Machining of Conductive / Non-Conductive Materials by Hybrid Machining

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ABSTRACT

The electrochemical discharge machining (ECDM) process is mostly applied for machining non-conducting engineering ceramic materials, such as aluminum oxides, zirconium oxides, and silicon nitrides, etc. Experiments on ECDM have been carried out according to designed experimental plan based on standard orthogonal array (L,) to identify the optimal parametric conditions of ECDM process using Taguchi method of parametric optimization. In this study, the signal-to-noise (SIN)ratio and the ANOVA analyses are employed to find the relative contributions of the main machining parameters, such as applied voltage, electrolyte concentration and inter electrode gap in controlling the machining performance, such as material removal rate and radial overcut of the ECDM process. The confirmation of experimental results under optimal parametric condition are provided to ensure the improvement in quality characteristics of the ECDM process. The highly purified non-conducting zirconium oxide is used as work piece material and aqueous KOH in stagnant condition as electrolyte with three different concentrations (i.e., 15 per cent, 25 per cent and 20 per cent). The applied voltage of pulsed D C power supply has three levels of 50 V, 60 V and 70 V and the three different inter electrode gap setting considered for the experiments are 20mm, 30mm and 40mm respectively.

Key words: *Electro- Chemical Discharge machining (ECDM), High strength High temperature Resistant Material, Material removal rate, Applied Voltage, and electrolyte concentration.*

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1. INTRODUCTION

The electrochemical discharge machining (ECDM) process is expected to have tremendous applications for machining non-conducting engineering ceramic materials, such as aluminum oxides, zirconium oxides, silicon nitrides, etc. Such non-conducting ceramic materials have wide industrial applications in bearings, computer parts, artificial joints, cutting tools, electrical and thermal insulators, electronic devices, aerospace components, etc. due to their superior properties, such as high compressive strength, high wear resistance, high strength-to-weight ratio and high hardness characteristics'. The present need of every industrial organization is to improve the quality of its machining processes and reduce the cost continuously so as to compete on price and performance and to maintain profitability. To meet the commercial and the industrial requirement of ECDM of non-conducting ceramic parts, extensive research is needed to improve the quality characteristics of ECDM process through parametric design and optimization analysis based on Taguchi method of robust design. Electro-chemical Discharge Machining(ECDM),a hybrid machining process of Electric Discharge(ECM) process and are mainly used for micro-machining and scribing hard and brittle non-conductive materials such as glass (mainly pyrex, plexi and optical), ceramic, refractory bricks, quartz and composite materials. The schematic of the basic ECDM process is shown in Fig.1.

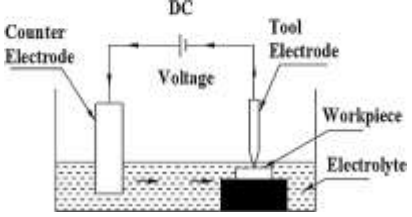

Fig.1 Electro chemical discharge machine

2. BRIEF HISTORY

Crichton et al. carried out a comparative study of EDM, ECM and Electro Chemical Arc Machining (ECAM) processes. They have reported that EDM and ECM can machine only conducting materials while ECAM can machine both conducting and non-conducting materials. McGeough et al. conducted a theoretical and experimental study of ECAM and reported that voltage and feed rates play a major role in Material Removal Rate (MRR). They have reported a higher MRR at higher feed rate and higher voltage. Crichton and McGeough conducted experiments on ECAM with pulsed voltage circuit. Machining rate in terms of MRR was reported [5] times more than of ECM and EDM process and is represented in Fig. 1.They have observed four different stages of electrical phenomena in the pulse circuit as:- (1) high frequency voltage and current oscillations, (2) high rate electrochemical action, (3) low rate electrochemical action and (4) electro discharge action. Tandon et al. have machined Fibre Reinforced Plastic (FRP) composites with Electro Chemical Spark Machining (ECSM) process. The experiments are conducted for an output response of maximum MRR, minimum TWR, Relative Tool Wear Rate (RTWR), lower average overcut and top overcut. They have reported that MRR, TWR increases with reduction in RTW with increase in voltage and conductivity of the electrolyte. Raghuram et al. have studied the influence of rectified DC voltage, smooth DC voltage and current on concentration of the electrolyte in ECDM process. They have found that the external circuit parameter- inductance could give constant power supply to ECDM process.

3. MODELING

ECDM is complex machining process hence its modeling requires certain assumptions. To make the analysis of ECDM following assumptions are considered

1. Work piece material is assumed to be homogeneous and isotropic.
2. It is a single spark phenomenon.
3. Spark location is randomly distributed on tool surface immersed in electrolyte.
4. All sparks are considered to be identical during the whole machining period.
5. Only a fraction total sparking, heat flux is dissipated in to the work piece shape of heat flux is assumed to be Gaussian distributed. From the experimental studies of Kulkarni et al for single spark, the heat affected zone is circular and the crater is dome shaped. So reflecting the shape crater, we can approximate the nature of the heat flux as Gaussian.
6. The process condition during machining is kept constant.
7. Material removal by cavitation effect is neglected. All material removal is caused by thermal melting and chemical dissolution in ECDM is dependent on the temperature rise caused by sparks.

4. MECHANISM OF MATERIAL REMOVAL IN ELECTRICALLY NON CONDUCTIVE MATERIALS

Bhattacharya et al , reported that the machining in ceramics took place mainly due to spark discharge action across the gas bubble layers formed on the work piece surface. Each electrical discharge causes a focused stream of electrons to move with a very high velocity and acceleration from the cathode (or tool) towards the work piece and ultimately creates compressive shock waves on the work piece surfaces. The phenomenon is accomplished within a few microseconds and the temperature of the spot hit by electrons could rise to a very high value. As this temperature reach above the melting point of the work piece material, it melts and finally evaporates the material. The high pressure of the compressive shock waves creates a blast, causing metallic vapors to form wear products in the shape of metallic globules, leaving craters in the work piece surface. The material removal from the work piece surface during electrical spark discharge is proportional to the pulse energy of the spark, which is released as heat during machining. Some researchers have pointed out that the heat generated by the electrical sparking rather than melting of the hard and brittle ceramics may cause the ceramic materials to spall. This phenomenon is known as thermal spalling, where the material removed is due to mechanical failure without melting. A complex temperature gradient is established due to the sudden temperature change in the machining area of the ceramic materials. It creates internal stresses that may be sufficient to overcome the bond strength of the ceramic grains, resulting in mechanical erosion. The proposed gas bubble formation and sparking phenomenon are exhibited in figure 2. They conducted an experimental study onAl_2O_3 to find the effect of applied voltage (70-90 V),electrolyte concentration (i.e., NaOH at 20wt%,25wt%, 30wt% concentration) and tool tip shape (i.e, flat front – straight side wall / taper side wall, curvature front – taper side wall shown in figure 3)on material removal rate and radial overcut under the effect of pulsed DC. It was observed that material removal rate & radial overcut increased with the increase in applied voltage & the increase in electrolyte concentration. Machining at high voltage developed micro-crack while at higher concentration, overcut was increased. The effective range of parametric combination for moderately higher machining rate and dimensional accuracy was centered around 80 V applied voltage and 25wt% NaOH electrolyte solution. Similar results were obtained while machining with NaOH / KOH electrolytes. It was observed that applied voltage had more significant effect on MRR, ROC and HAZ than other parameters. Tool tip was also reported as a prominent factor for controlling spark generation in ECDM.

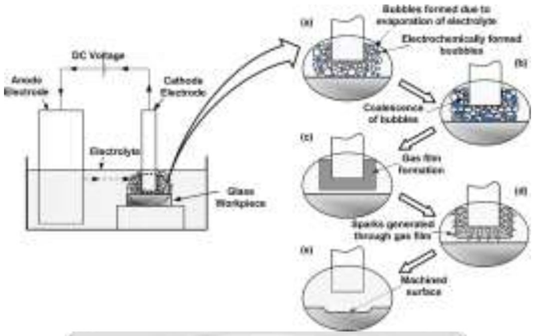

Fig.2 Material removal mechanism of ECDM operation.

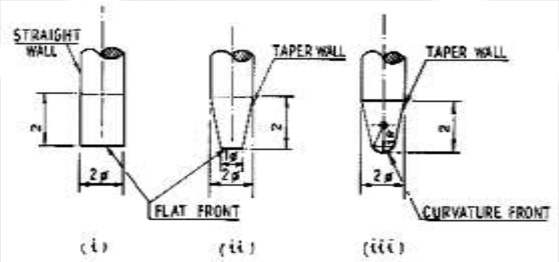

Fig.3 Different geometrical shapes of the tool tip used

Taper sidewall-curvature front tool tip causes maximum amount of electrolyte availability in sparking zone which creates maximum number of sparks and thus increases MRR compared to flat front -straight sidewall tool tip / flat front – taper side wall tool tip where the availability of electrolyte in the gap between tool and job is very less as they are always in contact with each other due to the gravity feed force and thus causing occurrence of lower number of sparks.

5. ENHANCEMENT IN MATERIAL REMOVAL

Performance of a machining process can be primarily defined by its MRR, the quality of surface it produces and the tolerance obtainable in the processed part. In ECDM, the process performance is dependent on various important parameters.

5.1. EFFECT OF TOOL-ELECTRODE SHAPE

The needle shaped tool-electrode when compared with cylindrical tool-electrode results better at higher drilling speed for low voltages. The mean drilling speed attained with needle tool electrode is reported to be about ten times faster than the cylindrical tool-electrode. Wuthrich et al. have explained that in the needle-shaped tool, the discharges are concentrated at the tip of the tool-electrode. In general, the discharge density is higher for smaller cross-sectional tool-electrodes that results in higher material removal rate. This effect is significant at low voltages only in the discharge regime. As soon as tool-electrode reaches the hydrodynamic regime, drilling speed becomes almost independent of the voltage. They further observed that in the hydrodynamic regime the difference between the needle-shaped and cylindrical tool is hardly visible. However, it was suggested that the promotion of electrolyte flow inside the micro hole can be achieved by flat side wall tool-electrode.

5.2. EFFECT OF VOLTAGE

Increase in applied voltage increases the MRR due to generation of more hydrogen gas bubbles resulting in greater amount of discharge energy at the sparking zone. But there is a limit to the material removal rate. Jawalkar found that when applied voltage is increased to 100 V, the MRR starts decreasing due to entrapping of debris in the spark gap. Consequently, it becomes difficult to flush out the entrapped debris quickly enough by the electrolyte. At the same time for high voltage, some micro-cracks will be produced in the machining zone due to excessive heat generation. With further increase in applied voltage, these micro cracks may propagate and lead to the total rapture of the work piece. Similar results had been observed by other authors at an applied

voltage of 100 V, ceramic work samples broke due to total rapture. Further, as the applied voltage changes, the dynamics of the electrolysis process changes which might affect the overall
MRR.

5.3. EFFECT OF ELECTROLYTE CONCENTRATION

The MRR increases with increase in electrolyte concentration as the more electrochemical reactions occur between the cathode and the anode which generates greater number of sparks. This results in more gas bubbles at the sparking zone. Further increase in electrolyte concentration (250 g/l NaOH) leads to decrease inactivity of EDM action resulting in lower MRR. Also, as the concentration of electrolyte increases the electrolyte become more viscous that leads to smoother machined surface. Increase in concentration of mixed solution of KOH and NaOH from 5.5 wt% to 15 wt% on the other hand leads to improvement in electrical conductivity enhances the chemical etching. Similar results were also reported by while working on silicon nitride work piece with NaOH solution.

5.4. EFFECT OF DEPTH OF HOLE

In ECDM, the specified work material can be machined only up to a certain depth known as the “limiting depth” for a particular combination of applied voltage and electrolyte conductivity. The potential difference between the tool-electrode and the electrolyte decreases during the process as the tool keeps penetrating inside the work. This potential loss is mainly due to accumulation of gas bubbles on the tool-electrode that restricts the electrolyte flow to the tip of tool-electrode, which results in reduction of discharge activity and lowering chemical etching. Both effects result in lowering the MRR. Therefore, machining beyond the limiting depth in ECDM is very difficult. Jui et al. [10] tried to enhance the limiting depth by using high aspect ratio micro-tools for deep micro hole
drilling on glass with low electrolyte concentration and rotation of the tool-electrode. Their results also show that the overcut, tool wear and hole taper were reduced by 22%, 39% and 18% respectively due to use of lower concentration of electrolyte.

5.5. EFFECT OF INTER-ELECTRODE GAP

Increase in inter-electrode gap increases the inter-electrode resistance that affects the electrical conductivity of the electrolyte. As the inter-electrode resistance increases, the critical voltage required for gas film formation also increases that decreases the MRR. when the inter-electrode gap was increased from 20 to 40 mm. Jawalkar has found MRR increasing and decreasing kind of effect as electrode spacing increased from 50 to optimum levels while machining optical glass at voltage levels of 60, 70 and 80 V. They reported marginal increase of material removal from 3.5 mg at first level (50 mm) to 3.8 mg at second level (100 mm). This second level was considered as the optimum level. The increase in material removal at optimum electrode spacing is due to availability of adequate space for chemical reactions to occur and disposal of gases without any interference.

5.6. EFFECT OF ELECTROLYTE LEVEL

The electrolyte level above the work piece surface is also an important parameter that affects the machining process. If the electrolyte level varies that result in variable discharge activity, variable inter-electrode resistance which affects the process of chemical etching. Boissonneau and Byrne recommended that fresh electrolyte has to be supplied continuously as the electrolyte evaporates during machining.

6. RESULTS AND DISCUSSION

Fig.4. Shows optical Images (50X) of borosilicate glass Machined with 5wt % NaOH.

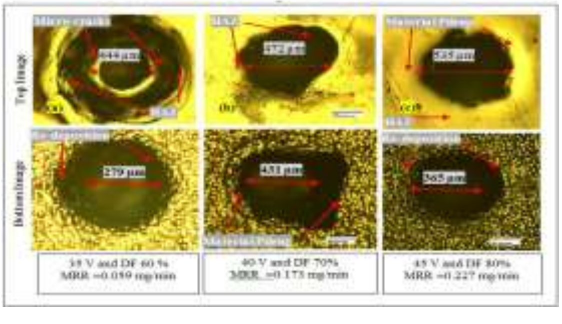

Fig.4.Optical Images (50X) of borosilicate glass Machined with 5wt % NaOH

Figure 4.(a) shows MRR is lower at low voltage and at low duty factor. This is because at low voltage, spark intensity is very low and liberated heat energy is not enough to melt and evaporate the material. Figure 4.(b) shows the irregular shaped micro-holes formed at 40 V and 70% duty factor. The KOH in the electrolyte mixture is responsible for this uncontrollable etching on the silicon surface. Figure 4.(c) show that MRR increases with increase in voltage and duty factor. This is due to high intensity sparks formed at the tool surface which facilitates the quick machining of larger diameter on the silicon wafer surface. Figure 4 shows the optical images (50X) of silicon wafers machined with 10 wt % NaOH and KOH. Other process parameters are mentioned on the figure with obtained MRR. It shows that optical images of borosilicate glass with micro-cracks on the surface. MRR obtained is more at lower voltage and medium duty factor. So duty factor plays a major role in controlling the MRR with mixed electrolyte. It shows lower MRR compared to initial condition. This is due to material pile up on the surface of silicon wafer due to high intensity spark produced at high voltage on tool surface.

7. CONCLUSION

This study reveals that much has been discussed about the electrochemical discharge phenomenon and its application while machining electrically conductive and electrically non conductive materials. Since material removal in ECDM has been well explained, continuous improvement for its development is in progress and it is being effectively used to machine electrically conductive HSHTR materials with higher material removal rate and improved dimensional accuracy than ECM & EDM. This discharge phenomenon has also been used to machine electrically non conductive materials and the process was named as ECDM. It was observed that ECDM had low machining efficiency due to inherent machining problems, therefore materials like glass, quartz, composites etc. those having ability to melt (at discharge temperature) were machined by this process. Researchers have also reported that ECDM could be a viable solution for machining electrically non conductive HSHTR ceramics, but realizing low efficiency of the process hybrid machining especially involving abrasives or electrically conductive powder mixed electro chemical discharge machining may further improve the machining performance.

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