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Dependence of Tribological Performance of Engine Oil on the Carbon-Based Tribofilm Formation with Different Bonding Hybridization Content

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In this study, tribological performances of different carbon-based tribofilms have been conducted. CPCa and Ni nanoparticles generate carbon-film with high sp^2 content that can reduce friction to ~ 0.08, but this film is easily delaminated which increases friction after a period of sliding. Meanwhile, CBCa generates a carbon-based tribofilm with high sp^3 content that produces more stable but slightly higher friction (~ 0.1). However, CBCa and Ni nanoparticles deliver a significantly lower wear rate than CPCa which outperforms even conventional ZDDP additives. This study sheds light on future research of manipulating carbon-based tribofilm structure with desirable friction and wear performances.

Keywords: carbon-based tribofilm, friction, wear, catalytic effect

1. Introduction

Carbon-based tribofilms have recently been an efficient solution to reduce friction and wear. Several approaches have been implemented to generate the carbon-based film, including carbon-precursors, and catalytic additives. The structure of the carbon-based tribofilm is similar to diamond-like carbon (DLC) coating but their properties are different [1]. The properties of DLC-films is dramatically dependent on the sp^2- and sp^3-bonding fraction [2]. High sp^2 hybridization content results in softer film and provides better friction performance. However, it is not clear whether the *in-situ* generated carbon-based tribofilms from catalytic dissociation of oil and tribopolymerization of carbon-precursors have similar behaviors. Understanding the relationship between the chemical bonding configuration and the tribological performance of these carbon-films is beneficial to formulate the desirable carbon-film functional additive packages.

2. Methods

2.1. Friction and wear evaluation

Tribological performances of different lubricant additives (Table 1) are evaluated by UMT Tribolab. The testing conditions are 10 N applied load (equal to 1.26 GPa Hertzian pressure), 0.1 m/s sliding velocity, room temperature. The tested disc is AISI 52100 bearing steel (R_a = 515 nm) while the tested ball is GCr15 bearing steel (R_a = 20 nm). The calculated λ, via Hamrock-Dowson equation [3], is 0.26, thus, an extreme boundary lubrication regime ensues.

Table 1: Tested lubricants and additive concentration

PAO4	100% PAO4
CPCa	PAO4 + 2.5 wt.% CPCa
CBCa	PAO4 + 2.5 wt.% CBCa
Ni	PAO4 + 0.1 wt.% CBCa
ZDDP	PAO4 + 2.5 wt.% ZDDP

2.2. Tribofilm characterization

SEM/EDS is applied to study tribofilm composition. Raman microscope is utilized to characterize the sp^2- and sp^3-bonding configuration of carbon-based tribofilm. FIB/STEM/EELS will be further utilized to study the bonding fraction and verify the tribofilm structure.

3. Results

Tribological performances of the carbon-based tribofilm from CPCa, CBCa, and Ni nanoparticles are significantly different which are attributed to different sp^2/sp^3 bonding ratios.

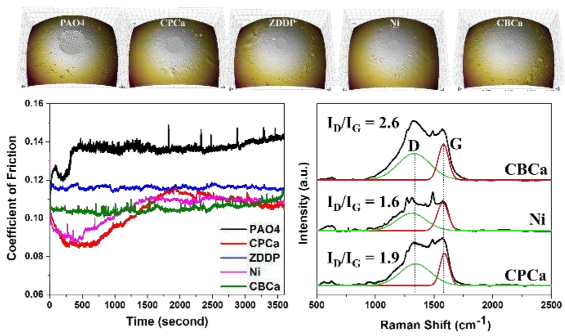

Figure 1: Tribological performance of different additives relating to the sp^2/sp^3 bonding fraction.

4. Discussion

The cycloalkane geometry has a significant impact on the bonding configuration of carbon-based tribofilm formation. Ni nanoparticles reveal their catalytic effect that generated the carbon-based tribofilm from the PAO oil. High sp^2 content generated from CPCa and Ni nanoparticles results in low friction but non-stable film. Meanwhile, high sp^3 content from CBCa results in much stable film and low wear rate outperforming ZDDP additives but it increases friction slightly.

5. References

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