Wear and Friction of Hydrogen Aged DLC Coatings

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Introduction

- Tribology is the study of friction, wear and lubrication. Research in low friction coatings is motivated by the importance of lubricants in environments where grease and oils are impractical or impossible.
- A greater push has been placed on greener energy sources, especially hydrogen. The environments where hydrogen is used as a fuel source often undergoes hydrogen embrittlement which happens when the small hydrogen atoms absorb into the metals and other materials around it. Development in Diamond like Carbon (DLC) coatings could potentially work to reduce this and provide a protective layer to hydrogen permeation, making hydrogen as a fuel source more practical.
- A DLC coating is a mixture of graphite-like sp2 bonds and diamond-like sp3 bonds. Since DLC coatings are amorphous, it can be hard to determine the tribological properties of the coating without running experiments. If the DLC is more graphite-like (sp2) it will generally have a lower coefficient of friction while if it is more diamond-like (sp3) it will have properties resembling greater hardness and durability.
- In previous research, the effects of hydrogenated DLC coatings were studied in relation to its tribological properties. The friction coefficient of the hydrogen-free DLC is very high (0.75) initially. However, the hydrogenated DLC provided a friction coefficient of 0.005 initially. These coefficients differed by a factor of more than 200 [1].
- We are furthering the concepts of this research by adding the variable of heat-treatment to the DLC coating with hydrogen and studying the impacts of the tribological properties.

Materials

Sample List
Unaged
300°C 1hr 500°C 1hr 700°C 1hr
300°C 24hr 500°C 24hr 700°C 24hr

- DLC coatings were deposited using Plasma-Enhanced Chemical Vapor Deposition (PECVD)
- Samples were tested using a custom built tribometer
- A tribometer is a device used to measure friction, normal load, and wear between two surfaces. For this work we used a ball on flat configuration.
- A tube furnace was used to age the samples at different temperatures under 1atm H_2 environment

a)

b)

Figure 1. a) Charred 700°C 24hr sample **b)** Testable 300°C 24hr Sample

Methods

- The wear tests on the DLC samples were done using a linear reciprocating tribometer.
  - Probe: 3 mm ruby ball
  - Speed: 2 mm/s
  - Load: 1000 mN or 1 N
  - Environment: Inert Nitrogen gas (O_2 and H_2O <0.01 ppm)
- During testing, the tribometer was set to apply a normal force of 1N to the sample which created a contact pressure of ~600 MPa between the ball and the coating. During the stripe testing, 6 regions were made with 10, 100, 1000, 10,000, and 50,000 cycles.

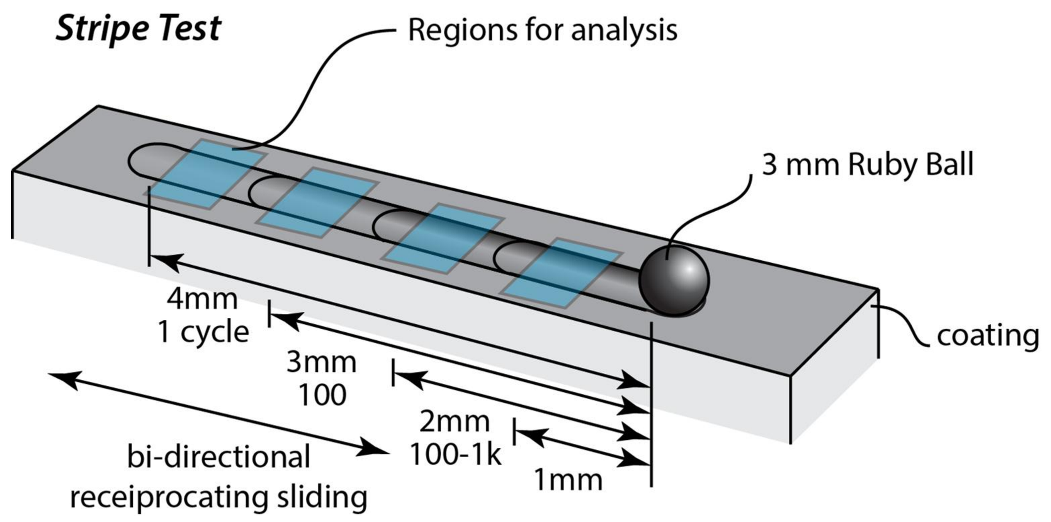
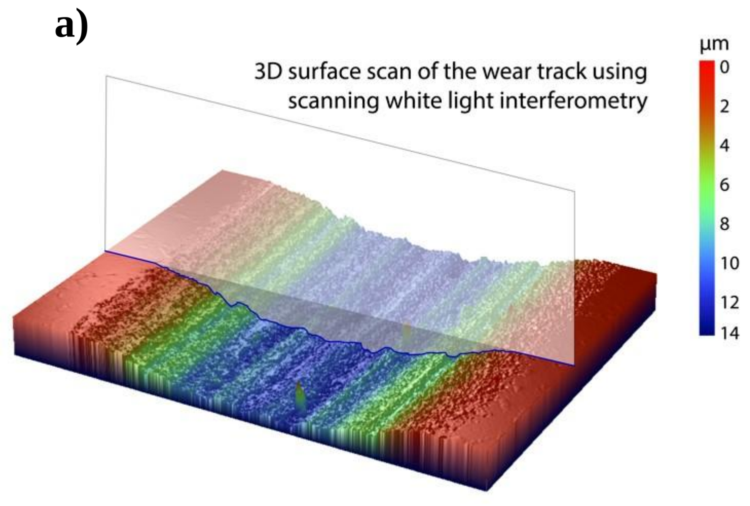


Figure 2. Stripe Test

- After the stripe test in the tribometer, the samples are moved to a Scanning White Light Interferometry (SWLI) for analysis. Here, scans are taken of the sample that evaluate the depths at each point on the surface of the sample that allow the topography to be analyzed [2].

a)



b)

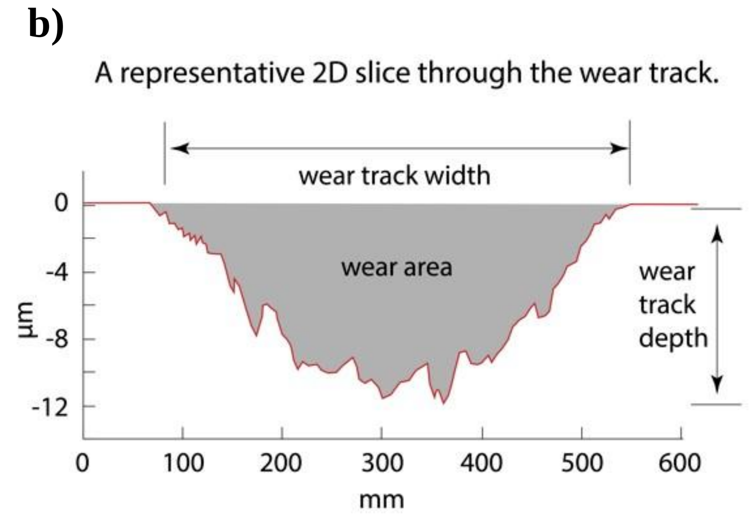


Figure 3. a) 3D Wear Track scan **b)** Wear Scar line scan

- Wear rate for each wear cycle section is calculated using

$$K(mm^3\ /\mathrm{Nm}) = \frac{V(mm^3)}{F_N\,(\mathrm{N})d(\mathrm{m})} = \frac{1000(\mathrm{mm/m})A(mm^2)s(\mathrm{m})}{2F_N(\mathrm{N})C(\mathrm{cycles})s\,(\frac{m}{cycle})} = \frac{1000\ A}{2F_N C}$$

(where V is the worn volume, F_N is the applied normal load, d is the total sliding distance, A is the wear scar cross-sectional area, L is the wear scar length, S is the reciprocating stroke length, and C is the total number of cycles.)

Results and Future Work

- The data shows a trend towards improved friction and wear rates after moderate aging, especially in the initial cycles. We believe it is due to better stability of the transfer film. (Depth of wear scars at 50,000 cycles ~150nm)
- The 500°C sample had the lowest average wear rate ($2.29\times10^{-7}mm^3/Nm$) between 1000 cycles and 10,000 cycles when aged 1 hour in H_2. All samples except 700°C had a wear rate between $10^{-7}mm^3/Nm$ and $10^{-6}mm^3/Nm$.
- The sample tested at 500°C had a steady state friction coefficient of 0.0151, the best overall between 1000 cycles and 10,000 cycles when aged 1 hour in H_2.
- Temperatures exceeding 700°C compromised the coating's integrity, resulting in cracking and charring of the samples. (see Figure 1a)

Future work:

- Structural characterization of DLC: Raman spectroscopy - Raman was done but not included. This would show Hydrogen content in films, changes in carbon hybridization, and bonding in sample.
- Conduct aging in a different environment without hydrogen. We plan to perform N_2 aging at Sandia National Labs to determine whether the observed changes are due to hydrogen exposure or simply the temperature profile.
- Perform the friction and wear testing during aging process or in a hydrogen environment. We also plan to test in different environments as well (air/humid).

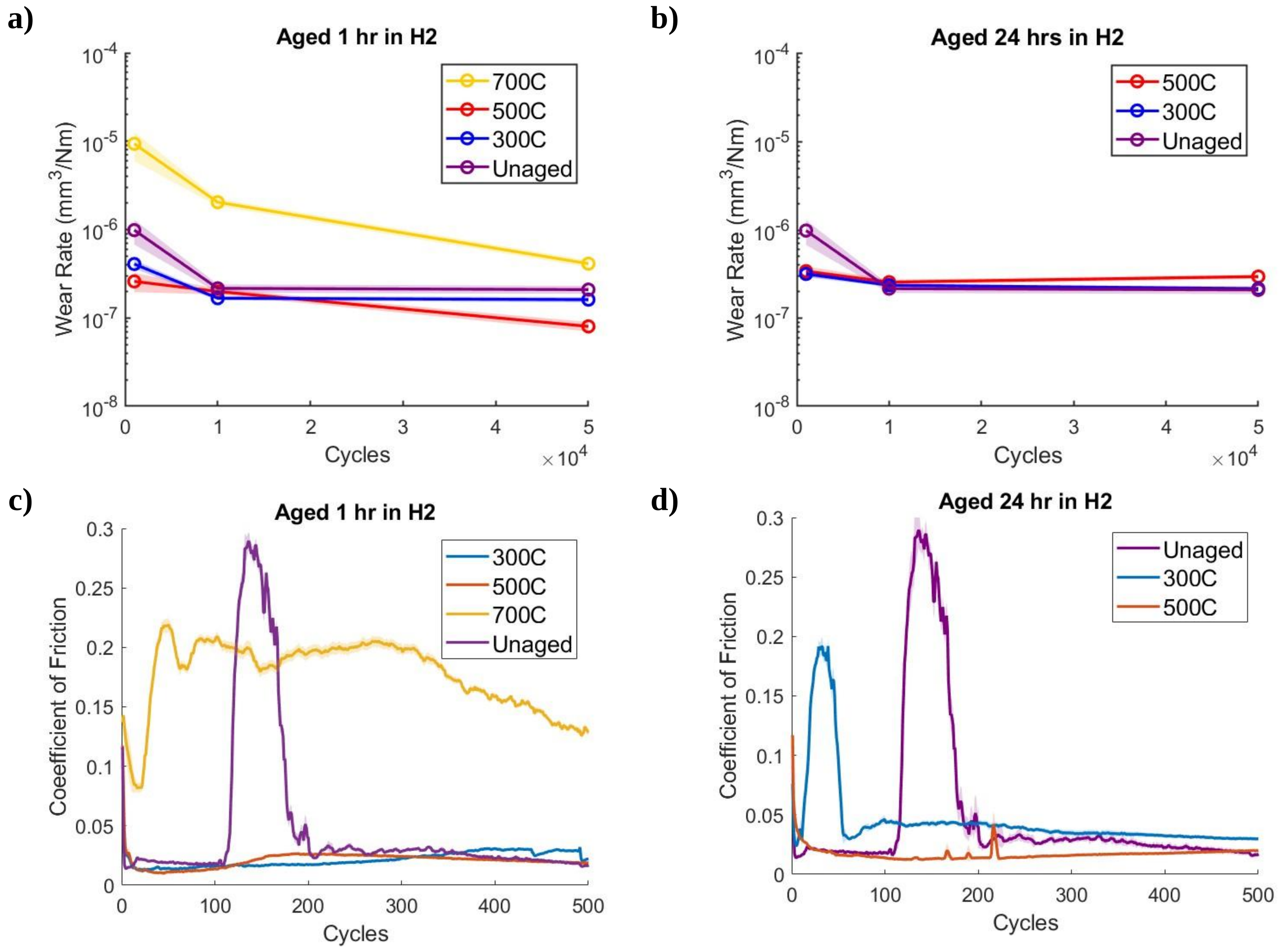


Figure 4. a) DLC aged 1 hour in H_2 wear rate **b)** DLC aged 24 hours in H_2 wear rate **c)** DLC aged 1 hour in H_2 friction **d)** DLC aged 24 hours in H_2 friction

Acknowledgement and References

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