Generation of Microtextured Characteristics using Maskless Electrochemical Micromachining

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Abstract. To minimize and control friction and wear, the manufacture of microtextured characteristics on circular micropatterns is an innovative approach to extend the life of mechanical systems and components and enhance their reliability and performance. The form, size, and surface quality of circular micropatterns developed on stainless steel surfaces using maskless electrochemical micromachining directly affect the service life and function of textured surface. This article presents the experimental study on the generation by electrochemical micromachining of circular micropatterns on stainless steel. The effect of process variables such as inter-electrode gap (IEG), flow velocity and machining time on current density, current efficiency, material removal rate (MRR), surface roughness, and diametric taper angle are examined during the generation of circular micropatterns. The best parameters obtained from the experimental results are 100μm IEG, 4.4 m/s flow velocity and 3 minutes machining time for producing this micropattern. An attempt is also made to analyze the optical and 3D images of circular micropattern from the experimental results.

1. INTRODUCTION

Electrochemical micromachining based on anodic dissolution principle is very helpful to modify the shape of materials. The regulated modification of surface topography's form, size and surface quality produces the same micropattern, known as microsurface texture and used in many engineering fields, such as promoting benefits such as improving surface adhesion, improving tribological properties, increasing light absorption, reducing drag in aerodynamic applications, etc. [1]. Different microstructures having micro square and circular pattern are innovative loom for the dropping of rubbing in sliding mechanism [2, 3]. Micropatterns are acting as fluid reservoirs to hold the lubricants between two mating mechanical components for reducing friction. This texturing surface also reduces the increase in abnormal temperature during movement of automotive components. Two hybrid wire electro discharge machining processes and EMM are used to manufacture the collection of microelectrodes as cylindrical columns [4]. This process has some heat affected problems during generation of microelectrodes array and it takes more time for overall machining process. The micro...
A dimple array is produced successfully using a 275μm tool electrode by ECM process [5]. Jet-electrochemical machining method is used to make the dimple array on carbide metal alloys. This method is suitable for the controlled material removal due to restricted area of electric current by a confined area of jet [6]. Both processes produce one by one micro hole and take more time to produce the dimple collection. Through-mask EMM is used to make dimple arrays using PDMS mask [7]. This TMEMM method with laser machining is applied to construct dimple pattern on titanium alloys [8]. But the laser process scatters the uniformity of micropattern. The dry-film photoresist mask is employed to produce on a cylindrical inner microstructured surface using TMEMM. For masking of individual workpiece, photolithography process combines with number of stages [9]. This photolithography process is necessary for every machining. This technique is very time-consuming and costly for mass production. For machining of micro dimple array using TMEMM is very costlier than maskless EMM because masking is necessary for individual workpiece using UV photolithography, X-ray lithography, etc. Individual masking is time consuming matter. Various surface texturing patterns are successfully fabricated using sodium chloride electrolyte by maskless electrochemical texturing (MECT). For MECT tools, electrical discharge machining method is used on AISI 430 ferritic stainless-steel plate [10]. But this process has heat affected zone. Different elementary investigations have also been done by various surface structuring methods such as LBM [11], AJM [12], EMM [13, 14], etc. But electrochemical micromachining uses the anodic dissolution method for the removal of materials from the selective area of workpiece in electrolytic cell. So, electrochemical micromachining can be considered as a promising method for micro circular pattern generation due to high machining performance, material hardness and strength independence, etc. The aim of this research paper is to create the experimental setup and developed flow system for producing microstructures. The effect of process parameters on current density, current efficiency, MRR, surface roughness and taper angle has been investigated i.e., IEG, machining time, and flow velocity. The study has been analyzed based on experimental analysis to obtain the best results.

2. EXPERIMENTAL PROCEDURE

The developed setup has EMM cell, electrical unit and electrolyte supply arrangement as shown in Figure 1. The cell has fixture arrangements of electrodes, power unit and inlet and outlet ports. It is built by Perspex material. The vertical cross flow electrolyte system is devised for producing the better surface finish. The pulsed power is controlled by a constant voltage mode from the electrical unit (DOSF 20-60, Matsusada, Japan). The patterned tool containing micro circular pattern of 187µm has fabricated with SU-8 2150 mask using UV exposure system. The textured tool is employed with the precision micrometer to maintain inter electrode gap. The correctness of patterned tool is more imperative for the circular patterned quality and accuracy. Stainless steel is one of the advanced materials in micro engineering applications and utilized as job material. The ranges of selected variables i.e., machining time, flow velocity and IEG are 3 to 6 minutes, 3.2 to 4.4 m/s and 100 to 250μm keeping other parameters fixed i.e., 10V voltage, 30% duty ratio, 20g/l mixed electrolyte concentration of NaCl and NaNO\textsubscript{3} and 190kHz frequency. Microfeatures of micropatterned surface are observed using profilometer and microscope. Taper Angle ($\theta$) is measured using the equation,

$$Taper\ angle(\ ^\circ) = \tan^{-1}\frac{R}{d}$$  \hspace{1cm} (1)

Where, the radial overcut is R and d is the machined depth.
3. RESULTS AND DISCUSSION

The experimental study focuses on the observation in the form of graphs of the effect of IEG, flow velocity and machining time on the microtextured features of produced micro circular pattern. Figure 2 depicts the effect of IEG on current density, MRR and current efficiency with fixed parameters such as flow velocity of 4.4m/s and machining time of 3 minutes. The current density, current efficiency and MRR reduce with rising IEG. The current density decreases due to higher ohmic resistance. With rising IEG, MRR decreases due to uneven etching for the distribution of uncontrolled current density. The current efficiency declines because of the non-uniform current flux distribution across the micromachining area. As a result, with the rise in IEG, anodic dissolution decreases progressively as the voltage drop increases through the electrolyte. Figure 3 depicts the influence of IEG on surface roughness and taper angle. The surface roughness and taper angle increase with increasing IEG. The surface roughness increases with increasing IEG due to non-uniform etching for unrestrained current flux distribution. The taper angle increases because the micropatterned periphery increases due to irregular current flux distribution with greater stray current effect and lower depth.
Investigation is conducted to carry out the outcome of flow velocity on current density, MRR and current efficiency with fixed process variables i.e., 100μm IEG and 3 minutes machining time as shown in Figure 4. Due to higher anodic dissolution, the current density increases with rising flow velocity. The current efficiency rises with increasing flow velocity because of higher machining capability for the availability of higher current density. The MRR increases with augmenting flow velocity owing to controlled machining for the removal of sludges. Figure 5 shows the effect of flow velocity on the surface roughness and taper angle. The surface roughness increases with rising velocity because of uneven etching and then decreases due to uniform etching. The taper angle decreases with rising flow velocity owing to controlled machining across the micromachining zone and then increases due to non-uniform anodic dissolution.
The effect of texture time on current density, current efficiency and MRR with fixed parameters, i.e., 100μm IEG and 4.4 m/s flow velocity, is shown in Figure 6. The current density rises with increased machining time due to higher current flow. Because of higher anodic dissolution for extended machining time, the current efficiency increases. For regular machining, MRR increases and then decreases due to non-uniform machining. In Figure 7, the effect of machining time on surface roughness and taper angle is illustrated. The surface roughness decreases because of even etching and again increases for non-uniform machining. The taper angle increases owing to lower machining localization and then reduces for uniform machining and again increases for uncontrolled machining.
Figure 6. Effect of machining time on current density, current efficiency and MRR

Figure 7. Effect of machining time on surface roughness and taper angle

4. ANALYSIS OF MICROGRAPHS

Investigation has been carried out with SU-8 2150 mask by EMM process. On stainless steel substrates, the micro circular pattern is shown before machining in Figure 8(a). During machining, this mask does not warp and reused nineteen times since this mask has a higher tolerance limit, greater sustainability, etc. as shown in Figure 8(b). These consequences imply that this mask has additional effectiveness for generating many micropatterns with higher shape accuracy and efficiency.
Figure 8. Masked tool (a) before machining (b) after machining

The microscopic image of the micro circular pattern is created at a particular parametric combination i.e., machining time of 3 minutes, IEG of 100μm, flow velocity of 4.4 m/s, as shown in Figure 9. Almost all micro impressions remain the appropriate and homogeneous patterned shape and size owing to regular anodic dissolution with better machining conditions. The machined depth produced is almost the same due to uniform etching for managed current density distribution. The surface quality is also consistent throughout the textures because of consistent etching along the pattern.

Figure 9. Regular micro circular pattern

Figure 10 displays the 3D image and 2D surface roughness profile of micro circular impression. The magnitude of surface roughness is 0.0713μm.

Figure 10. 3D micro circular profile with 2D surface roughness profile
5. CONCLUSIONS

The distinctive microtexturing process is used cheaply for the manufacture of high quality micropatterns using a single tool. The effect of process parameters is experimentally studied on machined features of micro circular patterns. It is promising to summarize the following conclusions:

- The masked tool is more prominent for generating nineteen machined samples using maskless EMM method.
- Using the established setup, higher flow velocity, lower machining time and lower IEG are suggested for producing high quality micropatterns.
- The best parametric setting of 50μm IEG, 3 minutes machining time and 4.4 m/s flow velocity can be obtained from the investigation.

However, to build different microtextured patterns in various advanced applications, it will further explore the development of intricate complex patterned tool and tool movement strategy.

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