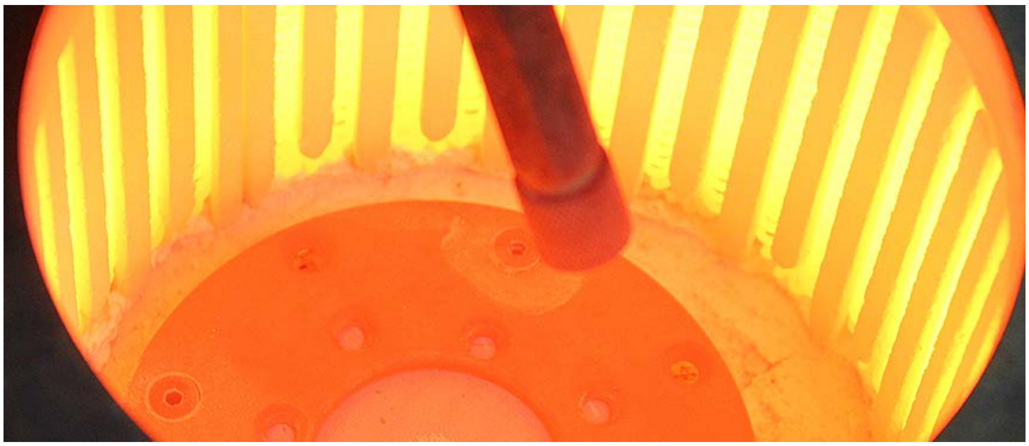
NANOVEA®
A Better Measure.

ARC RECIPROCATING WEAR AT HIGH TEMPERATURE



Prepared by
Duanjie Li, PhD

6 Morgan, Ste156, Irvine CA 92618 · P: 949.461.9292 · F: 949.461.9232 · nanovea.com

INTRO

Wear is a process of removing material on a surface as a result of mechanical action of the opposite surface[1]. It is influenced by a variety of factors, such as temperature, speed, load, reciprocating and many others. Temperature plays a critical role on the extent of wear damage to materials. Wear at high temperature has a complex nature, involving different wear mechanisms such as adhesive wear, abrasive wear, surface fatigue and oxidation wear[2].

IMPORTANCE OF ANALYZING ARC RECIPROCATING WEAR AT HIGH TEMPERATURE

ASTM G133 [3] is a widely used standard setup for testing the reciprocating sliding wear behaviors of materials. Due to the back and forth movement of the sample involved during the arc reciprocating wear testing, it is challenging to design an oven that fully enclose the sample and reaches a high and homogenous temperature. Our previous study has shown that the material tested using reciprocating and rotational setups can exhibit significantly different wear behaviors. Therefore, in order to study the reciprocating wear behaviors of materials at elevated temperatures, we developed the arc wear test setup. It rotates the sample stage for pin-on-disc test and continuously oscillates it clockwise and counterclockwise, creating a arc reciprocating sliding motion for the sample. The contact of the wear process can be totally enclosed in a large oven which ensures uniform and stable temperature up to 950ºC surrounding the sample and the counter material.

MEASUREMENT OBJECTIVE

The wear mechanism of a stainless steel SS304 plate sample is measured in a controlled and monitored manner using the arc reciprocating wear test setups at the room temperature and 800ºC for comparison. In this study, we would like to showcase the capacity of Nanovea Tribometer in measuring the reciprocating wear of materials at high temperatures.

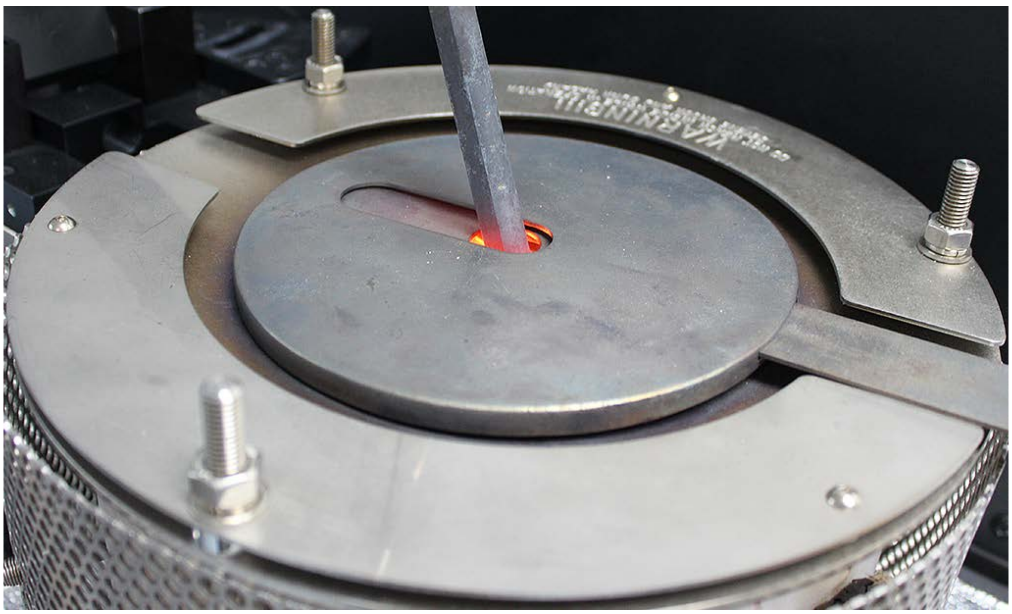


Fig. 1: The oven for the arc wear tests.

TEST PROCEDURE

The tribological behavior, e.g. coefficient of friction, COF, and wear resistance of the stainless steel SS304 sample was evaluated by Nanovea Tribometer using arc reciprocating wear test setups. The wear tests were carried out at the room temperature (RT) and 800ºC in an oven for comparison. The arc test setup allows measuring reciprocating wear at elevated temperature in an oven up to 950ºC. The contact of the wear process is totally enclosed in the large oven. The thermal couple is set up to directly touch the back on the ball inside the ball holder to achieve the best accuracy of the temperature reading. A SiN ball tip (6 mm dia., Grade 100) was applied against the tested samples. The test parameters are summarized in Table 1. Wear track profiles were evaluated by the Nanovea Optical Profilometer, and the wear track morphology was examined using optical microscope.

Test parameters	Value
Normal force	10 N
Speed	250 mm/s
Number of strokes	10000
Temperature	RT or 800ºC

Table 1: Test parameters of the wear measurement.

RESULTS AND DISCUSSION

The COFs recorded in situ are shown in Fig. 2. The arc reciprocating wear motion consists of continuous back and forth movements, resulting in COF of positive and negative values. The sample tested at the RT exhibits a low COF below 0.2 during the first minute run-in period, followed by an abrupt increase to high values above 0.5 in the rest of the wear test. In comparison, the sample tested at 800ºC shows a high COF at the beginning, which progressively decreases throughout the wear test.

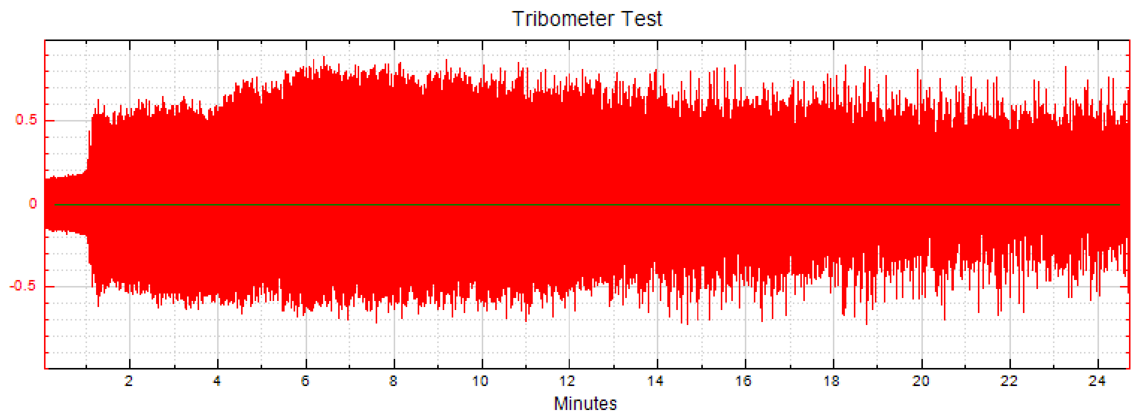
The 3D wear track profiles of the SS304 sample after the arc reciprocating tests were measured using Nanovea non-contact optical profilometer as shown in Fig. 3, and the 2D cross section wear tracks are compared in Fig. 4. The wear volume calculated using the Nanovea analysis software is comparable at 0.030 and 0.032 mm^3 for the arc reciprocating wear tests at the RT and 800ºC, respectively. However, it is interesting to observe that after the same number of strokes at different temperatures, the wear track of SS304 sample shows very different morphology.

The wear tracks of the SS304 sample after the wear tests at the RT and 800 ºC were examined and compared under optical microscope as displayed in Fig. 5. The sample tested at RT exhibits a wear track with parallel grooves. During the run-in period, small work hardened wear debris were progressively generated due to the wear on the SS304 surface by the SiN ball. As the wear track surface got worn out and roughened, more directional scars on the SS304 surface were created by the abrasion of the hard debris trapped between the sliding surfaces.

In comparison, the wear track created at 800ºC shows a different morphology. When the SS304 sample was exposed to a high temperature environment at 800ºC, oxide film formed on the surface and generated a harder layer. Due to the low hardness of the metal underlying the oxide layer, the high concentrated shear stress at the contact point plastically deformed the metal underneath and damaged the oxide layer during the wear process. Such a process led to exfoliation of the oxide flakes and formation of the peculiar morphology of the wear track as shown in Fig. 5 b&d.

Two distinct wear mechanisms were observed in this wear study carried out at the RT and at 800°C, demonstrating the importance of analyzing the wear behavior of the materials using the test conditions in the realistic application environment. It illustrates that wear mechanism can change drastically when the tribosystem is exposed to different temperatures. The versatility of the Nanovea Tribometer allows measuring the rotative and linear reciprocating wears in one single system under various conditions, including high temperature, lubrication, tribocorrosion and others, making it an ideal tool for research/testing labs dealing with a variety of materials applied in different tribological conditions.

(a)



(b)

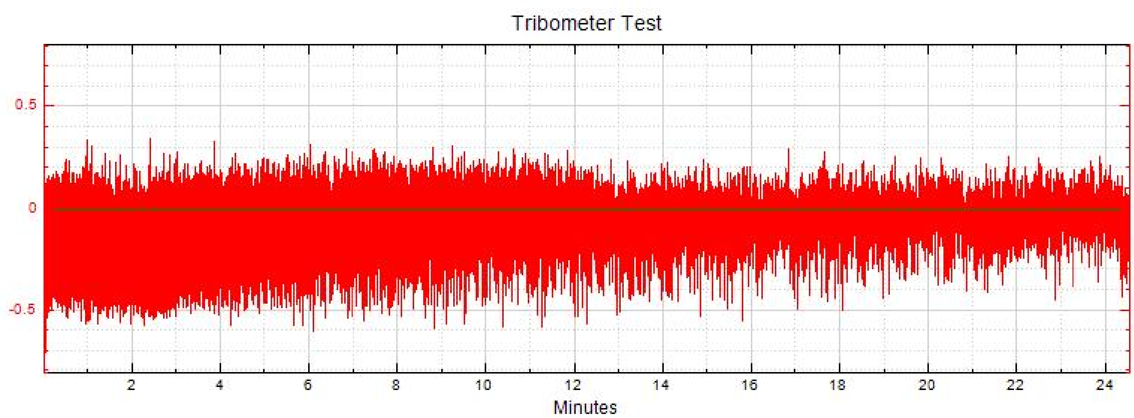


Fig. 2: Coefficient of friction during the arc wear test at (a) room temperature and (b) 800°C.

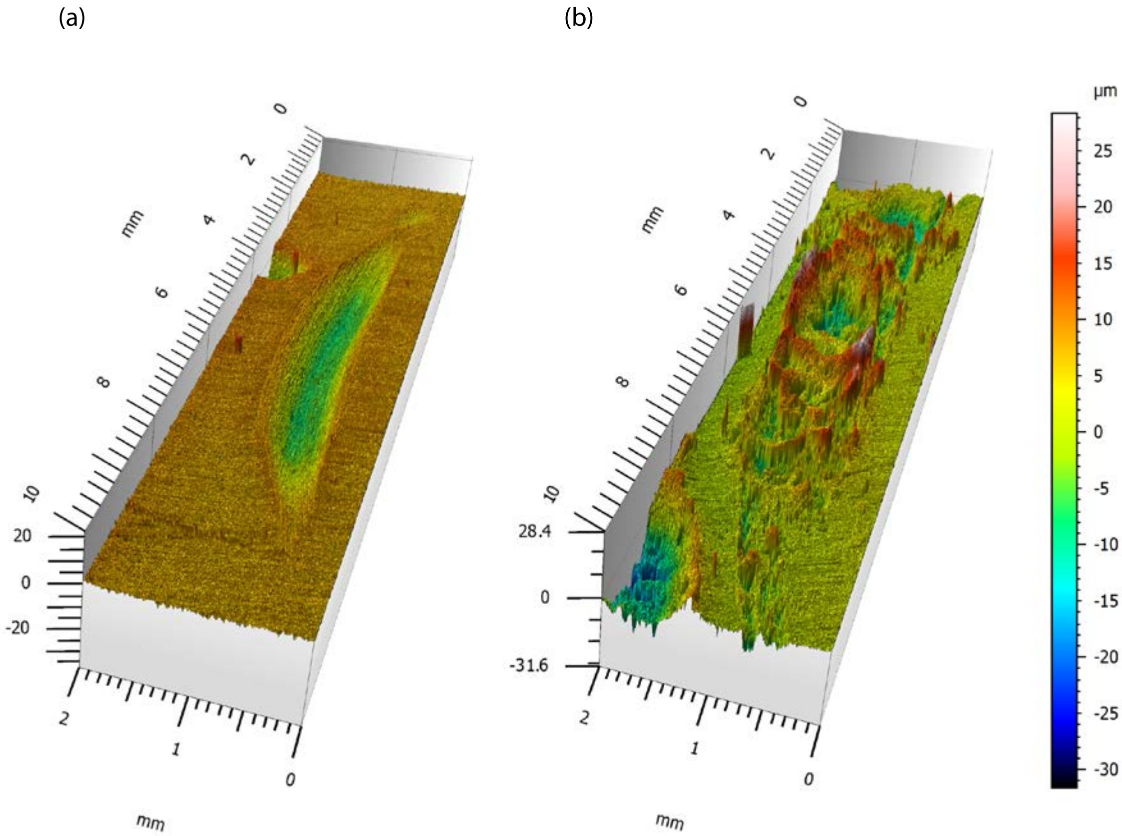


Fig. 3: 3D wear track surface after the wear test at (a) room temperature and (b) 800ºC.

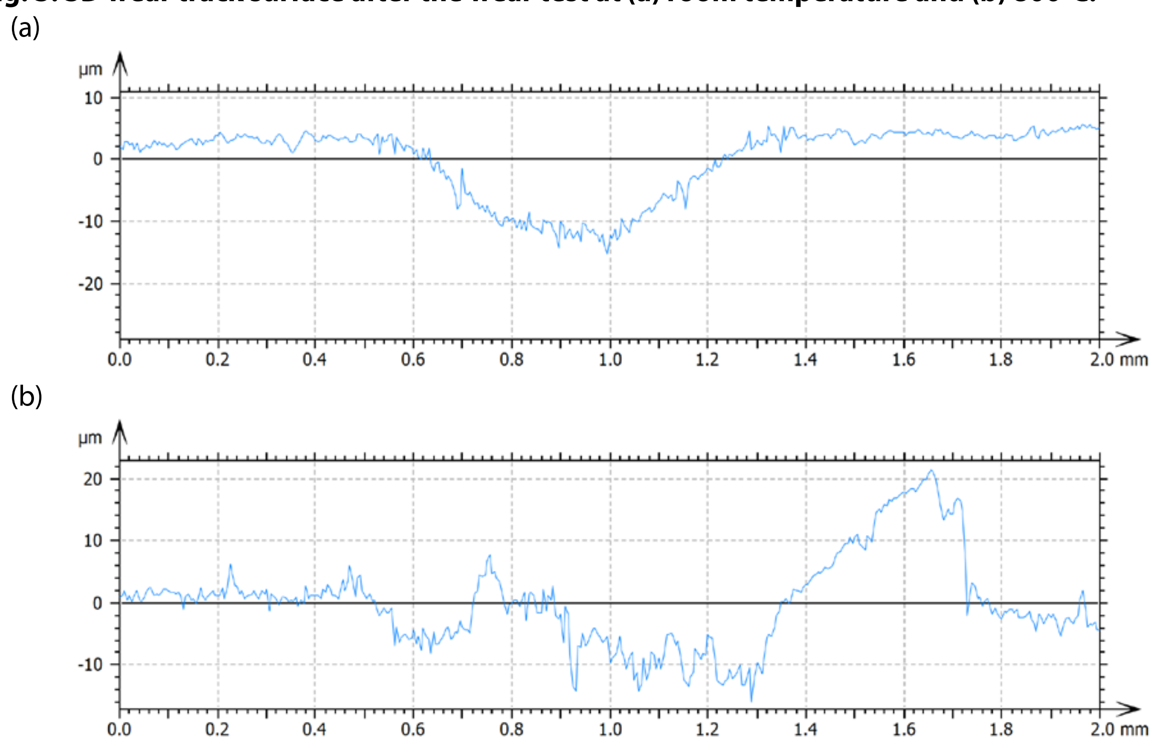
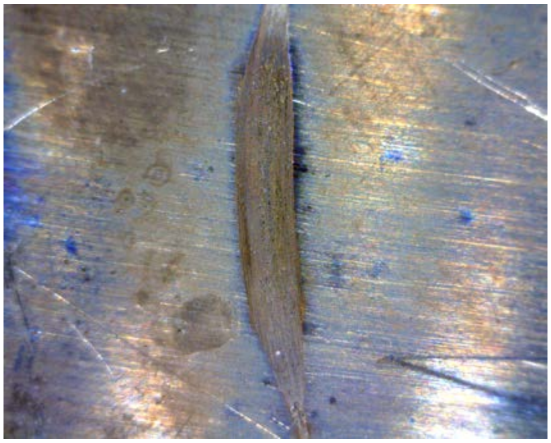
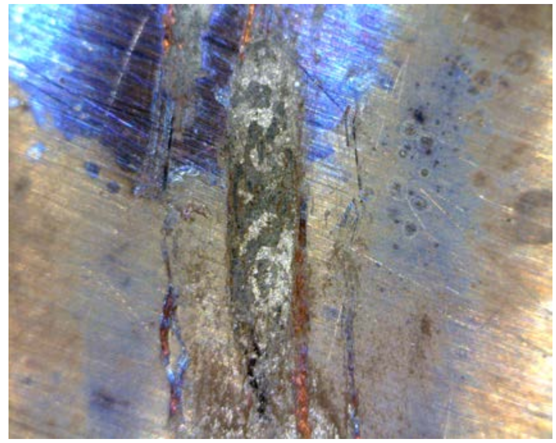


Fig. 4: Cross section wear track profiles of the sample after the reciprocating arc wear test at (a) room temperature and (b) 800ºC.

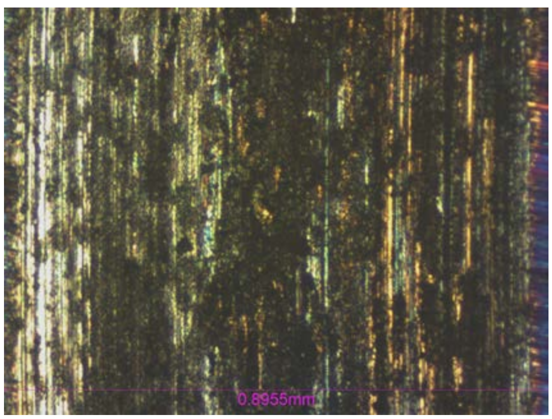
(a) Wear track (RT):



(b) Wear track (800 °C):



(c) Wear track (RT, 50X):



(d) Wear track (800 °C, 50X):

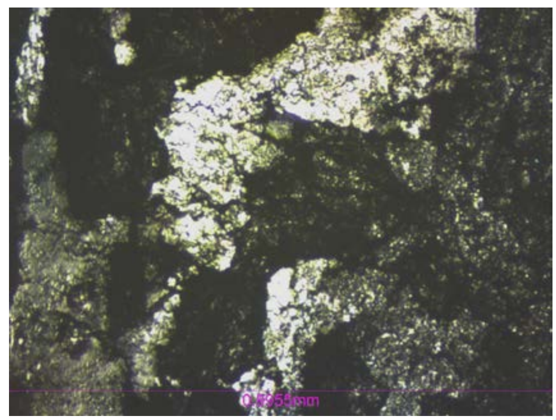


Fig. 5: Wear track images after the reciprocating arc wear tests.

CONCLUSION

In this study, we carried out a comprehensive analysis on the high temperature wear behavior of a SS304 sample using the arc reciprocating wear setup. The self-tuned high quality motor of Nanovea Tribometer possesses a 20bit internal speed and a 16bit external position (>0.006°) encoder, ensuring users to measure the arc reciprocating wear in an accurate and repeatable manner. With comparable wear rates, the SS304 exhibits significantly different wear mechanism measured at the room temperature and 800°C. This demonstrates the importance of investigating the wear mechanism at the temperature used in the realistic application. The arc wear test setup enables measuring reciprocating wear at elevated temperatures in an oven up to 950°C.

Nanovea Tribometer offers precise and repeatable wear and friction testing using ISO and ASTM compliant rotative and linear modes. It provides optional high temperature wear, lubrication and tribocorrosion modules available in one pre-integrated system. Such versatility allows users to better simulate the real application environment and improve fundamental understanding of the wear mechanism and tribological characteristics of various materials.

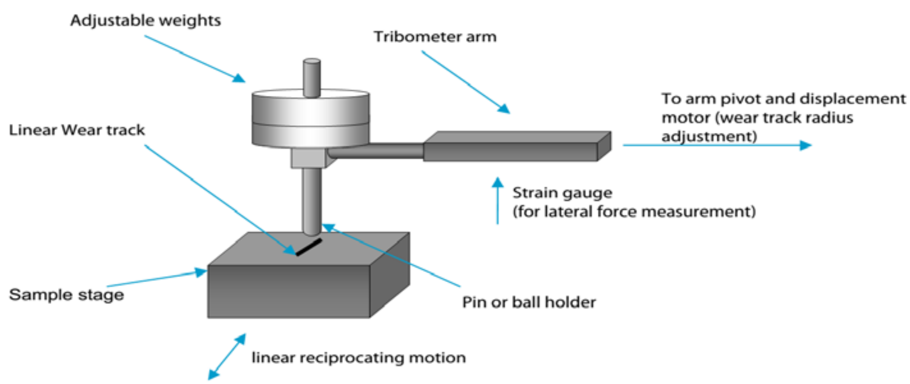
Optional 3D non-contact profiler is available for high resolution 3D imaging of wear track in addition to other surface measurements such as roughness.

Learn More about the Nanovea Tribometer and Lab Service

APPENDIX: MEASUREMENT PRINCIPLE

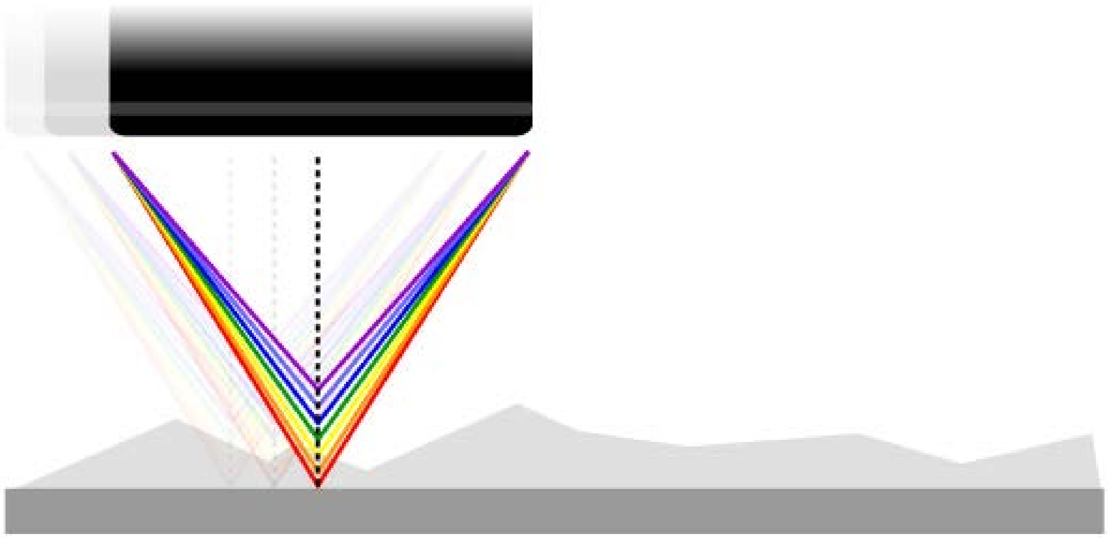
RECIPROCATING WEAR PRINCIPLE

A flat or a sphere shaped indenter is loaded on the test sample with a precisely known force. The indenter (a pin or a ball) is mounted on a stiff lever, designed as a frictionless force transducer. As the plate slides in a linear reciprocating motion, the resulting frictional forces between the pin and the plate are measured using a strain gage sensor on the arm. Wear rate values for both the pin and sample may also be calculated from the volume of material lost during a specific friction run. This simple method facilitates the determination and study of friction and wear behavior of almost every solid state material combination, with varying time, contact pressure, velocity, temperature, humidity, lubrication, etc.



3D NON-CONTACT PROFILOMETER 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.



Unlike the errors caused by probe contact or the manipulative Interferometry technique, White light Axial Chromatism technology measures height directly from the detection of the wavelength that hits the surface of the sample in focus. It is a direct measurement with no mathematical software manipulation. This provides unmatched accuracy on the surface measured because a data point is either measured accurately without software interpretation or not at all. The software completes the unmeasured point but the user is fully aware of it and can have confidence that there are no hidden artifacts created by software guessing. Nanovea optical pens have zero influence from sample reflectivity or absorption. Variations require no sample preparation and have advanced ability to measure high surface angles. Capable of large Z measurement ranges. Measure any material: transparent/opaque, specular/diffusive or polished/rough.

REFERENCES

[1] Rabinowicz, E. (1995). Friction and Wear of Materials. New York, John Wiley and Sons.
[2] Jones, M., H., and D. Scott, Eds. (1983). Industrial Tribology: the practical aspects of friction, lubrication, and wear. New York, Elsevier Scientific Publishing Company.
[3] ASTM G133 - 05(2010). Standard Test Method for Linearly Reciprocating Ball-on-Flat Sliding Wear.