

# Critical concentration of Oxygen and Water molecules for Continuous Low Friction of Hydrogenated Carbon Nitride Coatings

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Extremely low friction ( $\mu < 0.05$ ) obtained in friction system of  $\text{Si}_3\text{N}_4/\text{CN}_x\text{:H}$  in  $\text{N}_2$  atmosphere with relatively low  $\text{O}_2$  concentration and humidity has a limited life even if there is no difference in the presence of coating and/or transfer film. Such lifetime is drastically extended above a certain value of  $\text{O}_2$  concentration and humidity in  $\text{N}_2$  atmosphere, and in which extremely low friction continues up to 50,000 cycles set in this experiment. It suggests the possibility of a semi-permanent low friction system by continuous formation of low frictional interface due to tribochemical reaction.

**Keywords:** durability, carbon nitride coating, low friction, nitrogen atmosphere

## 1. Introduction

Hydrogenated carbon nitride ( $\text{CN}_x\text{:H}$ ) is recognized as a coating capable of exhibiting extremely low friction ( $\mu < 0.05$ ) in nitrogen gas ( $\text{N}_2$ ) atmosphere by forming low friction interface due to tribochemical reaction [1]. For a wide range of applications of such extremely low friction, its durability is an important issue.

In this study, therefore, we focus on the effects of oxygen ( $\text{O}_2$ ) concentration and relative humidity (RH) in the  $\text{N}_2$  atmosphere, which are thought to affect the formation of low friction interface, and clarify the durability of such low friction of friction system with  $\text{CN}_x\text{:H}$ .

## 2. Methods

Ball-on-disk friction tests with  $\text{Si}_3\text{N}_4$  ball and  $\text{CN}_x\text{:H}$  coated SiC disk were conducted under  $\text{N}_2$  atmosphere.

In  $\text{N}_2$  atmosphere,  $\text{O}_2$  concentration and RH were controlled in the range of 0.0001~0.05 vol.% and 0.01~5 %RH respectively. Applied load and sliding speed were 1 N and 0.05~0.25 mm/s respectively.

## 3. Results and discussion

Fig. 1 shows typical friction property of  $\text{Si}_3\text{N}_4/\text{CN}_x\text{:H}$  under  $\text{N}_2$  atmosphere when both  $\text{O}_2$  concentration and RH are relatively low. Although it shows stable and extremely low friction ( $\mu < 0.05$ ) after running-in, it transits to an unstable value of about 0.1 after a certain friction cycle. Even after the increase in friction, however, no film delamination of coatings or presence of transfer film is observed on interface. This suggests that there is a lifetime as a system for extremely low friction ( $\mu < 0.05$ ), which is different from the lifetime of the coating that shows low  $\mu$  value of 0.1~0.2.

Fig. 2 shows the effects of  $\text{O}_2$  concentration and RH in  $\text{N}_2$  atmosphere on such lifetime. In case of relatively low  $\text{O}_2$  concentration and RH, the lifetime is seen in several thousand cycles. However, when the  $\text{O}_2$  concentration and RH are above a certain value, the extremely low friction ( $\mu < 0.05$ ) continues up to 50,000 cycles set in this experiment.

These results suggest that the durability of low friction increases sharply in  $\text{N}_2$  atmosphere where  $\text{O}_2$  and  $\text{H}_2\text{O}$  molecules are present above a certain concentration, and the tribochemical reaction for forming low frictional interface continues to occur.

## 4. Conclusions

1. Even if there is no difference in the presence of coating and/or transfer film, a lifetime which keeps extremely low friction ( $\mu < 0.05$ ) before transition to the normal low  $\mu$  value of 0.1~0.2 is existed.
2. There are critical values of  $\text{O}_2$  concentration and relative humidity in  $\text{N}_2$  atmosphere, above that extremely low friction ( $\mu < 0.05$ ) continues up to 50,000 cycles set in this experiment.

## Reference

- [1] N. Yamada, et al., "Effect of Oxygen on the Self-formation of Carbonaceous Tribolayer with Carbon Nitride Coatings under a Nitrogen Atmosphere", Tribology letters, 1, 65, 2017, 1-11.

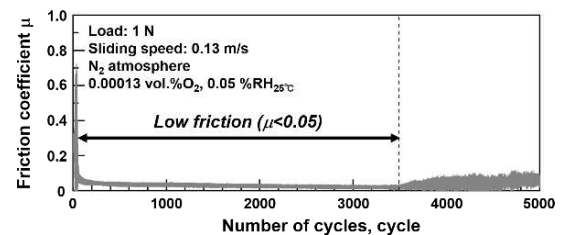


Fig. 1 Friction property of  $\text{Si}_3\text{N}_4/\text{CN}_x\text{:H}$  under  $\text{N}_2$  atmosphere (0.0001 vol.%  $\text{O}_2$ , 0.05%RH).

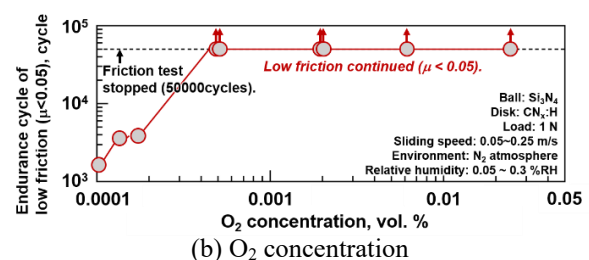
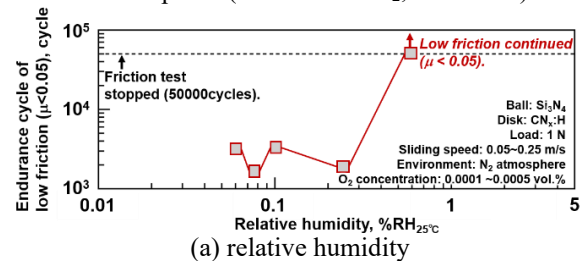


Fig. 2 Durability of low friction of  $\text{Si}_3\text{N}_4/\text{CN}_x\text{:H}$  as functions of (a) relative humidity and (b)  $\text{O}_2$  concentration.