미생물을 이용한 금속 정밀가공에 관한 기초연구

Preliminary Study On Metal Micromachining Using Microorganism

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1. Introduction

Various micromachining techniques with specific advantages have been pursued for making small devices. According to the energy used, machining process can be classified into physical, chemical and biological [1]. However, the use of biological process in machining is still limited. Since the 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. The innovative use of microorganism in micromachining is one of them. Machining process that use microorganism as the tool to remove metal from a work piece, also known as biomachining, is considered more environmentally friendly than other means [2,3,4]. Some advantages of using microorganism functions include low energy consumption, high energy efficiency and low cost [5]. Moreover, since the metabolic microorganism is utilized, no a damaged layer or a heat-affected zone in the machined surface is generated [1]. Microbiologists have discovered several bacterial species with applications in mining and recovery of radioactive waste, known as bioleaching. These microorganisms are useful in these applications because the bacteria can oxidize and reduce metals as part of their energy production cycle. Furthermore, some of these microorganisms that dissolve materials can consume Fe or Cu, key industrial materials [3]. Bacteria of the general *Thiobacillus* and *Leptospirillum* are generally acknowledged to be amongst the most important microorganism in bioleaching.

Acidithiobacillus ferrooxidans, formerly known as *Thiobacillus ferrooxidans*, was the species used in the preliminary biomachining work by some researcher [1,2,3]. In this preliminary study, *Acidithiobacillus ferrooxidans* was also chosen for its documented ability to biomachine cooper. The objective of this study is to characterize the surface roughness and to quantify the material removal rate in biomachining for 3 different machining time. Both parameters are important to achieve the precision biomachining in the future. For manufacturing engineers, the concept of biomachining opens a new paradigm in micro-machining. Bacteria used in biomachining as tools are commercially available and can be cultured continuously. So these tools are renewable.

This paper will present the biomachining experiment, including bacteria culturing and workpiece preparation, and comparison of the surface roughness and visible surface characteristics of the workpiece before and after the biomachining experiments.

2. Biomachining Experiment

The procedure of biomachining is consist of three main process, (1) bacteria culturing as part of tools preparation, (2) workpiece preparation and (3) MRR calculation procedure using Cu-foil as shown in figure 2. The following section will explain the procedure in detail.

Acidithiobacillus ferrooxidans was obtained from the American Type Culture Collection (ATCC) No. 21834 as a bacterial broth ATCC. An environment with pH about 2.5 and a metal to serve as the source of electrons in the respiration process is required for growing *Acidithiobacillus ferrooxidans*. 1 ml of ATCC *Acidithiobacillus ferrooxidans* broth was mixed into the 5 ml 9K media. The bacteria were cultured at 26°C in the 15 mL tubes of the 9K media for several days, until the color change in the media became apparent. Continuous cultures of *Acidithiobacillus ferrooxidans* were subcultured by taking several mL from tubes and mixing them into 250 mL Pyrex flasks, each filled with 150 mL of sterile 9K media. Each flask was prepared with a vented top of tightly packed medical gauze and autoclaved. All operations involving interaction with the bacteria and/or media were conducted under a bacterial hood with positive flow high efficiency particulate air (HEPA) filter to avoid contamination. The inoculated flasks were then incubated at 35°C and shaken at 120 cycles per minute. Using this culturing procedure, populations grew for 4 to 6 days, after which a sample was aseptically removed and used to repeat the culturing.

To characterize surface finish effects after bacterial machining, high purity Cu blocks, 12x12x10 mm in size, were used as workpiece. For each experiment, the Cu block were mounted in resin, such that desired surface was placed upright and uncovered. The desired surface of Cu blocks were polished using 800 grit SiC abrasive disk wheels. The polished surfaces were examined using camscope micrograph both before and after each experiment. A profilometer was used for surface roughness measurement. The arithmetic average roughness, Ra, was taken to represent the change quantity of surface roughness. Before used in machining process, the mounted workpiece sanitized by soaking in 100% ethyl alcohol and then air dried. The workpieces were placed into sterile cylinder jar filled with about 150mL of bacterial broth. As a control, one cylinder jar was filled with sterile 9K media. The sealed jars were then incubated 35^{o}C without shaking. At the end of the machining time, the Cu blocks were removed, rinsed with deionized water and air dried. Camscope micrograph and surface roughness measurement were taken again, with same parameter as the measurement before biomachining process.

A 99.8% Cu foil, 0.025 mm in thickness, was chosen for the material removal rate study. Then Cu foil was cut into 10x10mm samples. The foil pieces were sanitized in the same manner as the Cu blocks, and then submerged in sterile media or bacterial broth under identical conditions to the copper blocks, then removed, rinsed, and air dried in the end of machining process. The mass before and after each experiment was measured, and the change in mass was converted to the volumetric, Material Removal Rate (MRR) using standard density values.

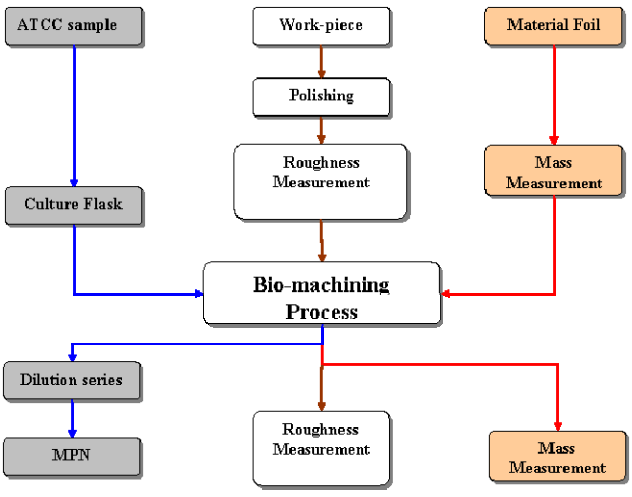

Fig. 1. Biomachining procedure

MPN method was used to determine the concentration of bacteria in the broth.

3. Result

The surface appearance of workpieces before and after biomachining process was significantly changed as shown in the figure 2. This change is also happened for all machining time. This change is agreed with the change of average arithmetic surface roughness, Ra. The changes in Ra for 6, 12 and 18 hours machining processes are 0.77um, 0.78 and 1.5 um respectively as shown in figure 3. The changes occur with initial Ra before machining 0.44, 0.36 and 0.39 um for 6, 12 and 18 hours samples respectively. The change in Ra from 6 hours to 12 hours insignificantly increased. In contrast, this change significantly increased from 12 hours to 18 hours.

The change in mass of Cu foil in bacterial solutions is used to quantify the material removal rate (MRR). For a control, the Cu foil was placed in the media without bacteria for 6 hours. Insignificant changes in mass, typically less than 0.003 g, were observed in the sample presumably due to the acidic nature of the media. Based on the change in mass of Cu foil and density of Cu, the graph in figure 4 was made. This graph showed that MRR decrease sharply from 6 to 12, different from 12 to 18 hours. The concentration of bacteria used in the beginning of biomachining is 9.3 x 10^{-7} organism/mL. This concentration is agreed with the number of bacteria for same culture time presented by UNO [1].

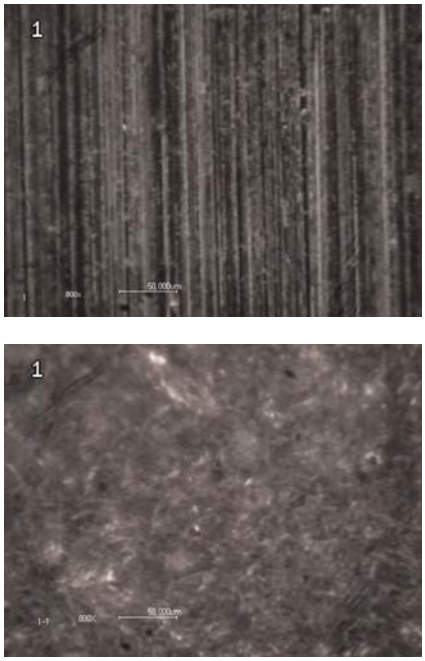

Fig. 2. Workpiece surface in 800x magnification (a) initial surface (b) after 6 hours biomachining.

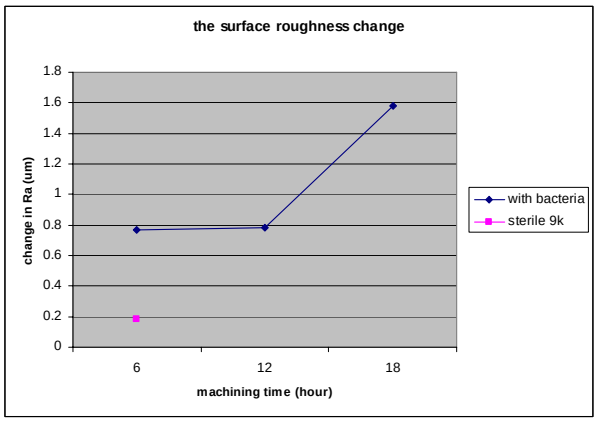

Fig. 3 The change in Ra before and after biomachining process for 3 different machining time.

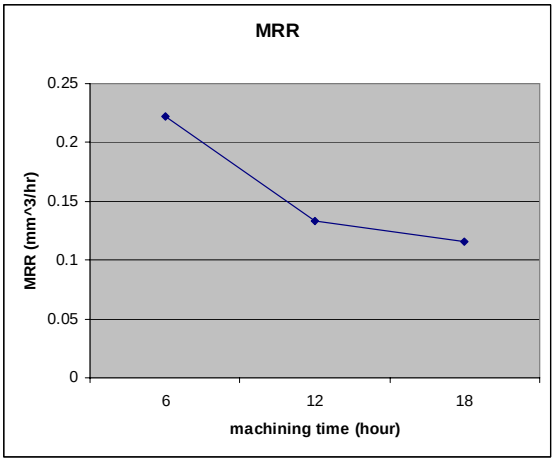

Fig. 4 MRR of biomachining process

4. Conclusion

The arithmetic average of surface roughness (Ra) increased after biomachining for initial Ra value about 0.4 um. The change of Ra increased for 6, 12 and 18 hours of machining process. The MRR of biomachining decreased with increasing machining time from 6 to 18 hours under initial concentration of 9.3 x 10^{-7} organism/mL.

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