Study on Concentric Mutual Lapping for Improvement in Sliding Surface Function of SiC Ceramics

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Abstract. In this study, the ring shaped SiC ceramics applied to sliding components are selected as specimens. In the surface of SiC ceramics, many scratches penetrating the inner edge to outer one are generated in random direction by conventional lapping. The scratches affect the surface functions in prevention of fluid exuding from the outer side to the inner side of SiC ring and have low friction force on the finished surface as a sliding material. In this study, the concentric mutual lapping is proposed to remove the scratches by conventional lapping. Then, the surface topography is evaluated quantitatively by the white light interferometer and proposed the vectorial and quantitative analysis of surface profile. As a result, the concentric mutual lapping can remove scratches quickly by the conventional lapping. And then circumferential scratches along a lapping direction were generated. In addition, we analyzed effect of surface topography on the surface function as a sliding material by sliding tests. From the investigation, it turned out that the concentric mutual lapping suppressed the difference in surface functions depending on the sliding direction.

Introduction

Silicon carbide (SiC) ceramics are not only high in hardness, excellent in wear resistance but also heat resistance, and withstand chemical attack compared with metals and other non-oxide ceramics. Therefore, SiC ceramics is used as a functional structural in various fields [1, 2]. In particular, SiC ceramics is also used as a sliding material because SiC ceramics has properties such as abrasion resistance and heat resistance. The subject of this study is ring-shaped SiC ceramics of a sliding material. The surface of the ring-shaped SiC ceramics (SiC ring) is finished by wet lapping. The lapping has advantage of making high dimensional and high-precisions shape. Therefore, good aspect of the finished coarseness can be obtained easily [3]. However, many scratches are generated in random direction on the workpiece surface. On the SiC ring, as a sliding material, fluids exude due to scratches which are penetrated the inner edge to outer one. Because of scratches generated in random directions, there is a difference in the amount of exudate depending on the direction of rotational sliding, and influences the surface function as a sliding material. Therefore, in order to prevent the difference in exudate rate caused by the difference in rotational sliding direction and increase in exudate rate and friction coefficient, we proposed a concentric mutual lapping which sliding the workpieces with each other via an abrasive for the purpose of removing scratches by conventional lapping. Furthermore, it is judged whether or not individual scratches on the conventional lapping surface and the concentric mutual lapping surface penetrate the inner edge to outer one of the sliding surface using the white light interferometer and the analysis model. We also focused on the angle and the mean cross-sectional area of each penetrating scratch and evaluated quantitatively. Finally, the effects of concentric mutual lapping on the surface function of SiC ring are investigated by the sliding tests and the quantitative evaluations of the surface texture on conventional lapped surfaces and those by concentric mutual lapping.

Evaluation method of scratches

As shown in Fig.1, on the surface of the SiC ring, many scratches were made in random directions by conventional lapping. When the SiC ring is used as a sliding material, exudates are generated through scratches penetrating the inner edge to outer one of specimen. Therefore, by observation using white light interferometer and an analytical model, we investigated whether or not scratches penetrated the inner edge to outer one of the workpiece and the gross-sectional area of scratches. The analytical model of the scratches is shown in Fig.2. The image in the frame of Fig.2 is the measurement result of the white light interferometer. And it can analyze the coordinates, angle, volume and length of each scratch in the field of ϕ 1.4 mm. The field view is set at the center of the inner and outer edge of the workpiece. The line connecting the center of the field and the workpiece center is defined as the y axis while the intersection of the y axis and inner edge is the origin. And the tangent of the inner edge at the origin is defined as the x axis. In this coordinate system, the angle of an arbitrary scratch is θ, and the y coordinate of the y intercept of the scratch is Q. When the straight line of the angle θ is in contact with the inner edge of the workpiece, the y coordinate Q_m of the y-intercept is given by the following eq. (1)

$$Q_m = \left(\sqrt{\tan^2\theta + 1} - 1\right) r_1 \tag{1}$$

Here, r_1 is the inner radius of the workpiece (8.0 mmR). When Q is smaller than Q_m, it can be determined that the scratch penetrates the inner and outer edge of the workpiece. When Q is larger than Q_m, it can be judged to be non-penetrating. We determined penetration or non-penetration in accordance with each observed scratch. In addition, the scratches cross-sectional area which is thought to affect exudate generation was calculated from length and volume of scratches. This measurement was carried out on the entire circumference of the workpiece at a total of 40 points every 9 degrees around the center of the workpiece [4, 5].

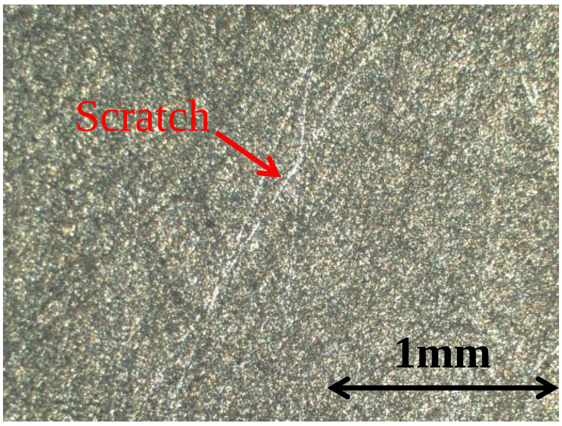

Fig.1 Conventional lapping surface

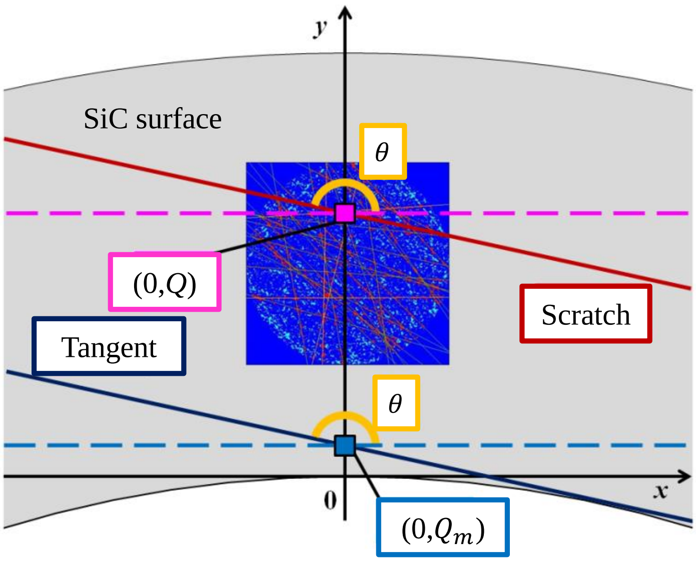

Fig.2 The analytical model of the scratches

Experimental method

Concentric mutual lapping

The schematic and steps of concentric mutual lapping are shown in Fig.3. The workpiece is attached to each holder so as to be vertically concentric, pressed with a predetermined load via an abrasive, and polished by rotating the upper holder. At that time, the pressing force is measured by a crystal piezoelectric sensor installed in the lower holder. In the polishing process, a polycrystalline diamond compound (3 μm in grain size) was used as an abrasive, and the rotation speed was 600 rpm, the pressing force was 30 N, and the lapping time was from 1.0 to 6.0 s

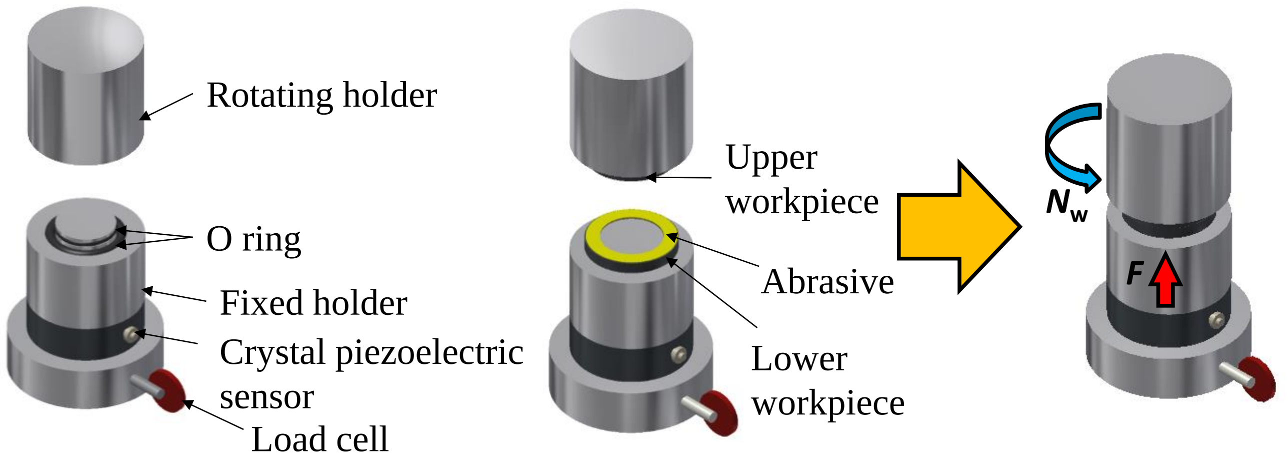

Fig.3 The schematic and steps of concentric mutual lapping

Exudate measurement and friction torque measurement test

The sliding tests were carried out to measure the exudate rate and the friction coefficient of the sliding surface of SiC ring. Figs.4 and 5 show the outline of exudate measurement testing machine and friction torque measurement testing machine. The SiC ring is connected to the motor and rotated. The mating ring is fixed to the liquid tank, and the rings are caused to slide each other. In the exudate measurement test, the amount of test solution exuding from the outer side to the inner side of the sliding surface was measured. In the friction test, the friction coefficient during sliding was measured. The torque generated on the sliding surface can be measured by the load cell. Carbon ring was used as the mating ring, and the sliding direction was carried out by clockwise and counterclockwise.

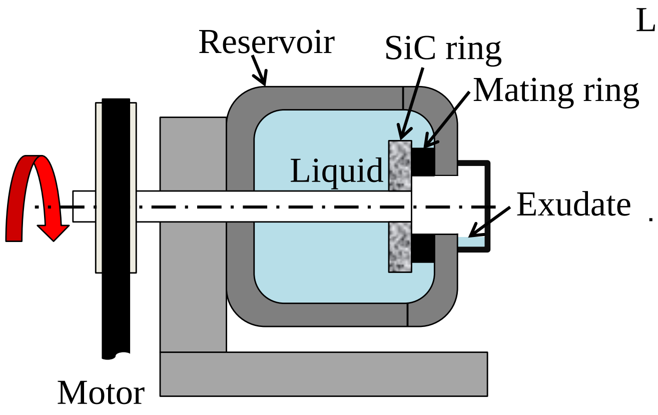

Fig.4 Exudate measurement testing machine

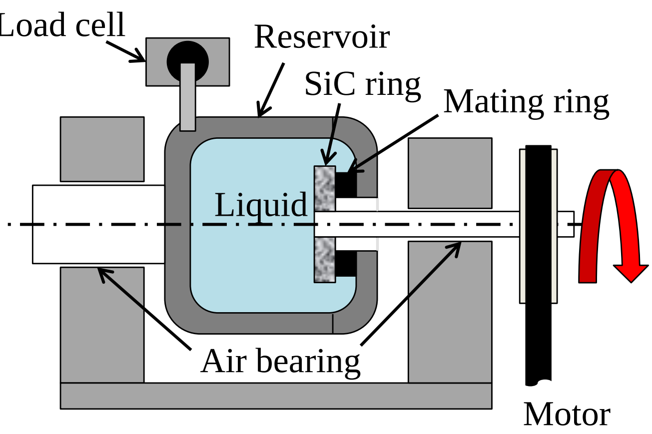

Fig.5 Friction torque measurement testing machine

Result and discussion

Fig.6 shows the transition of the gross-sectional area and the analytical image of the surface at the conventional lapping surface and the concentric mutual lapping surfaces. As shown in the figure, there are many penetrating scratches on the conventional lapping surface. However the gross-sectional area of penetrating scratch is significantly reduced 2.0 s in machining time, while non-penetrating scratches increased after 4.0 s. Therefore, in concentric mutual lapping, it was found that penetrating scratches on the conventional lapping surface were removed first. Thereafter, the non-penetrating scratches in the circumferential direction increased. In addition, the upper and lower workpieces had almost the same result in the gross-sectional area. Figs.7 and 8 show the exudate rate and friction coefficient from the result of exudate and friction torque measurement test. As can be seen from Fig.7, the exudate rate on the conventional lapping surface was greatly different between clockwise and counterclockwise. The exudate rate showed large value under clockwise. This is because scratches are generated in random direction on the conventional lapping surface. Also, the friction coefficient conflicts with the exudate rate and friction coefficient shows small value in the case of clockwise. Therefore, we consider that the fluid film on the sliding surface becomes thick due to the large exudate rate. On the other hand, as shown in Figs.7 and 8, under the concentric mutual lapping surface, it can be said that the surface function could be improved because both the value of exudate rate and friction coefficient decrease. In addition, they were almost same for clockwise and counterclockwise. The penetrating scratches existing in an irregular direction by conventional lapping are substantially removed.

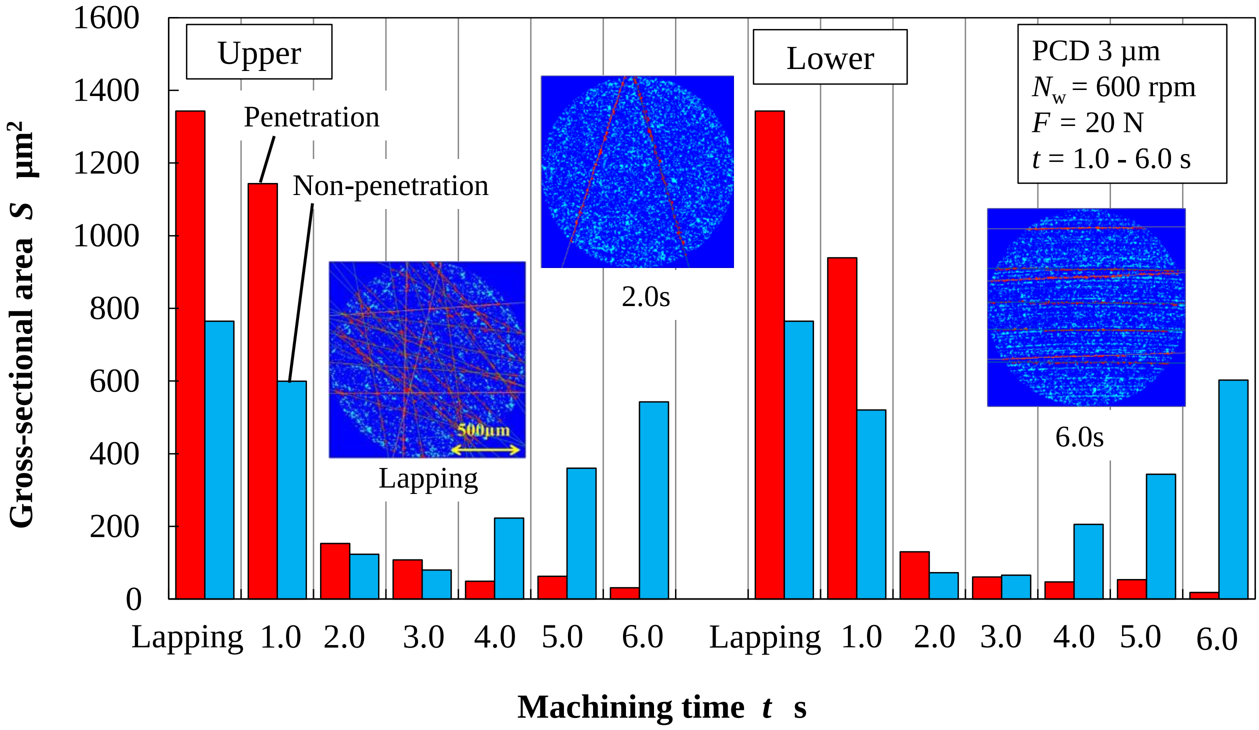

Fig.6 The transition of the gross-sectional area and the analysis image

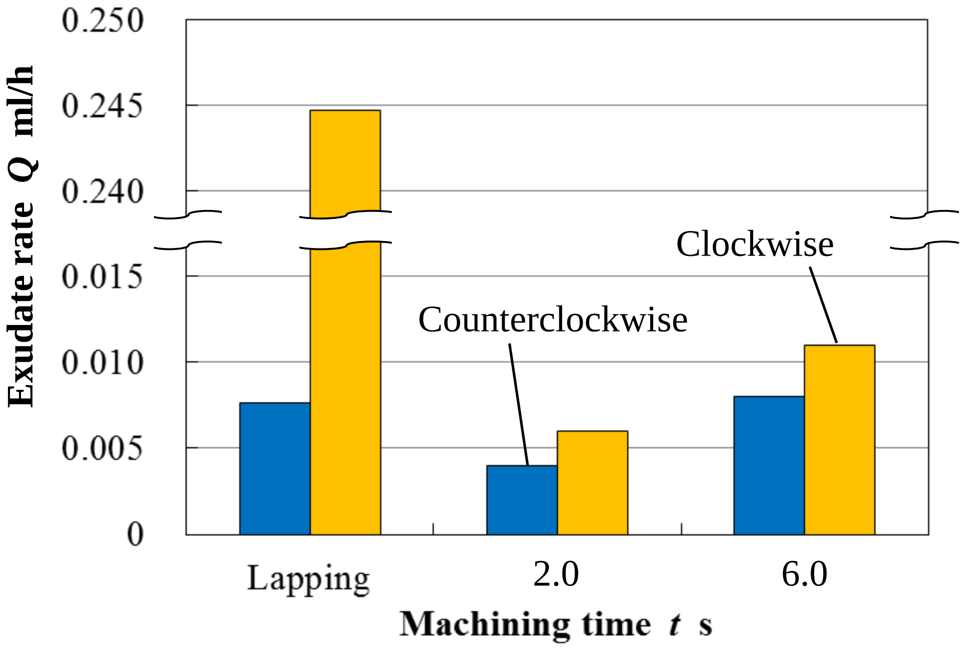

Fig.7 Relationship between machining time and exudate rate

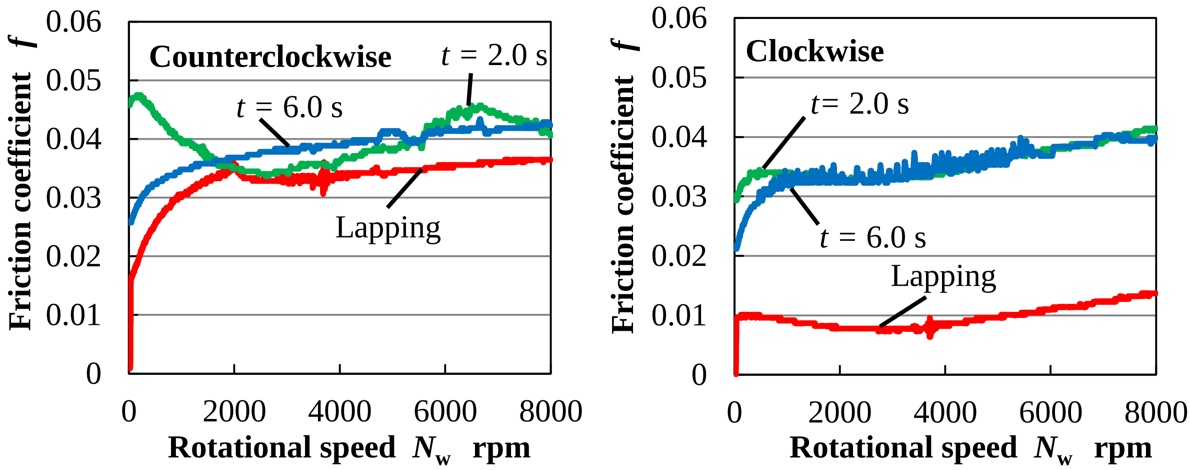

Fig.8 Relationship between rotational speed and friction coefficient

Summary

In this study, the concentric mutual lapping was applied to the conventional lapping surface of SiC ceramics to change the surface texture of the sliding surface. In addition, in order to clarify the relationship between the surface function and the surface texture, the directionality of the scratches was quantitatively evaluated. Then, the surface functional evaluation test was conducted on the processed workpiece, and the influence of concentric mutual lapping was examined. The results obtained are as follows.

(1) By the concentric mutual lapping, scratches generated by conventional lapping are removed first. Thereafter, scratches in the circumferential direction increase on the processed surface.
(2) From the results of the sliding test, we found that the exudate rate and friction coefficient on the sliding surface were in a reciprocal relationship.
(3) By removing scratches due to conventional lapping by carrying on concentric mutual lapping, the difference depending on the sliding direction of the surface function can be made sufficiently smaller than the conventional lapping surface.

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