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Effect of trace moisture content on friction of carbon fiber filled PTFE in high purity gas

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ABSTRACT – Effects of the moisture content in high purity gas on friction characteristics of carbon fiber filled PTFE was investigated by pin-on-disc tests. Results showed that the reduction of moisture content in gas tend to decrease friction coefficient. Analyses of transfer films by XPS, FT-IR, Raman spectroscopy, and laser microscopy showed that a part of the transfer film consisted of thin and smooth carbon layer and the area of smooth layer became larger with lower moisture content in gas. Therefore, the trace moisture might have some influence on the formation of the smooth carbon film.

1. INTRODUCTION

PTFE has self-lubricity, and PTFE composites with filler materials are used as a sealing material in gas compressors and valves [1]. In addition, some studies [2] have shown that the type of gas environment and its moisture content influences the frictional characteristic of sliding materials. In this study, sliding tests of carbon fiber filled PTFE in high purity gas environments were carried out and the moisture content of the test gas was controlled at ppm level to investigate how the trace moisture content in high purity gas influence the frictional characteristic of PTFE composites.

2. METHODOLOGY

Sliding tests were carried out with a pin-on-disc type friction tester. It was installed in a vacuum chamber equipped with a moisture control unit to control the trace moisture content in high purity gas environment at ppm level.

Pin specimens were prepared from 20 vol.% carbon fiber filled PTFE, and SUS440C was used as the disc specimens. Surface roughness (Ra) of disc specimens were adjusted to 0.05μm by using waterproof abrasive papers before sliding test. Other experimental conditions were listed in Table 1. Before starting an experiment, the chamber was evacuated to 5.0×10^{-4} Pa, and then filled with N_2 gas. Initial 10000 m sliding was conducted as a running-in and friction and wear behavior was evaluated during the following 40000 m sliding.

3. RESULTS AND DISCUSSION

3.1 Sliding Tests

Figure 1 and 2 show the transition of friction coefficient with sliding distance. When the tests were carried out with a contact pressure of 1 MPa, friction coefficients were about 0.1 under the condition A and B, at low moisture content in the gas. However, under the condition C, with the second highest moisture content in the gas, it increased to about 0.35. Furthermore, under the condition D, with the highest moisture content in the gas, the friction coefficient eventually increased to 0.4. In addition, when the test was conducted with a contact pressure of 3 MPa, the friction coefficient was about 0.08 under the condition E, at low moisture content. On the other hand, under the condition F, in which the moisture content was higher than E, friction coefficient was about 0.13. These results indicated that friction coefficient decreased with reducing the moisture content in N_2 gas under the same contact pressure.

Table 1 Test condition.

Atmosphere	N_2	
Sliding speed	2m/s	
Sliding distance	10000m(running-in)+40000m	
Contact pressure	1MPa	3MPa
Moisture content	A(1.3-1.8ppm)	E(1.6-1.8ppm)
	B(3.0-3.4ppm)	F(45-53ppm)
	C(13-14ppm)	
	D(56-60ppm)	

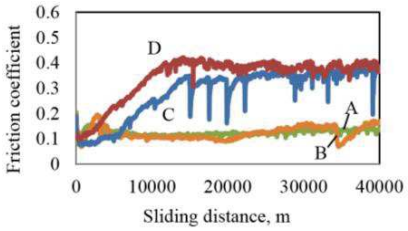

Figure 1 Friction coefficient with different moisture contents at 1MPa.

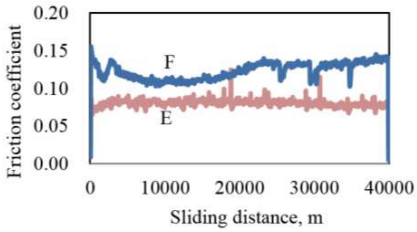

Figure 2 Friction coefficient with different moisture contents at 3MPa.

3.2 Analyses of Transfer Film

After sliding test, some analyses of transfer films formed on disc specimens were carried out. First, to investigate the presence of PTFE, transfer films were analyzed with FT-IR mapping by peak area intensity of spectra (peak area from 1150 to 1280 cm^{-1}), but the presence of PTFE was not confirmed in all disc specimens. After the FT-IR analysis, XPS analyses were conducted. The C(1s) spectrum of all samples showed a clear peak derived from carbon at around 284eV. However, the peak of PTFE at around 689eV was not observed. These results revealed that PTFE didn't adhere to the disc specimens and transfer films mainly consisted of carbon from the filler material.

To analyze the amount and structure of transferred carbon, Raman spectroscopy was conducted. Raman spectrum is considered a combination of D and G peaks by the Gaussian curves. The carbon peak is characterized by a large G peak close to 1580 cm^{-1} with broad peak shoulder close to 1360 cm^{-1} [3]. Based on the results, Raman mapping by peak area intensity of spectra (peak area from 900 to 1800 cm^{-1}) was carried out to investigate the carbon distribution in transfer films. Figure 3 shows the laser microscope image and the result of Raman mapping of the disc specimen in condition C. The peak intensity from point (a) was stronger than that from point (b). It means that the amount of transferred carbon at the point (b) is limited compared with that at point (a). The Raman mapping indicated that the area in which the amount of transferred carbon was small corresponded to the white parts in the laser microscope image.

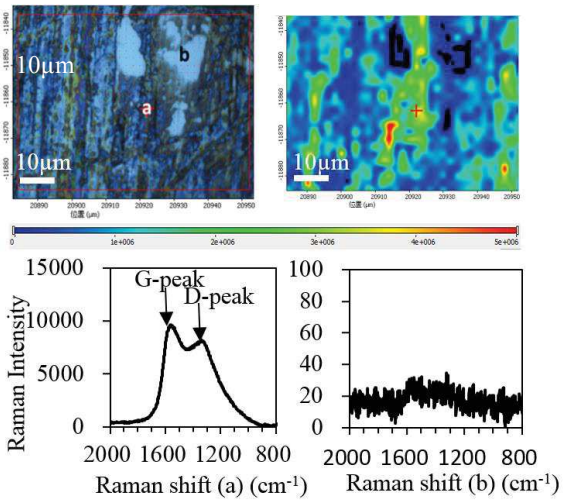

Figure 3 Raman spectra and mapping of transfer film formed on disc specimen (Condition C, Scale bar = 10μm).

In addition, the surface profile of white parts in condition C was measured by laser microscope. From this analysis, the surface profile of white part was very smooth compared with other parts in the transfer film. Laser microscope images of the disk surface with all test conditions were summarized in Fig. 4. Comparing these images, it indicated that the area of white parts in the transfer films was relatively large in the specimens, which showed lower friction coefficient. From these results, it was suggested that the thin and very smooth carbon layers might be contributing to decrease friction coefficient. In addition, the area fraction of the thin and smooth carbon layer in the transfer film was large when moisture content in gas was small. Therefore, the moisture content in gas had some influence on the formation of the smooth carbon layer in the transfer films.

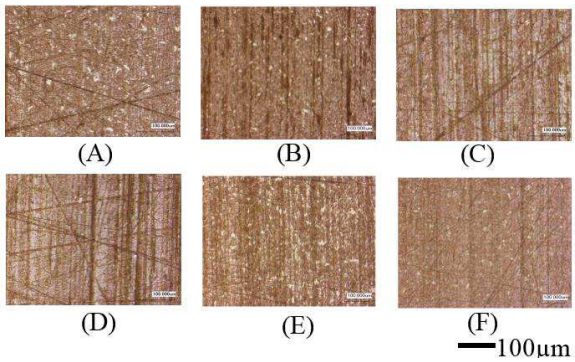

Figure 4 Pictures of transfer films formed on disc specimens by all conditions.

4. SUMMARY

In this study, sliding tests were conducted between carbon fiber filled PTFE and SUS440C to investigate how trace water content in a high purity gas influences the friction characteristics. Results of sliding tests and analyses of resultant transfer films indicated that the reduction of the trace water content in gas tended to decrease friction coefficient under the same contact pressure. Furthermore, if a thin and smooth carbon layer was successfully formed on some parts of disk surface, friction coefficient could be reduces. Further experiments and detailed analyses would be needed to confirm the detailed mechanism.

5. REFERENCES

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