Additive Interaction and Mechanism Analysis of Fullerene-Doped Lubricants

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1. Introduction

As a countermeasure against global warming, there is an urgent need to reduce CO_2 emissions, and the widespread use of EVs is an urgent issue One of the measures to improve the efficiency of reduction gears for EVs is to increase the electric power cost of EVs. Methods to reduce friction loss include smoothing sliding parts and applying a hard, low-friction diamond-like carbon film. On the other hand, the authors have focused on oil with nanoparticles added, which can reduce friction not only in some parts but also in all parts to be lubricated.

The proposed low-friction mechanisms of nanoparticles under lubrication include rolling action, protective film formation, repair effect, and polishing action. However, the low-friction mechanism of DLC films is thought to be the formation of a low-shear layer between the C-OH groups formed on the surface layer and polar oils, which reduces friction (Fig.1) [1].

In this study, we focused on the interaction between fullerenes and Ca detergents, one of the major oils considered to be an inhibitor of friction reduction by fullerenes, and investigated the effects of structure, base value, and addition amount.

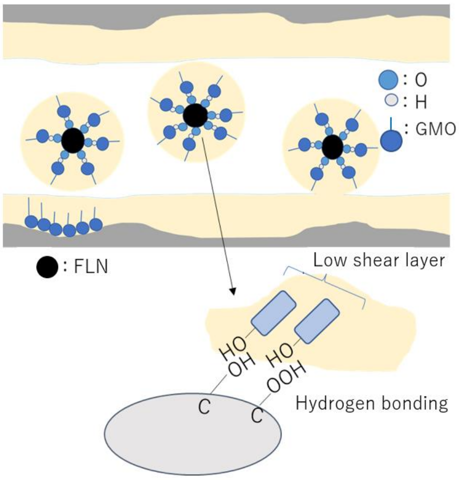


Fig.1 Low-friction mechanism model.

2. Testing method

Glycerol monolate (GMO) was added to the base oil, polyalphaolefin (PAO4), at 1.0 wt% as a dispersing agent and friction modifier. Fullerene (FLN) with 99.5% purity was added at 0.1 wt%. As a basic comparison, 0.1, 0.2, and 0.3 wt% of basic Ca sulfonate TBN300 (Ca-SuTBN300), 0.3, 0.5, and 1.5 wt% of neutral Ca sulfonate TBN20 (Ca-SuTBN20), and 0.2 and 0.44 wt% of Ca salicylate (Ca-) were added. The mixture was dispersion-mixed in an ultrasonic cleaner for 480 s for a total of 4 times. Friction tests were performed using the ring on disk method. The disk specimen was SCM440 (HRC48-50) with a surface roughness of Ra0.05. The ring specimen was a hollow cylinder (Φ20/Φ30) of S45C hardened steel (HRC45), and the test surface was a cylindrical end face with a surface roughness of Ra0.3.

An Olympus laser microscope (OLS4000-SAT) was used to measure the surface roughness, and the secondary particle size of FLN in the oil was measured by dynamic light scattering (Zetasizer Nano ZSP) using base oil with FLN concentration diluted to 0.01 wt%. After the friction test, to analyze the additive reaction film, the thickness of the film was measured from the elemental distribution and depth profile of the additive components using a PHI710 scanning Auger electron spectrometer manufactured by ULVAC.

3. Experimental results and consideration

Fig.2 shows the friction coefficient at the end of the test for each specification, organized by the synthetic surface roughness of the ring and disk after the test. compared to PAO4+GMO+FLN, the friction coefficient worsened with synthetic surface roughness for all specifications containing Ca detergents. This trend was more pronounced with increasing amounts of additives, especially for TBN300 Ca sulfonate. For the same sulfonate, the trend was moderate for TBN20. On the other hand, the synthetic surface roughness and coefficient of friction for Ca salicylate were worse than for base oil + GMO + FLN, but were not affected by the amount of Ca salicylate added.

Fig.3 shows the friction coefficients at the end of the test sorted by Ca content, and a rough correlation was observed between Ca content and friction coefficient. On the other hand, Ca-SaTBN225 was less affected by Ca content, especially at 0.44 wt%, deviating from the overall trend.

To confirm the effect of the reaction film generated by the Ca additive on the coefficient of friction, the depth of Ca distribution was examined by Auger spectroscopic analysis of the depth profile of the disk after the test and is summarized in Fig.4. The thickness of the film was highly dependent on the amount of Ca-SuTBN300 added. Ca-SuTBN20, on the other hand, was as thin as 5 nm regardless of the amount added, and Ca-SaTBN225 was as thick as 30 nm, but the effect of the amount added was not observed. Fig.5 shows the results of the friction coefficients for each film thickness. The coefficient of friction increased as the film thickness increased, showing a good correlation. However, for Ca-SuTBN20, a difference in the coefficient of friction was observed even though there was no difference in film thickness. Fig.6 shows the results of a comparison of the Ca distribution on the Ca-SuTBN20 disk after the test. 0.3wt% Ca was partially distributed on the disk surface, while 0.5wt% Ca was uniformly distributed on the surface, indicating that the coverage ratio is an influential factor in addition to the film thickness. Based on the above results, a friction model for the coexistence of fullerene and Ca detergents is shown in Fig.7, and it is considered that the Ca detergents affect the surface adsorption of GMO and the subsequent flattening by the thickness and distribution amount of the reaction film, thereby inhibiting low friction caused by fullerenes.

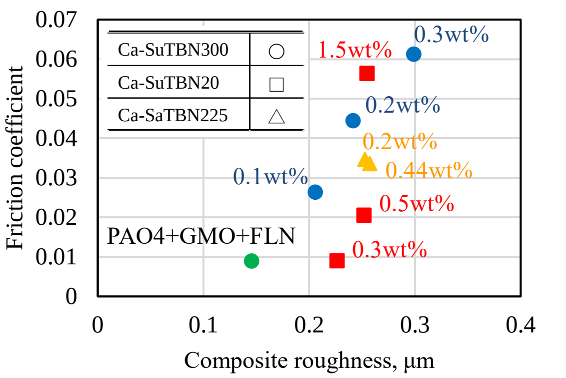


Fig.2 Coefficient of friction at synthetic roughness of FLN dispersion with Ca detergents.

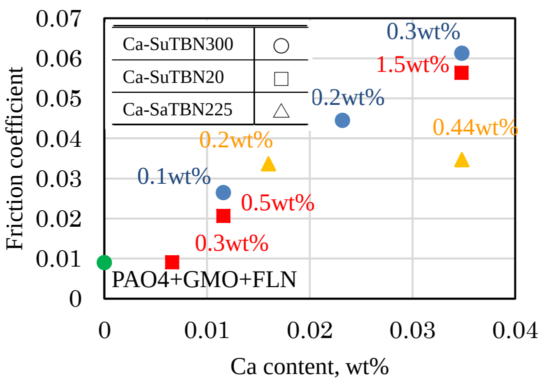


Fig.3 Coefficient of friction for each Ca-based cleaner with respect to Ca content.

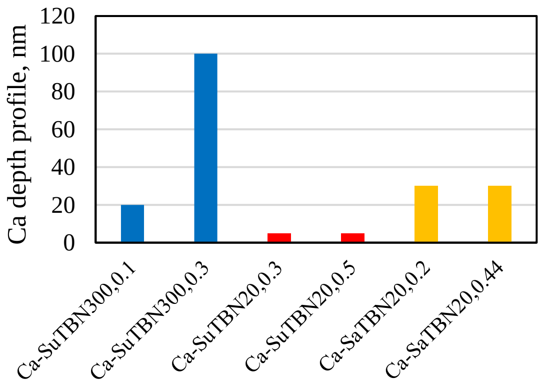


Fig.4 Ca depth distribution on disk surface after addition of each Ca detergents.

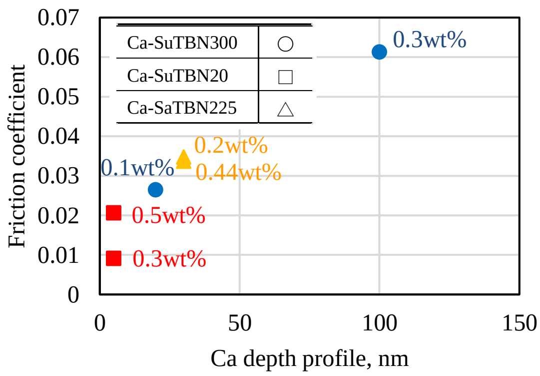
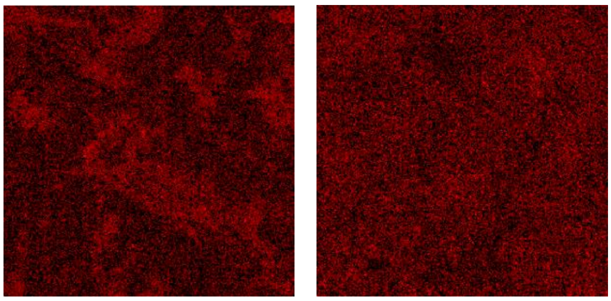
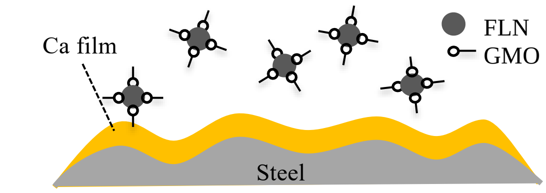


Fig.5 Friction Coefficient in Ca Depth Distribution on Disc Surface.

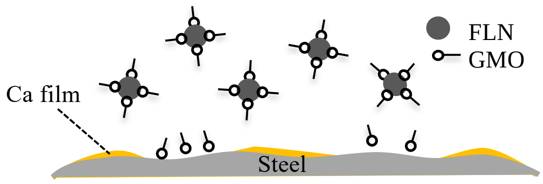


a) Ca-SuTBN20 0.3wt% b) Ca-SuTBN20 0.5wt%

Fig.6 Ca distribution on disk surface measured by Auger spectroscopy.



a) Ca film is formed on the entire surface and friction reduction is suppressed.



b) Ca film is partially formed and low shear layer is formed in some areas.

Fig.8 Friction model for the coexistence of fullerenes and Ca detergents.

4. Conclusion

(1) When coexisting with fullerenes, the addition of Ca detergents tends to worsen synthetic surface roughness and increase the coefficient of friction.

(2) Ca salicylate TBN225 was positioned between Ca sulfonate TBN300 and TBN20, and no effect of the amount added was observed.

Reference

1) Y. Iwashita, et. al., Tribology conference 2023 Spring Tokyo, Proceedings B39, p156-157.

2) Y. Mabuchi, et. al., TRIBOLOGY TRANSACTIONS, Vol.43(2000), 2, p229-236.