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Measurement of the grinding fluid distribution in the contact arc using scattered light: Effect of the table speed on grinding fluid distribution

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Abstract

Grinding generates more heat than cutting due to its principle. For this reason, grinding fluid at a high flow rate is required for cooling, lubrication, and chip evacuation. Although optimizing the grinding fluid flow rate supplied is highly effective in reducing the power consumption of grinding machines, a method easily applied on-site has not yet been developed, and the situation has not yet been fully achieved. Therefore, it is currently necessary to supply a higher flow rate of grinding fluid than sufficient. Our study aims to develop a simple method for determining whether the grinding fluid is provided appropriately. First, we attempted to observe the distribution of grinding fluid in a contact arc using a high-speed camera and transparent work material to conduct in situ observation. We have also developed a method that can easily detect the presence of grinding fluid by irradiating light at a high inclined angle to the grinding wheel surface and detecting where light is scattered and turns white by grinding fluid that has filled the pores. In this report, images of the grinding wheel surface were taken from behind the workpiece, and the distribution of the grinding fluid filling the pores was estimated by image processing. The effect of the grinding machine table's reciprocating motion on the contact arc's liquid supply was also observed.

Fluid, Grinding, Image, In-process measurement

1. Introduction

Recently, a global push has been made to reduce greenhouse gas emissions to conserve the environment. Machine tools comprise various components and devices and offer scope for reducing energy consumption. The coolant pump consumes about 32% of the machine's total power, and the total power consumption of auxiliary equipment, such as mist collectors, amounts to about 85% [1].

Due to its principle, grinding generates more heat than cutting, and grinding fluid at a high flow rate is required for cooling, lubrication, and chip evacuation. Although optimizing the flow rate of the grinding fluid supplied is highly effective in reducing the power consumption of grinding machines, a method easily applied on-site has not yet been developed. Therefore, it is currently necessary to supply a higher flow rate of grinding fluid than is sufficient.

Several methods have been proposed to measure the grinding fluid's effect and the fluid's volume reaching the contact arc during the grinding process[2-4]. However, these studies have not observed the transient changes in the flow rate and distribution of grinding fluid in the contact arc when the table is in motion, as in an actual grinding process.

Our study aims to develop a simple method for determining whether the grinding fluid is appropriately supplied. First, we attempted to observe the distribution of grinding fluid in a contact arc using a high-speed camera and transparent work material to conduct in situ observation. Changes in the observation results with varying table speeds were discussed.

2. Observation experiment

2.1. Observation method

A porous grinding wheel was used to make it easy to discriminate the pores; the specifications are shown in **Table 1**. The workpiece material was a transparent acrylic plate. The observation apparatus was fixed on the table of the UPZ315Li grinding machine manufactured by Okamoto Machine Tools, and the acrylic plate was fixed on the observation apparatus.

Figure 1 shows a schematic of the observation apparatus. The camera was positioned sideways using a mirror to ensure a sufficient distance for the camera to focus on the workpiece. High light intensity is necessary for taking images with a high-speed camera, and two fiber light sources from the backside of the acrylic plate illuminate the wheel surface.

The camera was fixed inside the observation apparatus and moved with the workpiece to enable the capture of images. At the same time, the table was in motion, which was an actual grinding process.

The grinding fluid in the contact arc exists as a very thin liquid film, and the difference in pixel values that change depending on the thickness of a liquid film is small and insufficient to discriminate the existence or non-existence of the grinding fluid.

Figure 2 shows the detecting method for the existence of grinding fluid. The existence of grinding fluid in the pores was easily determined by scattering light from the cloudy grinding fluid. First, light from a fiber light source configured that incident on the grinding wheel surface from an inclined angle, as shown in the left side of Fig. 2, to cast a shadow in pores. Then, pores appear dark in taken images. In that condition, when grinding fluid-filled pores, the pores turn brighter, as shown on the right side of Fig. 2. In this case, the pixel value is changed significantly; it is easily discriminated and robust against sensor noise, etc. An example of pore discrimination by image processing is shown in the lower part of Fig. 2. The red pixels are discriminated as pores with dry or less grinding fluid.

The area percentage of pores filled with grinding fluid (filled pore rate) was calculated using the equation below.

$$\text{Filled pore rate} = \left(1 - \frac{\text{Number of red pixcel}}{\text{Number of red pixcel in dry}}\right) \times 100$$

2.2. Our previous study

In our previous study, changes in the area of pores filled with grinding fluid (filled pore rate) were observed on the surface of the grinding wheel when the grinding machine table was stopped, and the flow rate of the supplied fluid varied.

An experiment on grinding mild steel was also carried out under the same liquid supply conditions, with a 2.5 m/min table speed.

As shown in **Fig. 3**, even after the filled pore rate was saturated, the grinding state changed as the liquid flow rate increased. The difference between the conditions of the two experiments was whether the table was in motion or stopped, which seemed to affect the results. This report observed changes in the Filled pore rate due to the table speed.

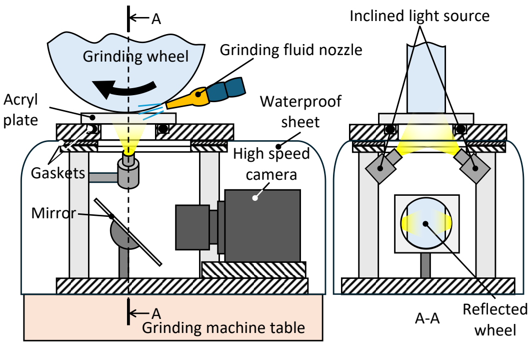

Figure 1. Observation apparatus

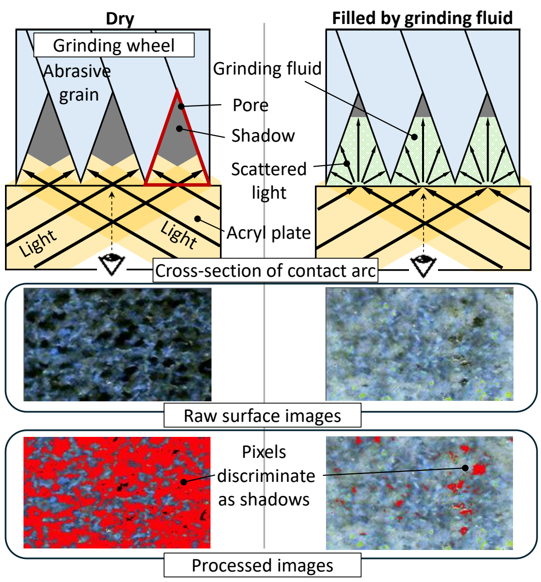

Figure 2. Detection method of grinding fluid

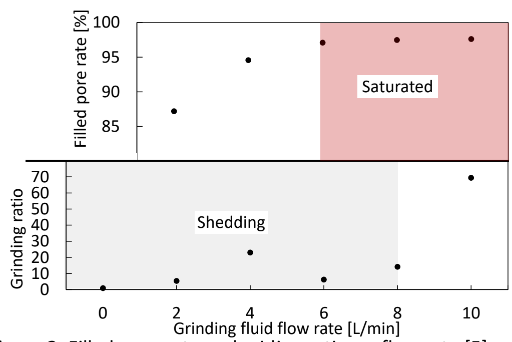

Figure 3. Filled pore rate and griding ratio vs. flow rate [5]

2.2. Observation condition

The observation condition is shown in Table 1. Although the results are not presented in this report, preliminary experiments showed that table speeds up to 2.5 m/min, as the previous study had no significant effect on the Filled pore rate. Therefore, in the present experiment, observations were carried out at 5 m/min intervals, changing the speed to 30 m/min. Observation in the no-grinding fluid-supplied condition was carried out with water supplied, as a reflection of microscopic scratches on the acrylic surface in the dry state hindered the observation.

The calculated number of red pixels from the image processing was averaged over several frames. The number of images to be averaged was varied, as shown in Table 1, to keep the table travel distance constant in the image set used for calculating each table speed.

Table 1 Observation condition

Exposure time	1/120,000 s
Frame rate	20,000 fps
Type of grinding wheel	93DA60/80FISVPH901W, 3M
Speed of the wheel	1,700 min^{-1}
Table speed	5, 10, 15, 20, 25, 30 m/min
Number of averaged frame	600, 300, 200, 150, 120, 100
Grinding Fluid	FX-90, Noritake CO. LTD.
Fluid flow rate	6.3 L/min

Result and discussion

Figure 4 shows the observation result. Changes in the filled pore rate in the contact arc did not appear at table speeds below 25 m/min. This result suggests that the grinding state change associated with increased fluid volume after the filled pore rate saturates in our previous study is caused by the grinding fluid cooling the workpiece outside the contact arc.

However, as the current observation method makes it difficult to distinguish between grinding fluid and bubbles, further studies are required on the effects of changes in the proportion of bubbles in the grinding fluid.

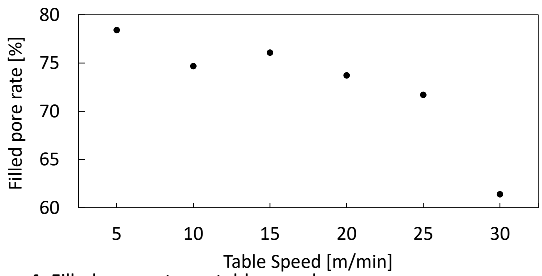

Figure 4. Filled pore rate vs. table speed

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