MICRON RANGE COMPLEX STRUCTURE IN MICRO-ELECTROCHEMICAL MACHINING- A REVIEW

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Abstract

The major problem in the micro-manufacturing is concerned with achieving the good dimensional accurate products with the better surface finish, high MRR, no tool wear, absence of stress and no heat-affected zone. Micro-machining proved itself as a promising solution of this major problem. In recent days, industries are regularly looking for fabricating the micro-components which can be able to perform their complex functions in the sensitive areas of electronics, automotive, biomedical and optics. Now a day for miniature components micro-machining plays a very important role, its techniques are excellent to machine any complex shapes with good accuracy and bright surface finish. Material with any value of the hardness can be machined easily with all the offered advantages of micro-machining in the electrochemical micro-machining process (EMM). In this article; review of different methodologies and effect of machining parameters were studied along with different electrolytes; which plays a significant role in electro chemical micro-machining. The objective of this study is to know about the optimum micro-machining parameters for the EMM process and it is also much important to find out the research gap through the different studies. In this study, it has been found out MRR and overcut are depends upon the voltage, electrolyte concentration, IEG, pulse ON/OFF time, pulse duration, pulse frequency, RPM of the tool and flow rate of electrolyte. The proper selections of parameters in EMM are essentials for achieving the overall improvement in the micro-machining operation.

Keywords: *Micro-Manufacturing, Micro-Machining, Electrochemical Machining (ECM), Electrochemical Micro-Machining (EMM).*

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1. INTRODUCTION

The techniques of material removal play as a key role in the component fabrication. Various high strength alloys were difficult to machine with the conventional processes. The material removal in these alloys with traditional tools results in the damage of tool as well as work piece. Many non-traditional machining methods have been developed in order to remove the limitations of traditional processes. Electro chemical machining is one of them among those non-traditional machining processes. This process is used in the industry within the last decade. Now a day, to have microproduct in limited space is the trend in the society. So micro-machining technology is helpful in saving energy as well as material and enhances the functionality at the same time. Generally, the machining upto the dimension between 0.1μm to 1mm is termed as micro-machining. Electrochemical micro-machining (EMM) is proved itself as a promising micro-machining process that has various advantages like no wear on tool, no cutting force, stress-free machining surface, with ability to machine the complex structures precisely. In EMM, the work piece acts as anode & micro tool as cathode and both are dipped in electrolyte separated by a small inter electrode gap [4]. The removal of atom occurs due to anodic dissolution. The electrolyte is used to make the common path between the work piece specimen & cathode tool. It not only completes the electric circuit between the tool and work-piece, but also allows the desired chemical reactions to be occurred for machining. The shape of the work-piece after the machining will be the mirror image of the cathode tool due to anodic dissolution [5].

1.1 Need of EMM

The term micro-machining concerned to the removal of material that ranging from some microns to millimetres. There are several non-conventional machining processes that have already been employed for the various functioning in order to obtain the ultra-precision machining. These processes are such as electro-discharge machining (EDM), laser beam machining (LBM), ultrasonic machining (USM) etc. Some processes cause the formation of the micro-cracks on the surface of the work-piece and also forms the heat-affected zones. However EMM technique does not produce any thermal or mechanical stresses on the work-piece specimen as it is versatile to machine any type of the material. EMM also have additional advantages such as they offers higher MRR (Material removal rate), produces no tool wear and any complex shape can be obtained with high accuracy & good surface finish. The execution of machining in EMM is determined by the anodic behaviour of the work-piece specimen in a present electrolyte. Hence EMM seems to be a very hopeful future micro-machining technique in many areas of applications.

TABLE I. MACHINING CONDITIONS IN EMM

Sr. No.	**Author & Year**	**Workpiece**	**Tool**	**Electrolyte**	**Input parameters**	**Output parameters**	**Methodology**
1.	Bhattacharya B. et al. (2002)		Platinum wire of diameter 0.4mm	Sodium chloride, Sodium nitrate			Setup of EMM has been developed.
2.	Park J.W. et al. (2002)	Stainless steel -304 disc	Bronze	Sodium nitrate, Sodium chloride	a. Machining voltage- 12,10,8 V b. current-500A c. pulse duration- 0 to 25 s d. Electrode gap- 0.1 to 0.2 mm	a. Depth of grooved profile	Two concentrations of electrolytes : aq.sodium nitrate & aq.sodium chloride are investigated
3.	Bhattacharya B. et al. (2003)	Maskless copper plates of 6mm×4mm×0.4mm	Platinum wire of diameter 200 µm	Sodium nitrate	a. Machining voltage- 4 to 10V b. Pulse on time-5 to 15 ms c. Electrolyte concentration- 10 to 25 g/l d. Frequency -50 Hz	a. MRR b. Overcut	variation of MRR and overcut were observed for the various predominant EMM parameters such as applied voltage, electrolyte conc., pulse on time
4.	Bhattacharya B. et al. (2003)	Maskless copper plates of 6mm×4mm×.4mm	Platinum wire of diameter 250µm (silicon nitride coating on side walls of tool)	Aq. Solution of sodium nitrate	a. Machining voltage- 4 to 10 V b Electrolyte conc.-10 to 25 g/l c. frequency- 50Hz d.pulse on time-15ms	a. MRR b. Overcut	one parameter at a time.
5.	Xiang Lu et al. (2005)	Ti6A14V Alloy cylinders	Metal nozzle diameter of 300 µm	Sodium bromide	a. Machining voltage- 150V & 200V b. current-45mA c. jet pressure-175 & 280kPa d. electrolyte flow rate- 0.73 & 1.17m/s	a. Depth/Width ratio of micro holes	Micro holes pattern on the Ti surface are machined by Jet-EMM is compared with the TMEMM process

6.	Bhattacharyya B. et al. (2007)	Bare copper plates of 15×10×0.15mm	Stainless steel of diameter 237.2µm, 112µm, 102.5µm	Sodium nitrate	a. Electrolyte conc.- 15,20,25 g/l b. voltage-3V c. Frequency - 55Hz d. Tool feed rate- 0.144mm/min e. Amplitude - 4.5 & 8 V-RMS f. pulse on/off ratio- 2:1 g. Tool vibration in kHz range- 3,8,13,18,23. Hz range-50,100,150, 200	a. Overcut b. MRR	one parameter vary at a time; MRR and Accuracy is to be observed
7.	Lee E.S. et al. (2007)	STS-420 Disc	Tungston carbide	HCL	a. Machining voltage- 1.5~3V b. Applied frequency- 10kHz~1MHz c. pulse duration- 100ns & 5µs d. electrolyte conc- 0.5M e. IEG- 100µm	a. Hole diameter	experiments performed by changing the pulse on time and voltage between the tool and work piece with 1µs pulse duration
8.	Munda J. et al. (2008)	Bare Copper plates of 15×10×0.15mm	Stainless steel wire of diameter 335µm	Sodium nitrate	a. pulse on/off ratio – 0.5,1.0,1.5,2.0,2.5 b. Voltage- 2.5,3.0,3.5,4.0,4.5 V c. Electrolyte conc.- 10,15,20,25,30 g/l d. Frequency Hz- 35,40,45,50,55 e. Tool vibration frequency- 100,150,200,250,300 Hz	a. MRR b. ROC	RSM , ANNOVA
9.	Joseph J.M. et al. (2010)	Hastelloy B-2	Tungsten wire	HCL	a. pulse durations- 200,100,50, 25 ns b. Electrolyte conc.- 1, 2 Mol/l c. tool diameter- 5 , 15 µm d. Machining rate- 1.8µm/s	a. Gap width of holes b. Average diameter of holes c. Standard deviation	Four sets of experiments were performed; Two parameters were fixed in each set;
10.	Yong Liu et al. (2010)	Nickel plate of 100µm thickness	Cylindrica-l tungston	Hydro sulphuric acid , Hydrochloric acid	a. Electrode diameter- 3 to 20µm b.Pulse frequency- 0.5 to 2MHz c. Electrolyte conc.- 0.2 Mol/l d. Machining voltage- 3.5 to 5 V e. Pulse on time-40 to 90 ns f. Feed rate- 0.1 to 0.6 µm	a. Groove width b. MRR	one parameter varies while others are fixed at a time.

11.	Malapati M. et al. (2011)	Bare copper plates of 15×10×0.15mm	Tungston of diameter 300µm	Sodium nitrate	a.Pulse frequency-40,50,60,70,80 KHz b. Machining voltage-7,8,9,10,11 V c. Duty ratio-30,40,50,60,70 % d. electrolyte conc.-50,60,70,80,90 g/l e. Feed rate-150,175,200,225,250µm/s	a. MRR b. Width overcut c. Length overcut d. Linearity of micro-channel	Scanning movement strategy, RSM, ANNOVA
12.	Wang S. et al. (2011)	Stainless steel (0Cr18Ni9) of thickness 5mm	Tungston wire of diameter 20 µm	sodium nitrate	a. Machining voltage-8,10,12 V b. Tool feed rate-0.1 to 0.5µm/s c. Electrolyte flow rate- 0.25 to 1.50 m/s d. conc.- 10,20,50 g/l e. initial machining gap- 100 & 60µm	a. Number of electric short circuits	control system software performs functions: trajectory control and gap control ; each flow rate is repeated 20 times , recording the number of short circuits; for machining stability each process parameter is repeated 10 times to check the number of short circuits
13.	Saravana D. et al. (2012)	SDSS-2205 Plate OF 50mm×10mm×0.216 mm	Stainless steel 0f diameter380µm (side walls coated with bonding liquid)	Sodium nitrate	a. Electrolyte conc.-0.4,0.45,0.5 Mol/l b. Current- 0.6 &0.8 A c. Voltage- 8,9,10 V d. Duty cycle-33.33, 50, 66.66 % e. Frequency – 30,40,50 Hz	a. MRR b. S/N ratio	Taguchi L-18 , ANNOVA , Minitab-15
14.	Wu Jing et al. (2012)		Hollow structured tool		a. Radius of tool-10,30,50,70 µm b. Duty cycle- 0.2, 0.5, 0.8 % c. Electrolyte flow-0.001, 0.01, 0.1,0.5 m/s d. pulse period-200 µs e. IEG- 20µm	a. Temperature b. Dissolution depth	PDE,ALE
15.	Thanigaivelan R.et al. (2012)	Copper of thickness 200µm	Stainless steel electrode of diameter 460 µm	Sodium nitrate	a. Electrolyte conc.-20,25,30 g/l b. Machining voltage-5,7,9 V c. Duty cycle-50,34,65 %	a. Overcut b. MRR	Taguchi L-18 , ANNOVA

					d. Frequency- 40,45,50 Hz		
16.	Kumar D. A. et al. (2013)	Stainless steel sheet - 304 of diameter 60µm	HSS cylindrical tool of diameter 500µm	Sulphuric acid	a. Machining voltage- 15 to 27 V b. pulse on time- 450 to 1050 ns c. Pulse frequency- 700 to 1100 kHZ d. Electrolyte conc.- 0.1 to 0.5 mol/l d. IEG -100µM	a. Variation in taper angle	One parameter has been varried at a time while others are kept constant; Constant parameters: electrolyte agitation rate , RPM of tool, IEG ; Variable parameters : Machining voltage , pulse on time, pulse frequency, electrolyte conc.
17.	Yong L. et al. (2013)	Nickel plate of thickness 100µm	Tungsten wire (side insulated with polyamide) of diameter 106µm	Nitric acid	a. Pulse voltage- 7~12V b. Feed speed- 0.25~8µm/s c. Pulse duration- 3~40µs d. Duty ratio- 0.2,0.25,0.33,0.5,0.67 %	a. Diameter variance	To controlling the shape & size of the hole: the diameter variance with the pulse voltage, pulse duration , duty ratio & pulse frequency ; For tapered hole: one parameter is varied while others are kept constant;
18.	Lai Lei-Jie et al. (2013)	n-GaAS Wafer	Platinum ring and saturated calomel electrode	Sodium Bromide , L-Cystine, Sulphuric acid	a. Electrolyte conc.- 0.1 M NaBr, 0.1 M L-cystine, 0.5 M sulphuric acid b. polarizing potential	a. Machining tolerance b. Surface roughness	Coarse approach, Fine approach, SEM, AFM

19.	Thanigavelan R. et al. (2013)	Stainless steel plate of 200 micro meters	160 mico meters conical shaped tool electrode	Acidified sodium nitrate (prepared by mixing 0.05 mol/L of sulphuric acid to the standard electrolyte of sodium nitrate)	a. Machining voltage- 5 to 9 V b. Pulse on time- 5-17.5 ms c. Electrolyte conc.- 20 to 25 mol/l	a. Machining rate b. Overcut	one parameter varies while others kept fixed; two types of elecrolytes are used during the experiments
20.	Ghoshal B. et al. (2015)	SS-304 Stainless steel sheet	Fabricated tungsten of diameter 115µm and conical tool of 10° and 13°	Hydrosulphu-ric acid	a. Electrolyte conc.- 0.1,0.2,0.3,0.35 M b. frequency-5,6,7,8,9 MHz c. Duty ratio- 35,40 % d. Feed rate i> 115µm straight tool- 0.3125,0.40,0.625, 0.781 µm/s ii>13°taper angle - 0.26, 0.347,0.39, 0.625 µm/s iii>10° taper angle- 0.125 at 9MHz and 0.2 M , 0.208 at 9MHz and 0.3 M	a. Overcut b. Surface roughness c. Kerf angle d. Taper angle	For particular machining conditions three samples were measured ; Experiments performed to check the variation of response parameters with the input parameters.
21.	Chang Yuan-Jen et al. (2015)	SUS-304 of $58\times55\times2mm^3$	WC Electrode of KG-7 grade	Sodium nitrate		a. surface roughness b. Depth of machined holes c. Overcut	
22.	Yue P. et al. (2015)	Stainless steel plate	Tungsten wire	sodium nitrate	a. Electrolyte solution conc.- 6% b. tool feed rate-0.1 to 0.15µm/s c. IEG-10,13µm d. pulse width- 5µs e. Duty cycle- 0.5	a. Diameter of holes	Vibration excitation mechanism, compares machining accuracy

Bhattacharyya B. et al. (2002) developed an EMM system in which all the components and subcomponents should integrated in such a way to fulfil all the requirements in the micro-machining domain [1]. In this study, detailed knowledge of all the components and subcomponents of the EMM setup was described. This developed EMM system was worked on the DC pulsed power supply with voltage ranging from 0-15V & current ranging from 0-5A. The machining base was of 300×50×30mm in which vertical column: 300×200×20mm main driving screw: ø10×150 L, 40tpi, 50mm thread, main screw nut:25×50×40mm, 40tpi of internal thread, machining chamber: 100×200×80mm3, bearing: 10mmbore, 10mm thick. The stepper motor of stepper angle: 1.8°, step angle frequency: 5%, holding torque: 40N-cm, weight: 0.5k g was utilized by the setup. A centrifugal pump of power: 0.125HP/ 0.09 KW, AC: 240V, which was responsible for the flow of electrolyte in the setup used to meet the micro-machining requirements.

Park J.W. et al. (2002) compared the two electrolytes i.e. aqueous $NaNO_3$ and NaCL on the basis of machined groove at the work-piece of stainless steel-304 [14]. The machined groove surface have a regular depth and uniform profile when NaNO3 was used. An optimum IEG of 0.1~0.15mm has been maintained during this study to enhances the chemical reaction. The results computed from a PECM program, the control over groove width was easier with the application of short pulse duration than the DC current. The groove width found much smaller as 3.8µm, 4.5µm, 5.1µm for 10s of pulse interval with 8V, 10V, 12V than width obtained by continuous DC current. A specially designed cathode able to distribute current uniformly throughout its surface was recommended in order to control the groove width precisely.

Bhattacharyya B. et al. (2003) indicated process parameters such as electrolyte concentration and machining voltage as the most effective parameters which disturbs the MRR and accuracy during the machining of mask less copper plate with the tool made up of platinum wires [2]. With the electrolyte concentration of 25g/l, pulse on time 15ms, frequency 50Hz, the MRR increases less rapidly from 4-6V and 7-10V than it increases in the range from 6-7V. In the voltage range from 7-10V, MRR attains its maximum value so with the low rate, MRR increased in this zone. The MRR increases with low rate in this zone due to increase in the dissolution efficiency at the concentration of 20-25g/l than it increases in the concentration range from 10-20g/l. Due to the less localization effect at higher voltage i.e. more than 7V, the overcut phenomena is more predominant. Higher concentration of electrolyte also leads to the more overcut. The combination of electrolyte concentration as 15g/l and machining voltage as 10V is used to machine a hole with higher MRR and better accuracy on a very thin copper plate.

Bhattacharyya B. et al. (2003) developed a new setup for in-depth research on the EMM process parameters to fulfil all the requirements of machining process. In this study when mask-less copper plates was machined with platinum wire at the fixed machining parameters i.e. electrolyte concentration of 25g/l , frequency of 50 Hz and pulse on time 15ms , the MRR founded increase with the increase in applied voltage. MRR also found increases with the higher electrolyte concentration. Due to the generation of micro sparks at the 10V, 15ms and 50Hz, the shape of the hole was not proper. At 6V, 25g/l, 50Hz and 15ms, the MRR was high but the shape was not regular due to the low voltage at this parametric combination. The appreciable MRR and overcut was obtained at the 10V machining voltage, 15g/l concentration of NaNO3, 12.5ms pulse on time and 50Hz of frequency [3].

Xiang Lu et al. (2005) developed a new technique named Jet EMM, which is capable of producing deep holes on the titanium surface. In this study, when the applied voltage was lower than 100V then etching process not done properly as well as damaged the nozzle tip and also influenced the surface quality of titanium [9]. A current density of 45A/cm3 generated at 200V to achieve a higher-depth machining rate. The effect of voltage founded less on diameter than on width. At 175-280Kpa of jet pressure, the etching process carried out smoothly. Jet pressure lower than 175Kpa could not have a stable effect on the titanium work-piece where as when pressure was above 280 kpa, drastic sparking occurred between the nozzle and the work-piece. Jet pressure of 280 kPa was chosen for the stable processing during machining. As Jet EMM compared with the TMEMM in the study, the jet EMM was founded as the technique which could machine the surface of any curvature as TMEMM is restricted to flat surfaces.

Bhattacharyya B. et al. (2007) investigated the influence of the newly developed micro-tool vibration system on the process parameters [4]. In this study, the experiments were performed on the bare copper plate by stainless steel with KHz range i.e. 3, 8, 13, 18, 23 and Hz range i.e. 50, 100, 150, 200. The MRR observed more for 20 g/l than 15 g/l concentration of NaNO3, due to the high current density occurred because of higher concentration at 3V of applied machining voltage, 5HZ power supply frequency and pulse on- off time of 2:1. In KHz range, there was no significant effect founded on the MRR. The 15g/l of electrolytic concentration reduced the overcut. In Hz range, two different amplitude i.e. 4.5V-RMS and 8V-RMS were selected. MRR founded almost same for both the values of amplitude and higher from KHz range. The overcut was about 40% less at 4.5V-RMS than from the 8V_RMS. In the Hz range of experiments, it was finding that the 150-200 Hz of micro tool vibration frequency and 15-20 g/l of electrolytic concentration gives the optimized MRR with lesser overcut. This study was evident that the micro tool vibration system is excellent for achieving better MRR and accuracy.

Lee E.S. et al. (2007) manufactured the micro-hole of diameter 40μm accurately and machined the surface of 80μm thick stainless steel-420 with high quality by using ultra-short voltage pulses [10]. In this study microprobe with diameter under 10μm was pre-machined by applying 4V for 20s in 30% sulphuric acid to remove the tungsten carbide film on the work piece which prevents the electrochemical reactions. The reverse taper shape was obtained with 4V of voltage in the first step and then by applying small voltage of 0.8V in the second step, the sharp shape of the tip was manufactured. The tool electrodes were made by EMM in this work. The size of the hole was kept on increment with the increase in voltage as well as with pulse on time. The diameter of the hole was 58μm at 500ns pulse on time & 2V machining voltage and it was about 100μm at 100ns pulse on time & 1.5V machining voltage. At the same condition of voltage i.e 1.5V, the accuracy of machining was affected as the pulse interval changed from 1μs to 5μs. Better shape accuracy of machining could be obtained from controlling the duration time of pulse voltage.

Munda J. et al. (2008) developed the comprehensive mathematical model for correlating the higher order and interactive influences of machining parameters through response surface methodology approach [12]. In this research, RSM proved itself as an effective tool for the analysis of the parameters. At lower machining voltage ranging from 2.5V to 3.5V, the increase in the rate of material removal was higher as compared to the voltage ranging from 3.5V to 4.5V. The MRR was founded increasing with the increase in any process parameters except pulse on time. The MRR initially increased at the low voltage frequency of 35Hz and after achieving the maximum value, MRR started decreasing with further increment in the pulse on/off ratio. The radial overcut (ROC) decreased from 2.5V to 3V and then increased in the voltage ranging from 3V to 4.5V. At 15g/l -20g/l of electrolytic concentration, ROC decreased as the occurrence chance of micro-spark was reduced due to the increase in concentration. The higher value of ROC was obtained at every higher level of the process parameters except frequency of tool vibration. The optimum values had been resulted by considering MRR and ROC simultaneously are as 3V of machining voltage, 15g/l of electrolyte concentration, 42.118 Hz of voltage frequency, 300Hz of tool vibration frequency, and 1:0 of pulse on/off ratio.

Joseph J.M. et al. (2010) fabricated the micro-features up-to approximately 3µm in depth into the Hastelloy B-2 [7]. The size of structure is controlled through the combination of various process parameters i.e. the micro-scale size of tool electrode, duration of ultra-short pulses, depth of machining. The gap width was the measure of resolution of machining in the study. The same tool was machined by using 200ns, 100ns, 50ns and 25ns pulse durations. The gap width decreased with the shorter pulse duration for both 1 mol/l and 2 mol/l concentrations of HCL. In this study, the work-piece was grounded approximately 100µm thickness to allow this grounded specimen to penetrate the machined features. The aspect ratio was about 2:1 for the features machined on the work-piece with the pulse duration of 100ns. As tool fed deeper to the Hastelloy B-2, slower feed speed was selected because rate of the anodic dissolution decreased with 50 ns pulse duration. Size resolution on the Hastelloy B-2 is too much dependent upon the pulse duration. This work presented that the EMM with ultra-short pulses is a viable and strain free micromachining strategy for the industrial relevant material.

Yong Liu et al. (2010) successfully obtained a complex structure on nickel plate with high precision and good surface quality [22]. Experiments were performed by using cylindrical tungsten as tool. The range of voltage between 4.0-4.5V in the study was founded as the perfect applied voltage. Machining accuracy get reduced as the voltage and pulse on time were increased. The MRR increased less in the 50-90ns range of pulse on time as it was increased in the range of 40-50ns. With the increase in the range of pulse frequency between 1.0-2.0MHz, the groove width rises so the accuracy was become poor. The feed rate of 0.2µm/s was observed for the better accuracy in the study. The electrodes of small diameter 3-5µm higher the machining accuracy as groove width increased slowly. The complex structure with good surface quality was obtained by applying 1MHz pulse frequency, 0.1mol/l H_2SO_4+0.05mol/l HCL concentration, 4.5V machining voltage, 8µm diameter of electrode and 0.2ms feed rate.

Malapati M. et al. (2011) highlighted the influence of the process parameters on the response parameters such as MRR, accuracy, linearity of the generated micro-channel [13]. In this study scanning movement strategy was used for the generation of any complex micro-channel with the cylindrical shaped tool made up of tungsten. MRR increased upto the 50% of duty ratio due to the lower value of pulse on time than off time. Above 50% of duty ratio, there was no sufficient removal of dissolved product due to the higher value of pulse on time than the pulse off time. At lower duty ratio and machining voltage, WOC (Width over cut) was minimum. At the 30% of duty ratio and 150µm/s of feed rate, the LOC (Length over cut) increased with the increase in the electrolytic concentration. High concentration of the electrolyte increased the rate of dissolution, thus a passive layer was formed in the working zone disturb the localization resulted more LOC. Improved linearity of generated micro-channel on the bare copper plate was observed at the low machining voltage and concentration of electrolyte.

Wang S. et al. (2011) adopted the axial flow of electrolyte to produce micro-structures of the high aspect ratio with the tool made of tungsten wire [20]. In this study, machining efficiency was observed improve when the flow rate of the electrolyte was below 0.75m/s and as the value of flow rate crossed the 1.0m/s, stability of the process became worse because of the formation of wire electrode vibration due to the occurrence of short circuit between the tool and work piece. At 8V, the short circuits occurred often due to the low rate of dissolution and at 12V, the side gap was oversized and more rate of dissolution occurred at the sides of groove. When the 10V voltage was applied, no short circuit was occurred, resulting in the better machining. A bell shape was formed and surrounding part of the work-piece which was far away the tool, also undergoes dissolution due to electric current lines acting in the initial machining period. With the combination of 10V, 1.0ms flow rate and 10g/l $NaNO_3$ electrolyte concentration, the micro-structures were fabricated on the 5mm stainless steel with aspect ratio of 31.

Saravana D. et al. (2012) identified the optimal process parameters for machining SDSS-2205 [17]. Stainless steel of diameter 380µm was used as tool. Taguchi L-18 was used in the study. The percentage contribution of every parameter on MRR is determined by the ANNOVA using Minitab-15 software. The MRR increased with the higher concentration of electrolyte and higher voltage upto 9V. With pulse on time only removal of the material takes place. As the frequency increased in the experiments, the MRR started decrease with decrease in pulse on time. From the results it was found that the duty cycle contributes approximately 42% to the MRR. The electrolyte concentration, current and voltage followed the duty cycle in this work. Frequency affects least to MRR. The maximum rate of material removal could be obtained at 0.6 amp of current, 9V of voltage, frequency of 30 Hz, electrolyte concentration of 0.5M/l and duty cycle of 66.66%.

Wu Jing et al. (2012) proposed a cathode tool of hollow structure for improving the removal of heat and stability of the flow rate during the micromachining [21]. A 2D channel of 150µm in width and 600µm in length was comprised cathode surface, anode boundary by using geometrical model. The electrolyte velocity was obtained using fluid flow model by solving incompressible laminar Navier-Stokes equations. It was found from the study that velocity of the electrolyte seriously impact the convection effect on heat removal as it rapidly declines 0.1m/s , accounting for one fifth of the initial value . For tracking the movement of anode boundary and the feed of the cathode tool, the moving mesh (ALE-Arbitrary Langrangian-Eulerian) method was used in this study. From the study it was observed that the hollow tool with small radius and a solid tool did not able to remove the heat in IEG due to the weak convection. Temperature (T) crosses 35°c within 600µs showed an ascending tendency when the radius of the tool was chosen as 30µm or high. The temperature increased mildly at the beginning and after then kept stable at 25°c which provided a better machining environment for the process. The T rises rapidly as 10°c only in 200μs of pulse on time due to the weak convection. There was no decline in the value of T if the velocity is under 0.1m/s. The T decreased from 25°c to 21°c is about 200μs processing time when the 0.5m/s velocity was applied. When the duty cycle exceeded 0.5, there was a big rise in the T. The difference in the values of the T with values of duty cycle i.e. 0.8, 0.5 reached 11°c with in only processing time of 1000μs. So in order to balance the dissolution rate and temperature, the medium pulse rate and duty cycle were fairly necessary. It was also seen in the study that the hollow cathode tool with an interior channel, compared to solid tool was more conductive to fluid flow.

Thanigaivelan R.et al. (2012) evaluated the machining performance in terms of MRR and overcut [19]. Experiments are performed on the basis of Taguchi L-18 orthogonal array. The concentration flux decreased at higher voltage, resulting in the stray current in machining zone produces higher over cut as per the analysis from S/N curve. The MRR of copper increased rapidly due to more dissolution as pulse frequency was increase. The F value obtained from the Fisher test had a significant effect on the performance characteristics, when the values of parameters were change. The stainless steel of diameter 460μm was used as the tool. As per ANNOVA results, the EMM process was more influenced by the higher concentration of the electrolyte because large no. of ions were associated with the machining operation which lead to higher overcut. The duty cycle contributed only 11.73% to the overcut. With the increased in pulse frequency, the average current density increased which lead to increase in dissolution efficiency. From the analysis of S/N ratio and ANNOVA, it is found that the combination of 25g/l concentration of NaNO3, machining voltage of 9V, 40Hz of frequency and 34% of duty cycle were give the maximum MRR. These values of parameters are obtained through a confirmation test.

Kumar D. A. et al. (2013) analysed about the taper angle variation of the machined micro holes on the stainless steel [8]. In this study, an automatic gap control system was used to control the IEG for the precise machining. The charging and discharging of the dual layer capacitor on the both sides of the electrodes was responsible for the material removal. The taper angle did not vary significantly above 18V and 600ns, thus gave stable machining. It took several hours for a single hole below 15V and 450ns pulse on time. The taper angle of the hole found decreasing upto 1000KHz of frequency and after that it started increasing because of increase in the over machining time. At 0.4 mol/l of H2SO4, the minimum value of taper angle was observed due to uniformity in flushing condition. The variation of maximum 10 minute to minimum 30 second time consumption was achieved for machining holes. The minimum value of taper angle is obtained at the 0.4M/l H2SO4, 700KHz frequency, 600ns pulse duration and 21v machining voltage. The experiments were to be needed for optimizing parameters at every time when the electrode and electrolyte are changed during the study.

Yong L. et al. (2013) shaped a straight cylindrical hole drilled on the surface of nickel by EDM into the tapered hole by EMM [23]. The internal diameter of tapered hole varies with depth of hole. The holes with 185μm were machined by applying pulse voltage of 160V, pulse duration of 5μs and pulse duration of 10μm through the electro discharge machining (EDM). As voltage varied from 7-12V and other parameters remains constant as 10μs for both pulse duration and pulse interval, the diameter increased linearly from 185μm to just below the 260μm.The diameter of the drilled holes decreased rapidly as feed speed varied from 0.25-8μm/s at machining pulse voltage of 10V and pulse interval being kept at 10μs.The diameter also varied almost linearly with the duty ratio of 0.2, 0.25, 0.33, 0.5, 0.67. A hole of 175μm of inlet diameter and 200μm of outlet diameter is machined by varying only pulse voltage from 7~10V. Another hole of inlet diameter 181μm and 203μm of outlet diameter is machined by varying feeding speed from 10~0.5μm/s.

Lai Lei-Jie et al. (2013) tested the performance of high quality EMM instrument by CELT (Confined Etchant Layer Technique) [11]. The n-GaAS wafer was used as the work-piece. By using coarse and fine approach , the work piece and tool comes in contact with nanometre accuracy. In this study, tool electrode was made by coating a PMMA (polymethylmethacrylate) microlens array mold with titanium of thickness 10nm and platinum of thickness 50nm. For the generation of etchant Br2, the potential of tool electrode was held at 1.0V. The potential of tool was cut off and the work-piece withdrawn to a distance of 2cm away from the tool electrode after the etching for a certain period of time i.e. 300s. The whole operation was repeated 12 times and it took 3600s of etching time to finish the machining operation. The fabricated microlens array of 3.5μm in depth and surface roughness was less than 8.0nm validated the excellent performance of this novel EMM instrument.

Thanigavelan R. et al. (2013) compared the performance of acidified NaNO3 electrolyte and NaNO3 during EMM of stainless steel [19]. The amount of sludge produced by NaNO3 as compared to acidified NaNO3 .The machining rate was linear for the range of 7-9V, due to less-by-products produced the use of acidified NaNO3 . It was observed from the SEM that the machined hole with acidified NaNO3 electrolyte had lesser overcut compare to NaNO3 within 7-9V range. In relation with pulse on time ranging from 15-17.5m/s, the overcut increased gradually for acidified NaNO3 and it was increased very fast with NaNO3. With the higher concentration i.e. 20-25 mol/l of NaNO3 as compared to acidified NaNO3 had less rate of dissolution. The overcut founded linear for both the electrolytes in this range of concentration. From the results, it is found that the type of electrolyte influences the MRR and overcut. The rate of dissolution is higher at 15-17.5ms pulse on time for the acidified NaNO3 as compared to NaNO3. For achieving higher MRR and lesser overcut acidified NaNO3 is recommended.

Ghoshal B. et al. (2015) investigated the parameters of the process in order to reduce the overcut, taper angle and corner deviation for the machining of stainless steel-304 [6]. Fabricated tungsten of φ115μm and conical tool of 10° and13° taper angle were used in the investigation. Results of the experiments evident that the overcut mildly increased with the increase in pulse voltage frequency ranging from 5-6MHz and upto 9 MHz it was decreases. At 9 & 5MHz of pulse power, the 8 & 10μm overcuts of micro-channel were measured. The micro-channel of length 500μm took 36min of machining time at 9MHz with feed rate of 0.3125μm/s whereas only 23min was consumed for the generation of micro-channel of the same length at 5MHz with 0.47μm/s of feed rate. The value of entry overcut was 2.5μm & 20μm at the respective depth of 10μm & 70μm because at the top surface the time of tool stay was higher. Overcut increased with the increase in concentration of electrolyte. The increase in the rate of overcut was find very small between the 0.1 - 0.2 M/l of electrolyte concentration where as Ra value decreased from 0.103 to 0.048 μm with respect to the 0.1 and 0.3 M/l concentration resulted good surface quality. . The taper angle decreased linearly as the micro-tool depth increased vertically. The value of taper angle was 23° at the depth of 35μm where as micro-channel generated was taper less when the tool extended 45μm i.e. at 70μm with 5MHz of pulse power. The corner points were founded as curved because more metal dissolved due to more time stay by the tool at the turning points. For avoiding the slag deposition on micro tool, 5MHz pulse frequency and 0.2M/l of electrolyte concentration is recommended for the higher productivity with better surface quality and lesser overcut.

Chang Yuan-Jen et al. (2015) proposed a dual laser-assisted deposition method to protect the electrode and reduce the degradation of accuracy [5]. The experiments in study were performed on the SUS 304. The Nd:YAG with 532nm of wavelength was used to induce Ti plasma from the target where as another laser i.e. fibre laser with 1090nm wavelength was used to increase the ionization of plasma and to preheat the WC electrode. Die-electric TiO2/ TiN film is deposited on the WC electrode in an ambient condition. The deposition rate and adhesion between the electrode and deposited film were affected by the electrode and target distance. The three i.e. 0.5, 0.75, 1 mm distances were inspected in the experiments. The average film thickness was measured as 6.22, 5.76 and 3.53μm at the distances of 0.5, 0.75, 1mm.The rate of deposition was increased by 76.1% at 0.5 mm as compared to the 1 at 1mm because the process was being carried out at ambient condition. The temperature at the surface of electrode was higher as the entire electrode was covered by plasma at 0.5mm than the temperature at the larger distance. The rate of growth increased from 1.12nm/pulse to 1.97nm/pulse for all the three cases because of adhesion due to higher temperature which promoted the film formation on the electrode. In this study, Ti compound coated over electrode with the thickness of 18.8μm and 14.6μm were reduced by 11.2μm and 5.1μm due to the discharge induced in the IEG. On the other hand, the 5.2μm thick coating of Ti compound on the electrode had lesser overcut and did not show any reduction during the process. Results shows that , the coated electrodes had smaller overcut than without coated electrodes. The surface roughness between 11nm to 17nm is obtained with coated or without coated electrode by the use of electrolyte jet.

Yue P. et al. (2015) compared the machining accuracy obtained by EMM using DC power, pulse power and cathode vibration feed system [15]. An etching experiment with a static voltage, NaNO3 electrolyte of 6% concentration, without using vibrating electrode, 0.15μm/s of tool feed rate & D.C. supply took 45 minutes to machine a micro hole on the 0.2mm thick steel plate. The average diameter of the holes for five times was 151.86μm (front) & 146.90μm (back) where as it took 60 minutes for machining a micro hole with average diameter of 113.16μm (front) & 105.53μm (back) by applying 4V of pulse voltage, 5μs of pulse width & 0.5% of duty cycle with better machining accuracy as compared to the D.C. power supply. With the exciting vibration frequency of 125 Hz, the amplitude of the frequency was measured as 5μm, which was proper for the better etching experiments. The average diameter of the hole was measured 97.98μm (front) and 92.45μm (back) for five times by using DC voltage of 3.5V when the initial machining gap was 13μm and tool pole feed speed was 0.11m/s . With the $NaNO_3$ electrolyte, 5μs of pulse width and 50% of duty cycle, a 100μm hole was produced by ultra-short pulses. On replacing the ultra-short pulses to the cathode vibration feed, the average diameter of the hole was smaller than 100μm.

2. CONCLUSION

This study has overviewed the micro-machining of different metals, non-metals, alloys and compounds with the any value of hardness & different parameters and it was found that the EMM is a good machining technique due to less machining cost, less time required for machining, high MRR, no tool wear and high surface finish.

Effect of micro-machining parameters on the MRR, overcut and surface roughness were studied through this review article. It has been found that the output parameters such as MRR and overcut are largely depends upon the electrolyte concentration, voltage and inter-electrode gap. EMM can become very useful with right tool, right machine and optimum micro-machining parameters. Most of the work on EMM has been reported as successful by selecting optimum micro-machining parameters. The micro-machining of composite materials, smart materials was not reported till now. So that the some work is still need to be done on these materials to check the effects of different micro-machining parameters on the overcut and MRR.

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