Effect of saw wire surface texture on slicing performance of rock in vacuum

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Abstract
In-situ analysis is demanded for the investigation of rock samples in future lunar and planetary explorations. Slicing the rock sample with a saw wire is preferable to observe its interior directly. In this paper, the slicing performance was tested with various types of saw wires. A self-made wire-sawing machine was installed in a vacuum chamber. The thrust force was applied with a constant-load spring. Basalt rock was used as a specimen. The slicing performance with a full coated saw wire with electroplated nickel, three types of saw wires on which the grit were exposed and resin bond saw wire was compared in air and vacuum to investigate the effect of the surface texture. The machining depth in vacuum did not depend on the feeding speed. Saw wire, Rock, Vacuum, Nickel, Bond, Surface texture

1. Introduction

Three large vertical holes were found on the Moon in SELENE mission by JAXA, and their explorations are planning as UZUME project [1, 2]. They have a potential of bases not only for developing the Moon but also for transferring to Mars. In-situ analysis is demanded for the investigation of rock samples in future scientific explorations. Slicing the rock sample is preferable to observe its interior directly. Because coolant cannot be used in vacuum, a life-time of a grinding wheel or shaving blade will be shortened. It is expected for a saw wire to keep performance because of successive supply of cutting edges [3, 4]. However, the machining amount was decreased with a decrease of the vacuum pressure because nickel to fix diamond grit on a core wire adhered on a rock specimen in vacuum and the grit slipped on nickel [5]. The measured temperature during slicing was much lower than the melting point of nickel [6]. The original hardness of nickel and pores on the rock surface caused the adhesion.

In this paper, the slicing performance was tested with saw wires with various surface textures such as grit density and thickness of electroplated nickel layer.

2. Structure of wire-sawing machine

Fig. 1 shows a self-made wire-sawing machine with dimensions of 370 mm × 150 mm × 198 mm [5]. It was installed in a vacuum chamber. The thrust force was applied with a constant-load spring. Two bobbins were rotated with two 50-W AC servo motors mounted on the side wall of the vacuum chamber with rotational feedthroughs. The tension and feeding velocity of the saw wire was controlled simultaneously.

Table 1 shows the machining conditions. Basalt rock which has similar structure and strength to lunar mare rock was used as a specimen. The tension, thrust and feeding speed were milder than ones for slicing ingots in semiconductor industry because the saw wire was fed with the small motors. Each reciprocation and adjustment of the length took 18 and 10 s, respectively.

| Wire speed | 0.1, 0.5, 1.0 m/s |
| Pressure | Air, Vacuum (10⁻² Pa) |
| Number of reciprocations | 15 |
| Tension of saw wire | 2.0 N |
| Length at constant speed | 5 m |
| Thrust force | 1.6 N |
| Specimen | Basalt (Shizuoka, Japan) 10 mm × 15 mm × 15 mm |

3. Experiments

Table 2 shows the specifications of saw wires. The slicing performance with a full coated saw wire with electroplated nickel, three types of saw wires on which the grit were exposed and resin bond saw wire was compared in air and vacuum to...
investigate the effect of the surface texture. The saw wires except the resin bond one were dressed before slicing.

Table 2 Specifications of saw wires

<table>
<thead>
<tr>
<th>Wire type</th>
<th>Core wire mm</th>
<th>Grit size µm</th>
<th>Plating thickness µm</th>
<th>Grit Density 1/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill-coated</td>
<td>ø0.20</td>
<td>30-40</td>
<td>14</td>
<td>300</td>
</tr>
<tr>
<td>Exposed A</td>
<td>ø0.20</td>
<td>30-40</td>
<td>31</td>
<td>820</td>
</tr>
<tr>
<td>Exposed B</td>
<td>ø0.20</td>
<td>30-40</td>
<td>11</td>
<td>810</td>
</tr>
<tr>
<td>Exposed C</td>
<td>ø0.20</td>
<td>30-40</td>
<td>25</td>
<td>1680</td>
</tr>
<tr>
<td>Resin</td>
<td>ø0.20</td>
<td>40-60</td>
<td>-</td>
<td>300</td>
</tr>
</tbody>
</table>

Fig. 2 shows examples of the saw wires after slicing at a feeding speed of 0.5 m/s (30 m/min) in vacuum. Because debris adhered on the surface due to electrostatics in vacuum was small, it did not deteriorate the performance. The nickel bond layer of the full-coated saw wire wore more in air than in vacuum. However, the grit hardly wore both in air and vacuum as shown in Fig. 2 (a). The grit shed from the exposed saw wires B and C with thinner bond layer and the resin bond saw wire as shown in Figs. 2 (c), (d) and (e). Although the kerf was sometimes slanted as shown in Fig. 2 (f), the depth was measured from above by the confocal method with an optical microscope.

Fig. 3 shows the relationship between the machined depth and wire feeding speed in air and vacuum. The machined depth in vacuum was smaller and varied more than in air. The machined depth with the resin bond saw wire was almost the same as the other electroplated saw wires because of the small thrust force. The influence of the surface texture and feeding speed was analysed by two-way analysis of variance. The machined depth was increased with an increase of feeding speed of the saw wire in air. It is found by the analysis of variance that these factors significantly affected. The machining depth in vacuum, however, did not depend on the feeding speed with a P-value over 5%. The interactions between the factors were still unclear because of a small number of the trials. The diamond grit was coated with nickel even for the resin bond saw wire to enhance the gripping force of the grit. Nickel was observed on the bottom of the machined groove by energy dispersive X-ray spectrometry (EDS). This caused the decrease of the machined depth. In the case that the grit surface was initially exposed, the adhesion of nickel was decreased. The smaller grit density decreased the real contact area and increased the pressure so that the depth of cut increased and the machining amount was increased.

The machined depth with the exposed saw wire A and resin bond one were relatively large and were not decreased very much in vacuum. The machining amount with the full-coated saw wire decreased in vacuum because of the adhered nickel.

4. Conclusions

This paper discussed the influence of various types of saw wire on slicing performance. The exposure of the grit from the electroplated nickel, large gripping force of the grit and increasing the pressure due to the low grit density increased the machined depth.

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References