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Short Communication

Reciprocating Tribological Properties of Carbonaceous Hard Coatings in Boundary Additive-Containing Oil Lubrication

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Introduction

In modern society, the environmental impact of greenhouse gases from automobiles has become a significant concern, underscoring the urgent need to improve fuel efficiency. It is reported that friction losses in engines and transmissions account for approximately 16.5% of input energy, highlighting the importance of reducing these losses [1]. Currently, Diamond-Like Carbon (DLC) coatings are applied between the piston and cylinder to help reduce friction losses [2]. DLC has an amorphous structure that combines the sp^2 configuration of graphite with the sp^3 configuration of diamond. Its hardness and Young's modulus can be adjusted by altering the sp^2/sp^3 ratio and hydrogen content. Additionally, Y Liu et al. [3] reported that wear of DLC coating became more severe under reciprocating friction compared to unidirectional friction [3]. This increased wear is primarily caused by the reduced accumulation of wear debris on the friction surface during reciprocating motion, making it more difficult for wear debris and tribo- films to form compared to unidirectional friction.

Based on the facts above, it is crucial to achieve low friction in environments where tribofilm formation is challenging to maintain under reciprocating sliding conditions. However, most research on DLC coating for low friction under MoDTC-containing PAO8 lubrication has been conducted under unidirectional sliding conditions, with few studies being investigated on the triboloogical properties of DLC under reciprocating friction. Therefore, this study aims to evaluate the tribological properties of DLC under reciprocating sliding in MoDTC-containing PAO8 lubrication. A reciprocating sliding friction tester will be used to develop strategies for achieving further friction reduction.

Methodology and Results

In this study, PAO8 with a viscosity of 7.94×10^{-3} Pa·s at 80 °C was used as the base oil for the MoDTC-containing lubricant. The lubricant was prepared by adding 3000 ppm of MoDTC to PAO8. The ta-C coating was deposited on SUJ2 rollers with a diameter of 5 mm, and the properties of the DLC coatings are listed in Table 1. Ni-Cr steel disks with a surface roughness of approximately Ra = 5 nm were used as the counterpart material. A reciprocating roller-on- disk friction tester was employed to evaluate the tribological properties. The load and friction force were measured using strain gauges attached to leaf springs, with a sampling frequency of 50 Hz. The lubricant temperature was maintained at 80 °C, and the reciprocating cycle frequency was set to 0.33 Hz.

Table 1: Properties of DLC coatings.

	ta-C
Thickness t, µm	1.4
Hardness H, GPa	62.3
Young's modulus E, GPa	578
Surface roughness R_a, nm	58

The normal load was increased from 1.0 N to 2.5 N in 0.5 N increments every 100 cycles, then decreased back to 1.0 N using the same increments, for a total test duration of 35 minutes. All initial Λ values were below 0.05, ensuring that the experiments were conducted under boundary lubrication conditions. The progression of the friction coefficient was analyzed by dividing the absolute value of the measured friction force by the applied load. The friction progression curve was obtained by averaging the friction coefficient over 50 cycles before and after each measurement (Figure 1).

Figure 2 shows the friction coefficient of ta-C coating under MoDTC-containing PAO8 lubrication. The average friction coefficient for the cycles ranging from 0 to 100, 300 to 400, and 650 to 700 cycles were 0.138, 0.104 and 0.122, respectively. It has been confirmed that the friction coefficient gradually decreases with increasing load. Additionally, Figure 3 shows the friction coefficient for the last one cycle at each load during the load-increasing phase. It can be observed that the friction coefficient decreases significantly at the low-speed positions approaching the dead centers when the load is 2N or higher. This suggests that a sufficient amount of tribo-film was generated at these locations, contributing to the friction reduction. Figure 3 shows the SEM image and EDS elemental mapping of sulfur on the roller surface after the friction test. Accumulation of tribo-film was observed on both sides of the wear scar. Additionally, the detection of sulfur indicates the formation of tribo-film derived from MoDTC additives. This result suggests that the friction reduction is attributable to the products derived from MoDTC additives.

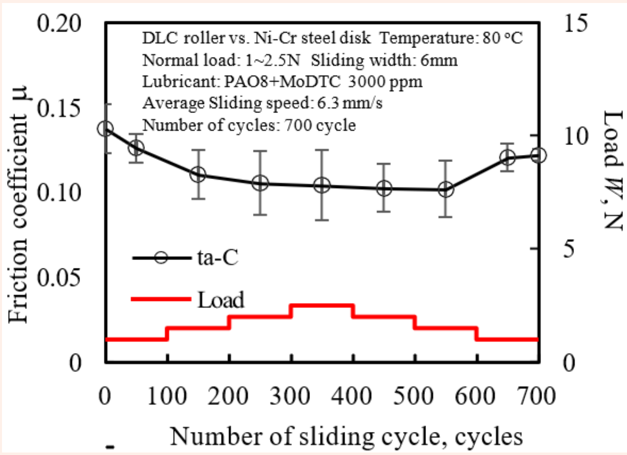

Figure 1: Friction coefficient under MoDTC-containing PAO8.

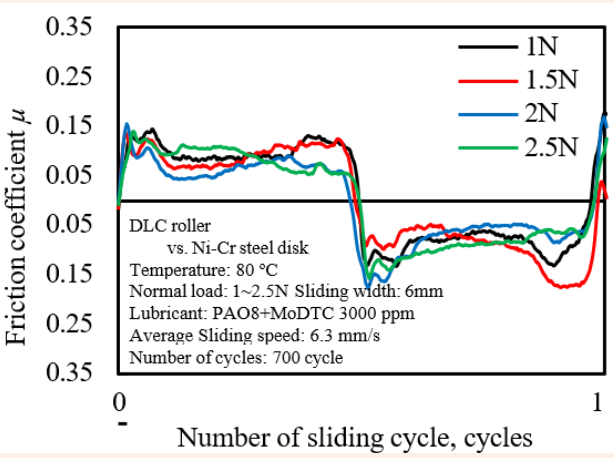

Figure 2: Friction coefficient at last one cycle.

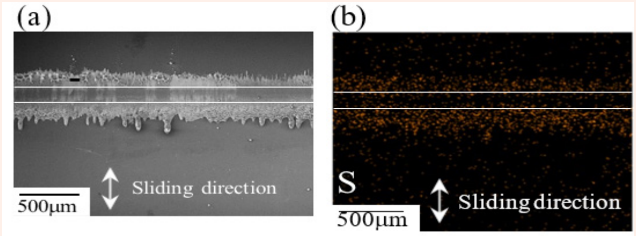

Figure 3: Analysis of roller surface (a) SEM image (b) elemental mapping of sulfur after friction test.

Conclusion

In this research, the tribological properties of DLC coating under MoDTC-containing PAO8 lubrication were evaluated using a reciprocating sliding friction tester to investigate friction reduction effect of DLC in reciprocating friction. The friction test was conducted using the ta-C roller, against the Ni-Cr steel disk. After the friction test, EDS analysis was performed on the roller surface to estimate the composition of the tribofilm. The findings are as follows,

a. The friction coefficient of ta-C coatings decreased as the load increased. Furthermore, the friction coefficient decreased significantly at low-speed positions approaching the dead centers, suggesting that a sufficient tribo-film is being formed near these positions.

b. EDS analysis of the roller surface after friction tests under MoDTC-containing PAO8 lubrication revealed the accumulation of tribo-film containing sulfur on both sides of the wear scar. This result suggests the friction reduction effect is due to the formation of tribo-film derived from MoDTC additives.

References

1. Holmberg K, Andersson P, Erdemir A (2012) Global energy consumption due to friction in passenger cars. Tribology International 47: 221-234.
2. Ciulli E, Ruggiero A (2024) Proceedings of ITS-IFToMM 2024. ITS-IFToMM 2024. Mechanisms and Machine Science 160: 13-22.
3. Liu Y, Chen L, Jiang B, Liu Y, Zhang B, et al. (2021) Origin of low friction in hydrogenated diamond-like carbon films due to graphene nanoscroll formation depending on sliding mode: Unidirection and reciprocation. Carbon 173: 696-704.