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Friction reduction of SiC mechanical seal by carbon nanofiber film

D. Okishio[1], H. Tani[2,*], R. Lu[2], S. Koganezawa[2], N. Tagawa[2]

[1)] Graduate School of Kansai University, Suita-shi, Osaka 564-8680, Japan.
[2)] Mechanical Engineering Department, Kansai University, Suita-shi, Osaka 564-8680, Japan.

[*]Corresponding e-mail: hrstani@kansai-u.ac.jp

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ABSTRACT – A carbon nanofiber film was formed on the surface of a SiC mechanical seal by the SiC decomposition method, and friction test was carried out both in water and dry conditions using the combination of CNF film on SiC. The findings confirmed that CNF reduces the friction coefficient of the sliding surface.

1. INTRODUCTION

Mechanical seals are used for machines handling fluids and gases to prevent their inflow and outflow. Sintered SiC having excellent mechanical properties such as high heat resistance and high strength is the commonly used material for mechanical seals. It is understood that SiC causes low friction by generating SiO_2 through tribochemical reaction with water during sliding in water [1–4]. However, at the start of machine operation or when handling highly volatile liquid, the seal sliding surface becomes dry condition that means the sliding in atmospheric environment, leading to wearing of the seal sliding surface, which is a debilitating issue.

The SiC surface decomposition method is a technique for generating carbon nanotubes (CNT) oriented vertically on the surface of SiC by heating a SiC single crystal in high-temperature vacuum [5]. We found that porous carbon nanofiber (CNF) membranes with CNT complex entangled could be produced by heating sintered SiC in high-temperature vacuum in the same way as mentioned above. Furthermore, it was confirmed that CNFs formed by using the SiC surface decomposition method have lower friction than the SiC surface does in the pin-on-disk friction test in water.

In this study, we investigated the development of a mechanical seal capable of reducing friction and wear in dry condition by forming CNFs on the sliding surface of the SiC mechanical seal.

2. EXPERIMET

2.1 SiC decomposition method

In this experiment, the rotation primary ring and stationary ring of sintered SiC as parts of mechanical seals were heated at 1500 °C under $1.0{\times}10^{-4}$ to 10^{-5} Pa for 24 h in a high-temperature vacuum heating chamber.

2.2 Friction test

Figure 1 shows a schematic of the friction tester used to test the mechanical seal. The mechanical seal had a rotation primary ring (sliding surface: ϕ 44 mm, height: 13.5 mm) and a stationary ring (sliding surface: ϕ 41 mm, height: 18.5 mm). The rotating part of the mechanical seal was attached to the rotating shaft and the stationary ring was installed on the rotating table. These two parts were then brought into contact with each other under a load of 58.6 N and then rotated at 100 rpm to 1500 rpm (relative speed = 0.2 m/s to 3.5 m/s). In this experiment, the friction test was carried out both in water and in atmospheric environment at a temperature of 20 to 22 °C and relative humidity of 50%. The wear test under dry condition was conducted under a load of 58.6 N and a rotation speed of 1300 rpm (relative speed = 3.0 m/s), and the experiment was terminated when the mechanical seal broke due to severe wear of the seal surface.

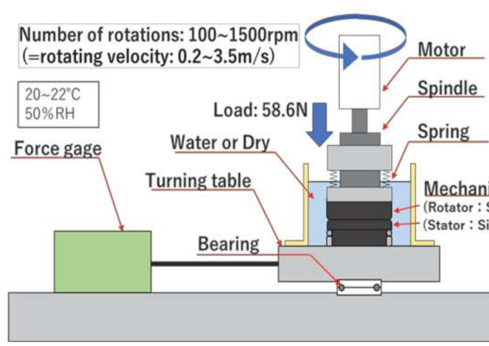

Figure 1 Schematic drawing of experimental apparatus of friction test [5].

3. RESULTS AND DISCUSSION

The cross-sectional SEM image of the CNF film on the sintered SiC substrate is shown in Figure 2. When sintered SiC is heated in high-temperature vacuum, the residual oxygen reacts with the Si atom on the surface to form SiO, and only Si is selectively released from the SiC surface. The remaining carbon atoms then react to form C=C bonds, thereby generating porous CNFs.

The Raman spectra of sintered SiC and the obtained CNFs are shown in Figure 3. In the Raman spectrum of sintered SiC, two peaks arising from the SiC structure are observed. On the other hand, in the Raman spectrum of CNF, a G peak at about 1600 cm^{-1} arising from the sp^2 structure of graphene, a D peak at about 1350 cm^{-1} originating from the disorder of the sp^2 structure, and a G' peak at about 2700 cm^{-1} can be observed. Both the G peak and G' peak are stronger than the D peak and indicate a graphite structure with relatively high crystallinity.

Figure 4 shows the friction coefficient under water condition with SiC/SiC and CNF/SiC as the combinations of rotating part and fixed part of the mechanical seal, respectively. The friction coefficients of both the combinations increased at a low speed. However, in the respective low speed regions of 100 rpm to 400 rpm, the friction coefficient of CNF/SiC was smaller than that of SiC/SiC. It is considered that the SiC/SiC combination did not sufficiently produce SiO_2 generated by the reaction between SiC and water, and thus, the friction coefficient increased. However, in CNF/SiC, the friction coefficient reduced since CNFs played the role of a solid lubricant such as graphene. Therefore, a low friction of the SiC mechanical seal can be expected using CNFs especially in a low speed region.

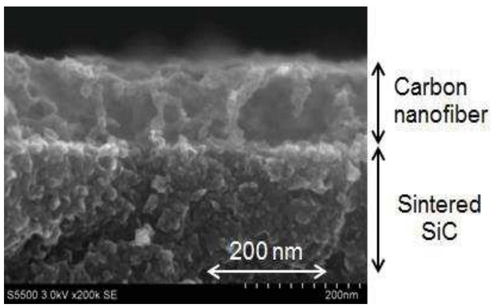

Figure 2 Cross section of CNF film on sintered SiC substrate observed by SEM [5].

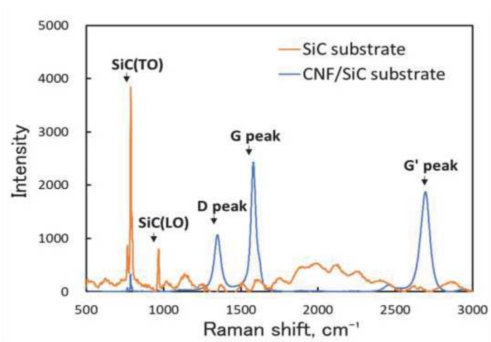

Figure 3 Raman spectra of SiC substrate and CNF film on sintered SiC substrate [5].

Further, the results of friction test under atmospheric environment for the same combinations are shown in Figure 5. This experiment was carried out until the mechanical seal was broken, and the experiment was terminated at the point indicated by ✖ in the figure. The SiC/SiC combination seal broke at about 240 s after the start of the experiment, whereas the CNF/SiC combination seal broke at about 3640 s. The friction coefficient of SiC/SiC combination was about 0.50 to 0.70, whereas the friction coefficient of CNF/SiC was about 0.3. Moreover, in SiC/SiC, a large amount of abrasion powder was generated, which is thought to be related to the increase in friction coefficient. From this result, lower friction can be expected from CNF/SiC than from conventional SiC mechanical seal when the sliding surface becomes under atmospheric environment.

4. CONCLUSIONS

By forming CNFs on a SiC mechanical seal, the wearing of the sliding surface could be ameliorated.

Compared to conventional SiC mechanical seal, the CNF/SiC combination demonstrated low friction in water condition especially at a low speed, as well as under atmospheric environment. Therefore, tribological properties such as anti-wear can be expected from CNF/SiC at the start of machine operation and in atmospheric condition due to unexpected situations.

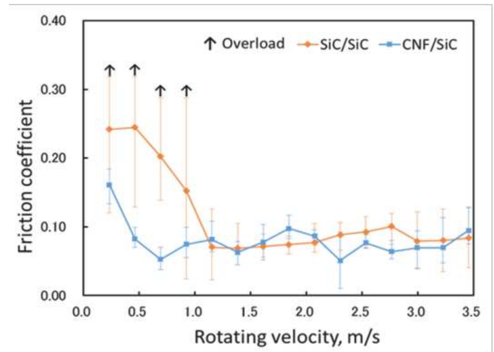

Figure 4 Friction coefficient under water condition as a function of rotating velocity [5].

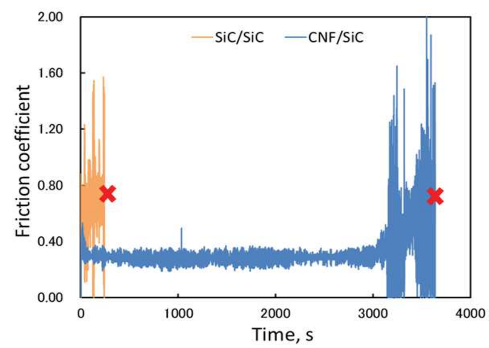

Figure 5 Friction coefficient under dry condition as a function of experiment time [5].

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