Journal of Manufacturing Processes 35 (2018) 700–714

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

journal homepage: www.elsevier.com/locate/manpro

Influence of various flow methods during fabrication of micro ellipse pattern by maskless electrochemical micromachining

S. Kunar*, B. Bhattacharyya

Production Engineering Department, Jadavpur University, Kolkata, 700032, India

ARTICLE INFO

Keywords:
Maskless EMM
Micro ellipse pattern
Flow methods
Reusable masked tool
Machining accuracy
Depth
Surface roughness

ABSTRACT

Electrochemical micromachining is extensively exploited to fabricate various surface textures, which have been used in many applications such as biomedical, defense, aerospace, tribology, etc. Maskless electrochemical micromachining (EMM) is a promising method for fabricating micro ellipse patterns with controlled shape, size and surface quality, which is based on electrochemical etching. In this paper, the effect of hydrostatic and three electrolyte flow methods is investigated during generation of micro ellipse patterns utilizing developed maskless EMM setup and SU-8 2150 masked tool. The developed setup consists of EMM cell, electrode holding devices, electrolyte circulation system and electrical connections. A patterned tool using SU-8 2150 mask can generate many high quality machined samples. The influences of major process parameters such as machining voltage, inter electrode gap, duty ratio, pulse frequency and electrolyte flow rate are explored on major and minor axis overcuts, machining depth and surface roughness (R_a) using hydrostatic and three different electrolyte flow methods during micro ellipse pattern generation. A mathematical model of the current efficiency is also developed to estimate the effectiveness of hydrostatic and different flow methods. An attempt has also been done to analysis the effects of hydrostatic and different flow methods during fabrication of micro ellipse patterns. From the experimental analysis, only upward vertical cross flow electrolyte method is recommended for the fabrication of uniform micro ellipse pattern with major axis overcut of 24.02 μm, minor axis overcut of 20.35 μm, controlled depth of 15.50 μm and surface roughness (R_a) of 0.0208 μm.

1. Introduction

With the advancement of miniaturized parts of modern industries, micromachining technology has involved for fabricating various shapes and sizes of microparts due to its capability to save space, material and energy. Micromachining technology is used to generate various microstructures containing micro square, slots, rectangular patterns, etc. on workpiece. These textured patterns and their characteristics have played the significant role in the behavior of engineering components. For instance, microtextured patterns can decrease friction, wear and tear between moving surfaces by entrapping wear debris and scars and improving lubrication. Textured surfaces have also broadly used in anti-reflective insulation to generate the functional surfaces for biomedical applications and light guide plates. Textured surfaces can increase evaporation efficiency in spray cooling compared to flat surfaces. Surface textures have most significant applications in many advance fields like optical, biomedical technologies, automotive, aerospace, etc. [1–3].

Various microfabrication techniques are available to fabricate different types of surface textures for various applications and many researchers have engaged to generate various micropatterns using different methods. Sandwich-like electrochemical micromachining is used to generate various surface textures such as squares, hexagons and micro dimple patterns using stagnant electrolyte system in the electrochemical cell [4]. This process is not suitable for fabrication of textured patterns because insoluble by-products may accumulate in the micromachining zone for the unavailability of electrolyte flow and reduces the dimensional uniformity of surface textures. Sandwich-like electrochemical micromachining process using porous metal cathode is used to fabricate deeper micro dimples without flow of electrolyte in the machining chamber. The effect of thickness of porous metal cathode, pore size and machining time on micro circular dimple dimensions is investigated in this process [5]. In this process, sludges and gas bubbles may accumulate in porous metal cathode during machining due to lag of electrolyte flow and deteriorate the machining accuracy of micro dimple. A double-sided through-mask electrochemical machining (TMEMM) process is utilized to produce micro dimple array with low taper angle using lateral flow of electrolyte [6]. A modified TMEMM

* Corresponding author.
E-mail address: sandip.sandip.kunar@gmail.com (S. Kunar).

https://doi.org/10.1016/j.jmapro.2018.09.005
Received 26 April 2018; Received in revised form 29 July 2018; Accepted 1 September 2018
Available online 24 September 2018
1526-6125/

process is applied to generate the micro hole-array on the curved surface using multiple electrolyte flow passages in the entire cathode and the influence of machining voltage, external force, duty ratio and mask thickness on dimple diameter and depth is investigated [7]. Through-mask electrochemical micro-machining (TMEMM) is a suitable method to fabricate textured patterns and shows the island formation in the micro dimples using flow of electrolyte [8]. Through-mask electrochemical micromachining is employed to generate three dimensional topographies on titanium in electrochemical cell using stagnant electrolyte [9]. The stagnant electrolyte deteriorates the machining accuracy of surface topographies due to accumulation of by-products in the machining zone. High-precision topographies have been fabricated by through-mask EMM on cylindrical objects without flow of electrolyte and these surface textures are practical example of the rotor-bearing system. This method is capable to fabricate different micropatterns such as square, hexagon, or other intricate shapes on cylindrical objects [10]. Through-mask electrochemical micromachining is applied to generate surface textures using flow of electrolyte vertically and the auxiliary anode is used to reduce the lateral undercut in the mask and improve the localization of surface texture [11]. But, through-mask EMM process is costly and time-consuming process for individual masking of each workpiece. Maskless electrochemical micromachining (EMM) is applied to fabricate surface structures using vertical cross flow electrolyte system [12]. Maskless electrochemical microfabrication is utilized to fabricate the micropattern on copper substrates in acidified and nonacidified media using flow of electrolyte [13]. A simple method of maskless electrochemical micromachining is used for the generation of varactor micropattern on stainless steel substrate using vertical cross flow electrolyte system for many applications, i.e., radio frequency (RF) circuits, parametric amplifiers, etc. The effects of process parameters such as pulse frequency, inter electrode gap, machining voltage, duty ratio and flow velocity on performance characteristics, i.e. depth and material removal rate are investigated [14]. A simple method of maskless electrochemical texturing is used for texturing on metallic surfaces and the effects of electrolyte flushing conditions and pulse history are investigated on current efficiency, material removal rate and feature definition [15]. Maskless electrochemical texturing process is used for texturing on cylindrical surface and effects of process variables such as voltage, inter electrode gap and texturing time are studied on depth, overcut and anodic dissolution localization using passing electrolyte through perforated microcavities of the tool [16]. An alternative method of surface texturing based on electrochemical dissolution is used for generation of various textured patterns such as dots, trace-dots and chevrons using flowing electrolyte through the tool cover [17]. Various cost effective surface texturing methods are used for generation of textured patterns which are suitable for tribological applications [18]. Surface textures, especially micro ellipse pattern can reduce the friction coefficient entrapping of wear particles, secondary oil effects and additional hydrodynamic pressure as well as improved wetting properties [19]. Electrochemical machining using pulse current is used to study the influence of different pulse parameters on anode potential, surface texture, surface roughness and current efficiency [20].

Modern micromachining technology creates its possibility to optimize the interfacial properties of sliding surfaces by controlling the shape and dimensions of textured micropatterns. Many methods have been applied to generate micropatterns, including chemical etching, conventional micro-turning, electrochemical machining, ultrasonic machining, reactive ion etching, etc. All these processes lead to problems of post-machined cleaning cost, more rework, degradation of surface quality, etc. But, an alternative method of maskless electrochemical micromachining is used for fabricating micro-ellipse pattern than other ECM and advanced methods because it has high machining rate, bright surface finish, no tool wear, heat affected zone and cracks, reusability of masked tool, no effect of material hardness and toughness, etc. The limitation of this process is the machining accuracy of generated micropattern. The machining accuracy of micro ellipse pattern improves by smaller inter electrode gap between tool and workpiece in this process.

Maskless electrochemical micromachining can fabricate many high quality micro ellipse patterns with short time and low cost by a single masked patterned tool and enhances the dimensional uniformity of micro-ellipse patterns. In this paper, an experimental setup consisting of EMM cell, tool and workpiece holding devices, electrical connections and electrolyte flow guiding scheme has been developed to carry out the experimental investigations for micro-ellipse pattern generation. One textured cathode tool with SU-8 2150 mask can generate many micro ellipse patterns. The generation of micro-ellipse patterns is investigated using hydrostatic and various electrolyte flow methods. The effects of major process parameters like machining voltage, inter electrode gap, duty ratio, pulse frequency and electrolyte flow rate on machining accuracy, machining depth and surface finish of micro-ellipse pattern are investigated using hydrostatic and different flow methods. A mathematical model of the current efficiency is developed to evaluate the effectiveness of hydrostatic and different flow methods during generation of micro ellipse patterns. An attempt has also been done to analysis the machined characteristics of micro-ellipse patterns to obtain the suitable machining combination using suitable electrolyte flow method.

2. Experimental method

2.1. Experimental setup

The developed maskless EMM setup for production of micro ellipse patterns consists of various subsystems, namely, electrochemical micromachining cell, power supply system and electrolyte flow system. The EMM cell has tool and workpiece holding devices, power supply connections, electrolyte flow guiding scheme between tool and workpiece, electrolyte inlet and outlet segments. The cell is made of Perspex, which is transparent material and it has enough strength to endure high electrolyte flow rate. Inlet and outlet segments of the cell are made of stainless steel to avoid corrosion resistance. Workpiece and tool fixtures are also made of Perspex. Electrolyte is supplied through tool and workpiece by the high pressure gear pump. The electrolysis products are collected at the bottom of electrolyte reservoir and can be easily removed from the electrolyte reservoir. Electrolyte flow rate can be controlled by the control valves. Excess of electrolyte is bypassed to the electrolyte reservoir. Flow meter is utilized to measure the flow rate. Pressure gauge is employed to measure the flow pressure. The DC pulsed power supply with square pulses is utilized to provide the electrical connections to tool and workpiece. It has in-built function generator with ultra fast responses and protection functions. Fig. 1 shows the indigenously developed maskless experimental setup. Fig. 2 shows the disassembled parts of EMM cell with electrode fixtures and constricted electrolyte flow path.

For conducting the experiments for micro ellipse pattern generation, SU-8 2150 negative photoresist (MicroChem) is used to generate the micro ellipse pattern on stainless steel (grade 304) sheets. SU-8 2150 negative photoresist is used on SS sheets due to its high structural strength, higher adhesion strength, etc. For subsequent UV exposure, SS-304 sheets are cleaned with acetone, de-ionized water and isopropyl alcohol. SS sheets are dehydrated on a hotplate at 195 °C for about 15 min. After cooling, a thin layer (about 18 nm) of OmniCoat (MicroChem, USA) is spincoated at 3500 rpm and baked at 200 °C for 8 min as an adhesion promoter. SU-8 2150 (MicroChem, USA) negative photoresist is applied as a coating material. SU-8 2150 is spincoated at 2500 rpm for achieving a thickness of 210 μm. After subsequent prebaking at 70 °C for 60 min and 90 °C for 8 min, the coated sample is exposed under high intensity ultraviolet light for 1 min 12 s. After post-baking at 70 °C for 6 min and 95 °C for 20 min, SU-8 developer is applied for 5–10 min for the generation of micro ellipse pattern having major axis length of 613 μm and minor axis length of 424 μm on SS-304