Tribological properties of Cr-doped diamond-like carbon films under additives-containing ester oil

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1. Introduction

Minimizing friction and wear is essential for improving the efficiency and lifespan of mechanical systems, given the strict environmental regulations aimed at conserving energy. Advanced tribological methods such as nano-layered coatings [1], nano-additives [2], and micro-textures [3] have been explored, but their high production costs and complexity have limited their widespread adoption. Thus, conventional methods like surface coatings and lubricants remain prevalent. Low-viscosity oils, especially ester oils, have garnered attention for their energy-saving potential and superior performance across a wide temperature range [4]. However, their thin oil film can lead to increased wear and surface damage under boundary lubrication conditions. To address this, lubricant additives like molybdenum dithiocarbamate (MoDTC) and zincdialkyldithiophosphate (ZDDP) are frequently employed to reduce friction and wear. Diamond-like carbon (DLC) coatings, particularly those doped with metals like chromium-doped DLC (Cr-DLC), have shown promise in enhancing tribological properties by interacting with these additives [5]. Cr-DLC coatings have demonstrated effective friction reduction by promoting the complete decomposition of MoDTC, but further research is needed to understand their role under ester oil lubrication with a binary-additive package of MoDTC and ZDDP.

2. Experiments

Cr-DLC coatings were fabricated using a hybrid plasma deposition method that integrates bipolar plasma-based ion implantation and deposition (PBII&D) with RF magnetron sputtering. The tribological performance of the coatings was evaluated using a reciprocating tribometer. All sliding experiments were performed under boundary lubrication conditions, with a sliding frequency of 1 Hz and an 8 mm stroke length. The tests were conducted at a normal load of 3 N, a temperature of 80°C, and lasted for 15 minutes. An ester-based synthetic oil was used, which was mixed with a binary additive package containing MoDTC and ZDDP. Raman spectroscopy and X-ray photoelectron spectroscopy (XPS) were utilized to study the tribofilm formed due to the tribochemical reactions involving these additives.

3. Results and discussion

The tribological behavior was significantly influenced by the inclusion of lubricant additives. Fig. 1 shows the variation in coefficients of friction (COFs) over cycles under different lubrication conditions. When Ester, without any additives, was used as the lubricant, as shown in Fig. 1(a), the COFs were relatively unstable during the initial cycles but stabilized within a range of 0.07–0.08 after approximately 300 cycles. These COF values indicate that the sliding conditions were typical of boundary lubrication.

When MoDTC was added to the Ester lubricant, the COF values for both coatings were recorded around 0.09–0.13 throughout the cycles (see Fig. 1(b)). Although the introduction of chromium led to some improvement in COFs, the values were still higher than those observed with Ester alone. Moreover, the elevated COFs did not indicate the presence of MoS_2 in the tribofilm. The tribological performance under Ester + MoDTC lubrication can be explained by competitive adsorption driven by the ester oil. The polar nature of the ester functional group brings about this competitive adsorption, limiting MoDTC's access to the surface and thus deteriorating its lubricating ability.

The addition of ZDDP to the Ester + MoDTC lubrication caused a significant reduction in COFs for both coatings. As shown in Fig. 1(c), the COF values for DLC and Cr-DLC stabilized at 0.062 and 0.044 after approximately 150 and 300 cycles, respectively. This reduction in friction is primarily due to the formation of a MoS_2-rich tribofilm. The combination of MoDTC and ZDDP is known for its synergistic effect in promoting the formation of MoS_2. According to Martin et al. [6], ZDDP preferentially forms a phosphate-rich tribofilm that facilitates the effective diffusion of intermediate Mo oxysulfide ($Mo_2S_2O_2$), generated from the decomposition of MoDTC. ZDDP plays a crucial role by supplying sulfur atoms, which sulfurize the intermediate Mo oxysulfide. This process hinders a chemical pathway of MoO_2 to MoO_3, and conversely, results in a higher concentration of MoS_2.

The tribological characteristics of the coatings under 0W20 lubrication were also investigated to compare the lubricating performance of the model oils, as shown in Fig. 1(d). The coatings exhibited low and stable COFs after about 300 cycles, comparable to those observed under Ester + MoDTC + ZDDP lubrication.

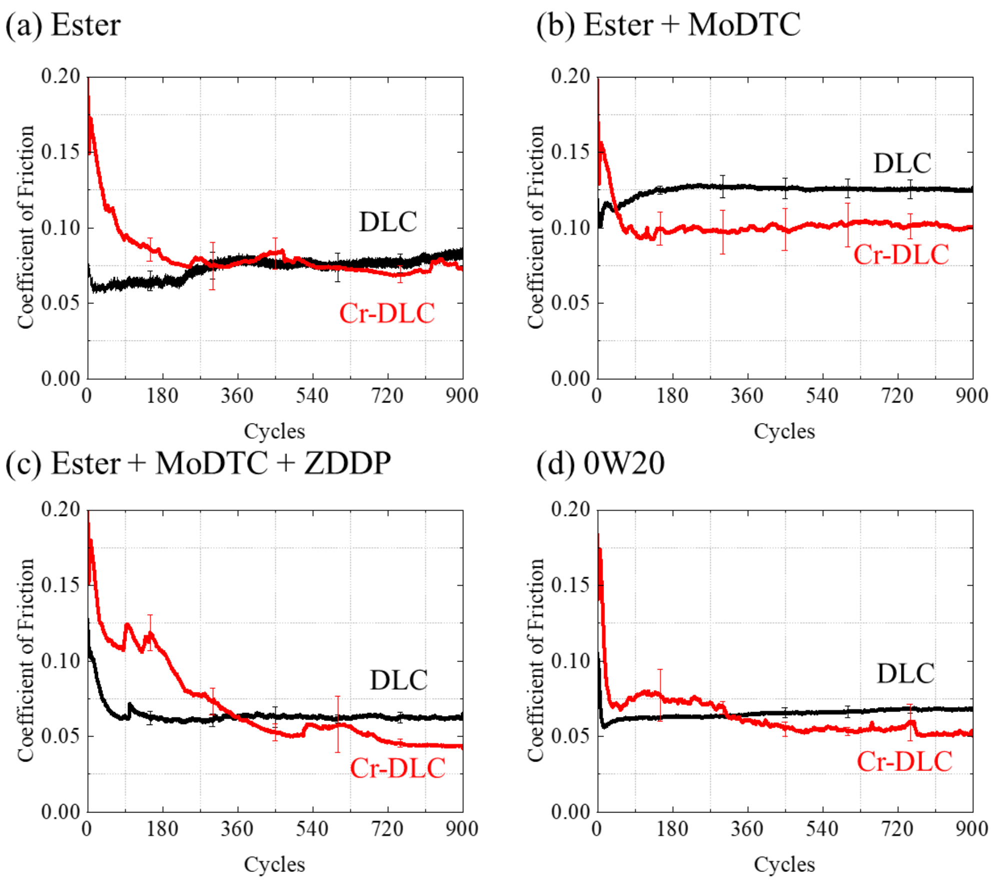

Fig. 1 The coefficients of friction with respect to cycles under (a) Ester, (b) Ester + MoDTC, (c) Ester + MoDTC + ZDDP, and (d) 0W20 lubrication for DLC and Cr-DLC coatings.

4. Conclusion

This research highlights the tribological properties of DLC and Cr-DLC coatings under additives-containing ester oil lubrication. The results demonstrate that while ester oil alone can stabilize the COF over cycles, its lubricating performance is limited. The introduction of MoDTC to the Ester lubrication resulted in an increased COF, suggesting that ester-induced competitive adsorption impedes the lubricating ability of MoDTC. However, the addition of ZDDP to the Ester + MoDTC lubrication significantly improved the tribological performance, as evidenced by the formation of a MoS_2-rich tribofilm, which effectively lowered the COF for both DLC and Cr-DLC coatings.

References

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