INVESTIGATION OF MACHINING CHARACTERISTICS OF ELECTROCHEMICAL MICROMACHINING MACHINE (EMM)

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Abstract
To make use of full capability of Electrochemical Micro-Machining (EMM), a meticulous research is needed to improve the material removal, surface quality and accuracy by optimizing the various EMM process parameters. Keeping this in view, an indigenous development of EMM machine set-up has been considered to carry out a systematic research for achieving the satisfactory control on EMM process parameters to meet the micromachining requirements. In this study an EMM machine has been developed and experiments were conducted to study the influence of some of the major process parameters such as machining voltage, electrolyte concentrations, pulse on time and machining current on machining rate and accuracy. The effect of shape of the tool electrode tips on EMM has been investigated experimentally with 304 Stainless Steel (SS) sheets. The machining rate and overcut are significantly influenced by the shape of the tool electrode tips.

Keywords: Electrochemical micromachining, 304 stainless steel, Machining rate, Overcut, Tool Tip Shape.

1 Introduction
Micromachining is the process of removing material in the form of chips or debris having size in the range of micron. There are various techniques which can be employed for the manufacturing of microproducts. Micro-Electro Mechanical Systems (MEMS) based manufacturing employs techniques such as photolithography, chemical-etching, plating, LIGA and laser fabrication. While non-MEMS-based manufacturing often implements techniques such as mechanical machining, Electro Discharge Machining (EDM), Electrochemical Machining (ECM), laser cutting/patterning/drilling, embossing, injection molding, forging, extrusion, and stamping (Qin et al. 2010). In the midst of the various capable techniques, electrochemical micromachining (EMM) is considered for its advantages such as high Material Removal Rate (MRR), small forces acting on the work piece are required as well as low stresses and better accuracy (Wolfgang Ehrfeld, 2003). Research on EMM has been pursued worldwide, Bhattacharyya and Munda, (2003) have conducted experiments with the developed set-up by varying the machining voltage, electrolyte concentration, pulse on time and frequency on copper plate. According to the study they reported that a considerable amount of MRR at moderate accuracy can be achieved with machining voltage of 6-10V, pulse on-time of 10-15ms and electrolyte concentration of 15-20g/l. Zhao et al. (2006) have developed an experimental set-up for micro ECM with machining state detection unit and optical encoder. According to the experiments they concluded that by using low concentration electrolyte, low machining voltage and high frequency short pulse current, the machining gap can be reduced to about 10 µm. They also drilled a deep micro-hole of 100 µm in diameter on 750 µm thickness SS. Schulze et al. (2010) have theoretically and experimentally studied the applications of the pulsed EMM using ultra nano-second and short micro-second
pulses on machining accuracy and surface quality. Their study reveals that the both the type of pulses prove their legitimacy for micromachining with high accuracy. Swain et al. (2012) discussed the importance of coating of micro tools in electrochemical machining. Rathod et al. (2013) have presented a new approach for machining microhole and microgroove using sidewall insulated microtool by dip coating using liquid solution made of polymer and resin dissolved in isopropyl alcohol and use of acetone for opening the front end of the microtool. In this way, 33.78% reduction in radial overcut of micro hole and 58.64% reduction in width overcut of microgroove were observed. Taper angle was reduced from 40.57° to 18.00° and 58.39° to 25.20° for microhole and microgroove, respectively. Vanderauwera et al. (2013) studied the influence of different process parameters, electrode geometry and electrode rotation on the process performance. Experiments showed that the best performance in terms of removal rate, surface quality and accuracy. Hung et al. (2013) have developed the helical electrode with ceramic and epoxy insulation coating. The process parameter could obtain effective improvement on average hole diameter from 426.5 µm to 232.0 µm.

From the above literatures, it is observed that the researchers have developed the experimental set-up and studied the performance of EMM. However, further studies are required to improve the process parameters and commercialize the technology. Hence an EMM set-up has been developed and influence of various process parameters such as pulse on time, machining voltage, machining current and electrolyte concentration on machining speed and overcut have been studied.

2 Experimental Setup

The developed EMM machine set-up shown in figure 1 mainly consists of machining structure, pulsed power supply and Inter-Electrode Gap (IEG) control system. The machine structure made is made up of mild steel and it consists of base plate, vertical column, angle plates for housing the stepper motor and tool feed mechanism. The machining chamber is housed on the base plate with pump and filter. A pulsed power supply of 20 V and 30 A with the capability for varying voltage, current and pulse width was used. IEG control is a key factor influencing machining accuracy during EMM. The current value between the tool electrode (cathode) and work piece (anode) was measured continuously using current sensor. The output of the current sensor is amplified and converted into digital signal using amplifier and analog to digital converter. The status of machining is judged by microcontroller via the current samples. In case of a short circuit, there will be a current jump-up and this is sensed by the current sensor. Then, a decision is made to withdraw the tool electrode to maintain the set gap. When the tool electrode is withdrawn, it stops at the place several micrometers away from the point where jump-up was detected. At this point, it waits according to the programmed value so as to flush the IEG clear of all debris and then it moves forward to maintain the set gap. Tungsten wire of diameter 380 µm is used as a tool electrode (cathode). The side walls of tool electrode are coated with bonding liquid. 304 SS of thickness 300 µm is used as the work piece (anode). The work piece is rigidly held in a position by using fixture. A fresh sodium nitrate of varying concentration is used as the electrolyte in the experiments. The work piece is immersed in sodium nitrate (NaNo3) electrolyte. The power supply is applied with the constant pulse frequency of 10 Hz.

Figure 1 EMM Setup
3 Results and Discussion

3.1 Preliminary experiments to study the performance of EMM machine

The scheme of experiments was designed to investigate the control of the desired performance characteristics of process parameters of EMM set-up so as to utilize the developed EMM machine set-up properly. The experiments are conducted to determine the dominant process parameters such as pulse on time in millisecond (ms), machining current in ampere (A), electrolyte concentration in mole/liter (mole/l) and machining voltage in volts (V) on machining rate and overcut. Experimental results are plotted in the form of graphs as shown in Figures 2 (a-d). Based on the figure 2 (a) the machining rate increases with increase in pulse on time. The machining speed is maximum at a pulse on time of 30ms and decreases with increase in pulse on time. Overcut also increases with increase in pulse on time. The most effective range for pulse on time is 25-30ms for a moderate machining speed and lower overcut. It is clear from the figure 2(b) that the machining current has no effect on machining rate and overcut. However, the machining is found to be increasing linearly in the range of 0.7 to 0.8 A. Based on the figure 2 (c) the machining speed as well as overcut increases with the increase in electrolyte concentration. An electrolyte concentration of 0.23-0.29 mole/l gives moderate machining speed and lower overcut. Figure 2 (d) shows influence of machining voltage on machining speed and overcut. The machining speed and overcut increases with machining voltage. The effective range of voltage for machining rate and overcut is found to 12-15V. Hence, for this EMM machine set-up the most effective range for machining voltage, pulse on-time, machining current and electrolyte concentration for higher machining rate and minimum overcut can be considered as 12-15 V, 25-30 ms, 0.7-0.8 A and 0.23-0.29 mole/l.

Figure 2 (a) Effect of pulse on time on machining rate & overcut at 15V, 1A, 0.23mole/l

Figure 2 (b) Effect of machining current on machining rate & overcut at 16V, 35ms, 0.23mole/l
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According to the preliminary experiments it is observed that, the machining rate decreases as the machining depth increases due to the difficulty of maintaining the flow of electrolyte deep inside the micro hole. Added to this, hydrogen bubbles evolved during machining in the machining gap interfere with electrolyte diffusion. Hence, inadequate diffusion of electrolyte changes the machining conditions, the machining rate decreases significantly with increasing depth. Researchers worldwide are developing various methods to overcome the problem of electrolyte diffusion. Hewidy et al. 2001, Ahn et al. 2004, Westely et al. 2004, Bhattacharyya et al. 2004, Ebeid et al. 2004, Yang et al. 2007, Tsui et al. 2008, Wang et al. 2010 and Fan et al. 2010 have improved the electrolyte diffusion by using different tool electrodes design. In this study different tool tip shape of Φ464 shown in figures 3 (a-d) were considered to improve machining rate and overcut. The figures 3 (a,b,d) are optical microscope images with 10x magnification and figure 3 (c) is the SEM micrographs of the truncated cone tip. Based on the preliminary experiments conducted, the process parameters have been chosen and fixed for electrolyte concentration as 0.29mole/l and machining current as 0.8A. Since, the experiments are conducted at 50Hz frequency the range of machining voltage and pulse on time were chosen as 7-10V and 5-20ms.

Figure 2 (c) Effect of electrolyte concentration on machining rate & overcut at 16V, 1A, 35m

Figure 2 (d) Effect of machining voltage on machining rate & overcut at 1A, 35ms, 0.23mole/l.

3.2 Effect of pulse on time and machining voltage on the machining rate for different tool electrode tip shapes

Figures 4-5 shows that the machining rate increases with increase in pulse on time and machining voltage. The increase in pulse on time and machining voltage increase the current density required for material dissolution, which leads to increase in rate of machining. The use of flat tip tool electrode reduces the machining rate due to insufficient flow of electrolyte towards the machining zone. The truncated cone tip electrode produces higher machining rate since, the tip shape allows sufficient flow of electrolyte across the face of the tool. In conical with rounded tip, the bottom portion of the tip diameter is lesser when compared with the top portion. At an initial stage of machining, bottom portion of the tip is exposed to the workpiece surface. Though the diameter of the exposed tip is small, the potential required for material removal is sufficient and
hence the machining rate is faster. For wedged electrode the machining rate is higher when compared to conical with rounded tip and flat electrode with lesser accuracy. The current density distribution in the case of the wedged electrode is narrow which improves the localization of the current resulting in higher machining rate.

![Figure 4 Effect of pulse on-time on machining rate](image)

**Figure 4** Effect of pulse on-time on machining rate (Machining voltage: 10V, Electrolyte concentration: 0.29mole/l and Frequency: 50 Hz)

The current density distribution in the case of the wedged electrode is narrow which improves the localization of the current resulting in higher machining rate.

![Figure 5 Effect of machining voltage on machining rate](image)

**Figure 5** Effect of machining voltage on machining rate (Pulse on-time: 15ms, Electrolyte concentration: 0.29mole/l and Frequency: 50 Hz)

3.3 Analysis of overcut based on SEM micrographs

Figures 6 (a-d) shows the SEM pictures of the micro holes drilled using various tip shapes for the same machining conditions. Figure 6(a) exhibits the SEM micrograph of a machined micro hole with flat electrode. The overcut is found to be more compared to other micro holes. Figure 6(b) shows the micro hole machined by conical with rounded electrode with lesser overcut. Figure 6(c) shows the micro hole machined with truncated cone tip resulting in moderate overcut and circular hole. Figure 6(d) is the optical microscope picture of the machined micro hole by wedged electrode and it is evident from the figure that the non-uniformity of electrolyte flow towards the machining zone reduces the accuracy and resulting in elliptical hole. So, it can be concluded that the wedge side supplies sufficient amount of electrolyte solution and other side restricts the flow, resulting in improper machining. It can also be inferred from Fig 6 (a-d) that overcut is influenced by shape of the tool tip.

Based on the Fig 6(a-d) the overcut for flat tip electrode is more when compared to truncated cone tip and conical with rounded electrode. In small inter electrode gap (IEG) the current concentration inside the gap is much higher. The insufficient flow of electrolyte cannot remove the debris resulting in higher overcut. In the case of conical with rounded tip shape, the smoothness of the tip and absence of sharp edges result in lesser overcut. In wedged electrode, the electrolyte solution distribution along the wedged side will be more compared to other side.

![Figure 6 SEM of the machined hole](image)

**Figure 6 SEM of the machined hole** (Machining voltage: 10 V, Pulse on-time: 7.5ms, Electrolyte concentration: 0.29mole/l and Frequency: 50 Hz) a) Flat tip b) Conical with rounded tip c) Truncated cone tip (d) Wedged electrode

4 Conclusions

1. An EMM machine set-up has been developed and the various parts are designed based on the requirements. The EMM machine set-up comprises of the following systems. Machine
set-up structure, IEG control system and pulsed power supply system

2. Based on the preliminary experiments, the most effective range for machining voltage, pulse on-time, machining current and electrolyte concentration for higher machining rate and minimum overcut can be considered as 12-15 V, 25-30 ms, 0.7-0.8 A and 0.23-0.29 mole/l at 10 Hz frequency respectively.

3. Wedged electrode produces elliptical hole for same machining condition compared to other tool tip shapes.

4. For machining micro holes on 304 SS, the truncated cone tip electrode is suggested for higher machining rate and conical rounded tip electrode is suggested for lower overcut.

References


