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A Review on Optimization of Machining Parameters in ECDM

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Abstract - *Electrochemical Discharge Machining is unconventional hybrid machining process which combines the features of electrochemical machining (ECM) and electro discharge machining (EDM). This machining process is able to machine hard and brittle non-conductive materials such as glass, ceramics, refractory bricks, quartz, composite materials and electrically conductive materials such as steel, copper, tungsten etc. Features with high aspect ratio and complicated geometry can be created by Electrochemical Discharge Machining. Electrochemical Discharge Machining (ECDM) find a wide range of applications in advanced industries like Nuclear reactor, Automobiles, Aeronautic, MEMS. This paper reviews various notable works related with the effective parameters of ECDM and optimization of parameters by different optimizing techniques, also gives future scope in the Electrochemical Discharge Machining.*

***Key Words*: Electrochemical Discharge Machining, MRR, TWR, Taguchi methodology.**

1. INTRODUCTION

Electrochemical Discharge Machining is a non-conventional machining process which is used for machining conductive and non-conductive brittle materials which are difficult to machine by conventional machining process. ECDM can be used in machining complicated shapes, groove, channels, micro holes, and micro cavities. ECDM is characterized in its work result by high material removal rate of the work piece material, low tool wear rate, reduced machining time, and low surface roughness of the produced features.

1.1 Working Principle of ECDM

A work piece is immersed in an electrolyte solution. The tool-electrode is dipped a few mm in the electrolytic solution. Tool electrode material must be conductor of electricity. A servomechanism maintains a space of about the thickness of a human hair between the tool electrode and the workpiece, preventing them from contacting each other. The counter electrode has a much larger surface than the tool. When the D.C. voltage supply is applied between the tool-electrode and the counter-electrode causes the flow of electric current through the electrolytic cell, electrolysis happens. When the voltage is increased, the density of sparks increases and more and more bubbles grow, developing Hydrogen gas bubble layer around the tool and Oxygen bubbles layer around the counter electrode. Sparking phenomena is observed in the film where electrical discharges happen between the tool-electrode and the surrounding electrolyte. The work piece is heated by the spark energy which raises the local spot temperature to a very high value, sufficient for melting and vaporization. The spark generation along with electrochemical action results in the material removal. The performance of ECDM process is objective function of material removal rate, tool wear rate, radial overcut and surface roughness; subject to process parameters like electrolyte concentration, voltage, current, inter-electrode gap, pulse-on-time, tool feed rate, rotational speed of tool, duty factor, tool-workpiece gap, machining time, and tool tip geometry. The basic components of Electrochemical Discharge Machine are the tool electrode (cathode), counter-electrode (anode), tool holder, power supply, servomechanism, controller, electrolyte solution, work piece, machining chamber and machining table. There are various types of electrodes used in research work such as Copper, Stainless Steel, HSS, Tungsten Carbide, Tungsten etc. The counter-electrodes used for research work are Zinc, Copper, Platinum, Graphite, Steel, Carbon etc. The work pieces used for research work are Borosilicate glass, Pyrex glass, Soda-lime glass, Quartz, Stainless Steel, Copper, Brass, Silicon, Alumina, Tungsten Carbide, Tungsten etc. Commonly used electrolytes are Sodium Hydroxide (NaOH), Potassium

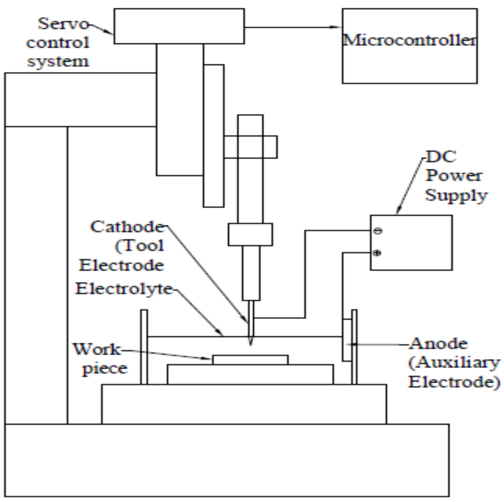

Fig-1: Electrochemical discharge machining schematic setup.

Hydroxide (KOH), Sodium Chloride (NaCl), Sodium Nitrate ($NaNO_3$) etc.

2. LITERATURE SURVEY

Mohit Sharma et al. [1] fabricated experimental set up of ECDM process. Aqueous solution of NaOH was used as an electrolyte. Chemically immune glass was used as work piece material. High Speed Steel (HSS) electrode was used as a tool. Taguchi and ANOVA method were used to optimize the machining parameters. They have reported that applied voltage, electrolyte concentration and inter-electrode gap significantly affect the MRR. Applied voltage has a contribution of 57.74 % and 37.07 % contribution of Electrolyte concentration, for affecting the Material Removal Rate (MRR). Maximum MRR was obtained, at applied voltage of 60V, electrolyte concentration of 25 % and inter-electrode gap of 60 mm.

Sumit K. Jui et al. [2] investigated on high aspect ratio micro tools made up of tungsten carbide, used to drill deep micro holes on Borosilicate glass using steel as an anode. Surface features less than 100 um have been successfully machined. They have revealed that lower electrolyte concentration reduces overcut by 22%, thus increasing the aspect ratio of the micro holes and rotation of the tool electrode improves the circularity of the machined hole. The surface roughness of machined hole was found to be in the range of 250–350 nm. Lower electrolyte concentration reduced tool wear and hole taper by 39% and 18% respectively. An aspect ratio of 11 was achieved with 1 M NaOH, voltage setting at 40V, 30 µm tungsten carbide tool feed at 1 µm/s.

Mohammad Reza Razfar et al. [3] investigated on longitudinal oscillation applied to the cathode electrode during the electrochemical discharge micro drilling of Soda-lime glass and the effects of vibration parameters including vibration amplitude, vibration frequency and vibration waveform on machining speed and the achieved hole depth were examined. According to the results, the vibration does not have significant effect on the process while a rotating micro drill is used as the cathode electrode. In the case of the cylindrical rod, when a square waveform voltage is applied, resulting vibration improves the MRR up to 40% and deeper holes can be achieved in less machining time. Moreover, the results showed that applying voltage with sinusoidal waveform to the cylindrical rod has somewhat good effect on the MRR and can make maximum 20 % improvement in MRR of the ECDM process. Solution of NaOH was used as an electrolyte. Tungsten Carbide and stainless steel were used as cathode and an auxiliary electrode respectively.

Cheng Kuang Yang et al. [4] made an attempt to solve problem that both machining time and hole entrance diameter were found to increase with increasing machining depth, the increase becomes drastic when machining depth exceeds 250 µm. They have explored that the curved surface of the spherical tool electrode facilitates the flow of electrolyte to the electrode end, and enables rapid formation of gas film resulting in efficient micro-hole drilling so spherical tool electrode has advantages in enhancing both machining performance and shape accuracy of the micro hole. Tungsten carbide and graphite electrodes were used as an anode and cathode respectively. The results indicate that using spherical tool electrode, machining time was reduced by 83% while hole diameter was decreased by 65%.

Xuan Doan Caoa et al. [5] investigated on micro ECDM process in order to improve the machining of 3D micro-structures of soda-lime and Pyrex glass. Various micro-structures less than 100 µm in size such as Ø 60 µm micro-holes, a 10 µm-thin wall and 3D micro-structure were fabricated to demonstrate the potential for micro-machining of glass by ECDM. Solutions of NaOH and KOH were used as electrolyte. Platinum and tungsten electrodes were used as an auxiliary electrode and a tool respectively. The effects of the electrolyte, the pulse on/off-time ratio, the voltage, the feed rate, the rotational speed and the electrolyte concentration in the drilling and milling processes were studied for glass. Use of pulse voltage reduces hole size and improves surface quality. The smallest hole size was obtained in KOH (30 wt %) and the machining time was 17–18 min.

Sathisha N. et al. [6] developed the empirical models for grooving (channels) and drilling (holes) process of ECDM using Regression Analysis (RA) and the Artificial Neural Network (ANN) to predict the MRR. According to results, the prediction of ANN model for MRR for grooving is better as compared to the Regression model. ANOVA was used to identify the significant affect of process parameters. Electrolyte concentration is the significant factor for the maximization of MRR. Results indicated that 30% of electrolyte concentration, 60V of voltage, 0.03 mm of SOD is the optimal parameter combination for ECDM of soda-lime glass.

M. L. Harugade et al. [7] conducted experiments on ECDM according to Taguchi method (L9 array) to identify the effect of electrolyte solution on MRR. They have reported relative contributions of the main machining parameters, such as applied voltage, electrolyte concentration and inter-electrode gap. Copper electrodes were used as an anode and cathode. They have revealed that applied voltage is most influential parameter for MRR and electrolyte concentration is a secondary fact of concern affecting the MRR in ECDM of Soda-lime glass. For KOH electrolyte solution sparking rate is higher than the H_2SO_4; resulting in higher MRR.

Sanjay K. Chak and P. Venkateswara Rao [8] proposed ECDM of Aluminium oxide (Al_2O_3) ceramic by trepanning method and shown the possibility of drilling large size holes by comparatively smaller electrodes. KOH was used as an electrolyte solution and graphite as an anode. At greater machining depth, machining performance gradually deteriorates. To reduce this problem, a spring fed cylindrical abrasive electrode of 1.5 mm diameter has been used under the effect of parameters, namely, pulsed DC voltage, duty factor and electrolyte conductivity, to assess MRR, machined depth and diametric overcut. The results revealed that pulsed DC reduces the tendency of cracking at high voltage compared to smooth DC. Trepanning provides the scope for drilling deeper and bigger holes.

Baoyang Jianga et al. [9] established finite element based model to correlate spark energy and the geometry of removed material and concluded that the prediction of material removal in ECDM (drilling) is reasonable in terms of diameter and maximum depth of deeper holes. Energy of each spark generated was measured. The energy distribution proved that tapered tool improved the consistency of spark generation and suppressed the generation of minor discharges. The average energy for sparks was 3.8 mJ with 34 V electrode voltage. Tapered tool electrodes of tungsten were fabricated by ECM. Solution of NaOH was used as an electrolyte and stainless steel as an anode. Material removal was treated as heat transfer problem because electrical energy released by spark generation transfers into thermal energy on the work piece. Electrode voltage directly affects the machining efficiency, if the electrode voltage is too high, thermal cracks tend to happen.

Y.S. Laioa et al. [10] investigated the effects of Sodium Dodecyl Sulfate (SDS) surfactant added electrolyte on ECDM of quartz. Tungsten was used as tool material and KOH solution as an electrolyte. Experimental results revealed that; when the current density increases, and there is more bubble release around the electrode as compared with machining in the electrolyte without SDS. As a result, a less taper and a better quality but a little over size hole can be drilled with a higher engraving speed and certain electric power could be saved since less time is consumed for drilling.

Lijo Paul and Somashekhar S. Hiremath [11] investigated the effect of ECDM process parameters on MRR by conducting experiments according to Taguchi L9 orthogonal array. Tungsten carbide wire was used as a cathode and Graphite as an anode cathode to produce blind holes. Borosilicate glass has been applied as a work piece. Voltage, duty factor and concentration are taken as process parameters and reported optimum values as; voltage of 60V, electrolyte concentration of 30% wt and duty factor of 70%. MRR was found to be nonlinear. Response Surface Modeling (RSM) method was used to mathematically model the MRR and tool wear rate (TWR). The results revealed that MRR increases with duty factor, electrolyte concentration, voltage; and radial overcut decreases with increase in voltage, electrolyte concentration and duty factor. TWR is found to decrease with increase in concentration and increase with rise in voltage as most of heat will be dissipated through tool materials than through work piece or electrolyte.

V.K. Jain et al. [12] investigated on the mechanism of material removal in electrochemical spark abrasive drilling (ECSAM) of electrically non-conducting material like alumina and glass. Solution of NaOH was used as electrolyte. Abrasive cutting tool and Conventional cutting tools made of Mild steel were used as tool electrode. Response Surface Equations were obtained for evaluating MRR (in mg) with conventional cutting tool and abrasive cutting tool by varying supply voltage and electrolyte temperature. The results revealed that machining performance (both in terms of MRR and machined depth) of the ECSAM process using abrasive cutting tools keeps improving with an increase in supply voltage and temperature of the electrolyte.

Chih-Ping Cheng et al. [13] pointed out, while fabricating micro holes and micro channels on Pyrex work piece by spark-based electrochemical machining process; at the transition voltage, a stable electrochemical discharge activity could be generated, thus producing the smallest deviation of contour dimensions. Quality of gas film is the dominant factor that determines the machining qualities such as geometric accuracy, surface roughness and repeatability, current signals and machined contours were taken as indexes of gas film quality. The study has been carried out for different parameters like electrolyte concentration, voltage, electrolyte concentration, gas film quality and rotational speed of tool. KOH was used as an electrolyte solution. Tungsten Carbide and graphite plates were used as cathode and an auxiliary electrode respectively. It was observed that using the flat side wall tool instead of the cylindrical tool can mitigate the deterioration of gas film quality, which in turn enhances machining efficiency and accuracy.

V.K. Jaina and S. Adhikary [14] investigated the electrochemical spark machining (ECSM) process for cutting (grooving) of quartz using a controlled feed and a wedge edged copper tool; for different parameters like electrolyte concentration, voltage. Solution of NaOH was used as an electrolyte. ECSM with reverse polarity (ECSMWRP) cuts quartz plate at faster rate as compared to ECSM with direct polarity (ECSWDP), but produces higher overcut, higher tool wear and higher surface roughness. Both cathode and anode have been used as a tool. Chemical analysis of electrolyte solution, agrees with the feasibility of dissolution of quartz into solution due to chemical reaction. The conclusion carried out from this work was, the cutting is possible even if we make auxiliary electrode of small size and material removal in ECSMWRP is due to melting, vaporization and chemical reaction on quartz.

N. Sathisha et al. [15] conducted experiments to optimize ECDM response parameters like MRR and TWR to get the combination of significant process parameters (tool-work piece gap, voltage and electrolyte concentration) using Taguchi L9 orthogonal array with Grey relational analysis. The electrolyte used was solution of sodium hydroxide. Stainless steel and zinc plates were used as cathode and anode electrodes respectively to groove on soda-lime glass.

From ANOVA, they have reported that the percentage contribution of the Tool-Work piece gap is (96.9%) and showed the greatest impact on MRR and TWR. The Tool-Work piece gap of 0.015 mm, electrolyte concentration (weight %) and voltage of 50V was found the significant parameters combination.

Jana D. Abou Ziki et al. [16] investigated on the forces exerted on the tool-electrode during SACE Micro-drilling, for different tool feed-rates (1–80 mm/s), machining voltages (30 and 33V) and tool sizes. Less discharges occur at the tip resulting in poor heat transfer from the tool-electrode to the work-piece. The results revealed that for low depths, the rate limiting step is the work-piece face heating while for high depths it is the electrolyte (NaOH) flushing. A correlation between the force occurrence and the current signal is identified. This finding allows the usage of the current signal to detect the contact between the tool and the glass surface. Soda-lime glass has been applied as work piece material. Stainless steel electrode is used as cathode and anode.

Min Seop Han et al. [17] investigated on a new method to improve the surface integrity of ECDM process, used to fabricate glass micro surface. Borosilicate glass was used as work piece material and tungsten carbide as a tool electrode. Experiment results presented the product quality with respect to volume ratio of graphite powder mixed with electrolyte. It has been reported that the powder stabilizes discharge current as a result of discharge energy dispersion and reduces the critical breakdown strength resulting in the decreased spark energy per single discharge pulse. Experiment results showed that the use of electrolyte mixed with conductive particle improved the surface integrity of ECDM process. By use of 1.0 weight % graphite powder concentration in 30 wt% NaOH, the number of micro cracks was significantly reduced and the surface roughness was improved from 4.86 to 1.44 µm.

3. CONCLUSIONS

This paper is review of the relevant literature on materials, processing conditions and effective parameters in ECDM. The review reveals, many researchers have attempted primarily glass as the work material, however, there is hardly any resemblance in the relevant conditions and hence results. On further analysis of the experimental results through design of experiments, it was found that all the selected process parameters were significant. The applied voltage was the most influencing parameter for Material removal rate. Electrolyte concentration is the secondary parameter affecting the Material Removal Rate and Tool wear. From literature review, it is observed that, there is some work done on various work pieces which are difficult to be machined by conventional machining. More work need to done on the optimization of parameters for better performance of Electrochemical Discharge Machining.

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