主論文の要約

Name: DENG Xingrui

Title: カーボン系硬質膜の高温トライボロジー特性

Tribological properties of carbonaceous coatings at high temperature

Summary:

In modern industry, more and more sliding machines are subject to high-temperature environments. Solid lubricating coatings are primarily used to control friction and wear in high temperature environments, where conventional liquid lubricants cannot provide lubrication function due to deterioration and oxidation at high temperature. Solid lubricating coatings include nitrides coatings, carbides coatings, oxides coatings, carbon coatings, soft metals, polymers coatings and lamellar solids. Among these solid lubricating coatings, carbonaceous coatings attract much attention because of their excellent mechanical properties and tribological properties, such as low friction, high hardness and high wear resistance. However, the high temperature tribolgical behaviors and mechanism of carbonaceous are still not clarified yet up to now. Consequently, in this study, we prepared a-C:H, Si-DLC, CNx, BCN, ta-C coatings and investigated their thermal stability and high temperature tribological properties.

Firstly, we prepared hydrogenated DLC coatings, including a-C:H and Si-DLC by using Microwave-sheath Voltage-combination Plasma. But the axial thickness of the coating is non-uniformly distributed. Hence, we investigated the factors affecting the axial uniformity of DLC coatings on long rod. The axial distribution of ion density was evaluated by using a Langmuir Probe in Ar plasma that was generated along both DLC-coated and non-coated rods. It revealed that ion density along the axis of the DLC-coated rod decayed at a shorter distance than that along the axis of the uncoated one. Based on this result, the uniformity was improved greatly by optimizing the power and duty of DC power supply. Then a-C:H and Si-DLC were prepared by MVP method. The thermal stability of the a-C:H and Si-DLC films were investigated by performing an annealing test (100–700

ºC) in ambient air. Furthermore, the in situ high-temperature tribological properties on the films were investigated by performing a sliding test against a Si_3N_4 ball at elevated temperatures at 100, 200, and 300 ºC. Hardness measurements and a tribological test showed that Si-DLC had better thermal stability than a-C:H; however, Si-DLC had a higher friction coefficient and undergoes more wear than does a-C:H in the in situ high-temperature tribological test. The failure of Si-DLC is due to adhesive wear, whereas that of a-C:H is due to abrasive wear.

Then we focused on another candidate which was expected to show better thermal stability-boron carbon nitride (BCN) coating. In this work we studied the mechanical properties, thermal stability and tribological properties of ternary boron carbon nitride (BCN) coatings with controlled boron content. BCN coatings with different boron content (B at.%=0, 1, 5, 20%) were deposited by ion beam assisted deposition (IBAD). The thermal stability and oxidation resistance were investigated by weight loss method in ambient air. The results showed that the hardness and residual stress increased with boron content. At room temperature, the friction coefficient was in the range of 0.2-0.3 and did not change a lot with the boron content. At 300 ºC， $B_{0.05}CNx$ coating showed lowest friction coefficient(~0.1) among the four coatings, because the graphitized carbon transfer layer forms on the Si_3N_4 ball. The thermal stability and tribological properties of CNx coating can be improved by boron doping, but it is difficult to endure higher temperature (>300 ºC) because amorphous structure is easy to oxide.

Better thermal stability and tribological properties of ta-C was expected because it shows higher sp^3 content than hydrogenated DLC and BCN coatings. Then the tribological behavior of tetrahedral amorphous carbon (ta-C) coatings was investigated at elevated temperatures, from which it was found that it could be broadly defined by three distinct temperature regions: Region I at 23 and 100 °C; Region II at 200, 300, and 400 °C; and Region III at 500 °C. A qualitative analysis of the toughness and adhesion of the ta-C coatings within each of these regions was conducted by scratch testing. The hardness of ta-C coatings was evaluated at in situ high temperature environment. The formation of a transfer layer on Si_3N_4 balls in Region II was determined as the cause of a reduced friction and higher wear rate when compared with Region I. In Region III, the generation and propagation of cracks in the ta-C coating resulted in severe delamination.