Engineering Science and Technology, an International Journal xxx (2018) xxx–xxx

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

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

Full Length Article

Electrochemical microsurface texturing with reusable masked patterned tool

S. Kunar *, B. Bhattacharyya

Production Engineering Department, Jadavpur University, Kolkata, India

ARTICLE INFO

Article history:
Received 11 May 2018
Revised 25 July 2018
Accepted 1 August 2018
Available online xxxx

Keywords:
Maskless EMM
Micro circular pattern
Reused masked tool
Machining accuracy
Depth
Surface roughness

ABSTRACT

A unique and innovative concept of maskless electrochemical micromachining (EMM) method is used to generate the microsurface textures with low cost and short time. Maskless EMM setup consisting of EMM cell, electrode fixtures, electrode connections and constricted vertical cross flow electrolyte guiding scheme has been developed indigenously to carry out the experimental investigations for the generation of micro circular patterns. In this method, one reusable patterned cathode tool has been utilized to fabricate many high quality micro circular patterns economically. The effect of major process parameters like applied voltage, duty ratio, inter electrode gap, flow rate, pulse frequency and machining time on textured characteristics i.e. overcut, depth and surface roughness (R_a) has been investigated. Arrays of 8000 micro circular impressions are generated by maskless electrochemical micromachining. An analysis has been done to find out the best parametric combination on the basis of micrographs and experimental results.

1. Introduction

Electrochemical micromachining (EMM) method is a very useful technique to generate different micropatterns on conductive materials. The micropatterned surfaces act as lubricant micro-reservoir and enhance the tribo-characteristics of mating surfaces under lubricant condition. Controlled fabrication of shape, size and surface quality of surface topography generates identical micropattern, known as micro-surface texturing. Textured micropatterns are applied in different areas of engineering applications to promote benefits i.e. improvement of light absorption, improvement of tribological properties, etc [1]. Various methods are offered to generate the micropatterns such as reactive ion etching (RIE) [2], chemical machining (CM) [3], electro discharge machining (EDM) [4], abrasive jet machining (AJM) [5], laser beam machining (LBM) [6], etc. Reactive ion etching process fabricates high aspect ratios and precision textured surfaces on multicrystalline silicon. But it has low machining rate and the equipment cost is high. Chemical etching based Hydrogen Fluoride (HF) is a toxic process and very much difficult to control the shape and size of micropatterns on carbon steel. EDM creates heat affected layer, tool wear, etc on annealed 1045 steel and 6061 aluminium substrates. AJM creates low machining efficiency and high production cost on borofloat and PMMA substrates. LBM creates thermal changes and residual stress in the heat affected area on 42CrMo4 substrate. Tool based machining has several disadvantages during generation of surface texturing such as tool wear, heat generation, thermal damage of machined surface and tool tip, lower machining accuracy, etc. Steam exposure process is used to improve the morphologies of surface structure of chemically spark anodized titanium surface using 100 ml teflon-lined autoclave containing 5 ml distilled water [7]. Hydrothermal exposure is also utilized to enhance the surface topography of anodized titanium samples using 60 ml of 3.5 wt% NaCl solutions [8]. All these problems lead to increased post-machined cleaning costs, reduced quality, more rework and lower productivity. Again, surface texturing by those processes is strongly restricted due to formation of low quality machined workpiece.

Electrochemical micromachining method is applied to fabricate various complex shapes on pure nickel and super-alloy plates. Experiments are carried out on nickel and nickel-based super-alloys to investigate the influences of EMM parameters i.e. machining voltage, electrode diameters, pulse period and pulse on time on side gap [9]. Effects of parameters i.e. machining voltage, electrolyte concentration, duty ratio, pulse frequency and microtool feed rate are investigated on machining accuracy and machining rate during microchannel fabrication by electrochemical micromachining

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

Peer review under responsibility of Karabuk University.

https://doi.org/10.1016/j.jestch.2018.08.001
2215-0986/© 2018 Karabuk University. Publishing services by Elsevier B.V.

method on copper plates [10]. Micro dimple array having diameter of 300 μm and depth of 5 μm is successfully fabricated using a tool electrode of 275 μm by electrochemical machining method on AISI 440C specimen [11]. But, this process has low machining efficiency and takes more time to generate the dimple array by fabricating dimple one by one. Microholes and microgrooves are fabricated by electrochemical micromachining method on stainless steel (SS-304) and the effect of sidewall insulation is investigated on machining accuracy, surface finish and machining rate of machined microfeatures [12]. EMM is used to investigate the influences of process parameters such as micro tool vibration frequency, amplitude and electrolyte concentration for producing micro hole with high accuracy and appreciable amount of material removal rate on copper [13].

Modified TMEMM process demonstrates good machinability to generate micro dimples with uniform geometric profiles on non-planar and planar surfaces of stainless steel (SS-304) [14]. In TMEMM process, the auxiliary anode is also used to reduce the undercut and it enhances the machining localization in surface texture on aluminum alloy. The etch factor decreases with increase in voltage [15]. Micro dimples are generated on the hard chrome-coated surface using through mask electrochemical micromachining (TMEMM). Masking is generated by electroplating process on hard chrome surface [16]. But, electroplating process takes more time for fabricating of masking on each hard chrome surface. The square and circular shaped micro dimples are fabricated by TMEMM on hard chrome-coated surfaces and TMEMM shows the tribological aspects of textured surfaces [17]. Improvement in overcut of micro dimples is investigated by sandwich-like electrochemical micromachining. Different surface textures i.e. square, hexagonal, etc are fabricated by sandwich-like electrochemical micromachining on stainless steel (SS-304) [18]. But, this process is expensive and time consuming process for masking of individual workpiece and may deteriorate the machining accuracy of micro dimples due to accumulation of by-products. TMEMM process is used to investigate the influence of duty ratio on the machining accuracy and surface properties of the generated micro-dimples using very thin masks on stainless steel (SS-304) workpiece [19]. In through mask electrochemical micromachining, the patterned mask on conductive substance is anode i.e. workpiece and tool without pattern is cathode. In the set up arrangements, workpiece holding device is more critical because the mask may be damaged during holding of every patterned workpiece. The mask is also very costly substance. Before machining, every workpiece needs the mask, which increases cost and time in this process. It has low machining efficiency due to masking of every workpiece. The machining accuracy may be high due to the presence of insulation in the unexposed area of workpiece. But, the undercut of unexposed area increases in this process. Total machining time is more for one sample, which reduces the overall productivity. After machining, there is necessary for mask removal on each workpiece because masking is required on each workpiece before machining. The post machined cleaning cost and more rework are involved in this process. The surface quality may deteriorate during removal of mask on each workpiece. The material is removed locally which creates bottom surface of micro cavities as curve surface.

Maskless EMM process is used to generate micro circular pattern on stainless steel (SS-304) using three different electrolytes to show the effect of various process parameters on overcut and machining depth [20]. An electrochemical process is used to generate the microscale square patterns on a fully exposed copper workpiece. In this method, the micropattern tool is fabricated by photolithography process and used for generating the micropattern of lower depth [21]. But, the machining depth is very small i.e. 1.5 μm. The effect of process parameters i.e. machining time, frequency, duty ratio, electrolyte concentration and voltage on micro circular patterned characteristics i.e. machining depth, machining accuracy and current efficiency is investigated by maskless EMM on stainless steel (SS-304) [22]. Complex micropattern of varactor shape is produced by maskless EMM on stainless steel (SS-304) and the effect of process variables are investigated on material removal rate and machining depth [23]. A concept of maskless electrochemical process is used to transfer the micropatterns from cathode to anode. It is applied to copper dissolution in acidified and nonacidified media and achieved depth of micropattern is in the range of 1.5 μm [24]. Therefore, advance fields have been seeking an alternative process, which will be able to machine these materials without any appreciable degradation of the quality of micropatterned workpiece. But, it is still a challenging issue to find out the suitable advanced micromachining process. So, maskless electrochemical micromachining is a promising technique to generate the textured patterns because it does not depend on residual stress, tool wear and crack, material hardness and toughness [25]. In this method, the workpiece is positive and patterned tool is negative. The tool and workpiece holding processes are simpler; especially the tool is fixed and can fabricate large number of patterned workpieces on large area. The tool is insulated with photoresist, which contains micropattern. One patterned cathode tool can produce many textured workpieces on large area in parallel processing in short time without continuous masking of individual tool. It has high machining efficiency and low cost to fabricate several work samples by the use of single patterned tool, which are vital for industry applications. The accuracy of textured surfaces may reduce due to stray current effect across the micro pattern because there is no insulation on the workpiece. However, smaller inter electrode gap, good flushing condition and other suitable parametric combination can improve the accuracy of micro circular pattern. After machining, there is no necessary for mask removal from each workpiece because no mask is required on the workpiece during this process. There is no chance for the deterioration of surface quality of machined workpieces. There is no post-machined cleaning cost and rework of machined workpiece in this process. The material removal is more uniform due to its uniform current distribution which produces bottom surface of micro cavities as flat surface.

Therefore, a novel approach i.e. maskless electrochemical micromachining is proposed and investigated for micro circular pattern generation on stainless steel surfaces. This research paper also presents the development of EMM cell and setup with constricted vertical cross flow electrolyte system for micro circular pattern generation using reusable patterned cathode tool by maskless EMM. One masked patterned tool can be reused for generation of many work samples. There is no necessary for mask removal from each machined workpiece in this process, which is involved in through mask EMM process. The effect of major influencing process parameters i.e. machining voltage, duty ratio, inter electrode gap, flow rate, pulse frequency and machining time on overcut, machining depth and surface roughness has been investigated. An analysis has been drawn on the basis of microscopic images, 3D images and experimental results for shape accuracy and surface quality to find out the best parametric combination.

2. Experimental procedure

2.1. Experimental setup

Maskless EMM cell and system have been developed to fabricate micro circular patterns on stainless steel workpieces as shown in Fig. 1. This maskless EMM setup is well-planned, designed and developed for carrying out the experimental investigations. Maskless EMM cell consists of patterned tool and workpiece holding

Please cite this article in press as: S. Kunar, B. Bhattacharyya, Electrochemical microsurface texturing with reusable masked patterned tool, Eng. Sci. Tech., Int. J. (2018), https://doi.org/10.1016/j.jestch.2018.08.001