

미생물 미세가공을 활용한 구리의 재료제거율 특성 Specific Material Removal Rate on Biomachining of Copper

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1. Introduction

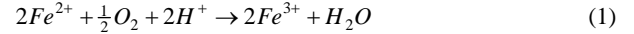
Miniaturization of various devices presents challenges in many areas of science and engineering include micromachining. Because environmental issues and the total machining cost are likely to have a significant impact on the widespread use of micromachining, alternative technologies are constantly being sought. Based on the approach used, machining processes can be classified as physical, chemical or biological [1]. However, the use of biological processes in micromachining is still limited. So, the innovative use of microorganisms in micromachining is an alternative technology that promisingly to be developed. Some advantages of biomachining that use microorganism as the tool to remove metal from a workpiece are considered more environmentally friendly than other means [2, 3, 4], low energy consumption, high energy efficiency and low cost [5]. Damaged layer or heat-affected zone generated in the desired surface can be avoided because of the utilization of metabolic microorganisms [1]. Moreover, the tools used in biomachining are renewable since they can be cultured continuously.

Researchers have discovered several bacterial species that able to extract specific metals from their ores as part of their energy production cycle, known as bioleaching, with applications in mining and waste treatment [6]. Moreover, some of these bacterial species can consume iron and/or copper, which are key industrial materials [3]. Bacteria of the genera, *Thiobacillus*, are generally acknowledged to be amongst the most important microorganisms in bioleaching. *Acidithiobacillus ferrooxidans*, formerly known as *Thiobacillus ferrooxidans*, was the species used in the previous biomachining work by some researchers [1-3, 5-9]. In this study, this bacteria was also used.

To characterize the material removal process, specific material removal rate (SMRR) was proposed to represent the amount of material that can be removed per unit time, per unit area and per unit cells concentration [4]. In this study, SMRR was used to characterize the biomachining process of copper using *A. ferrooxidans* for various machining times.

2. Biomachining mechanism

The basic concept of the biomachining mechanism is illustrated in Fig. 1. *A. ferrooxidans* has a biomembrane that consists of an outer membrane, peptidoglycan, periplasmic space, and inner membrane. Attachment process of bacteria on metal surface is mediated by *extracelullar polymeric substances* (EPS) surrounding the bacterias [6]. Iron-oxidase occurs in the periplasmic space and inner membrane. An Fe^{2+} radical that is transported to the periplasmic space from the culture fluid across the biomembrane loses an electron through the catalysis of the iron-oxidize [2]. This electron is then transported to oxygen with an electron transport chain (ETC) which couples a chemical reaction between an electron donor and an electron acceptor (O_2) to the transfer of H^+ ions across a membrane, through a set of mediating biochemical reactions. The overall reaction will be:



This reaction generates energy. The Fe^{3+} expelled from the cell is a strong oxidant and is able to oxidize pure copper (Cu^0) to Cu^{2+} . Therefore, a workpiece can be machined by the Fe^{3+} that is produced by *A. ferrooxidans*



The Fe^{3+} produced by *A. ferrooxidans* is reduced to Fe^{2+} by biomachining. Then Fe^{2+} can be re-oxidized to Fe^{3+} by the oxygen in *A. ferrooxidans*. Thus, a circulatory system is formed [2, 6, 7].

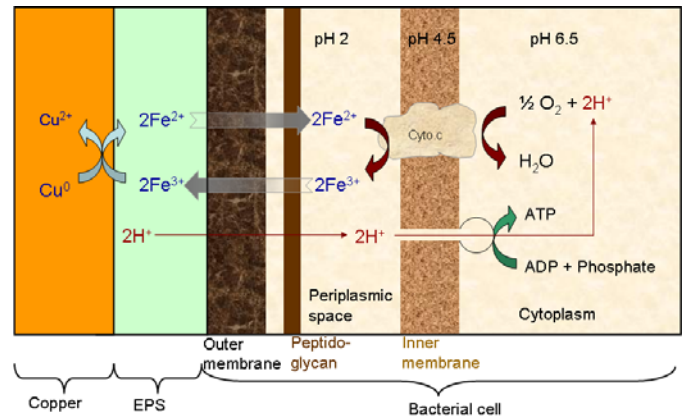


Fig. 1 Biomachining mechanism [2]

3. Experiment

Tools used in biomachining are *A. ferrooxidans* that obtained from the American Type Culture Collection (ATCC) No. 21834. An environment with a pH of about 2.5 and a metal to serve as the source of electrons in the respiratory process are required to grow *A. ferrooxidans*. One mL of *A. ferrooxidans* broth was mixed with 5 mL sterile 9K media containing potassium chloride, ammonium sulfate, magnesium sulfate, dipotassium phosphate, calcium nitrate, and ferrous sulfate [1, 2]. The pH of the media was adjusted to 2.5 with sulfuric acid. The bacteria were cultured at 26°C in the tubes containing the 9K media for several days, until the color of media changed. *A. ferrooxidans* were then continuously cultured by taking several mL from tubes and mixing them with 150 mL of 9K media in flasks.

The flasks were then shaken at 120 rpm and temperature 35°C. Bacteria populations grew for four to six days, after which a sample was taken and used to repeat the culturing. The most probable number (MPN) method was used to determine the concentration of bacteria in the broth. To avoid contamination, each flask was covered with a medical gauze and then autoclaved before being used. All processes that involving the bacteria or 9K media were also performed under a clean bench with air filter [3].

High-purity Cu blocks (12×12×10 mm³ in size) and Cu foils (10×10×0.025 mm³ in size) were used as workpieces. The Cu block surfaces were polished using 800-grit SiC abrasive disk wheels.

Before and after each biomachining experiment, the masses of workpieces were measured. To evaluate the depth of cutting result, additional Cu blocks were used. These blocks were covered by adhesive tape except the desired area. Before they were used in the machining process, the workpieces were sanitized by using ethyl alcohol and then air-dried.

The workpieces were placed in sterile jars filled with about 150 mL of bacterial broth. The jars were incubated at 35°C without shaking. After biomachining process, the workpieces were then removed, rinsed and dried. SEM micrographs were taken to evaluate the biomachining result.

4. Result

To calculate the specific material removal rate (SMRR) the following formula was used [4]:

$$SMRR = \frac{m}{tcA} \tag{3}$$

Where *m* is amount of metal removal in milligram (mg), *t* is machining time in hour (h), *c* is cell concentration in 10⁸ cells/ml and *A* is machined area in cm².

The SMRR result of copper biomachining was plotted as shown in the Fig. 2. The SMRR for copper biomachining was inversely proportional to the machining time. However, the rates of decreasing SMRR are different for six-to-12 hours and 12-to-18 hours. SMRR for copper foil and block are not so much different. The relative difference to the maximum value for 6 hours machining time is 20%. It relatively small compare to the result of MRR which was calculated by dividing the masses of removed material with the machining time. Fig. 3 revealed that the MRR difference between Cu foil and Cu Block at 6 hours machining time was 80% relative to maximum value. Thus, the SMRR is more general and not sensitive to the surface area of machining than MRR.

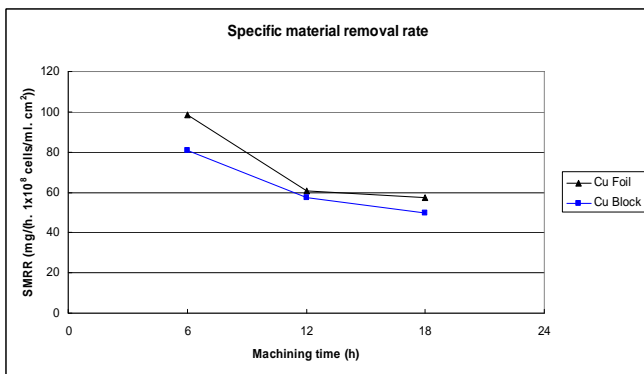


Fig. 2 Specific Material Removal Rate of Copper

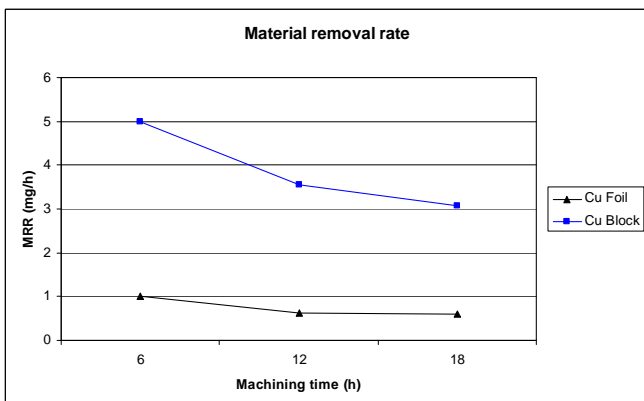


Fig. 3 Material Removal Rate of Copper

The example of biomachining result of copper using *A. ferroxidans* can be seen in Fig. 4. This result was captured after 12 hour machining time. The depth of machined surface was 24 um. The radius fillet was produced in machined part as shown in the figure.

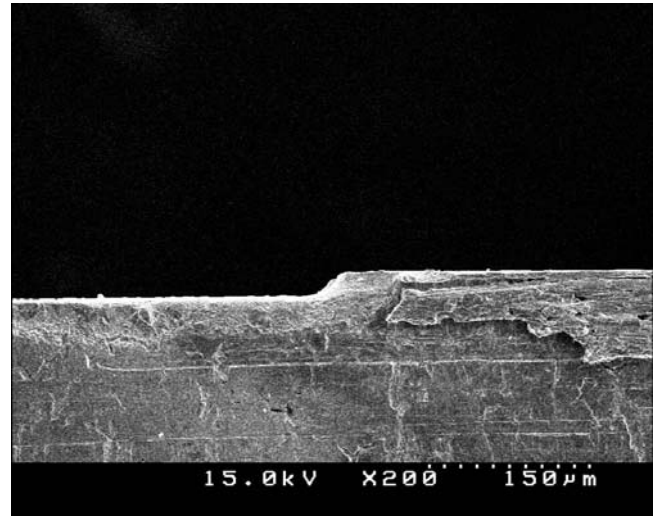


Fig. 3 Side view of copper biomachining result after 12 hours machining time.

5. Conclusion

In this study, the specific material removal rate of biomachining of copper was experimentally evaluated. The SMRR was inversely proportional to the machining time with various rates.

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