INFLUENCE OF THE PROCESS PARAMETERS ON ELECTRO CHEMICAL MICRO MACHINING - A BRIEF REVIEW

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Abstract: *Electro Chemical Micro Machining (ECMM) is an unconventional machining technique which is used in a large range of industries such as from medical to aero. This paper intends to go over the main points and some of the major parameters used in Electro Chemical Micro Machining which are going to affect Material Removal Rate (MRR), Dimensional Deviation or Over Cut (OC) and to review existing knowledge and draw attention to current challenges, restrictions and advantages in the field of ECMM.*

1. INTRODUCTION

The ECMM is relatively latest technique where machining is done by anodic dissolution during an electrolysis process which is important in many manufacturing industries like aero space, auto mobiles, bio-medical, nuclear power plants, thermal power plants, electrical and electronics etc. where the materials which are harder are difficult to machine. From the last 70 years the ECMM commenced as a profitable technique. In 1960's and 1970's more research work was conducted on Electrical Discharge Machining (EDM) about the same time the research work was slow on Electro Chemical Machining. The major focus for the progress of ECMM came from its major industrial applications having excellent properties similar to high strength-to weigh ratio, higher thermal conductivity and less thermal expansion, higher modules, lower ductility, higher toughness, higher wear resistance, higher impact strength, higher surface durability and lesser sensitivity to surface flows.

ECMM is using to manufacture various 3D micro-structures such as micro-holes and micro grooves and the accuracies of the order of +1 µm on 50 µm can be successfully used for high accuracy machining operations. The micro hole is the common demanding important basic element while fabricating micro-parts in the electronics, aviation and semiconductors industries which are best made in ECMM with good surface finish, tool wear can be neglected, there is no thermal damage and the extremely hard material can be easily machined for even complex shapes also are the most important advantages of ECMM. It is required to set its different machining parameters which effect Material Removal Rate (MRR), Over cut (OC) and surface roughness are electrolyte concentration, inter electrode gap, pulse frequency and duration, electrolyte selection, voltage and tool feed rate.

2. A BRIEF OVERVIEW OF PROCESS

ECMM is an anodic dissolution method where tool is cathode and work piece is anode respectively, which is divided by an electrolyte. At the point when the supply is given the current is gone

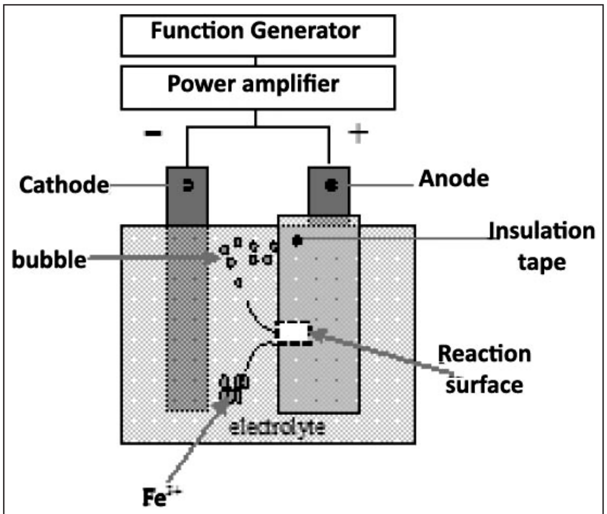

Fig 1. Working Principle of ECMM

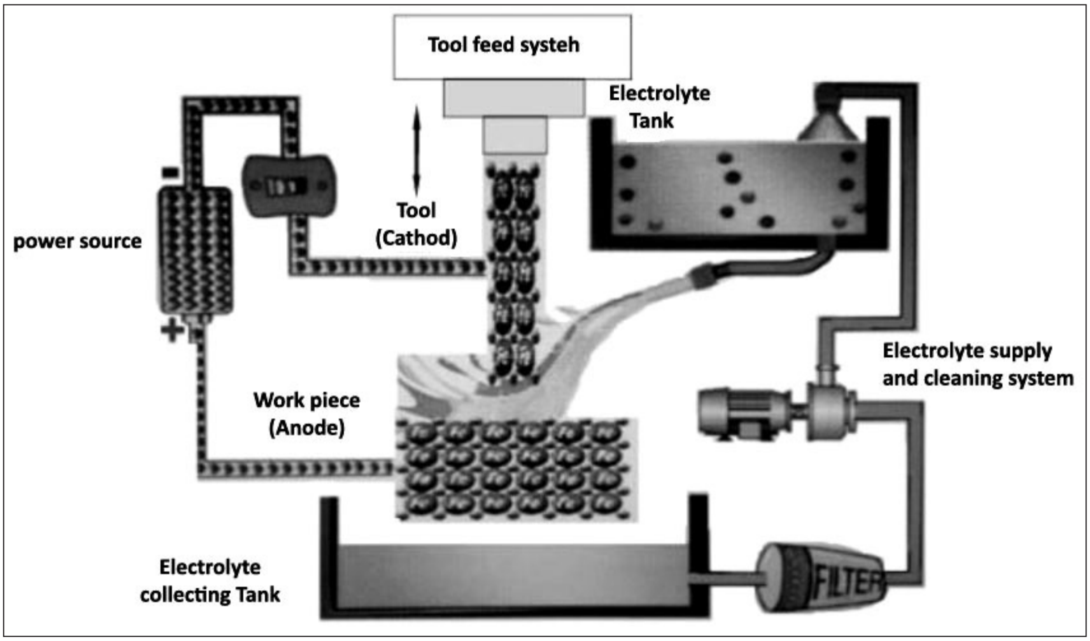

Fig 2. Schematic View of ECMM System

through the electrolyte, the anode work piece suspends locally, so that to get the final shape on the work peace as the tool shape. Keeping in mind the end goal to evacuate the response items and to disseminate the heat generated the electrolyte is pumped at high velocity through the gap of machining hole.

Machining execution in ECM is represented by the anodic conduct of the work piece material in a given electrolyte were featured in the title " Parametric control for optimal quality of the work piece surface in ECM " (S.K. Sorkhel, B. Bhattacharyya 1994). The research titled "Electrochemical machining new possibilities for micromachining" highlighted the setup of the electro chemical micro machine (Bhattacharyya B. 2002). The ECMM setup will help for doing depth research for gaining an attractive power of effective exertion has been prepared. Fig. 2 outlines a schematic perspective of an ECMM) structure set-up, which contains pulsed DC control supply, electrolyte stream system, machine controller, mechanical machining unit, micro tool drive unit, and so on.

The title "Advancement in electrochemical micro machining" (Bhattacharyya B 2004) the author highlighted the current developments and future trends of ECMM and stated that ECMM process of machining can perform for high precisely with efficiently. The titled "Experimental investigation on the influence of micromachining domain", to carrying out in-deep research an experimental set-up was developed (Bhattacharyya B 2003).

3. WORKPIECE MATERIAL

In current existence, to meet up the demands of extreme applications the material are developed with advanced and with metallurgical unique properties such as composites, super alloys and ceramics. Where these materials having properties like high hardness, toughness, more resistant to corrosion, fatigue and less heat sensitive. Because of these properties they are difficult to machine. The super alloy based alloying elements used in the applications of aerospace, marine turbine industries and industrial gas turbine, e.g. for hot sections of jet engines, for utilizing in diesel, bimetallic engine valves, for automotive applications and turbine blades. The Super alloys: Fundamentals and Applications. Cambridge (Reed, Roger C 2006). ECMM plays an significant role in aerospace for miniaturization of parts e.g. cooling holes in jet turbines blades, micro probes, micro needle for bio-medical application, and micro holes in fuel injection system, etc. The development of ECMM is thus important in the field of machining.

The composite materials are made with two or more materials through significantly different chemical properties or physical properties. When combined to or more material they turn in to material with different properties with individual. These materials are less expensive when

Table 1: Common Electrolytes for a Range of Metals

Metal	Electrolyte	Remarks
Aluminium and its alloys	$NaNO_3$	Excellent surface finish
Cobalt and its alloys	$NaClO_3$	Excellent dimensional control, excellent surface finish
Molybdenum	NaOH	NaOH consumed and must be added continuously
Nickel and its alloys	$NaNO_3$	Good surface finish
	$NaClO_3$	Good dimensional control, good surface finishing and low metal removal rate.
Titanium and its alloys	NaCl+NaBr+NaF	Good dimensional control, good surface finishing and good machining rate.
	$NaClO_3$	Bright surface finish, good machining rate above 24V
Tungsten	NaOH	NaOH consumed and must be added continuously
Steel and iron alloys	$NaClO_3$	Excellent dimensional control, brilliant surface finish, high material removal rate and fine hazards when dry
	$NaNO_3$	Good dimensional control, fine hazard when dry, low metal removal rates and rough surface finish

compared to traditional materials; these materials are very stronger and lighter in weight. Because of these improvements in the properties the composites are one of the important areas where a lot of research work has to be taken place. These materials are commonly used for bridges, buildings and structures such as swimming pool panels, boat hulls, shower stalls, bathtubs, race car bodies, storage tanks, cultured marble sinks, counter tops and imitation granite. The most progressive illustrations perform routinely on rocket in requesting conditions.

From the above discussion more work on research has to be done on different materials like Aluminium and its alloy, tungsten, molybdenum, cobalt and its alloy, composite materials which are harder and not possible to machine through conventional machining etc.

4. ELECTROLYTE SELECTION

Electrolyte is a necessary parameter which provides the required reaction to carry out. The properties of best electrolyte should be low viscosity, high conductivity, be inexpensive and noncorrosive. Sodium nitrate (NaNo3) and Sodium chloride (Nacl) are the most widely used electrolytes for ECMM. The electrolyte selection depends on the anode work piece material and the preferred result, i.e. Removal Rate or surface finish, accuracy and Material. The Table 1 shows some of the electrolytes used for work piece metals commonly machined with ECMM. The main types of electrolytes are Passive and non-passive. Passive electrolyte is a sodium nitrate which contains oxidising anions forms a protective oxide film that provides better precision. Non-passive electrolyte is a sodium chloride which contains more aggressive anions. In non-passive electrolyte the accuracy is lower and the MRR is much higher when compared with passive electrolytes.

Sometimes acidic electrolytes are preferred to avoid the build-up of machining products which can accumulate in the inter electrode gap (IEG) slowing machining. There was a high probability for the electrolyte being boiled by the power transmitted across the gap and this led to machining being stopped in an abrupt manner. For the selection of proper electrolyte to increase the accuracy during machining various research works have been performed.

From the past observations electrolyte is a fundamental parameter which provides the necessary reaction to occur and depends on the anode i.e. work peace material. Electrolyte is selected according to the anode material and mostly sodium nitrate and sodium chloride are used. It still needed more research work in the region of electrolyte type that can be utilized effectively and fluid kinematics for ECMM.

5. ELECTROLYTE CONCENTRATION

The electrolyte concentration is one of effective the machining parameter which plays a role in getting better machining accuracy and machining rates in ECMM. The electrolyte conductivity is determined with its concentration. If the concentration is higher the electrolyte conductivity is also higher. Sodium chloride is not preferred over sodium nitrate because at small gaps, the current efficiency and the current density are high ensuing in a higher MRR. For large gaps the efficiency and current density are low resulting in a low MRR. The electrolyte concentrations most generally used ranges are from around 30 g/L to 35 g/L. Without damaging the micro tool it can improve the suspension of metal. Many research works have been carry out to find out electrolyte concentration which affects ECM and ECMM machining.

The titled "Experimental investigation on the influence of electrochemical machining parameters on machining rate and accuracy in micromachining domain", (Bhattacharyya B 2003) observed and stated that the machining can be improved in accuracy and MRR with a high voltages, lower concentration and a modest value for pulse on time.

"Study of dominant variables in Electrochemical Micromachining" (Thanigaivelan R 2010) an experimental study was conceded to conclude the electrolyte concentration effects on stainless steel. The author absorbed that the machining speed reaches maximum at 0.23-0.29 mol/lit and which gives moderate lower overcut and machining speed.

An experimental study on the title "performance improvement of electrochemical machining process using oxygen-enriched electrolyte" (Ayyappan 2014) It is observed that from the experimental results the higher MRR occurs with higher concentration and in the oxygenated electrolyte of NaCl he got better surface finish for 20MnCr5 steel. When gaseous oxygen was sent into the electrolyte at different flow rate and pressure also observed that the MRR increase with higher concentration allowing more ions for ionization also confirmed that with electrolyte concentration increasing conductivity also increases initially but leveled off for further increased concentration

The research work title "Optimization of process parameters on machining rate and overcut in electrochemical micromachining using grey relational analysis" (Thanigaivelan and Arunachalam 2013) observed and stated that with 95% assurance the overcut was affected by electrolyte concentration during machining.

The experimental work on title "Fabrication of micro - features and micro - tools using electrochemical micromachining" (Jain VK, Kalia S, Sidpara A 2012) from the investigational work it is observed and stated that the increasing in concentration leads to decrease in machining localization occurs. The machining localization improved further than a limit of concentration. With the higher electrolyte concentration the ion mobility is delayed.

"Experimental investigation on the influence of electrochemical micro-drilling by short pulsed voltage" (Fan ZW, Hourng LW, Lin MY 2011) stated that machining overcut enlarges with concentration increase during machining nickel plate with electrolyte as sodium chloride with hydrochloride acid

"Electrochemical machining of the spiral internal turbulator" (Wang 2010) with the experimental work it was observed that the current density distribution was affected by the electrolyte concentration. The current efficiency and curacy also affected by the concentration in turn higher overcut occurs with higher concentration.

"Modelling of the liquid membrane electrochemical etching of a nano-tip" (Wu 2013) a nano-tip tool was created electrochemically. The Fig.3 below shows the cell setup of electrode where

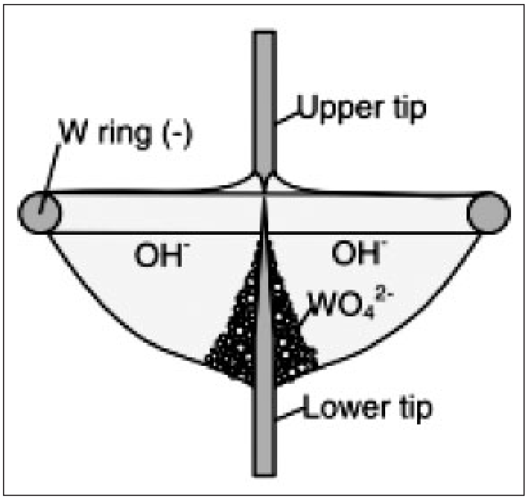

Fig 3. The Electrode Set up

the tool were shaped with wires which is placed in the center of cathode ring. The electrolyte is filled in the ring and using surface tension the tool-tip was created.

From the observation the micro tool diameter was created with increased in concentration the diameter increased due to the increase in concentration the MRR increases and the tool-tip was over etched at high electrolyte concentration affecting the tool-tip to drop off. It is understandable from the above observations that the electrolyte concentration should be higher to obtain maximum MRR, machining accuracy, improve machining speed and good surface finish. It should not be much higher because of over-etched at the tool tip. The electrolyte concentrations generally used in the ranges of around 30 g/L to 35 g/L. The electrolyte concentration for different work piece materials has yet to be finding out.

6. INTER-ELECTRODE GAP (IEG)

The Inter electrode gap is one of the significant parameter which is difficult to maintain the constant gap during the machining. The IEG maintained in ECM is higher than in the ECMM and the ranges are for ECM 100-600 µm and for ECMM 5-50 µm. Thus in the micro machining IEG becomes crucial and leads a better resolution. Fig.4. shows voltage profile.

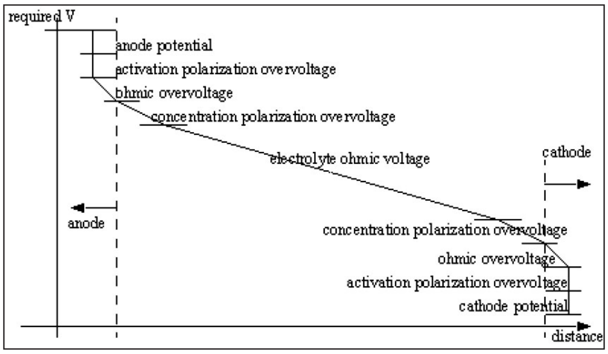

Fig. 4. Potential Profile Within the IEG

If IEG is smaller the applied potential is also smaller and has to attain the machining voltage and because of electrolyte resistance is reduced the ohm drop occurs. The dissolution of material is preferential closer to tool electrode because the higher potential created higher current density at that tip. A lot to research has to be done on how the IEG influences several parameters during machining. In the title "Electrochemical machining: new possibilities for micro machining" (Bhattacharyya B., Mitra S., Boro A.K., 2002) stated that with 1V (voltage) applied between the tool and work piece the electrical constant of the micro tool through work piece can be checked. "Influence of tool vibration on machining performance in electrochemical micromachining of copper" (Bhattacharyya B., Malapati M., Munda J., and Sarkar A., 2007) stated that the influence of micro tool vibration frequency on accuracy is illustrated in the Fig 5. Researchers need more attention in the area of dynamic gap control for effective MRR.

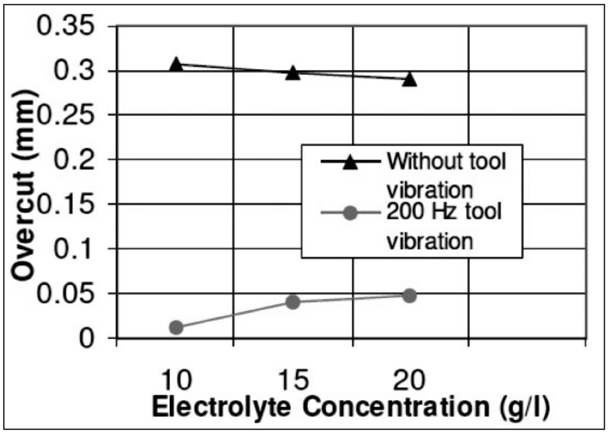

Fig 5. Machining Accuracy with and Without Tool Vibration

The research titled "Process monitoring of electrochemical micromachining" shows the importance of inter-electrode gap in ECMM set up (De Silva A.K.M 1998) Stated that the ECMM operated with small IEG has obtained high accuracy because of this the control process to maintain narrow gap has much more complex. This paper examined the discharge mechanism in order to prevent the spark formulation and gap manages approaches for narrow electric gap.

The paper titled "Electrochemical micro-machining: new possibilities for micro-manufacturing" (Bhattacharyya B 2001) highlighted the design and expansion of micro machine set up and a system has been developed for the control of IEG. This control system has pulse power supply, tool feed, controlled electrolyte flow and controlled tool feed. The researcher has effective utilization with the developed set up of ECMM for material removal mechanism.

From the above observations it is understandable that the IEG is significant parameter and to maintain constant gap between work and tool is a challenging task. The IEG maintained in the range of 5-50 μm and it will be influenced by the electrolyte concentration. The IEG is small the electrolyte resistance reduces and voltage also reduces. Approximately 1V can be used to check electrical constant between tool and work piece. With tool vibration of 200Hz machine accuracy increases and prevents spark. The microprocessor controlled system for IEG controlling has been developed for the effective utilization of ECMM.

7. TOOL FEED RATE

Tool feed rate is the important parameter to minimize overcut and maximize material removal rate in ECMM process. During machining process the inter electrode gap always ties to increase because of material removed from the work piece. To compensate the gap between tool and work piece the tool has to feed towards the work piece on the other hand the process always tries to attain equilibrium condition. The tool feed rate should be always equal to the linear MRR in order to avoid short circuit while machining.

ECMM with ultrashort voltage pulses an adaptable method with lithographical accuracy. (Kirchner V, Kock M, and Schuster R. 2003) first observed and stated that the feed rate was dependent on the current density, with Ultrasonic machining of titanium and its alloys: A review, (Rupinder Singh, J.S. Khambab 2006) stated that the feed rate influences IEG. The MRR is higher when current density is higher which requires lighter tool feed rate. During the ECM process the use of constant feed rate were reported by many papers where the feed rate matches dissolution rate to kept constant machining throughout. Researchers found that the very high feed rate will rapidly reduces IEG width later causing for short circuit and creating spark which can damage entire machine. To avoid sparking between tool and work piece an optimum feed rate was the maximum feed rate.

“An integrated approach for tool design in electrochemical micro machining”, Precision engineering (Jain, V.K., and Rajurkar, K.P., 1991) stated that with increased feed rate the MRR increases but it leads to non uniform dissolution because of increased temperature during the process.

The author noted that if feed rate increases the machining overcut decreases and many other researchers studied on this effect and in a couple of papers they stated that with increase in feed rate the dimensional inaccuracy increases.

The research work paper title “Influence of machining conditions on machining characteristics of Micro rods by Micro-ECM with electrostatic induction feeding method” (Wei Hana and Masanori Kuniedaa 2017) This paper describes a machining method of micro-rod with the electrostatic induction feeding method developed by the authors. With the axial feeding the increasing in the feed speed decreased taper angle, because the surface gap was mainly confined by the current. With the radial feeding the taper angle was increased with increasing the feeding distance due to above reason.

“Selected problems of micro-electrochemical machining” (Kozak J., Rajurkar K.P., and Makkar Y. 2004) stated about a feed rate of 63mm/min, sharpness of the tool edge decreases. “Expert Systems with Applications Towards next generation electrochemical machining controllers”: (Atkinson J., Labib A.W., Frost H.W. and Keasberry V.J. 2011) the authors used a fuzzy logic control method and expert system with application for ECM process. With this process an equilibrium gap can be prevented and possibly allow a small gap throughout machining and will improve machining accuracy.

From the past observations it is understandable that the feed rate is one of the important parameter to minimize overcut and maximize MRR. Feed rate depends on current density in ultrasonic machining. If current density is higher more MRR per unit time occurs. MRR increases with feed rate but it leads to non uniform dissolution because of increased temperature during the process. A fuzzy logic control approach and expert system has to use which prevents equilibrium gap and gives small gap and this is a promising technique for the improvement of machining accuracy.

8. PULSE FREQUENCY AND DUTY CYCLE

ECMM utilize a pulsed potential in order to get better resolution and supposed to have constant potential in ECM. The pulses are generally applied as square waves and with the variations in duration, amplitude and frequency. Fig. 6 illustrates the waveform used for ECMM.

During ECMM process pulse-on time is not equal to the pulse-off time as shown in the Fig. 6

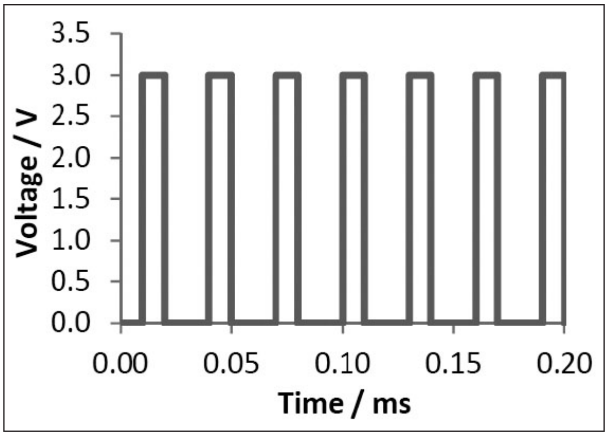

Fig 6. Pulsed Potential Wave

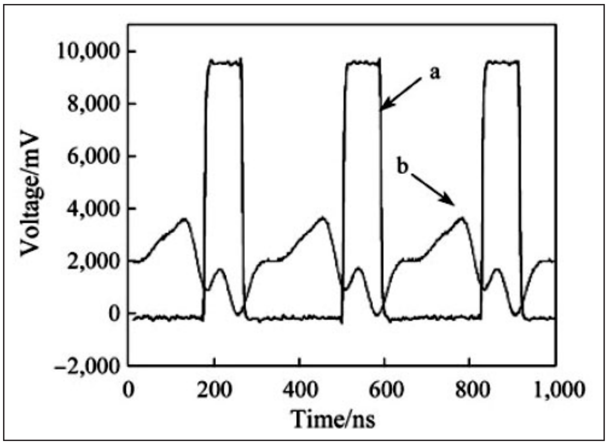

Fig 7. Plots of Waveform Captured During Micro ECM

The pulse-off time is longer in duration than pulse-on time because to provide sufficient time to take away the reaction products and to refresh the electrolyte in the IEG. The pulse-off time also permit for the fully discharge of double layer capacitor. During machining high frequency pulsed potential restricts chemical reaction at the anode to cathode in close proximity.

This indicates the time constant for EDL electrical double layer charging which changes with local separation between the electrodes. The nanosecond duration pulses are significant enough for charging EDLs. The potential drop in EDL is exponential of rate of electrochemical reaction.

In the pulsed current the ratio of power ON time to the total ON and OFF time is known as duty cycle. The frequency is known as the number of duty cycles used per unit time.

Frequency = $1/T_{total}$

The title "Manufacturing with micro ECM" (Stofesky D.B. 2006). Stated that pulsed power supply of frequency and duty cycle has been affected the material removal rate. A pulse rectifier is used and the preferred values of current, frequency, duty cycle and machining voltage has to set up before start the machining.

The research work paper titled "Electro-chemical micro drilling using ultra short pulses" (Se Hyun Ahn 2004). A unusual application of ECMM was discussed. With tens of nanoseconds period ultra short pulses are used to localize suspension area. High quality micro holes were drilled with 8 micron dia. on 304 stainless steel having 20 µm thicknesses. The consequence of pulse duration, pulse frequency and voltage on localization distance be studied.

The paper titled "Influence of tool vibration on machining performance in electrochemical micro-machining of copper" (Bhattacharyya B 2007). Discuss the influence of different process parameters in ECMM and stated that the most useful micromachining parameters values has been considered as 20g/l electrolyte concentration, 3V machining voltage and 55Hz frequency that can increase the higher MRR and accuracy.

The paper titled "Experimental study on electrochemical micromachining" (J. Munda, M. Malapati, B. Bhattacharyya 2005) stated that with medium concentration of electrolyte, average voltage and high frequency the higher MRR and preferred accuracy can be obtained. From the experimental analysis the optimum values obtained for frequency, electrolyte concentration and voltage are 55 Hz, 20 g/l and 3V respectively.

From the past observation it is understandable that the pulse frequency and duty cycle are essential to attain better resolution. Pulse-on time is usually shorter in duration than the pulse-off time, in order to remove reaction products. A pulse rectifier is used and the preferred values of current, frequency, duty cycle and machining voltage has to set up before start the machining. Ultra short pulses have to be used tens of nano second's duration to localize dissolution area. With medium concentration of electrolyte, higher frequency and average voltage gives higher MRR.

9. VOLTAGE

Voltage is one of the essential machining parameter which influences the MRR and accuracy.

From Faraday's laws the applied voltage can be predicted which affects the MRR through the relationship.

V = IR

Where V is the voltage and

R is the resistance.

In this case R is the resistance of the electrolyte. If the machining voltage is increased the MRR also increases and reaches to its maximum value through a particular value and starts decreasing due to the gradual generation of bubbles covered the electrode surface.

The title "Experimental investigation in to ECMM process" (Bhattacharyya B. and Munda J. 2003) stated that the power supply with constant current and voltage during machining process will influence the electrochemical machining. "A study of three dimensional shape machining with an ECMM system" (Tsuneo Kurita, Kunito Chikamori, Shinichirou Kubota and Mitsuro Hattori. 2006) An experimental set up for ECMM and IEG control system was developed. Titled "Theoretical and Experimental investigation on ECMM"(Zhang Z 2007). Experiments were carried out to make out the optimum process parameters for pulse on time, machining voltage, piezo oscillation amplitude and electrolyte concentration.

The paper titled "Influence of tool vibration on machining performance in electrochemical micro-machining of copper" (Bhattacharyya B 2007) highlights the influence of frequency and machining voltage on the surface finish material removal rage and accuracy stated that the most viable values that has been considered as 55Hz frequency and 3V machining voltage that can improve MRR and accuracy.

The research title "Investigation of Electro Chemical Micro Machining process parameters on Al- SiCp - Gr Composites using Taguchi Methodology" (B.Babu1, S.Dharmalingam, S.K. Karthikeyan, R.Karthik, V.Vairamani 2015) conducted an experimental to drilling on Al- SiCp - Gr Metal Matrix composites using ECMM and delivered methodology of machining process parameters optimization. Using Taguchi and ANNOVA, stated that the optimal values are frequency of 40 Hz, electrolyte concentration of 30 g/l and voltage as 6 V for higher MRR.

In the paper titled "Experimental study of overcut in electrochemical micromachining of 304 stainless steel" (Thanigaivelan R 2010) an experimental work was carried out to determine optimal machining condition to determine the optimal combinations of the machining process parameters the Taguchi experimental design has been applied. L16 Taguchi orthogonal array was used. The optimal combinations of machining process parameters levels for smaller overcut are pulse on time at 25ms, machining voltage at 12V, machining current at 0.8 A and then electrolyte concentration of 29 mole/l.

The paper titled "Effect of over voltage on Material Removal Rate during electrochemical machining" (Mukherjee S.K 2005) stated that with the usage of over voltage and electrolyte solution the voltage plays an essential task for equilibrium gap and feed rate of the tool. The MRR decreases with the increase in voltage and decreases the current efficiency where it is directly related to electrolyte solution.

From the above observations the voltage plays a vital role in MRR. If the voltage increased the MRR also increases and it reaches to maximum then starts decreasing due to the gradual generation of bubbles covered the electrode surface. To attain higher possible rate of MRR and accuracy the machining voltage should be 3V while machining copper material. The constant Voltage and current maintains gives most effective machining.

SUMMARY

The paper presented here is about the researcher's achievements and industrial applications produced in micro scale machining using ECMM. The objective of present paper is to put forward an overview and to sum up existing knowledge and draw attention to current challenges, therefore making a platform for further research.

1. The ECMM is the technique used to machining all kind of material which is having electrical conductivity. The ECMM having a wide range of industrial application. More research work has to be done on different materials like Aluminium and its alloy, tungsten, molybdenum, cobalt and its alloy, composite materials which are not possible to machine through conventional machining. Research effort on the ECMM and on super alloy materials remains relatively few.

2. The specific studies of each process parameters which are influencing the MRR and Dimensional deviation made by various authors are helpful to understand the behavior of each parameter.
3. Electrolyte concentration should be higher but not much higher and the common range used 30g/l to 35g/l.
4. The IEG is depending on the electrolyte concentration that is for higher concentration lower gap and fro lower concentration higher gap and the common range used is 5- 50 µm.
5. Tool feed rate should be equal to linear MRR and is depending on current density i.e for higher current density higher MRR. If the feed rate increases MRR also increases.
6. Pulse-on time is usually shorter than pulse-off time in order to remove reaction products. The average voltage, higher frequency and medium electrolyte concentration gives hither material removal rate.
7. Voltage and current should be maintained constant though out machining which gives most effective machining.

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