Performance enhancement of ECDM process on Al_2O_3 ceramics using tubular tool

M. R. Dhanvijay, B. B. Ahuja

Abstract— The ECDM process is mostly applied for machining non- conducting engineering ceramic material, such as aluminum oxides, zirconium oxides, and silicon nitrides, etc. Experiments on ECDM have been carried out according to designed experimental plan 9 data points on identified optimal parametric conditions of ECDM process found by Taguchi method of parametric optimization these are applied voltage (65 V), Duty factor (0.8), concentration of electrolyte (50 wt.%) and concentration of powder (2 wt.%). In this study, the signal-to-noise ratio for material removal rate and overcut were analyzed by Anderson-Darling Normality test. The improvement in overcut was achieved but needs more investigation in material removal rate.

Index Terms— Electrolyte, Anderson-Darling Normality test, MRR, OC, EDM, ECM, ECDM

1. INTRODUCTION

Hard materials are difficult to processes using traditional machining methods. ECM and EDM are processes better suited to process hard to cut, tough materials. Difficult to machine geometries can be machined using EDM and ECM. Faraday's laws of electrolysis define the material removal in ECM. The material removal rate is a product of the electrochemical equivalent of the metal and the current passed. The EDM process is a thermal process in which removal metal takes place by erosive effects of discharges. The metal removal rate is proportional to the product of the current and pulse duration. Although ECM and EDM differ in their concepts of metal removal, the similarities in their machining configuration have led to the development of a combined process.

The main advantages of ECDM over ECM or EDM are:

1. Machining rate would be higher if both ECM and EDM could occur during the same machining period.
2. The presence of an ECM phase in ECDM provides a continuous smoothing effect; the surface finish can therefore be enhanced.
3. ECDM process is cheaper to operate than ECM and /or EDM systems since the configuration of ECDM is exactly same as that of ECM.

2. LITERATURE REVIEW

ECDM has a cathode tool and an anodic workpiece and thus features the properties of both ECM and EDM. The tools are separated by a gap which is filled with an electrolyte. Pulsed D.C. power applied between them. This leads to the formation a gas film and discharge in the electrolyte. Electrochemical dissolution and electro discharge erosion of the workpiece are achieved on aluminum oxide ceramic material. Considering the gas film formation through joule heating mechanism was studied by Guilpin [1] and Fascio [3].

Kellogg suggested, the gas film formation in case of cathode as an active electrode is less stable as compared to anode as active electrode [5]. Wuthrich [13] concludes that in case of active cathode most of the heat is removed through electrode whereas in case of active anode most of the heat created is transferred to the electrolyte giving rise to stable gas film. He further explains this behavior by the different glow discharge locations. Chemically there is no difference in the effects in anodic and cathodic contact glow discharge electrolysis. According to faraday's law, the gas is produced electrochemically; moreover, the area available for electrochemical reaction is affected by the growth of gas bubbles on the electrode surface. In case of alkaline solutions, chemisorption of water molecules on free electrode sites leads to production of hydrogen. The situation is more complex in case of acid medium where in corrosion of the electrode as, at the over potential needed for oxygen evolution, the corrosion is resisted in case of alkaline medium hence is better. The electric current in the electrolytes is transported through ions and its mobility is function of ions and electrolytes temperatures. The viscosity of the electrolyte which affects the drift velocity of the ions is mainly affected by temperature. Changes in dielectric function of water and the degree of dissociation of the electrolyte are other effects of temperature [13]. Gas bubbles are produced at the electrodes during electrolytic decomposition.

Two steps are involved in formation of bubbles

i) Microscopic formation by as electrochemical process

ii) Macroscopic formation of bubbles by accumulation of the dissolved in the vicinity of the electrode [13]. The above physical steps follow a cycle. The growth of the bubbles on the electrode surface starts at defects like cavities. It is

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necessary that the electrolyte in the vicinity of the electrode is supersaturated with dissolves gas for nucleation and growth of bubbles. The bubbles are fed from the highly saturated surrounding electrolytes during their growth. The mean bubble departure radius can be expressed mainly as for property of electrode, the electrode wettability and the electrolyte but not on the current density. The activation of the nucleation sites may be influenced by current density.

Various external parameters like as concentration, pH of the electrolytes, polarity and potential of the electrode, wetting condition and the current density influence the bubble diameter distribution [5]. Using the analysis of the electrical discharge machining and telecommunication switches, Basak and Ghosh [11] proposed that each discharge carries a mean energy of 2000 and has duration of 0.1 ms.

Kulkarni et al. [6] depicted various measurements that shows after each discharge the temperature of workpiece increases above melting temperature of workpiece increases above melting temperature and may even rise above melting temperature of the material. It is estimated that most of the energy i.e. about 77-96% of the energy supplied to the process is utilized to heat the electrolyte and tool-electrode and only 2-6% is used for heating up the workpiece. However, the experiments by Kulkarni et al. were performed on metallic workpiece that all together have different conductivities as compared to traditionally machined using ECD (e.g. ceramic, glass). ECDM machining for ceramic material such as alumina is possible at high voltage above 50V compared with 20-30V for glass and quartz.

The influence of electrolyte is complex and cannot merely described as a function of concentration and temperature. As compared to other electrolytes each as KOH, NaCl, $NaN0_3$, NaF, HCl, andH_2S0_4; the NaOH electrolyte appears to have the most interesting properties in particular for glass and quartz [2, 7, and 9] and also for ceramic such as alumina [8]. In general, alkaline electrolyte result in better material removal rates compared with acid electrolytes [3]. The electrolyte influences the surface roughness of the machined surface. For instance, molten salt electrolytes of eutectic mixture of NaOH and KOH melting at 170℃ significantly improves the smoothness of the machined surface [2]. The local chemically etching is not assisted by addition abrasive material to the electrolyte. This effect can however, be combination with the appropriate tool-electrode motion for e.g. rotation or vibration. Thus the reduction in surface roughness is achieved through improved machining quality [10].

The use of powder-mixed electrolytes improves the conductivity of the electrolyte. Reduction in spark ignition voltage is achieved through addition of small conductive particles in the electrolytes that will promote heat conduction and results into reduction in dielectric strength in the gas film [4, 10].

As Han et al. [4] showed that by choosing the appropriate amount of conductivity, it is possible to enhance drastically the surface roughness of micro-hole drilled at a constant feed rate. By varying the wettability of electrode-electrolyte interface, reduction in the critical voltage is possible. This could be achieved by adding to the electrolytes liquid soap was added to 30wt% NaOH and 50%reduction in critical voltage was observed. Reduction in the gas film formation time and critical density was seen.

Applied voltage was the most influencing factor (70.14%) in the studies carried out by Jawalkar et al [14] using NaOH and $NaNO_3$ electrolyte on soda lime glass.

3. Experimental Setup

The ECDM setup used with steady electrolyte is as shown in Fig. 1. In this type of set up, electrolyte is steady i.e. there is no provision to supply fresh electrolyte every time. Machining chamber is filled with required electrolyte at start of experiment and it will last long till the experiment gets finish. Dead weight of 38 gm is placed on the top of tool holder to provide tool feeding force.

Electrode

Tubular copper tool outer and internal diameter are 0.5 mm and 0.2322 mm respectively and its length 50 mm is used as a cathode whereas the larger electrode known as anode is made of stainless steel. Gravity feed to tool-electrode was provided.

Processing cell

The electrolyte level is indeed an important parameter that affects the machining process. A variable discharge activity, and also affects the chemical etching of the ECDM process. Tool guide and machining chamber are made up of Acrylonitrile Butadiene Styrene (ABS) plastic. ABS plastic has higher corrosion resistance. It remains inert when comes in contact with chemicals, also it can withstand higher temperatures. Chamber dimensions are 130 × 130 × 45 mm (L × W × H).

Electrolyte

The electrolyte has two functions. First, it provides the electrical conductivity required to allow the formation of the gas film around the tool-electrode. Second, it etches the workpiece during machining. As a consequence, an appropriate electrolyte could be chosen for each material to be machined alkaline electrolytes, in particular NaOH.

The concentration is chosen as a function of the desired machining performances. Silicon carbide powder of 220 mesh (74-90 µm) was used.

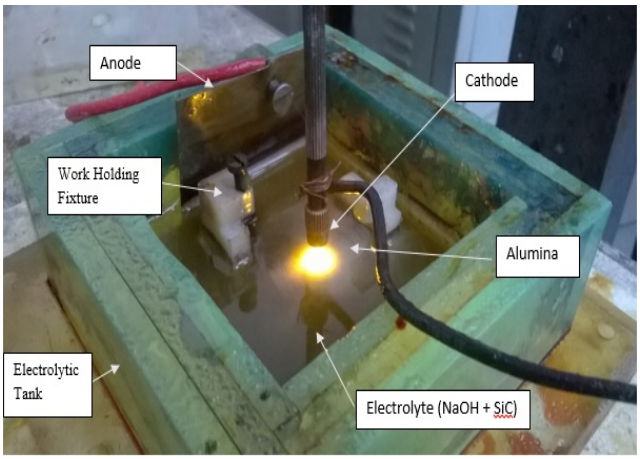


Fig. 1 Experimental set up for powder mixed ECDM with steady state electrolyte

Table 1 Experimental conditions for micro-hole machining on Al 99.5

Element	Description
Workpiece	Al 99.5 Dimension : 25mm x 25mm x 5mm
Electrode	Cathode-Copper tool of Diameter 500 µm, Anode- Stainless steel
Electrolyte	NaOH
Polarity	Negative (tool '-ve' and plate '+ve')
Voltage	55 to 65 volts
Concentration of Electrolyte	30 to 50 (wt. %)
Duty Factor	0.64 to 0.8
Concentration of Powder	2 to 4 (wt. %)

With this experimental the following process parameters were varied:

1. Voltage (volt):

DC voltage which is applied to the ECDM can be changed by using the DC pulse supply on which there is an arrangement provided to change the applied voltage.

2. Duty factor (%):

Duty factor is the ratio of pulse ON time to the total cycle time (pulse ON time + pulse OFF time). Duty ratio of the pulse supply can be changed by using the dc pulse supply on which the arrangement for different duty ratio is provided.

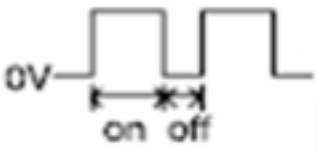


Fig. 2 Voltage pulse

3. Pulse on time (micro-sec):

Pulse on time is the fraction of total cycle time for which the pulse remains on and is shown in Fig. 2. . The pulse on time can be changed by arrangement provided on the DC pulse supply.

Table 2 Al 99.5 material technical specifications

Description	Value
Density	3.90gm/cc
Porosity	nil
Tensile strength	36±3k kpsi
Compressive strength	360±10 kpsi
Transverse breaking strength	±50 kpsi
Hardness	±823 R45N
Surface finish on lapped face	less than 0.3
Flatness on polished face	within 2 (light band)
Parallelism on lapped face	within 20 micron

Selection of the process parameter is done by using the pilot experimentation and the literature survey. Table 3 shows the process parameters with optimum level of MRR. The parameters selected are applied voltage (V), duty factor (DF), concentration of electrolyte in wt. % (C_{ele}) and concentration of silicon carbide powder in wt. % (C_{SiC}). The inter electrode gap is varied in the range of 20-30 mm.

Table 3 Input Parameters- Levels and coding for ECDM

Symbol	Factors	Level
A	Applied Voltage	65
B	Duty Factor	0.8
C	Concentration of electrolyte	50
D	Concentration of Powder	2

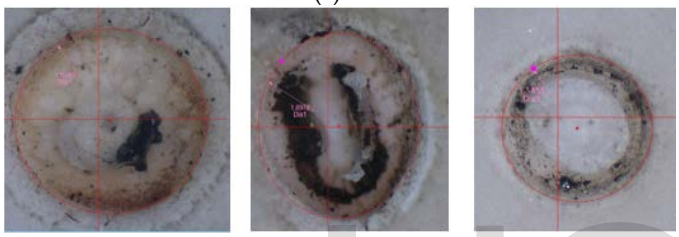
4. EXPERIMENTAL RESULTS

Experiments were conducted as per designed experimental plan and the performance or responses were measured for each experimental run. MRR and DOC were taken as performance criteria or responses. The amount of metal removed (MR) was measured by taking difference in weight of the specimen before (W_1) and after machining (W_2). The time taken for the each experiment was 20 min. The MRR can be evaluated as MR/t or ($W_1 - W_2$)/t, where t is the machining time. The outer OC is computed as (D - d), where D is the diameter of the drilled hole on specimen and d is the diameter of the tool. The measured experimental data is given in Table 4 below.

Table 4 Measured data of machining performance

Run	V	DF	Cele	Csic	Measured MRR(mg/min)	Measured DOC(mm)
1	65	0.8	50	2	0.06	0.6453
2	65	0.8	50	2	0.195	1.183
3	65	0.8	50	2	0.13	1.154
4	65	0.8	50	2	0.355	1.472
5	65	0.8	50	2	0.305	1.2622
6	65	0.8	50	2	0.265	1.1978
7	65	0.8	50	2	1.49	1.6434
8	65	0.8	50	2	0.365	1.7253
9	65	0.8	50	2	0.33	1.3155

Fig 2. Rapid I images of overcut for this experiment (a) 1 (b) 6 (c) 9



(a) (b) (c)

5. Anderson-Darling Normality Test

This test measures how well the data follow a particular distribution. If the p-value for the Anderson-Darling test is lower than the chosen significance level (usually 0.05 or 0.10), conclude that the data do not follow the specified distribution.

Normality test for overcut

The p-value obtained from Anderson-Darling test is greater than the chosen significance level is 0.05. So S/N ratio was decreased the process is under control. Calculated values for overcut are given in Table 5.

Table 5 Observed value of normality test for overcut

P- Value	Mean	Std. Deviation	Variance
0.373	1.2887	0.3168	0.1004

Normality test for MRR

The p-value obtained from Anderson-Darling test is equal to the chosen significance level is 0.05. So no improvement in S/N ratio is observed. Table 6 shows the observed values for MRR.

Table 6. Observed value of normality test for MRR

P- Value	Mean	Std. Deviation	Variance
0.005	0.38833	0.42615	0.1816

6. Conclusions

The present work is an attempt to study the feasibility of machining blind holes on alumina in ECDM using tubular electrode. The MRR and diametric over cuts are studied with optimal settings of applied voltage, duty factor, concentration of electrolyte, concentration of SiC powder. From the conducted experiments, the following conclusions are made:

1. Overcut is reduced by these optimal parametric setting applied voltage (65 V), Duty factor (0.8), Concentration of electrolyte (50 wt%), Concentration of Powder (2 wt%).
2. MRR is not increasing by this optimal parameter applied voltage (65 V), Duty factor (0.8), Concentration of electrolyte (50 wt%), Concentration of Powder (2 wt%) so we need more investigation on MRR.

References

[1] D. A. G. Bruggeman: Annalen der Physic 24 (1935), pp. 517-527.

[2] N. H. Cook, G. B. Foote, P. Jorden, B. N. Kalyani: "Experimental studies in electromachning." Trans. ASME, Journal of Engineering for Industry (1973), pp. 945-950.

[3] V. Fascio: Etude de la microstruction du verre par tincelageassit par attaquechimique: uneapproche electrochimique, Phd Dissertation Thesis 2691, Swiss Federal Institute Of Techonology (EPFL), Lausanne (2002).

[4] M. S. Han, B. K. Min, S. J. Lee: "Improvement of surface integrity of electrochemical discharge machining process using powder-mixed electrolyte." Journal Of Materials Processing Technology 191 (2007), p.224.

[5] H. H. Kellogg: "Anode effect in aqueous electrolysis." Journal of the Electrochemical Society 97 (1950), p. 133.

[6] A. Kulkarni, R. Sharan, G. K. Lal: "Measurement of temperature transients in the electrochemical discharge machining process." Temperature: Its measurement and control in Science and Industry 7 (2003), p.1063.

[7] H. Kurafuji, K. Suda: "Electrical discharge drilling of glass." Annals of the CIRP 16 (1968), p. 415.

[8] C.Tsutsumi, K. Okano, T.Suto: "High quality machining of ceramics." Journal Of Materials Processing Technology 37 (1993), p.639.

[9] C. T. Yang, S. S. Ho, B. H.Y an: "Micro hole machining of boroslicate glass through electrochemical discharge machining (ECDM)." Key Engineering Material 196 (2001), pp. 149-166.

[10] C. T. Yang, S. L. Song, B. H. Yan, F. Y. Huang: "Improving machining performance of wire electrochemical discharge machining by adding SiC abrasive to electrolyte." International Journal of Machine Tools and Manufacture 46 (2006), pp. 2044-2050.

[11] I. Basak, A. Ghosh: "Mechanism of material removal in electrochemical

discharge machining: a theoretical model and experimental verification." Journal of Materials Processing Technology 71(1997), pp. 46-53

[12] I. Zastawny, G. Aseyev: Properties of Aqueous Solution of Electrolytes, CRS Press, Boca Raton, (1992).

[13] Rolf Wuthrich, Jana D. Abou Ziki 'Micromachining Using Electrochemical Discharge Phenomenon: Fundamentals and applications of Spark Assisted Chemical Engraving, Elsevier 2nd Edition

[14] Jawalkar C. S., Sharma A K, Pradeep Kumar Investigations on performance of ECDM process using NaOH and $NaNO_3$ electrolytes while micromachining soda lime glass, Int. Journal of Manufacturing Technology and Management, Vol 28,Nos 1/2/3, 2014 pp 80-93.