Electrochemical Micromachining of Linear Micropattern on Stainless Steel Surface

S. Kunar¹, V. Pragna¹, A.K. Singh², M. S. Reddy¹

¹Department of Mechanical Engineering, Aditya Engineering College, Surampalem, India
²Department of Mechanical Engineering, Aditya College of Engineering and Technology, Surampalem, India

Corresponding author’s e-mail: sandip.sandip.kunar@gmail.com

Abstract. Maskless electrochemical micromachining process with SU-8 2150 masked tool has been introduced containing microstructures with higher profile accuracy that are generated on SS-304. In this research work, to make maskless EMM method with more cost-effective, substantial adaptations are provided to this technique and an advanced version of EMM process is applied for microtexturing. In this modified technique, a special microtextured cell unit including (micromachining cell, electrical connection, and electrolyte flow scheme) is assembled by the mechanical force and perpendicular cross flow system has been developed inside the cell. Experimentation is conducted to explore the machining influence of the advanced maskless EMM process for fabricating linear micropattern. The machining outcomes of voltage, frequency, and duty ratio on MRR, dimensional accuracy, textured depth, and surface roughness are investigated during microtexturing. The investigational research reveals that this advanced maskless EMM technique can generate highly identical micropatterns having MRR of 2.2 mg/min, width overcut of 19.76µm, textured depth of 14.4µm and surface roughness of 0.0307µm.

Keywords: Maskless EMM, microtexturing, reused tool, profile accuracy, textured depth, roughness

1. Introduction

Surface microtexturing has performed an essential role in the progress of many sophisticated areas viz., biomedical, aerospace, optics, energy, etc. Microtexturing techniques will become still more significant in the future. Maskless EMM is the anodic dissolution process, which is the converse of electroplating. Maskless EMM has numerous advantages viz., no burr, stress, and tool wear, smooth microtextured surfaces, and the capability to machine complex shapes irrespective to material’s hardness, etc. [1]. In maskless EMM, a photo resist patterned tool is prepared and the bare surface of masked tool flows the controlled current through textured masked tool and removes high amount of metal from the workpiece by anodic dissolution and forms replica of textured tool on work surface. Compared with through-mask EMM, maskless EMM provides higher output with low investment and
one patterned tool can generate many micropatterned samples over large area with high surface quality and high dimensional accuracy throughout the patterned area [2].

Different micropatterning methods are employed for advanced applications. Laser beam machining and abrasive jet machining (AJM) are the advanced techniques for surface micropatterning. In general, both processes have some limitations, viz. heat affected zone, low production efficiency, etc. AJM can fabricate the micropatterns on difficult-to-machine materials [3]. Abrasive jet machining produces micro dimples, which are suitable to reduce the friction coefficient [4]. Through-mask EMM is a micropatterning technique with comparatively moderate quality and high machining rate that generates good texture on job surface [5]. TMEMM is employed to generate micro dimples and the job surface is coated with an insulation, which covered a tool and a masked layer [6]. The micro morphology in the insulation is transferred to the job surface during electrochemical machining. This modified TMEMM have some advantages, viz. lower manufacturing cost and shorter time [7]. TMEMM is utilized to produce micro impressions on curved surface having diameter of 40µm [8]. Micropatterns are created on a tubular surface having 22.7µm depth and 94µm diameter using TMEMM [9]. It utilizes photolithography process to produce micromorphology on insulated layer. Though, the photolithography is a difficult method that significantly increases the production cost and decreases the machining productivity in TMEMM. EMM is applied to prepare good micro circular patterns with low cost in enclosed electrochemical cell [10]. Maskless EMM is used to create the microtexturesusing various wave shapes[11]. Micro circular impressions are made using maskless EMM [12].

In this study, an advanced method of EMM called maskless EMM, is developed to generate high-quality linear micropatterns and improve dimensional regularity in linear micropattern. In this method, the distribution of current flux is improved, which aids to attain a high dimensional accuracy. In modified method, linear micropattern is transferred to the work surface without photolithography of substrates. The setup is established with microtextured cell, electrode fixtures, flushing system, and power unit for carrying out the investigation. One patterned tool can generate many textured samples with high dimensional accuracy. The machining influence of significant variables on performance criteria is explored during micropatterning. An effort has been made to analyze the micrographs based on micrographs.

2. Experimental Procedure

Figure 1 demonstrates the developed system setup for conducting the experiments for producing linear micropatterns. The system has microtextured cell, flushing unit and pulsed DC power unit. The microtextured cell has tool and job fixtures, erect cross flow flushing system and connection facility of power supply. The machining unit i.e., cell is manufactured using Perspex material to avoid the rusting. The flow system of electrolyte is developed inside the machining unit. The electrolyte is supplied upright from below to above via the restricted direction of the cell between electrodes, as shown in Figure 1. This developed flow system is suitable for removing the sludges from the micromachining zone creating the extra back pressure at the upper side of the cell. The electrical connection is supplied to the electrodes from the pulsed DC unit. This power unit has inherent protection function and function generator with ultra-fast responses. LIGA process is employed for generating the linear micropatterned tool using SU-8 2150 mask having thickness of 203µm on stainless steel sheets. The width of linear slot is 445µm. Precision micrometer is used to maintain inter electrode gap settings.

Extensive pilot tests are conducted to finalize the influential process variables and ranges of variables for micropattern generation to perform the experimental investigation. Below and above ranges of these parameters have not acquired the satisfactory results with higher profile quality and dimensional accuracy. The voltage of 8 to 14V, duty ratio of 50 to 80%,and frequency of 10 to 25 kHzare the persuading process variables that are used to examine the machining effect on width overcut, material removal rate (MRR), machining depth, and surface roughness (R_a). Other attributes are static, viz. 1 minute machining time, 20g/l electrolyte concentration, 5.54m^3/h flow rate and 50µm inter electrode gap. The combined mixture of NaNO_3 (50%) and NaCl (50%) is selected as an electrolyte for experimentation. The output responses are monitored by Optical microscope, Atomic Force Microscope (AFM), and CCI Non-Contact Profilometer.
3. Results and discussion

The superiority of linear micropattern is controlled by machining rate, dimensional accuracy, textured depth, and surface quality. Investigational outcomes are plotted as various graphs and appraised the best micrograph with good quality.

Figure 2 displays the consequence of voltage on output measures with other static attributes, such as 50% duty ratio and 25kHz frequency. With greater machining voltage, the MRR increases because of more current. The width overcut grows with greater voltage because the distribution of current flux is uncontrolled. For increasing the machining voltage, the depth rises for greater machining localization. The $R_a$ increases with higher voltage owing to irregular etching for distribution of current flux. For high quality linear micropattern, lower voltage is proposed.
Figure 2. Variation of width overcut, MRR, depth and $R_a$ with voltage

Figure 3 depicts the outcomes of duty ratio on performance criteria with other static parameters i.e., 25kHz frequency and 8V voltage. Because of the longer pulse on time (texturing time), the MRR rises as the duty ratio rises. Higher texturing time removes more material from machining area. With a higher duty ratio, machining accuracy lowers as texturing time increases, due to uncontrolled distribution of current flux. The depth improves for greater duty ratio because of longer time, resulting in a greater localization effect. Because of the irregular etching, the surface finish reduces as the duty ratio increases. Lower duty ratio is suggested for better micropattern.

Figure 3. Variation of width overcut, MRR, depth and $R_a$ with duty ratio

Experimentation is accomplished to assess the machining influence of frequency on output requirements with other constant variables, such as 8V voltage and 50% duty ratio as exhibited in
Figure 4. With higher frequency, the MRR decreases because the repetition of the pulse on time decreases, resulting in less material removal. Since the texturing time decreases with higher pulsed frequency, the machining precision increases, and the stray current effect decreases. The micropatterned depth lowers with greater pulsed frequency because of lower machining time resulting lower controlled machining. Because of the shorter machining time, the surface finish improves with higher pulse frequency, which is responsible for regular etching. For précised micropattern, higher pulse frequency is suggested.

![Figure 4](image)

**Figure 4.** Variation of width overcut, MRR, depth and $R_a$ with frequency

4. Analysis of micrographs

The micropatterned tool is utilized for producing many high quality linear micropatterns owing to higher strength, high resistance capability, etc. The masked tool is shown in Figure 5(a) before machining. It is applied up to fabrication of twenty-one high-quality micropatterned samples. The quality of patterned tool is deteriorated after fabrication of twenty-one samples. Figure 5(b) demonstrates the patterned tool after texturing. It is demonstrated that this mask has ability to produce many good quality samples.

![Figure 5](image)

**Figure 5.** Textured tool (a) before texturing (b) after texturing

The micrograph of micropattern is fabricated at 8V voltage, 50% duty ratio and 25kHz frequency as shown in Figure 6. All impressions of linear micropattern are better in dimensional accuracy, size, and shape because of regular anodic dissolution and good flushing conditions. The textured depth is also
unvarying all over the micropatterned zone owing to regular dissolution. Regulated etching also improves the consistency of the surface. The generated regular linear micropattern has MRR of 2.2 mg/min, width overcut of 19.76µm, textured depth of 14.4µm and surface roughness of 0.0307µm. Figure 7 shows a 3D view of a micro impression segment with a 2D depth profile having value of 16.1µm. Figure 8 shows the roughness profile having value of 0.0539 µm.

Figure 6. Regular linear micropattern

Figure 7. 3D view and 2D depth profile

Figure 8. Roughness profile

AFM is utilized to take 3D view with 2D roughness profile of micro impression as shown in Figure 9 having the value of 190.89nm.
5. Conclusions

This advanced method is employed to produce high-quality linear micropatterns using developed electrolyte flow scheme and reusable masked tool. From the investigational analysis, the following deductions can be concise:

(i) With the developed setup and flushing scheme, an advanced EMM technique, maskless EMM, is used to generate good quality micro linear patterns.

(ii) One patterned tool can generate twenty-one high-quality micropatterned samples with high dimensional accuracy.

(iii) The best input parameters, viz. 8V voltage, 50% duty ratio and 25kHz frequency, can fabricate good quality micropatterns.

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