INTRODUCTION
Surface contacts represent a severe environment for even the most robust materials. High localized pressures and temperatures at asperity peaks can lead to a wide variety of wear regimes and chemical events that ultimately lead to the failure of a bearing surface.

Wear rates of sliding surfaces can be measured in a variety of ways. Mass measurements can be taken before and after tests to provide an average wear rate, provided that the materials of interest do not uptake or outgas mass in the test environment. A wide range of commercially available profilometers, interferometers, and optical/electron microscopes can be used to geometrically characterize material loss once a test is complete.

It is often desirable to perform real-time wear measurements and observe initial run-in (or transient) periods, sudden material failures, and other wear events. One approach is to monitor the relative normal displacement between two surfaces, then calculate a wear rate from knowledge of the contact geometry. This can be troublesome if both components of the contact are simultaneously wearing. Chemical events can also be monitored in real time through the use of in-situ spectroscopy [1].

In order to realize in situ surface analysis, we have developed a reciprocating tribometer that is easily adapted for use under multiple microscopes and analytical instruments. If wear evolution is a concern, a scanning white light interferometer (SWLI) can be used to monitor the wear of specific regions after each pass rather than at the end of the test. Optical microscopy can be applied to visually inspect the counterface for wear or wear debris during testing. Additional components will be developed in the future to make the design compatible with a Raman/Fourier Transform Infrared (FTIR) spectroscopy unit in order to observe chemical bond changes during tribological tests.

TRIBOMETER DESIGN
A schematic of the tribometer configured for use under a scanning white-light interferometer is shown in Fig. 1. The tribometer operates by reciprocating a flat plate under a normally-loaded hemispherical pin. Relative motion between the pin and counterface is provided by a servo-controlled lead screw stage. The normal force between the pin and counterface is adjusted by raising or lowering a manual micrometer stage. Normal and friction forces are measured by a six channel load cell. When adjusting the normal load with the micrometer stage, the load cell is kept in alignment with the sliding surface by a leaf spring parallelogram-type flexure (Fig. 2). Additionally, polyetheretherketone (PEEK) insulators make electrical contact resistance testing possible.

![Figure 1: Linear reciprocating tribometer design. (1) Reciprocating stage (2) Pin (3) Counterface (4) Normal load micrometer stage (5) Load cell (6) Leaf spring flexure (7) PEEK insulators (8) Microscope objective for wear observation (9) V-block pin holder](image-url)
Figure 2: The leaf spring parallelogram-type flexures keeps the load cell axes aligned.

Figure 3: In situ tribometer mounted on SWLI stage.

TESTING UNDER A SCANNING WHITE LIGHT INTERFEROMETER

As previously discussed, the reciprocating tribometer can be configured to complete friction tests under a scanning white light interferometer in order to monitor wear development as a test progresses (Fig. 3). Such testing is accomplished by executing single or multiple reciprocations of the stage while monitoring normal and friction forces. After a given number of cycles (one or more), the wear track area of interest is moved under the interferometer objective in order to perform surface measurements. In this way, average friction coefficient data and surface metrology data can be compared on a cycle-by-cycle basis. In one such test, a polished stainless steel counterface was reciprocated under a stainless steel sphere.

Test Conditions

The stainless steel pin used in this test was mounted with epoxy to a piece of steel tubing which was, in turn, clamped in the V-block holder (Fig. 1). After mounting the pin and counterface on the tribometer, the micrometer stage was lowered until a normal force of 3.5 N was achieved. With the assumption that the counterface could be modeled as an elastic half-space, the initial Hertzian contact pressure between the 3.2 mm diameter sphere and counterface was calculated to be 1.2 GPa. The stage was reciprocated over a 30 mm track length at a commanded sliding speed of 3 mm/s.

Test Results

The test continued for 120 cycles until the epoxy bonding the pin to the steel tubing failed. The average friction coefficient data and a three-dimensional surface map of a portion of the wear track were recorded after each cycle. The test results at several cycles are shown in Fig. 4. Surface height data has been magnified by a factor of 10.

Figures 4a and 4b show the evolution of the wear track as new scratches form and grow on the counterface surface. The combined friction and wear data allow the development of these scratches to be linked with increases in the friction coefficient as seen between cycles 1 and 7. Additionally, the SWLI surface data can be used to calculate surface roughness evolution and monitor the accumulation of wear debris (cycles 7-120).

FUTURE WORK

Currently, a chamber is being constructed to enable operation of the tribometer in a variety of gas environments. Additionally, future tests will include passing current through the pin and into the counterface to study contact resistance evolution. Finally, the tribometer will be modified to operate under a Raman/FTIR apparatus to monitor chemical changes under the contact.

REFERENCES

Figure 4a: Friction and wear results for a steel pin on a steel plate under a 3.5 N normal load. (A) Cycle 0, the nascent surface. (B) Cycle 1. (C) Cycle 7. (D) Cycle 40, debris is seen outside the wear track.
Figure 4b: Friction and wear results for a steel pin on a steel plate under a 3.5 N normal load. (E) Cycle 80, additional debris is observed. (F) Cycle 120.