Profile Characteristics of Biomachined Zinc

J Istiyanto¹, G Adhitama¹, B A Zulkarnaen¹ and Y Whulanza¹,²

¹ Department of Mechanical Engineering, Universitas Indonesia, Depok, Indonesia
² Research Center of Biomedical Engineering, Universitas Indonesia, Depok, Indonesia

E-mail : ganang.adhitama@ui.ac.id

Abstract. Biomachining is one of the alternative methods in micromachining, which is environmentally friendly and have high efficiency (eco-efficient). This method uses bacteria (this research used Acidithiobacillus ferooxidans), which can extract the metal by using oxidation-reduction reactions as a part of its life cycle. This study reports the characterization of the biomachining process using zinc (Zn) materials. Pattern making was done by the visible light maskless photolithography process using DLP (Digital Light Processing) projector, and the characterization was done by varying the biomachining time. Surface profile data and photos of the workpieces were obtained using 'SURFCOM' and 'Dino-Lite' microscope, respectively. The results of this study show the profile of the surface of biomachined zinc forms a valley shaped like, with the horizontal feed larger than the vertical feed, and for the depth, width, and surface roughness tend to increase, while for the material removal rate and specific material removal rate tend to decrease with the increase of biomachining time.

1. Introduction

Microfabrication is a process used to create physical objects, with the dimensions in the range of micrometers to millimeters [1]. One of the microfabrication technique is micromachining, the process of material removal in the range of microns (greater than 1 μm and smaller than 999 μm) [2]. Based on environmental issues, as well as the efforts to improve efficiency in the micromachining process, developments to obtain eco-efficient (high-efficiency environmentally friendly) alternative technologies keep continuing [3]. One of the alternative technology for solving this problem is the use of microorganisms in the micromachining process [4]. The process of micromachining that using microorganisms as cutting tools in material removal processes is called biomachining [3-5]. Biomachining is considered to be more environmentally friendly, as it can replace hazardous chemicals in chemical etching processes, besides that, several advantages of this process are low energy consumption, high energy efficiency, and low cost [4]. Biomachining process can also eliminate HAZ (Heat-Affected Zone) on the workpiece surface, and also tools (microorganisms) in biomachining process can be cultured continuously or can be said renewable [3-5].

The biomachining process occurs in parts of the body of the Acidithiobacillus ferooxidans bacteria, which is consisting of several layers of biomembrane. The biomembrane layer of the bacterium A. ferooxidans consists of the outer membrane, peptidoglycan, periplasmic space, inner membrane, and cytoplasm [4,5].
The oxidation or dissolution process of the workpiece by the indirect biomachining method is carried out by an intermediate solution (Fe$^{3+}$/Fe$^{2+}$ ion solution) [6]. This process is divided into two stages, in the first stage, Fe$^{2+}$ ions deriving from the culture medium are transported to the periplasmic space. In the periplasmic space and inner membrane, Fe$^{2+}$ ions will oxidize into Fe$^{3+}$ ions. The H$^+$ ion from the culture medium enters the cytoplasm and reacts with O$_2$ producing energy [3-5]. The process can be explained in equation (1).

$$2\text{Fe}^{2+} + \frac{1}{2}\text{O}_2 + 2\text{H}^+ \rightarrow 2\text{Fe}^{3+} + \text{H}_2\text{O}$$  \hspace{1cm} (1)

In the second stage, Fe$^{3+}$ ions that secreted out, which are a strong oxidant, oxidized the workpiece, turn the Zn$^0$ to Zn$^{2+}$, or in other words, the workpiece undergoes a material removal process by Fe$^{3+}$ ions that produced by A. ferrooxidans bacteria [3-5]. The process can be explained by the reaction in equation (2).

$$\text{Zn}^0 + 2\text{Fe}^{3+} \rightarrow \text{Zn}^{2+} + 2\text{Fe}^{2+}$$ \hspace{1cm} (2)

Then the Fe$^{2+}$ ion produced in this process can then be oxidized back into Fe$^{3+}$ ions on the body part of the bacterium A. ferrooxidans. This process then occurs continuously.

2. Materials and Methods

The workpieces used in this study is high purity zinc, in the form of the ingot (Zn block). The workpieces used dimension was 20 x 20 x 0.3 mm, which was grinded and polished before.

2.1. Maskless Photolithography Process

The photolithography process is aimed at making the pattern of bacteria feeding in the biomachining process by using a photoresist layer. In maskless photolithography, the exposure process is performed by using visible light from the DLP (Digital Light Processing) projector instead of UV light [7]. This research used dry film negative photoresist, with an exposure time 15 - 20 minutes, and developing time 2 minutes. The pattern that used in this study was three narrow line with the size 500 μm, and the pattern is created using the 'Microsoft Powerpoint' program on laptop / PC, the shape of the pattern is black, while the background is colored light blue (R: 0, G: 176, B: 240) [7].

![Figure 1](image1.png)

**Figure 1.** Maskless photolithography process. (a) apparatus scheme, and (b) pattern used.

2.2. Biomachining Process

In this study, the biomachining process was performed using A. ferrooxidans bacteria with 9K media [6], which had been cultured previously for several days until color changes occurred. MPN (Most Probable Number) method [8] chosen as the calculation method of the bacterial concentration in this research and the concentration used was 43 x 10^5 organisms/100 ml.
The biomachining process is carried out by immersing each workpiece into a 150 ml bacterial culture solution in a 250 ml beaker glass. The biomachining process carried out at 28°C - 30°C with a rotational speed of 150 rpm. In this study, biomachining time varied for 12 hours, 24 hours, and 36 hours.

![Figure 2. Biomachining process. (a) bacterial culture solution in incubator, and (b) Most Probable Number (MPN) method.](image)

### 3. Results and Discussion

#### 3.1. Workpiece Photos

![Figure 3. Surface photos of workpieces with 20X magnification for biomachining time. (a) 12 hours, (b) 24 hours, and (c) 36 hours.](image)

Figure 3. shows the surface photos of the workpieces using ‘Dino-Lite’ microscope AM7115MZT with 20X magnification. On the surface of the workpieces sample with 12 and 24 hours biomachining time, the shape of the line still looks clear, meanwhile for the 36 hours of biomachining time workpiece sample, due to over-horizontal feeding, the shape of the line looks blurry. The width of the line also increases with the increase of biomachining time.

#### 3.2. Surface Profile Data

The surface profile data retrieval process for each workpiece was done using 'SURFCOM' 2900SD3 Tokyo Seimitsu. The measurement data obtained are three profile contour data and three surface roughness data from each sample of workpieces.

##### 3.2.1. Profile contour

Figure 4. shows the development of the trend of profile contour for each sample of the workpiece. The profile contour of the surface of biomachined zinc forms a valley shaped like. As seen from the graph, the horizontal feed has a greater value than the vertical feed, or in the other words, the width of the...
profile increased faster than its depth. Also, the profile contour of the workpieces tends to look more uniformly with the increase of biomachining time.

Figure 4. Profile contour of the workpieces for various biomachining time.

Figure 5. shows the three-dimensional profile contour of the workpieces for various biomachining time, with the goal of showing the profile contour along the gap formed on the workpieces. This three-dimensional graph is made of some surface contour data along the gap for each sample of the workpieces. For the sample with 12 hours biomaching, the bottom part of the gap extends at the beginning and then narrows to the back, whereas for samples with 24 hours of biomachining time the bottom of the gap narrows in the center, and for samples with time 36 hours the size of the bottom of the gap is relatively the same, without any narrowing.

Figure 5. Three-dimensional profile contour of the workpiece for various biomachining time. (a) 12 hours, (b) 24 hours, and (c) 36 hours.
3.2.2. Depth, width, and surface roughness. Figure 6. shows the depth, width, and surface roughness of the gap that formed on the workpieces for each biomachining time. From all three graphs can be seen that the trend tends to rise, and the increase of the value on the y-axis is decreased with the increase of biomachining time. It can also be seen that the dimensions of the width of the gap are much different from the dimensions of the pattern which made in the photolithography process. One of the causes of this occurrence is due to the poor adherence of dry photoresist to the surface of the workpiece, resulting in much undercut (material removal in the surface that covered by photoresist [5]) during the biomachining process.

Figure 6. Surface profile data for various biomachining time. (a) depth, (b) width, and (c) surface roughness.

3.3. Machining Performance
In this study, the machining performance is presented as Material Removal Rate (MRR), and Specific Material Removal Rate (SMRR). The results of the calculation of the material removal rate and the specific material removal rate for each workpiece samples are shown in Figure 7., using mass density data of zinc, 7.13 g/cm³. From the graph (Figure 7.) can be seen that the MRR and SMRR values of the zinc workpieces tend to decrease with the increase of biomachining time.

Figure 7. Machining performance for various biomachining time. (a) material removal rate, and (b) specific material removal rate
4. Conclusion

The profile contour of the surface of biomachined zinc forms a valley shaped like, with the horizontal feed larger than the vertical feed, and the profile contour appears more uniformly with the increase of biomachining time. As for the value of surface profile data (depth, dimensions, and surface roughness) tend to increase, while for the machining performance (MRR and SMRR) tend to decrease with the increase of biomachining time.

For potential application in the industrial sectors, the biomachining process of zinc material can be applied to the waste recycle process of electronic component waste and the manufacturing process of a simple micro electronic component, since many electronic component uses zinc as materials.

References

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