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主 論 文 の 要 旨

論文題目 Boundary Lubrication Mechanisms of Diamond-Like Carbon Coatings with Oil Additives (添加剤を含む潤滑油中のダイヤモンドライクカーボンコーティングの境界潤滑メカニズム)

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論 文 内 容 の 要 旨

Huge amount of money and energy have been lost in the world due to the friction and wear in mechanical components. Diamond-like carbon coatings have desirable mechanical and tribological properties for many industrial applications like hard hardness, chemical inertness, low friction and high wear resistance. These coatings can be prepared by various deposition techniques. Mechanical and chemical properties of DLC coating strongly depend on the coating methods, hydrogen content, hybridization of carbon and dopant elements. Besides, tribological properties of DLC coating are significantly affected by extrinsic factors or test conditions such as humidity, temperature, surrounding environment and counter material. The excellent mechanical and tribological properties of DLC coatings make them promising candidate for engine components to control friction and wear in passenger cars. However, most of the engine components need to work under lubricated conditions and commercially available engine oils are formulated for ferrous surfaces. Therefore, interaction of DLC surfaces with the oils and the lubricant additives is not yet fully understood. On the other hand, it is known that engine components operate in a range of temperatures and it is an imported parameter for tribological properties of DLC, lubricants and lubricant additives.

The aim of this study is to clarify the ultra-low friction and wear mechanism of ta-C DLC under boundary lubricated conditions by testing in synthetic base oil poly alpha-olefin (PAO4), PAO+GMO, PAO+ZnDTP and PAO+GMO+ZnDTP. Besides, the role of temperature, additive concentrations and counter-material on the ultra-low friction and wear of non-hydrogenated ta-C DLC coating will be analyzed. Additionally, in order to better understanding of tribological properties and interactions between the DLC surfaces and oil additives, a wide range of DLC coating will be tested and compared with self-mated DLC/DLC contacts under same conditions in PAO and PAO+ZnDTP oils.

Tribological tests were performed in a pin-on-disc tribometer. Atomic Force Microscopy (AFM), Field Emission Scanning Electron Microscopy (FESEM), Nano-indenter, X-ray Photoelectron Spectroscopy (XPS), Raman spectroscopy and scanning white light interferometry were used for characterization of ta-C DLC and worn surface analysis. The results exhibit that ta-C give ultra-low friction in pure PAO for DLC/steel and DLC/DLC tribopair. GMO additivated PAO provide smooth run-in period for transition to ultra-low friction regime and also enhance the durability of coating. ZnDTP behave differently depending on the presence of ferrous surfaces on the contact. It forms pad-like wear protective tribofilm both on ta-C and steel surfaces for DLC/steel contact, while it form thin white layer on ta-C surfaces for DLC/DLC contact.

The results show that ta-C DLC were totally worn out in DLC/steel contact tested in base oil. The ta-C DLC exhibited totally different wear behavior in DLC/steel and DLC/DLC contact depending on lubricant formulation. The wear performance of ta-C DLC was found to have a clear dependence on combination of lubricant formulation, concentration of the lubricant additives and counterbody material. Using GMO and ZnDTP together does not show any synergistic correlation for steel/steel, DLC/steel and DLC/DLC combinations. The results obtained at high temperature show the significant and beneficial influence of oil additives on the wear performance of the coating. The results revealed that ta-C coated pin was experienced less wear, up to one order of magnitude, when rubbed against self-mated ta-C DLC and germanium disc compared to steel counterpart in base oil. It is explained that observed high wear against steel disc is due to thermally promoted tribo-chemical wear and rubbing against self-mated ta-C DLC and germanium eliminated this phenomenon.

The effects of hydrogen, doping elements and surface morphology on reactivity of DLC coatings have been studiedin terms of ZnDTP tribofilm formation and tribological performance of DLC coatings under boundary lubrication conditions. Six types of DLC coatings were tested: one non-hydrogenated amorphous carbon (a-C) coating, one non-hydrogenated tetrahedral amorphous carbon (ta-C) coating, two hydrogenated amorphous carbon (a-C:H) coatings, one silicon-doped hydrogenated amorphous carbon (Si-DLC) coating, and one chromium-doped hydrogenated amorphous carbon (Cr-DLC) coating. The results confirmed the ZnDTP derived pad-like or patchy tribofilm formation on the surfaces depending on kinds of DLC coatings. It is observed that hydrogen content and doping elements increased the pad-like tribofilm formation ability of DLC coatings. Doped DLC coatings exhibited better wear resistance than nondoped DLC coatings. Addition of ZnDTP additives in to the base oil significantly improved the wear resistance of hydrogenated DLC , silicon-doped hydrogenated DLC and chromium-doped hydrogenated DLC. Hydrogen-free tetrahedral amorphous DLC coating provided the lowest friction coefficient both in PAO (poly-alpha-olefin) and PAO +ZnDTP oils.