IN-SITU WEAR MEASUREMENT AT HIGH TEMPERATURE USING TRIBOMETER

Prepared by
Duanjie Li, PhD
INTRO

The linear variable differential transformer (LVDT) is a type of robust electrical transformer used to measure linear displacement. It has been widely used in a variety of industrial applications, including power turbines, hydraulics, automation, aircraft, satellites, nuclear reactors, and many others\(^1\). In this study we feature the add-ons of LVDT and high temperature modules of the Nanovea Tribometer which allow the change of wear track depth of the tested sample to be measured during the wear process at elevated temperatures. This enables users to correlate different stages of wear process with the evolution of COF, which is critical in improving fundamental understanding of the wear mechanism and tribological characteristics of the materials for high temperature applications.

MEASUREMENT OBJECTIVE

The wear process of the alumina silicate ceramic at different temperatures is simulated in a controlled and monitored manner using the Nanovea Tribometer. In this study, we would like to showcase the capacity of Nanovea Tribometer for in-situ monitoring the evolution of the wear process of materials at elevated temperatures.

Fig. 1: High temperature module for tribological evaluation.
MEASUREMENT PRINCIPLE

TRIBOMETER PRINCIPLE

The sample is mounted on a rotating stage, while a known force is applied on a pin, or ball, in contact with the sample surface to create the wear. The pin-on-disk test is generally used as a comparative test to study the tribological properties of the materials. The, coefficient of friction, COF, is recorded in situ. The volume lost allows calculating the wear rate of the material. Since the action performed on all samples is identical, the wear rate can be used as a quantitative comparative value for wear resistance.

![Schematic of the pin-on-disk test.](image)

**Fig. 2: Schematic of the pin-on-disk test.**

PRFOILOMETER PRINCIPLE

The axial chromatism technique uses a white light source, where light passes through an objective lens with a high degree of chromatic aberration. The refractive index of the objective lens will vary in relation to the wavelength of the light. In effect, each separate wavelength of the incident white light will re-focus at a different distance from the lens (different height). When the measured sample is within the range of possible heights, a single monochromatic point will be focalized to form the image. Due to the confocal configuration of the system, only the focused wavelength will pass through the spatial filter with high efficiency, thus causing all other wavelengths to be out of focus. The spectral analysis is done using a diffraction grating. This technique deviates each wavelength at a different position, intercepting a line of CCD, which in turn indicates the position of the maximum intensity and allows direct correspondence to the Z height position.
Nanovea optical pens have zero influence from sample reflectivity. Variations require no sample preparation and have advanced ability to measure high surface angles. Capable of large Z measurement ranges. Measure any material: transparent or opaque, specular or diffusive, polished or rough.

**TEST PROCEDURE**

The tribological behavior, e.g. coefficient of friction, COF, and wear resistance of alumina silicate ceramic plates was evaluated by Nanovea Tribometer. The alumina silicate ceramic plate was heated up by a furnace from room temperature, RT, to elevated temperatures (400 °C and 800 °C), followed by the wear tests at such temperatures. For comparison, the wear tests were carried out when the sample cooled down from 800 °C to 400 °C and then to room temperature. An Al₂O₃ ball tip (6 mm dia., Grade 100) was applied against the tested samples. The COF, wear depth and temperature were monitored in situ. The test parameters are summarized in Table 1. The wear rate, \( K \), was evaluated using the formula \( K = V/(F \times s) = A/(F \times n) \), where \( V \) is the worn volume, \( F \) is the normal load, \( s \) is the sliding distance, \( A \) is the cross-sectional area of the wear track, and \( n \) is the number of revolution. Surface roughness and wear track profiles were evaluated by the Nanovea Optical Profilometer, and the wear track morphology was examined using optical microscope.

<table>
<thead>
<tr>
<th>Test parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal force</td>
<td>3 N</td>
</tr>
<tr>
<td>Speed</td>
<td>5 m/min</td>
</tr>
<tr>
<td>Duration of test</td>
<td>500 cycles</td>
</tr>
<tr>
<td>Rotational speed</td>
<td>Adjusted according to change of radii</td>
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</tbody>
</table>

**Table 1: Test parameters of the pin-on-disk measurement.**

**RESULTS AND DISCUSSION**

The COF and wear track depth recorded in situ are shown in Fig. 4 and Fig. 5, respectively. In Fig. 4, “-I” indicates the test performed when the temperature was increased from RT to an elevated temperature. “-D” represents the temperature decreased from a higher temperature of 800 °C.
As shown in Fig. 4, the samples tested at different temperatures exhibit a comparable COF of ~0.6 throughout the measurements. Such a high COF leads to accelerated wear process which creates a substantial amount of debris. The wear track depth was monitored during the wear tests by LVDT as shown in Fig. 5. The tests performed at room temperature before sample heating up and after sample cooling down show that the alumina silicate ceramic plate exhibits a progressive wear process at RT, the wear track depth gradually increases throughout the wear test to ~170 and ~150 µm, respectively. In comparison, the wear tests at elevated temperatures (400 and 800 °C) exhibit a different wear behavior – the wear track depth increases promptly at the beginning of the wear process, and it slows down as the test continues. The wear track depths for tests performed at temperatures 400 °C-I, 800 °C and 400 °C-D are ~140, ~350 and ~210 µm, respectively.

The average wear rate and wear track depth of the alumina silicate ceramic plates at different temperatures were measured using Nanovea optical profilometer as summarized in Fig. 6. The wear track depth measured by Nanovea optical profilometer is in agreement with that recorded using LVDT. The alumina silicate ceramic plate shows a substantially increased wear rate of ~0.5 mm³/N m at 800°C, compared to the wear rates below 0.2 mm³/N at temperatures below 400 °C. The alumina silicate ceramic plate does not exhibit significantly enhanced mechanical/tribological properties after the short heating process, possessing a comparable wear rate before and after the heat treatment.

Alumina silicate ceramic, also known as lava and wonderstone, is soft and machinable before heating treatment. A long process of firing at elevated temperatures up to 1093 °C can substantially enhance its hardness and strength, after which diamond machining is required. Such a unique characteristic makes alumina silicate ceramic an ideal material for sculpture. In this study, we show that heat treatment at a lower temperature than the one required for firing (800 °C vs. 1093 °C) in a short time does not improve the mechanical and tribological characteristics of alumina silicate ceramic, making proper firing an essential process for this material before its usage in the real applications.

![Graph showing coefficient of friction during pin-on-disk tests at different temperatures.]

*Fig. 4: Coefficient of friction during pin-on-disk tests at different temperatures.*
Fig. 5: Evolution of wear track depth of the alumina silicate ceramic plate at different temperatures.

Fig. 6: Wear rate and wear track depth of the sample at different temperatures.
CONCLUSION

Based on the comprehensive tribological analysis in this study, we show that the alumina silicate ceramic plate exhibits comparable coefficient of friction at different temperatures from room temperature to 800 °C. However, it shows a substantially increased wear rate of ~0.5 mm²/N m at 800 °C. The enhanced mechanical/tribological properties were not obtained after the relatively short heat treatment up to 800 °C, demonstrating the importance of proper firing treatment of this ceramic.

Nanovea Tribometer is capable of evaluating the tribological properties of materials for applications at high temperatures up to 900 °C. The function of in-situ COF and wear track depth measurements allows users to correlate different stages of wear process with the evolution of COF, which is critical in improving fundamental understanding of the wear mechanism and tribological characteristics of the materials used at elevated temperatures.

Nanovea Tribometer offers precise and repeatable wear and friction testing using ISO and ASTM compliant rotative and linear modes, with optional high temperature wear, lubrication and tribo-corrosion modules available in one pre-integrated system. Nanovea’s unmatched range is an ideal solution for determining the full range of tribological properties of thin or thick, soft or hard coatings, films and substrates.

Optional 3D non-contact profiler is available for high resolution 3D imaging of wear track in addition to other surface measurements such as roughness.

Learn More about the Nanovea Tribometer

2 [http://www.mcmaster.com/#8477kac/=pryfm](http://www.mcmaster.com/#8477kac/=pryfm)