主　論　文　の　要　約

論文題目　Clarification of High Wear Resistance Mechanism of ta-CNx Coating Deposited by IBA-FAD System
(IBA-FAD 法による ta-CNx 膜の高耐摩耗性発現メカニズムの解明)

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論　文　内　容　の　要　約

Diamond-like carbon (DLC) coatings have desirable mechanical and tribological properties for many industrial applications due to its hard hardness, chemical inertness, low friction and high wear resistance. Among kinds of DLC coatings, carbon nitride (CNx) has got a great deal of attention for its impressive low friction. However, the insufficient hardness of CNx coating has limited the application. Therefore, a high hardness and high wear resistant type carbon nitride coating was developed with an ion beam assisted-filtered arc deposition (IBA-FAD) system, named as ta-CNx. ta-CNx coating is expected to have better mechanical properties than amorphous CNx (a-CNx), and also overcome the limit of residual stress of ta-C coating, making ta-CNx with great potential for the application of mechanical sliding parts. From the very few previous research, ta-CNx coating not only shows greatly improved hardness and wear resistance compared to previous a-CNx, but also it indicates that although nitrogen doping into ta-C coating will result in the decreased mechanical properties, the wear resistance also gets better unexpectedly. Thus, the high wear resistance mechanism of this ta-CNx coating still remained to be unclear. Meanwhile, tribological properties of this new potential coating under unlubricated condition has not been investigated yet.

The aim of this study is to clarify high wear resistance mechanism of ta-CNx coating deposited with IBA-FAD system under oil boundary lubricated and unlubricated condition. After investigating the effects of nitrogen doping on mechanical and micro-structural properties of ta-CNx, ball-on-disk friction tests will be conducted in synthetic base oil poly alpha-olefin (PAO4) with ta-CNx sliding against steel. Besides, the effects of temperature and counter-material on the friction and wear of ta-CNx coating will be analyzed to further confirm the wear mechanism in oil under boundary lubrication. Additionally, in order to get a comprehensive understanding of tribological properties of ta-CNx coating, ta-CNx coatings will also be tested in different temperatures and gas atmospheres in unlubricated condition.

In this study, ta-CNx coatings have been deposited on steel with N/C ratio of 0-11 at.% by IBA-FAD system. Doping nitrogen into ta-C will decrease the hardness, Young's modulus and surface roughness of the coating. For the micro-structural properties of ta-CNx, sp^2 structure increases and sp^3 structure decreases with the increase of nitrogen content. Nitrogen incorporation could also increase the fracture toughness of ta-CNx coating in favor of bearing greater applied load.

From ball-on-disk friction tests under PAO oil boundary lubricated condition, higher nitrogen content ta-CNx presents slightly lower friction and obviously better wear resistance, indicating that by nitrogen doping ta-CNx coating with more excellent tribological properties than ta-C. A suggested mechanism for low friction of ta-CNx coating is that after friction the softer high nitrogen content ta-CNx could be polished to be with much smoother wear surface and more likely to transit to mixed lubrication leading to decreased friction.

The wear behavior of ta-CNx coating strongly depends on the temperature and counter-material under base-oil lubrication. Results show that although ta-CNx shows obviously much lower wear rate compared to ta-C when rubbed against steel, and more slowly increasing wear with the oil temperature, sliding against alumina disks the wear rates present oppositely increasing tendency with the nitrogen contents, suggesting ta-CNx has lost its advantage over ta-C. Moreover, when sliding against alumina, the wear rates are almost not affected by the increasing temperature, therefore, it is hypothesized that better wear resistance of ta-CNx can be explained with the less tribo-chemical wear of thermally activated carbon atoms on the topmost surfaces of ta-C coating diffuse into the steel surface, since nitrogen doping could reduce this by partial passivation the surface active carbon. Due to the extremely low solubility of carbon in alumina, rubbing against it could totally eliminate the tribo-chemical wear, leading to the hardness of coating becomes the dominating factor for this pure mechanical wear.

In the unlubricated condition, it is found in this study that low nitrogen content ta-CNx coating could outperforms ta-C and high nitrogen content ta-CNx, with lowered friction and wear, reduced by half than ta-C for higher temperature (80 and 120°C), which is suggested to be caused by the remained hardness (45.01 GPa) and the less adhesion wear than ta-C, thanks to the passivation of dangling bonds of nitrogen doping effect. While sliding against sapphire, friction and wear of ta-CNx coating increase with the nitrogen content more significantly, and graphitization of the coating could also be found under 120 °C with decreased friction and without being worn out. Under the different gas atmosphere studied, the tribologcial properties of ta-CNx coating shows different character with a-CNx, but follows the essential property of hydrogen-free DLC, greatly decreased friction and wear with increase of environmental relatively humidity. Meanwhile, the oxygen in gas atmosphere could also attribute to oxidized wear of the coating to a certain extent, confirmed by the EDS analysis. Thus, humid nitrogen atmosphere shows the lowest the friction and wear for ta-CNx coatings.