ABSTRACT

The technological advancement in material science requires advancement in machining techniques also. The present trend in machining is towards micro machining of advanced materials for biomedical, aerospace, and nuclear reactor applications. The stress free machining has become one of the most important requirements for precision machining.

Electrochemical Machining (ECM) and Electrochemical Micromachining (EMM) are the processes which satisfy the above said characteristics and thus research is active in this field. Electrochemical Machining (ECM) process also known as anodic dissolution process is generally applied to deburring of microbores, nozzle holes and shaping of electrically conductive materials. This process also has the advantage of stress free machining as there is no tool to workpiece contact. The ECM process when it is applied to machine features less than 1mm, it is called as Electrochemical Micromachining (EMM) which has been gaining popularity in the production of biomedical, MEMS, aerospace and nuclear components.

The EMM process is influenced by many parameters such as voltage, current, current density, electrolyte concentration, electrolyte flow, electrolyte boiling, vaporization of electrolyte, variation in the electrical conductivity of electrolyte and sludge formation, to name a few. The diametrical overcut of the holes machined using EMM process and current efficiency of this process is determined by the influence of these parameters individually and due to the interaction among them.

Therefore, phase I of this work is aimed at finding the optimal combination of parameters of EMM process for minimizing the diametrical overcut and maximizing the current efficiency by Taguchi method and to investigate the influence of each parameter on diametrical overcut and current efficiency using a bare electrode with flat end.

The optimum combination of parameters to obtain minimum diametrical overcut were identified. It is observed that pH value of electrolyte, voltage, duty cycle and feed rate of tool have significant effect on achieving minimum diametrical overcut. The factors pH value of electrolyte, voltage, duty cycle and feed rate of tool contribute 27.5%, 22.5%, 11.5% and 10.2% to minimum diametrical overcut. The parameters for minimum diametrical overcut are identified. Minimum diametrical overcut is achieved at the pH value of electrolyte 2.3, voltage of 20 V, duty cycle of 50%, feed rate of 1.0 µm/s and sensitivity of 70%.

Among the three levels of pH values of electrolyte, diametrical overcut is minimum for the maximum value of pH of electrolyte. Maximum pH value lead to faster machining leading to reduced time for stray current machining, resulting in minimum overcut. In the case of voltage, the lowest value of voltage (20V) among the three levels chosen (20, 22 and 24 V) results in minimum diametrical overcut. Diametrical overcut increases with increase in voltage due to high current density developed around the edge of the tool that lead to additional metal removal and thus increased overcut.

Diametrical overcut is minimum for minimum duty cycle (50%). It is because, as the duty cycle increases, the duration of pulse on time increases resulting in higher dissolution time per voltage pulse. Stray current machining time increases with increase in dissolution time. It will increase diametrical overcut and pitting on the surface of the work material.

Diametrical overcut is minimum when tool feed rate is high. The increase in tool feed rate increases the void fraction resulting in reduced conductivity of the electrolyte and a decrease in diametrical overcut. Diametrical overcut reduces with increase in rotational speed of the tool. It is due to the prompt removal of sludge from the IEG due to the centrifugal force created by the rotation of the tool.

The optimum combination of parameters to obtain maximum current efficiency was identified. It is observed that pH value of electrolyte, feed rate of tool, duty cycle and voltage have significant effect on achieving maximum current efficiency. The factors pH value of electrolyte, feed rate of tool, duty cycle and voltage contribute 74.45%, 8.41%, 6.12% and 4.15% to maximum current efficiency. The parameters for maximum current efficiency are identified. They are pH value of electrolyte 2.3, feed rate of 1.1 μm/s, sensitivity of 60%, rotational speed of the tool 40% of maximum rpm, voltage of 24 V and duty cycle of 70%.

Current efficiency is influenced by the pH value of electrolyte. Higher current efficiency is obtained for the electrolyte with pH value 2.3 in which concentration of HF is 0.2 M. The etching property of HF plays a major role in determining material removal that results in higher current efficiency.

Minimum interelectrode gap results in maximum MRR. Higher feed rate of tool reduces the frontal gap leading to stronger electric field in the IEG. MRR and current efficiency are increased as a result. Current efficiency increases with increase in duty cycle due to longer machining time available at higher duty cycle. Increase in MRR results in increased IEG. Therefore, it must be compensated with higher tool feed rate.

Effect of rotational speed of tool on current efficiency has become negligible as current efficiency of the process is predominantly influenced by the etching action of the electrolyte. At higher sensitivity, MRR is high because wastage of current due to minor electrical shorts in the system is eliminated reducing wastage of time and electrical energy.

In Phase II of this work COMSOL Multiphysics V4.2a software is used for the simulation of EMM process. Experiments were conducted by machining blind holes in Titanium grade-2 sheet metal of 0.2 mm thickness for 40s and 70s time duration. The material removal pattern obtained through the multiphysics simulation was verified with experimental results. Results of phase II justified the use of multiphysics simulation to understand the process before conducting experiments.

The experimental results of phases I showed that electrochemical micro drilling with flat end bare micro electrode results in holes with more than 100% diametrical overcut for certain combination of process parameters. As the dimensional accuracy of the part or feature will be affected by overcut, it is decided to study the influence of tools with various end profile on diametrical overcut. This part is attempted in phase III. Therefore, an insulated micro electrode with flat end and bare micro electrodes with different end profiles are used in phase III of this study. Experiments are carried out for the optimum level of process parameters for minimum diametrical overcut. The diameter of the tools used for this purpose is 0.5mm and the thickness of Titanium grade 2 sheet used for electrochemical drilling is 0.25 mm. The diameter of the hole and the diameter of the stray machined zone of workpieces machined using the above tools were then measured using image processing technique. Similarly, the diameter of the hole and the diameter of the stray machined zone for each tool were obtained through simulation.

The results of phase III experiments show that the tool with conical end is capable of providing hole with minimum overcut. But, the machined surface shows large amount of pitting due to stray current attack. Tools with spherical end and stepped end provided holes with overcut more than that obtained using conical end tool. It is due to the maximum current density that occurred at the tip of the conical tool. In the case of microelectrode with spherical end, the current density distribution, although decreasing from the center to the edge, does not decrease as that observed with the conical tip micro-electrode. So, the machining due to low current density zones of the tool is inevitable that lead to overcut in the case of tools other than the conical end. This is also the reason for increased diameter of stray current machined zone which causes pitting of the surface of the work material.

In the case of insulated microelectrode with flat end, the current density is distributed throughout the edge. Since it is insulated, the stray current attack happened in front zone, transition zone and stagnation-transition zone respectively. So, pitting and etching on the outer surface of the hole is totally eliminated. The circularity of the hole is also very much improved compared to the holes obtained using the bare tools with different end profiles. Hence, insulated tool can be recommended. But, to reduce the overcut, that is, to make a hole of diameter 0.5 mm, a flat end tool of diameter 0.25 mm may be a suitable choice.

This study provides information on the optimum combination of input process parameters for minimum diametrical overcut and maximum current efficiency, simulation of EMM process using multiphysics software, fabrication of micro tools with different end profile and the most suitable tool profile which is capable of providing minimum overcut and stray machined zone and maximum current efficiency.