Tribology of Diamond Like Carbon after H_2 Exposure

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Introduction

- Tribology is the study of contacting materials in relative motion, such as friction, wear, and lubrication.
- Everyday examples of tribology include the brake pads in your car, the soles on your shoes, and the hinges on a door.
- Materials are lost as they wear down, which can affect their performance and require repair or replacement, which is both environmentally and financially costly.
- This study will focus primarily on diamond-like carbon (DLC) films. These are materials with high hardness, temperature resistance, and crucially, they are chemically inert.
- Alternative energy sources to fossil fuels are increasingly being considered by scientists and governments as industries shift to more sustainable practices.
- Hydrogen is of particular interest as they are used in fuel cells and only generate heat and water as products, as opposed to carbon dioxide, a known greenhouse gas.
- The mechanism behind the low friction behavior of DLC is bond passivation by hydrogen atoms, prompting our project to explore how high temperature exposure in H_2 affects DLC tribological properties.

Methods and Materials

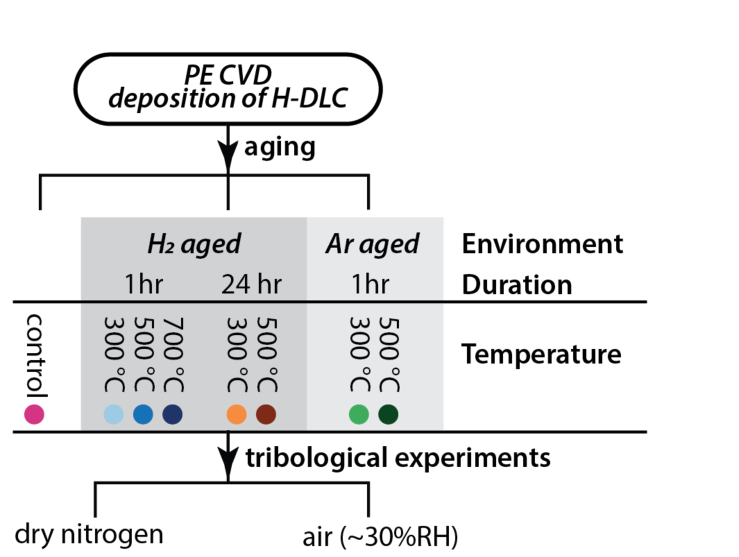
DLC deposition

DLC samples were prepared via plasma enhanced chemical vapor deposition (PECVD). Samples were sonicated in 1% Liquinox in 18M deionized (DI) water for 10 minutes, then rinsed in DI water for 5 minutes, followed by another sonication in acetone and isopropyl alcohol (IPA) for 10 minutes each.

Sample Aging

Samples were exposed to hydrogen gas in a split- tube furnace after the evacuation of air (nitrogen, oxygen) and heated at a rate of 10 C̊ / min to a temperature of 500 C̊ and held at that temperature for 1 hour. Samples were then cooled at a rate of 2 C̊ /min back to room temperature.

a)



b)

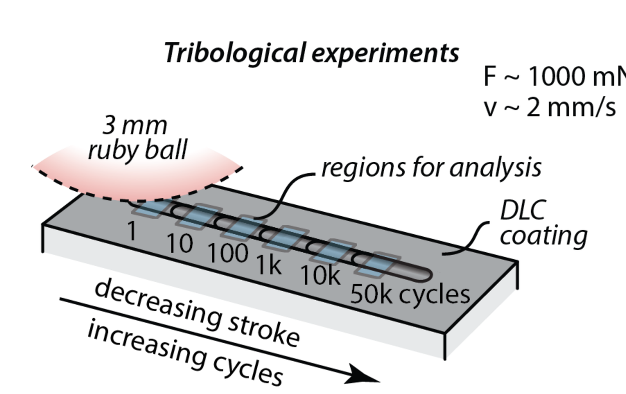


Figure 1a: Aging diagram
Figure 1b: Experimental setup

Methods and Materials

Experimental Procedure

Samples were slid against a 3 mm ruby ball mounted on a linearly reciprocating (back and forth motion) tribometer, resulting in a wear scar. This reciprocating motion constitutes a cycle – the wear scar featured regions of 100 cycles, 1000 cycles, and 10,000 cycles. Sliding occurred in a custom glove box with an environment of nearly pure dry nitrogen (<0.1 ppm O_2 and H_2O) and pressure of ~5 mbar. Wear scars were analyzed with a scanning white light interferometer (SWLI) and the data processed via custom MATLAB application. The volume loss was used to calculate the wear rate K using the formula below (Equation 1) [Van Meter et. al]:

$$K\ [mm^3 / Nm] = \frac{V\ [mm^3]}{F_N[N]\ d[m]} \qquad \textit{Equation 1}$$

X-ray Photoelectron Spectroscopy

Samples were analyzed using ambient pressure x-ray photoelectron spectroscopy (APXPS) a characterization technique used in surface science to analyze the chemical makeup of the surface (~10 nm probe depth). The area under the peaks in the high-resolution scans was used to find the surface content of oxygen and carbon and their proportion.

Results and Discussion

Friction data reveals a decrease in inconsistencies after aging as shown by the smoother graphs in figures 2a-c.

The wear rate significantly decreases with an increase in cycles as shown by the dramatic reduction between 1000 and 10,000 cycles (figure 3). Data for 100 cycles for samples 1 and 3 were omitted due to a lack of meaningful readings (100 cycles creates a very shallow region).

The proportion of oxygen relative to carbon decreases significantly when heated to 500 C̊. After cooling, some oxygen returns but is less than the original amount, as shown in figure 4.

These observations suggest that the reduction in friction and wear is due to the decrease in available oxygen groups on the interface, as shown in figures 5 and 6.

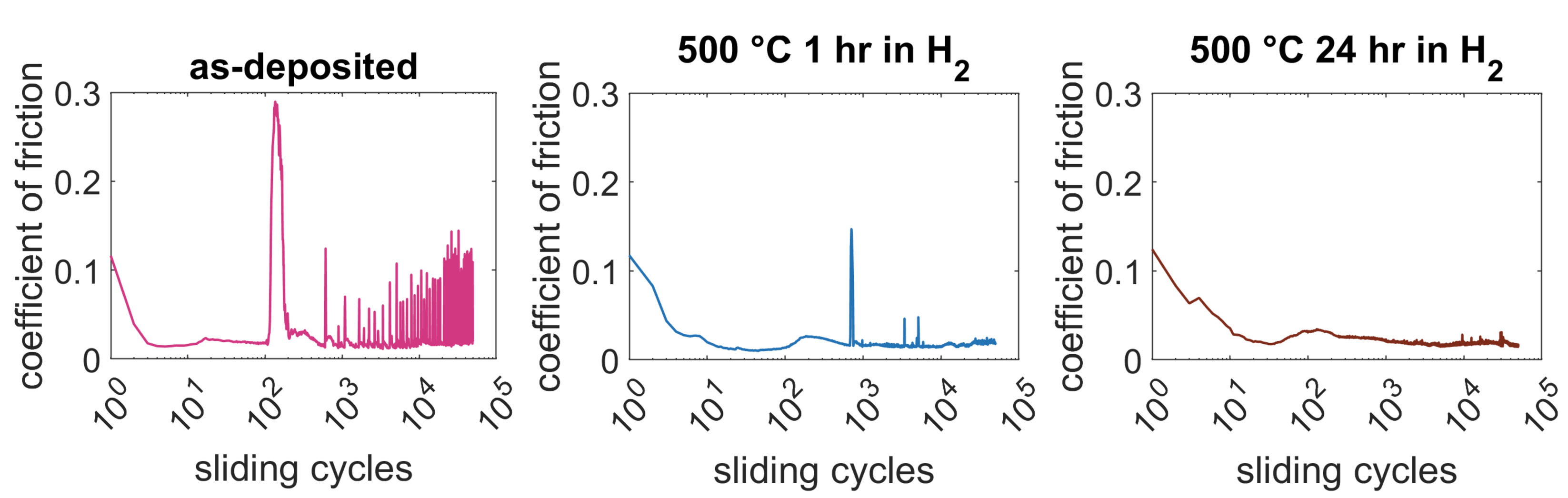


Figure 2a-c: Measured coefficient of friction on DLC samples as deposited (2a), after 1 hour in 500˚C (2b), and after 24 hours in 500˚C (2c).

Results and Discussion

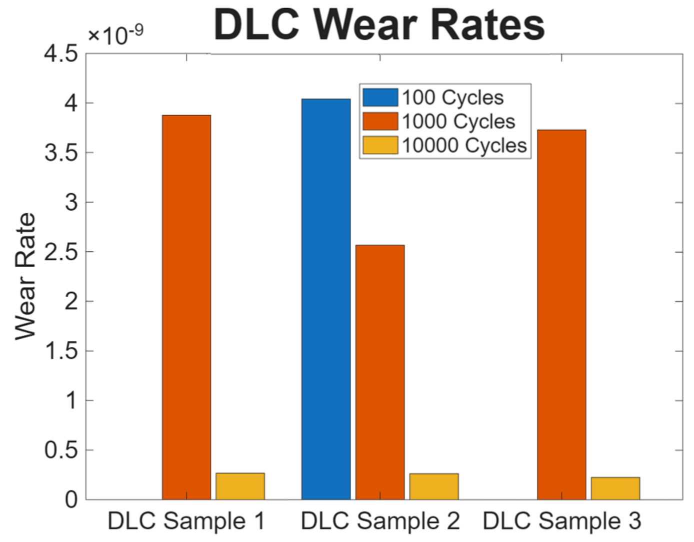


Figure 3: DLC Wear Rates

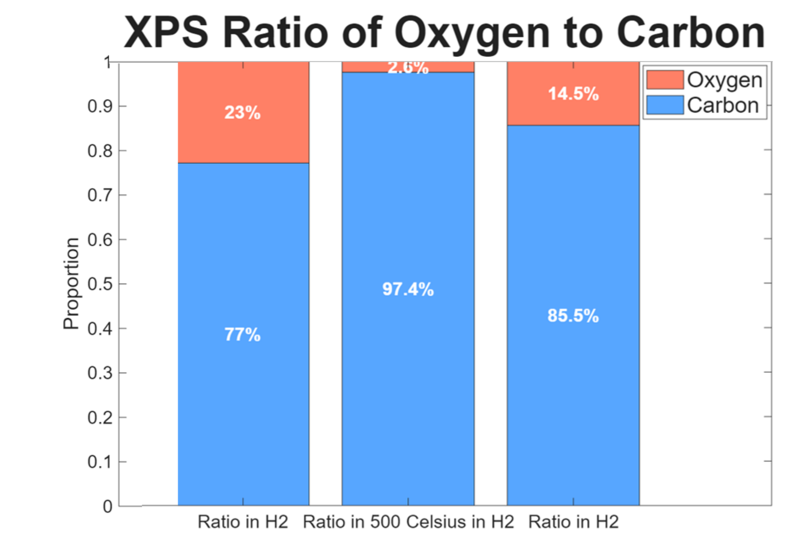
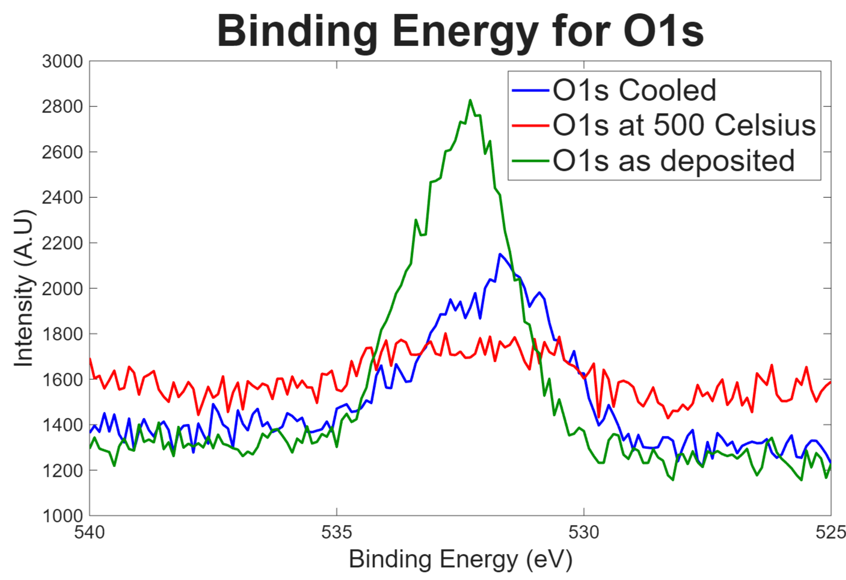
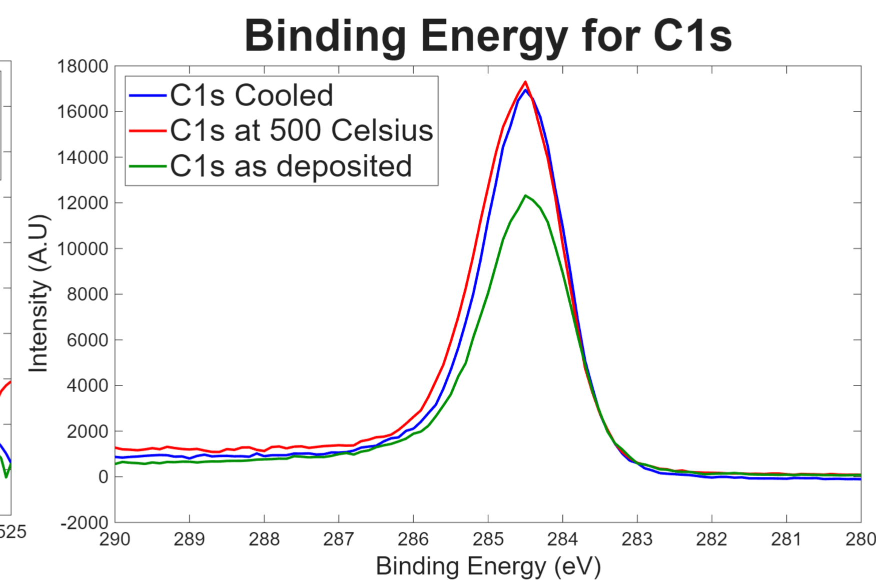


Figure 4: Proportions of Carbon and Oxygen





Figures 5-6: XPS Data of Oxygen (O1s) and Carbon (C1s)

Conclusion

- The data collected indicates that exposure to hydrogen decreases the wear rate significantly with the number of cycles.
- The phenomenon is likely due to the formation of a transfer film which reduces further wear.
- The coefficient of friction also exhibits more stable behavior after prolonged exposure to H2 as seen by the consistent decrease in figures 3-5.
- Due to the lack of oxygen groups, there is less reactivity with the transfer film, contributing to the steady decline in coefficient of friction. The lack of reactions stabilizes the transfer film and keeps the coefficient of friction low and steady.

Acknowledgement and References

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