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TRANSIENT BEHAVIOR OF NEAR FRICTIONLESS CARBON FILMS IN RECIPROCATING MICROTRIBOMETERY IN LOW HUMIDITY INERT ENVIRONMENTS

P. L. Dickrell
Dept of Mechanical and Aerospace Engineering
University of Florida
Gainesville, FL 32611

A. Erdemir
Energy Technology Division
Argonne National Laboratory
Argonne, IL 60439

W.G. Sawyer
Dept of Mechanical and Aerospace Engineering
University of Florida
Gainesville, FL 32611

ABSTRACT

Microtribological measurements of near frictionless carbon (NFC) films in controlled gaseous environments show that water vapor plays a role in the friction coefficient. These experiments also show that the NFC films initially have high friction in argon, which then decreases. This high friction does not reform over extended periods of exposure to Ar and low partial pressures of H_2O and O_2. Tests varying water vapor pressure show that under certain humidity conditions the friction coefficient can increases to values seen after extended periods of environmental exposure.

INTRODUCTION

Diamond-like carbon (DLC) films are of tribological interest due to their low friction, low wear rate, high hardness, and chemical inertness. These films can potentially be used in a wide range of applications, such as bearings, cutting tools, submersible parts, and biomedical applications. One class of diamond-like carbon coatings termed near frictionless carbon (NFC) that was developed at Argonne National Laboratory has been shown to sustain superlow coefficients of friction (<0.003) and wear rates ($<3^{-10}$ mm^3/Nm) in self-mated contacts. The tribological behavior of these films is sensitive to the environment, only realizing their low coefficient of friction and wear rate in inert, dry, or vacuum environments.

Due to the very different tribological characteristics in various environments, it is theorized that the gas-surface interaction on the NFC coatings is the cause for the variation in the friction coefficient and wear rate of the films. Another observation is that a certain amount of running-in is needed (regardless of environment) prior to realizing ultra-low friction coefficients. In microtribometer tests, the transient responses of these films was investigated, as well as the gaseous species believed to be responsible for the gas-surface interaction.

EXPERIMENTAL PROCEDURE

A low-contact-force tribometer was used to evaluate the friction performance of the NFC coating in self-mated contacts; this tribometer schematic is shown in Figure 1.

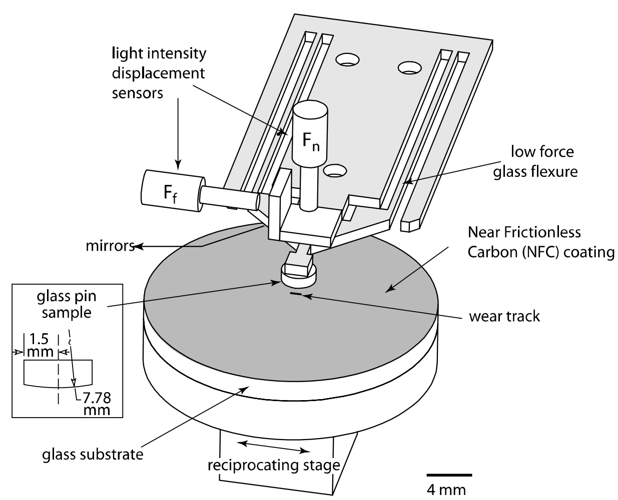

Figure 1 Schematic of the contact portion of a microtribometer that has a load range of 0.1 mN - 1N.

An environmental chamber controlled the gaseous species surrounding the contact. A dry argon flow maintained an inert gas environment within the chamber. This gas has a manufacturer reported purity of better than 5 ppm water and oxygen. During the testing a positive pressure was maintained and measured using a low-pressure gauge built into the chamber. An oxygen meter was also integrated and continuously sampled the environment during testing. For all tests reported here the oxygen partial pressure was less than 20 ppm; this includes tests during which water vapor was intentionally introduced using a bubbler with argon gas flow.

The counterface samples consisted of a 1-mm-thick borosilicate glass coated with 1-µm NFC-6, and the pins consisted of borosilicate glass lens that was also coated with 1-µm NFC-6 and had a 7.78-mm radius of curvature. The initial surface roughnesses were better than R_q=10 nm.

RESULTS AND DISCUSSION

Experiments at 0% relative humidity in dry argon (uncertainty of approximately 3% for all humidity measurements) under a 100 mN load and 18 mm/s sliding speed took over 2000 cycles before reaching a low friction coefficient condition. This behavior is shown in Figure 2. It Note that this initial friction coefficient is higher than 0.5, which is much higher than the friction coefficients traditionally seen with DLC films.

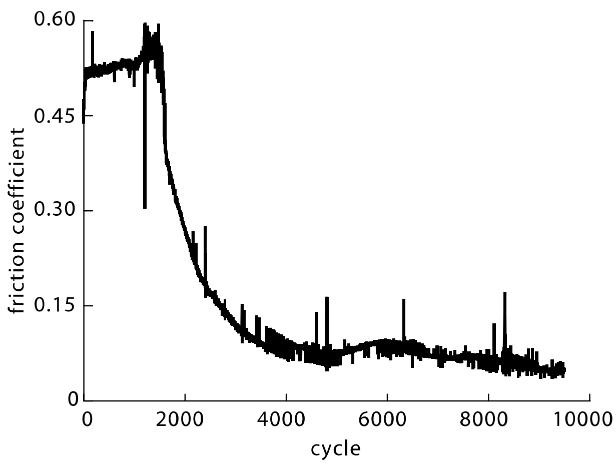

Figure 2. Initial response of the NFC films under 100 mN load and 18 mm/s sliding speed. The environment was Ar gas with less than 20 ppm O_2 and a reported relative humidity of 0%.

Following this initial breakthrough of the NFC surface, a series of experiments was run in the same environment to determine whether or not low partial pressures of water and oxygen were capable of forming a similar high-friction surface layer and over what time scale this layer formation was occurring.

The transient behaviors were strikingly similar for all of the experiments (Figure 3). This finding suggests that a surface effect happens relatively quickly and does not grow into the high-friction film indicated in Figure 2. The hypothesis is that either water or oxygen is responsible for these high-friction surface films. Using the same films and instrumentation, water vapor was added to the chamber without increasing the oxygen partial pressure. Figure 4 shows the friction response of these films to water vapor.

The water vapor shows a clear and adverse effect on the frictional characteristics of these films. However, even with very high concentrations of water vapor, the friction coefficients seen in Figure 2 were not observed, and the highest friction coefficient was similar to the starting values found during the exposure experiments shown in Figure 3.

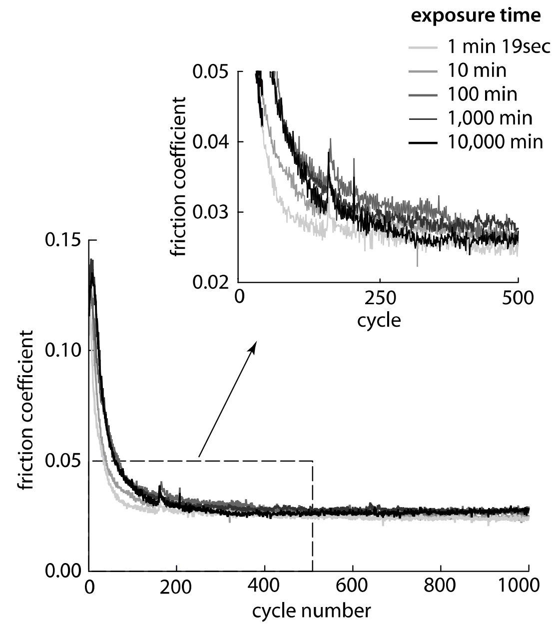

Figure 3 Friction coefficients for repeated sliding at the same location after separating the surface for specified periods of time in the controlled environment. The normal load was 3 mN and the sliding speed was 5 mm/s. 1,000 cycles were run for each condition.

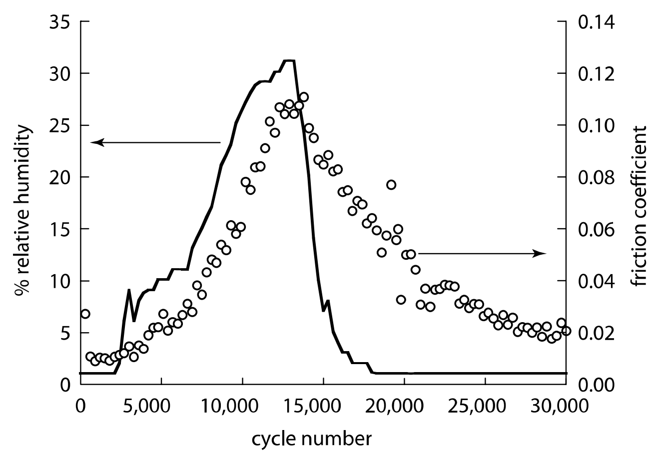

Figure 4. Friction coefficients over a single experiment varying the water vapor concentration while holding the oxygen partial pressure below 20 ppm. The contact load was 200 mN and the sliding speed was 4 mm/s.

CONCLUSIONS

(1) Low friction coefficients were achieved under microtribological (low contact pressure) sliding contacts of self-mated NFC.
(2) The NFC film initially had high friction which decreased to a low value after 2,000 repeated passes.
(3) Varying the exposure time over 5 orders of magnitude between contacts did not significantly affect the friction.
(4) Water vapor caused the high friction coefficient response, and though recoverable, the time constants were on the order of thousands of seconds.