utilization in thermal models, International Journal of Heat and Mass Transfer 55 (2012) 5053–5064

[51] Vineet Srivastava, Pulak M. Pandey, Study of ultrasonic assisted cryogenically cooled EDM process using sintered (Cu–TiC) tooltip

[52] M.P. Jahan, Y.S. Wong, M. Rahman∗, A study on the fine-finish die-sinking micro-EDM of tungsten carbide using different electrode materials, journal of materials processing technology 2 0 9 (2 0 0 9) 3956–3967.

[53] J. Murray, D. Zdebski, A.T. Clare, Workpiece debris deposition on tool electrodes and secondary discharge phenomena in micro-EDM, Journal of Materials Processing Technology 212 (2012) 1537– 1547

[54] Yin Qingfeng∗, Wang Baorui, Zhang Yongbin, Ji Fang, Liu Guangmin," Research of lower tool electrode wear in simultaneous EDM and ECM, Journal of Materials Processing Technology 214 (2014) 1759–1768

[55] S. Dewangan,S. Gangopadhyay and C. K. Biswas, Study of Surface Integrity and Dimensional accuracy in EDM using Fuzzy TOPSIS and Sensitivity Analysis

[56] M Manohara, T Selvarajb , D Sivakumara, Shibu Gopinatha and Koshy M Georgea, Experimental study to assess the effect of Electrode bottom profiles while machining Inconel 718 through EDM Process, 3rd International Conference on Materials Processing and Characterisation (ICMPC 2014), Procedia Materials Science 6 (2014) 92 – 104

[57] Mao-yong LIN , Chung-chen TSAO, Chun-yao HSU, Ai-huei CHIOU, Peng-cheng HUANG, Yu-cheng LIN, Optimization of micro milling electrical discharge machining of Inconel 718 by Grey-Taguchi method, Trans. Nonferrous Met. Soc. China 23(2013) 661−666

[58] Peng-fei BAI, Zi-chuan YI, Biao TANG, Guo-fu ZHOU, Solid-phase sintering process and forced convective heat transfer performance of porous-structured micro-channels, Trans. Nonferrous Met. Soc. China 24(2014) 900−906

