ELSEVIER

Journal of Materials Processing Technology 169 (2005) 485–492

Journal of Materials Processing Technology

www.elsevier.com/locate/jmatprotec

Experimental study on electrochemical micromachining

B. Bhattacharyya, M. Malapati, J. Munda

Department of Production Engineering, Jadavpur University, Kolkata, India

Received 14 June 2004; received in revised form 4 April 2005; accepted 8 April 2005

Abstract

Electrochemical micromachining (EMM) appears to be very promising as a future micromachining technique since in many areas of applications it offers several advantages that include higher machining rate, better precision and control and a wide range of materials that can be machined. Present paper will highlight the influence of various electrochemical micromachining parameters like machining voltage, electrolyte concentration, pulse period and frequency on material removal rate, accuracy and surface finish in microscopic domain. According to the present experimental study, the most effective values for micromachining parameters have been considered as 3 V machining voltage, 55 Hz frequency and 20 g/l electrolyte concentration that can enhance the accuracy with highest possible amount of material removal. It has been observed through SEM micrographs that low voltage, moderate electrolyte concentration and high frequency can improve the accuracy with lesser number of micro-sparks. Radial stray cut and on-line pulse pattern during generation of micro-sparks are also considered for selecting the effective zone of EMM parameters. This research development made in this area of EMM will open up many challenging possibilities for effective utilization of electrochemical material removal mechanism in the area of micro-manufacturing.

Keywords: Micromachining; EMM; Machining parameters

1. Introduction

Micromachining refers to small amount of material removal that ranges from 1 to 999 μm. Recent changes in societies demand have forced us to introduce more and more micro-parts into various types of industrial products. For example, the fuel injection nozzle for automobiles, several regulations arising from environmental problems have forced manufacturers to improve the design of the nozzle towards those of smaller, compact with high accuracy. Inspection of internal organs of human body and surgery without pain are universally desired. Miniaturization of medical tools is one of the effective approaches to arrive at this target. Micromachining technology plays an increasing decisive role in the miniaturization of components ranging from biomedical applications to chemical micro-reactors and sensors. Slots, complex surfaces and micro-holes used to be produced in large numbers, sometimes in a single work piece, especially in electronic industries. These things are performed by using conventional machining techniques also, but the problems generally faced are, such as tool wear, rigidity problem of the tool, heat generation at the tool–work piece interface. Sometimes, it is difficulty to produce complex shapes by using conventional techniques [1].

Non-traditional machining processes are getting their importance due to its versatility and controlled parameters. In non-conventional machining, most of the processes are thermal oriented, e.g. Electro discharge machining (EDM), laser beam machining (LBM), Electron beam machining (EBM), etc., which may cause thermal distortion of the machined surface. Chemical machining and Electrochemical machining are thermal free processes, but chemical machining cannot be controlled properly in this micromachining domain [2]. Electrochemical micromachining (EMM) appears to be a very promising micromachining technology due to its advantages that include high MRR, better precision and control, rapid machining time and environmentally acceptable and it also permits machining of chemically resistant materials like titanium, copper alloys, super alloys and stainless steel, which are widely used in biomedical, electronic and MEMS applications [3–5]. Gusseff first patented electrochemical machining (ECM) in 1929. But electrochemical machining was intro-

E-mail address: bb13@rediffmail.com (B. Bhattacharyya).

0924-0136/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmatprotec.2005.04.074

duced in the early 1960s in aerospace industries for shaping, finishing of larger parts. ECM machining process is applied to the micromachining range of applications for manufacturing of ultra precision shapes; it is called electrochemical micromachining. EMM is an effective method of producing variety of components for the aerospace, automotive, defense, electronic and biomedical industries. Attempts have already been made to develop an EMM experimental set up and carrying out pilot experimentation for achieving satisfactory control of EMM process parameters to meet the micromachining requirements [6]. A better understanding of the high-rate dissolution is urgently required for EMM to become widely employed manufacturing process in the micro-manufacturing domain [7]. Although research institute and researchers have already initiated some research in this area of machining, it still requires lot of research. However, to exploit full potential of EMM, in depth research is needed to improve the material removal, surface quality and accuracy by optimizing the various EMM process parameters. Keeping in view of these requirements, experimental set up has been developed to achieve precise micro-tool motion for investigating the influence of various major process characteristics, such as machining voltage, electrolyte concentration, frequency, pulse period, pulse on–off-time and micro-tool feed rate on the material removal and accuracy. Radial stray current effect and micro-sparks phenomena are also been considered for deriving most suitable process parameters.

2. Major characteristics of EMM

EMM offers several advantages as compared to chemical micromachining (CMM), such as higher unit removal, use of ecologically safe etchant, faster rate of material removal and machining of chemically resistant materials, i.e. titanium, super alloys and stainless steel, etc. The influence of current density, current distribution, anodic reactions and mass transport effects on unit removal and accuracy is very crucial. The shape of feature to be generated and its dimension depends not only on the dimensional features like micro-tool electrode and inter electrode gap (IEG) but also on position features, such as electrolyte flow direction, machining voltage and hydrodynamic conditions [8]. In order to achieve the effective and efficient micromachining, the role of following major EMM characteristics are to be investigated thoroughly through planned experimental study.

2.1. Role of power supply

Generally the nature of the power supply is either DC full wave rectified or pulsed DC. A full wave rectified DC supplies continuous voltage, where the current efficiency depends on the current density. Decrease in current density decreases the current efficiency, which can improve the surface finish and accuracy of form of the work piece. In pulsed DC, current efficiency is much more dependent on current density [9]. In order to achieve proper EMM, the current density is maintained as low and operating voltages of less than 5 V are required. If the current density and the voltage is high, concentration of reaction products are high and these reaction products cannot be removed properly due to narrow small inter electrode gap. The increasing contaminations of reaction products are caused to deposit in-between micro-tool and work piece, so that the work piece material no longer dissolves properly [10]. Furthermore, change in electrolyte concentration and temperature increases the electrical resistivity, which in turn affects the accuracy. For improving shape accuracy and finish, the IEG should be kept as small as possible. The small IEG is limited by the generation of unwanted electrical discharges, which can reduces the surface quality, accuracy and surface finish. High off-time ultra short pulses improve the localization of dissolution to sub-micrometer, i.e. enhance the accuracy. The anodic electrochemical dissolution occurs during the ultra short pulse on-time and the dissolved products, i.e. sludge, gas bubbles and heat can be flushed away from the inter electrode gap completely by the flow of electrolyte during pulse off-time. Pulses are used in the form of single pulses or multiple/group pulses to achieve necessary accuracy in the micromachining. Group pulses are preferred because of its ability to achieve the required dimension quickly with higher accuracy. For improving accuracy and surface finish, short pulse voltage with high off-time is preferred. 3D-micromachining is also achieved by the application of ultra short voltage pulses [11–13]. The accuracy can be improved by the application of high off-time ultra short pulse DC power supply.

2.2. Role of electrolyte

The electrolyte not only completes the electric circuit between the tool and work piece, but also allows the desired machining reactions to occur. Electrolyte must possess less throwing power apart from basic properties to increase the machining accuracy. EMM electrolytes are basically classified into two categories, such as passive electrolytes containing oxidizing anions, i.e. sodium nitrate ($NaNO_3$), sodium chlorate, etc., and non-passive electrolytes containing aggressive anions, i.e. sodium chloride. Passive electrolytes are known to give better machining precision. This is due to formation of oxide films and oxygen evolution in the stray current region. It is usual to work with $NaNO_3$ (pH 7) that can improve the dissolution of material without affecting the micro-tool. However, acidic electrolytes are advantageous due to formation of soluble reaction products, which can completely swept clean from the narrow IEG during machining without micro-tool being affected. By decreasing the electrolyte concentration, inter electrode gap can be reduced to a lower value for improving the micromachining efficiency. Additive chemicals, gas mixed electrolyte, acidic electrolyte, hot electrolyte, etc., are preferred to achieve better dimensional accuracy. Addition of additive chemicals like $NaHSO_4$ to the electrolyte to reduce the concentration of dissolved