主　論　文　の　要　約

論文題目　**Fundamental Friction and Wear Properties of Structure-Controlled ta-C (構造制御した ta-C の基本的摩擦摩耗特性)**

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論　文　内　容　の　要　約

Environmental concern regarding climate change and pollution due to human and industrial activity have alarming the researchers around the world to focus on sustainable development ranging from daily life product to the industrial heavy machinery. One of the biggest sources of environmental pollution and global energy source depletion is the automotive industry. From well to wheel of a passenger car, fuel did not efficiently consume due to friction and wear which cause both the waste of burning of limited fossil fuel and releasing of harmful gasses. Thus, diamond-like carbon (DLC) coating with excellent mechanical and tribological properties has been introduced to control and reduce the friction and wear in mechanical parts. In general, the tribological performance of the DLC is depending on several factors which are the properties of the coating itself and the environment such as working temperature, load, mating material, and the presence of chemical reaction. As such, mechanical components are often operated under severe high load conditions that cause DLC coating to react differently depending on the types of DLCs. Tetrahedral amorphous carbon (ta-C) is one of the hydrogen-free DLC coating types with excellent properties and the hardness of ta-C coating is varied upon its sp^3 content. Under low load conditions, ta-C coating could provide excellent friction and wear resistance. Nonetheless, high hardness ta-C coating could not sustain high wear resistance properties under severe high load conditions. Recently, the advancement in coating deposition technology has led to the introduction of structure to the as-deposited DLC. At such, two novel ta-C coatings were develops which are Pillar ta-C and Mesh ta-C. Both of these coatings present the new characteristic of ta-C which are hardness controlled along with the coating depth. Since both coatings were newly developed, thus clarification on the mechanical and tribological properties of the Pillar ta-C and Mesh ta-C needs to be done before the application. The aim of this study is to clarify the friction and wear mechanism of Pillar ta-C and Mesh ta-C under boundary lubricated conditions.

The first part of this study examined the tribological properties of novel Pillar and Mesh tetrahedral amorphous carbon (Pillar ta-C and Mesh ta-C). Subsequently, the comparison was made with conventional ta-C coating under base-oil lubrication via cylindrical-pin-on-disk tribo-tester. Analysis of wear track was conducted using field-emission-scanning-electron-microscope (FE-SEM), atomic-force-microscopy (AFM), and Raman-spectroscopy. The friction coefficient for Mesh ta-C and conventional ta-C revealed a similar pattern with regard to loads. The Mesh ta-C had excellent wear resistance, where the wear rates at loads of 20 N was 10 and 20 times lower than Pillar ta-C and conventional ta-C, respectively. High wear resistance of Mesh ta-C characterized by inhibition of brittle micro-fracture propagation, less in abrasive particle created during friction test, and suppressing the effect of graphitization-induced wear on the contact surface.

Wear by fracture is among the factors associated with the DLC coating failures in the tribological application. The study continues with the investigation on the link between the wear and the fracture-toughness on the novel Pillar and Mesh structure ta-C coatings, in addition to conventional ta-C coatings. The tribological properties of these coatings were examined under base-oil lubrication via ball-on-disk tribo-tester and the micro indentation technique was used to characterize the fracture toughness. The wear track and the indentation mark were analyzed using the optical microscope, 3D laser microscope and FE-SEM. The friction coefficient for ta-C, Pillar ta-C and Mesh ta-C is within the range of 0.071 to 0.106. Mesh ta-C indicated the highest wear resistance, followed by the Pillar ta-C and conventional ta-C. Also, Mesh ta-C demonstrated the highest fracture-toughness value with 16.6 $MPa \cdot m^{1/2}$, followed by Pillar ta-C with 13.4 $MPa \cdot m^{1/2}$ in contrast to ta-C. Greater resistance to wear for ta-C with Pillar and Mesh structure was detected with an increased fracture-toughness and improvement in crack propagation inhibition. Moreover, the Pillar and Mesh ta-C provides a superior rate of crack-energy dissipation as compared to the ta-C.

The effect of lubricant additives to the novel Pillar ta-C and Mesh ta-C coating, as well as conventional ta-C for comparison has been investigated. Three type of lubricants used in this study are, Mineral oil with MoDTC + ZnDTP + 5 CA, PAO4 + MoDTC, and PAO4 + ZnDTP. Subsequently, a comparison was made with the lubrication under base oil PAO4 via cylindrical-pin on disk tribo-tester. The result shows that the friction coefficient is lower under single additive PAO4 + MoDTC and PAO4 + ZnDTP lubricants due to the formation of Mo-derived and Zn-derived tribo-film. Furthermore, ta-C, Pillar and Mesh ta-C shows excellent wear resistance under Mineral oil with MoDTC + ZnDTP + 5 CA lubrication condition, followed by the lubrication under PAO4 + MoDTC and PAO4 + ZnDTP. Higher wear resistance of ta-C, Pillar ta-C and Mesh ta-C under additive oil lubrication is characterized by the formation of Mo and Zn derived tribo-film which protect against high wear, as well as improved the coating resistance to microfracture. In addition, the friction coefficient reduction only can be observed under the used of single additive lubrication.