Electrochemical Discharge Machining – An Overview

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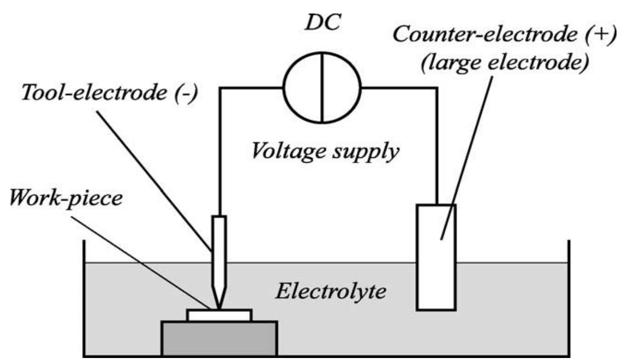
Abstract- The electrochemical discharge machining process has been proved as a potential process for machining of low machinability high-strength electrically non-conducting materials, but the mechanism of material removal during the process, by and large, is not yet understood. After almost 40 years of its first mention in literature, this technology remains an academic application. In this paper, the knowledge about electrochemical discharge machining process is reviewed up to this date. Some main limiting factors of the process are highlighted and possible solutions are discussed.

Keywords – Electrochemical discharge machining, Electrochemical discharge phenomena, Wire electrochemical discharge machining.

I. Introduction

Hard and brittle materials, like glass, engineering ceramics and some single crystalline materials are gaining increasing importance in the machine tools, aerospace, nuclear, electrical and electronics engineering field owing to their high strength to weight ratio, hardness, heat resisting capacity and high corrosion resistance. The main limiting factor for growing usage of those materials is its limited structuring possibility. Chemical etching technologies (like HF etching) are well established, though this process remains very slow and expensive for many industrial applications. Other processes like laser machining, ultrasonic machining and powder blasting can be used to machine those materials. But, with these processes, it is very difficult to obtain good surface qualities. A possible answer to machine those materials with good surface quality is Electrochemical Discharge Machining (ECDM). ECDM is a process, which combines the features of ECM and EDM. The major advantages of ECDM, over ECM or EDM are obtained in higher machining rate and machining non-conductive materials. When a voltage is applied across electrodes immersed in an electrolyte, electrochemical reactions take place, such as anodic dissolution, cathodic deposition and electrolysis of the electrolyte depending on the electrode-electrolyte combination. Due to the electrolysis of the electrolyte H_2 gas is liberated at the cathode and O_2 gas is liberated at the anode. H_2O bubbles are generated due to ohmic heating. If a suitable electrolyte is chosen and the electrodes are of grossly different in sizes, then beyond a certain value of the applied voltage, the smaller electrode (tool) is completely isolated from the electrolyte by H_2 gas and H_2O bubbles forming a gas film around the electrode. The electrical field in this film is high enough (typically 10^6-10^8 V/m [1]) to allow electrical discharges between the electrode and the electrolyte. The heat generated by this discharges and chemical etching contribute to the eroding of the machined substrate, if it is positioned in the near vicinity of the tool electrode (typically smaller than 25 μm for glass [2]). The practical implementation of ECDM is shown in figure.



ECDM is based on electrochemical discharge phenomena. The phenomenon of electrochemical discharge (ECD) was first observed by Taylor [3] in 1925. Later Kellog [4] showed that the phenomenon of small electric discharge could occur at the cathode tip in aqueous electrolyte. Recently Jain and Adhikary [5] showed that both cathode and anode can be used as a tool in ECDM. ECDM with reverse polarity (i, e, anode as a tool) removes material at faster rate as compared to ECDM with direct polarity but produces higher overcut, higher tool wear and higher surface roughness due to chemical reaction. ECD is first used for machining non-conducting materials by Kurafuji and Suda [6] in 1968. Several names are used in literature: 'Electrical discharge drilling' by Kurafuji and Suda [6], 'discharge machining of nonconductors' by cook et al. [7], 'electrochemical arc machining' by Kubota [8], 'electrochemical discharge machining' by Ghosh et al. [9], 'Micro Electrochemical Discharge Machining' by Langen et al. [10], 'Electrochemical Spark Machining' by Jain et al. [11], and 'Spark Assisted Chemical Engraving' by Langen et al. [12]. The diversity of names indicates the complexity of the process and the explanations of the nature of the electrical discharges are partially contradictory. The aim of this contribution is to review the literature up to this date.

II. MICRO-MACHINING WITH ECDM

ECDM offers various possibilities to machine different materials (see table). It can be distinguished among hole drilling, 3D machining and traveling wire machining.

Table: Overview of the published reports on ECDM

	Micro-hole drilling	3D structuring	TW-ECDM
Glass	100-500 μm [6,10,13,14,15,16,17,18,19], 1-2 mm [7,16,20,21,22]	100 μm X 1 mm [10,15,16]	1-10 mm [23,24]
Quartz	1-3 mm [20,25]		1-10 mm [24]
Plexiglass	[7]		
Ceramics (mainly Al_2O_3)	100-500 μm [26,27], 1 mm [20,25,28], [7]		1-10 mm [24]
Composites	1 mm [11]		[11,29]
Granit	[7]		

Typical dimensions of machined structure are mentioned in the table.

Machining with ECDM is a complex process influenced by several parameters. Until today it is not clear which parameters control mainly the machining. A pioneering study about the influence of several parameters, like electrolyte properties, applied voltage and others on the material removal rate was reported by Cook et al. [7], which were later confirmed by other research groups; the material removal rate increases with the applied DC voltage [20,25,28-33] and the electrolyte temperature [7,20,25]. Cook et al. [7] found that material removal rate increases with electrolyte concentration but latter investigations seem to indicate that there is an optimum before the rate decreases [28,29,34]. This behaviour follows the dependence of the electrolyte conductivity from the concentration.

The tool wear rate and the over-cut follow a similar behaviour as the machining rate in function of the applied voltage and the used electrolyte [11,25,29]. However the tool wear rate is about two magnitudes smaller than the material removal rate [29]. Hof et al [35] described a mechanism participating to tool wear. During electrochemical discharges not only cathodic currents are observed but some small anodic currents. This anodic current dissolves the tool-electrode by electrochemical dissolution. In the case of extremely small sharp AFM tips this effect can result in the total dissolution of the tool-electrode.

The effect of electrolyte on machining is complex and cannot be described uniquely in function of concentration and temperature. The machining process is partially a chemical one and therefore the nature of the electrolyte influences strongly the machining behaviour. NaOH electrolyte seems to have most interesting properties compared to other electrolytes (KOH, NaCl, $NaNO_3$, NaF, HCl and H_2SO_4) [7,30]. Molten salt electrolytes (eutectic of NaOH and KOH melting at 170°C) can drastically improve the smoothness of the machined surface [7]. The surface roughness of the machined work sample is influenced by the electrolyte and the applied voltage [14].

The voltage is mostly applied as a DC voltage. However applying high frequency voltage pulses is very interesting as removal rate increases for pulses in the micro-sec range and the machined surface quality is significantly improved [7]. Kim et al. [38] reported that the micro drilled surface becomes smooth when frequency of the voltage pulse increases and duty ratio decreases, though the MRR decreases with the decrease of duty ratio. They also reported that the tool wear rate and the clearance increase with a smaller diameter tool. Material removal rate is increased as well by introducing an additional inductance in the voltage generator circuit as was showed by Basak et al. [33, 36, 37].

Introducing artificially some bubbles into the process during machining was investigated by Jain et al. [29]. They found that the material removal rate decreases slightly as well as over-cut. This method may be used to increase machining precision. Yonghong et al. [39] showed that using side insulated tools and gas-filled method can drill a hole of greater depth and the shape accuracy is improved. Wuthrich et al. [40] reported that more reproducible machining can be done by decreasing the gas film thickness and the gas film thickness can be reduced by three ways, i) by relative motion between the tool and the electrolyte, ii) by adding some surfactants (liquid soap) into the electrolyte and iii) by controlling the mean distance of activated bubble nucleation sites. Yang et al. [41] reported that for wire electrochemical discharge machining (WECDM) the surface roughness and the slit expansion could be reduced by adding SiC abrasive to the electrolyte. They also reported that increasing the pulse frequency, reducing the duty factor and increasing the feed rate of the wire could reduce the slit expansion. Chak et al. [42] showed that the maximum depth of drilled hole could be increased and the average value of taper obtained could be decreased by using spring fed abrasive electrode with pulsed DC instead of gravity fed copper electrode with smooth DC. Han et al. [43] reported that the use of electrolyte mixed with the conductive particle improved the surface integrity of ECDM process. Bhattacharyya et al. [28] investigated the shape of the tool tip on MRR and over-cut. They suggested that flat front taper tool tip is highly effective for controlled machining.

III.CONCLUSION

Electrochemical discharges can be used to machine several electrically non-conductive materials. Even known since almost 40 years, this machining process remains an academic application and was until now never applied in industrial production. The research done until today mainly focused on experimenting the machining of various materials and investigating the effect of different parameters on the material removal rate. It was shown that a large class of materials can be machined. Not only simple structures as holes but as well as very complex structures can be machined. Material removal rates depend on a large number of parameters like material to be machined, used electrolyte, applied voltage, temperature, frequency of the pulsed voltage and duty ratio. It is, however, only recently that machining by electrochemical discharges was investigated from the electrochemical point of view. This aspect may bring some new findings on one side the fundamental understanding of the process and on other side on the practical implementation of the process. If this non-conventional machining process wants to become interesting for industrial applications it is absolutely essential that reproducible machining is obtained. For micro-machining application the reproducibility should be at least a few microns. One main challenge in reaching this goal is certainly the control of the gas film built around the tool-electrode in which happen the discharges. Not only that this gas film is necessary for machining to occurs, but the stability and dynamics of this film conditions the machining, in particular its resolution and its reproducibility. The electrochemical point of view may certainly bring some interesting inputs for this problem.

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