ROCK TRIBOLOGY
USING TRIBOMETER

Prepared by
Duanjie Li, PhD

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

INTRO

Rocks are composed of grains of minerals. The type and abundance of these minerals and the chemical bonding strength between the mineral grains determine the mechanical and tribological properties of the rocks. Depending on the geological rock cycles, the rocks are transformed and classified into three major types, including igneous, sedimentary, and metamorphic. They have different mineral and chemical composition, permeability and particle size, and such characteristics contribute to their varied wear resistance.

IMPORTANCE OF TRIBOLOGY EVALUATION FOR ROCKS

Various types of wear against rocks, e.g. abrasion and friction, take place during the drilling process of the wells and create huge direct and consequential loss due to repairing and replacement of drill bits and cutting tools. Therefore, the study on drillability, boreability cuttability, and abrasivity of the rocks are critical in the oil, gas and mining industries. Rock tribology research plays an important role in selecting the most effective and economical drilling strategy to improve efficiency, as well as conservation of material, energy and the environment. In addition, low surface friction is favorable to reduce the interaction of the drilling bit and the rock, so as to reduce tool wear and improve drilling/cutting efficiency.

MEASUREMENT OBJECTIVE

In this study, we simulated and compared the tribological properties of two types of rocks to showcase the capacity of Nanovea Tribometer in measuring the coefficient of friction and wear rate of rocks in a controlled and monitored manner.

Fig. 1: Pin-on-disk wear test on a limestone sample.

TEST PROCEDURE

The coefficient of friction, COF, and the wear resistance of two rock samples were evaluated by Nanovea Tribometer using Pin-on-Disc Wear Module. An Al_2O_3 ball (6 mm diameter) was used as the counter material. The wear track was examined using Nanovea non-contact profilometer after the tests. 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-section area of the wear track, and *n* is the number of revolution. Wear track profiles were evaluated by the Nanovea Optical Profilometer, and the wear track morphology was examined using optical microscope.

Please note that the Al_2O_3 ball as a counter material was used as an example in this study, any solid material with different shapes can be applied using custom fixture to simulate the actual application situation.

Sample	Limestone, Marble
Normal force	10 N
Wear ring radius	5 mm
Speed	100 RPM
Duration of test	10 min

Table 1: Test parameters of the wear measurements.

RESULTS AND DISCUSSION

The hardness, *H* and Elastic Modulus, *E*, of the limestone and marble samples are compared in Fig. 2 as tested using the micro indentation module of Nanovea Mechanical Tester. The limestone sample possesses a lower *H* and *E* of 0.53 and 25.9 GPa, respectively, compared to 1.07 and 49.6 GPa for marble. The relatively higher deviation of the *H* and *E* values measured on the limestone sample are related to its higher surface inhomogeneity due to its granulated and porous characteristics.

The evolution of COF during the wear tests of the two rock samples are plotted in Fig. 3. The limestone shows a rapidly increased COF to ~0.8 at the beginning of the wear test, and maintains this value in the rest of the test. Such a drastic change of COF is attributed to the penetration of the Al_2O_3 ball into the rock sample due to a fast wear and roughening process taking place at the contact face in the wear track. In comparison, the marble sample exhibits such significant change to high COF values after ~5 m sliding distance, indicating its better wear resistance compared to the limestone.

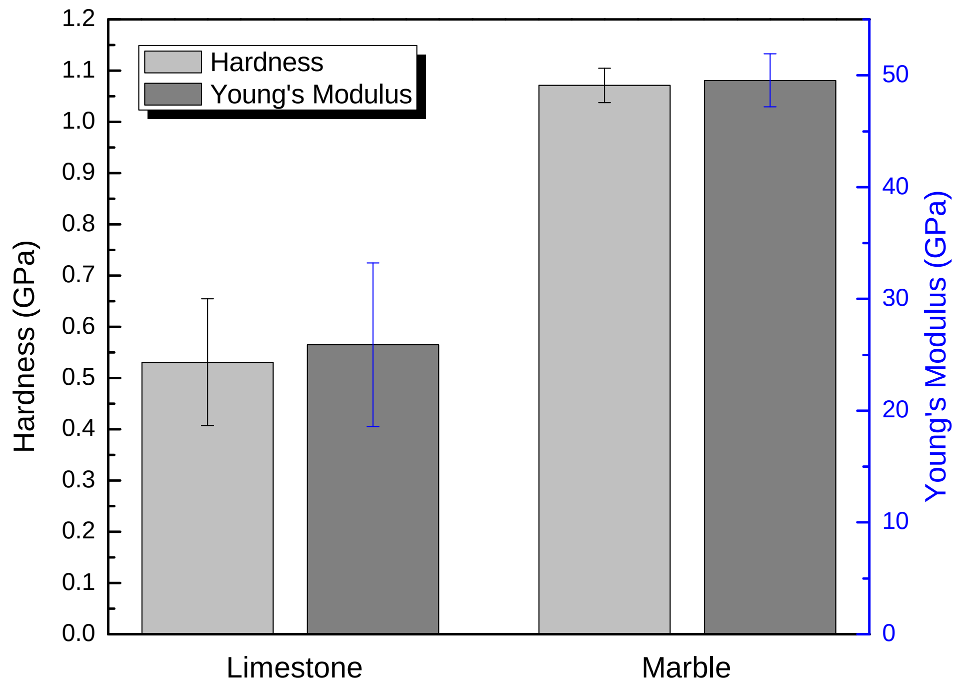


Fig. 2: Hardness and Young's Modulus of the limestone and marble samples.

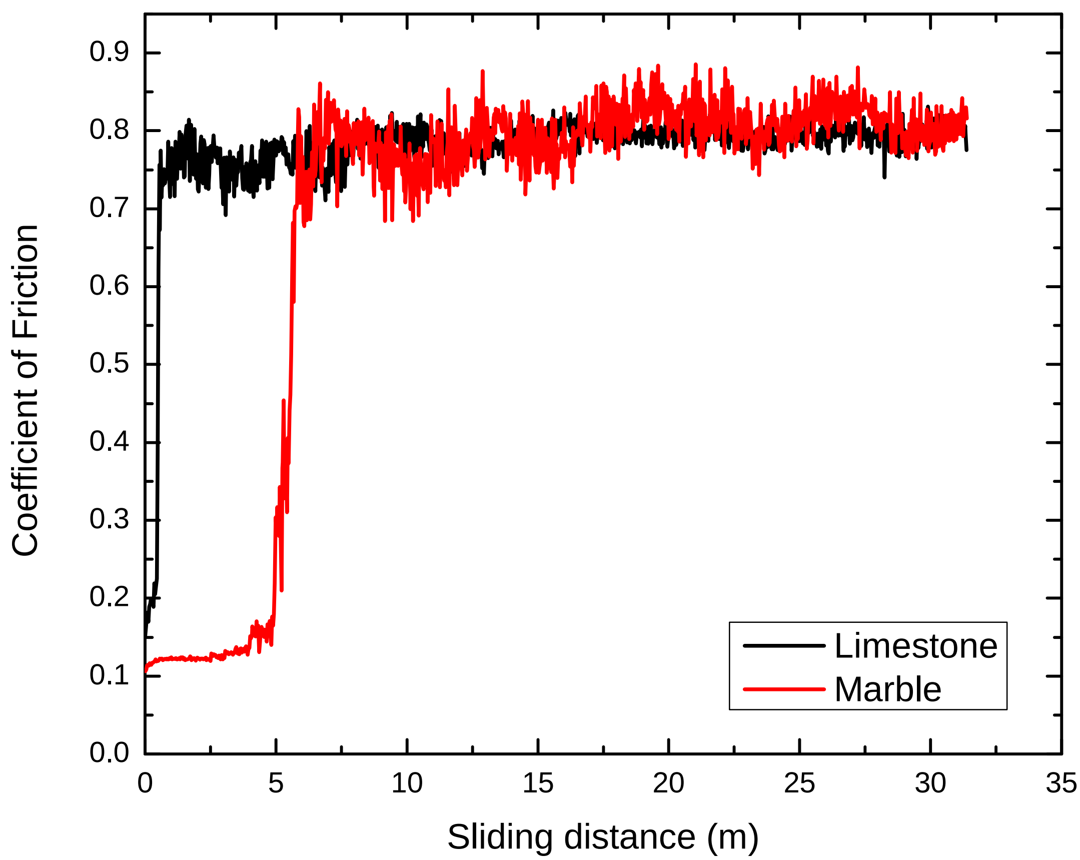


Fig. 3: Evolution of COF of the limestone and marble samples.

Fig. 4 compares the cross section profiles of the limestone and marble samples after the wear tests, and Table 2 summarized the results of the wear track analysis. Fig. 5 shows the wear tracks of the samples under the optical microscope. The wear track evaluation is in agreement with the observation of COF evolution: The marble sample, which maintains the low COF for the longer period, exhibits a lower wear rate of 0.0046 mm^3/N m, compared to 0.0353mm^3/N m for the limestone. The superior mechanical property of marble gives rise to its better wear resistance than the limestone.

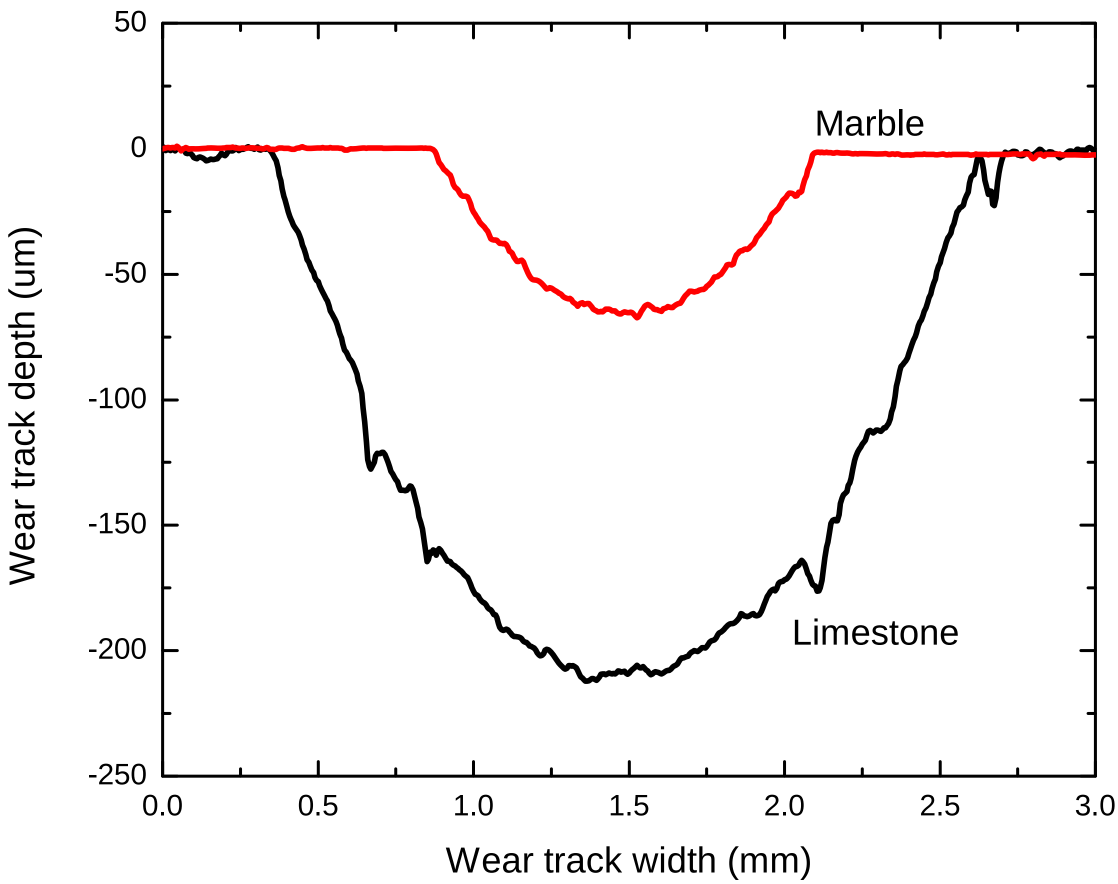


Fig. 4: Cross section profiles of the wear tracks.

	Valley area μm^2	Valley depth μm	Wear rate mm^3/N m
Limestone	35.3±5.9 ×10^4	229±24	0.0353
Marble	4.6±1.2 ×10^4	61±15	0.0046

Table 2: Result summary of wear track analysis.

(a) Limestone: (b) Marble:

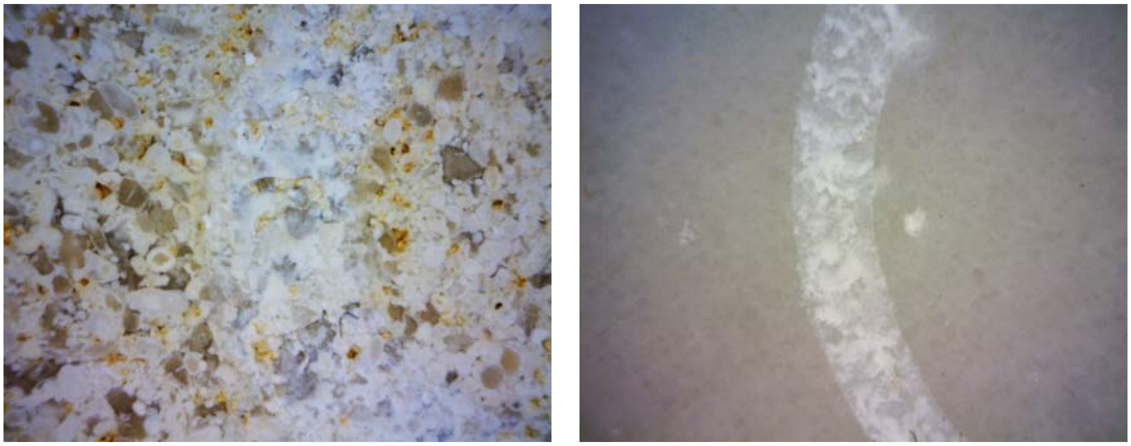


Fig. 5: Wear tracks under optical microscope.

CONCLUSION

In this study, we showcased the capacity of Nanovea Tribometer in evaluating the coefficient of friction and wear resistance of two rock samples, i.e. marble and limestone in a controlled and monitored manner. The better mechanical properties of the marble leads to its superior wear resistance. This contributes to the difficulty of being drilled or cut in the oil and gas industry, and on the other hand, it can significantly extend its lifetime serving as a quality building material such as floor tiles.

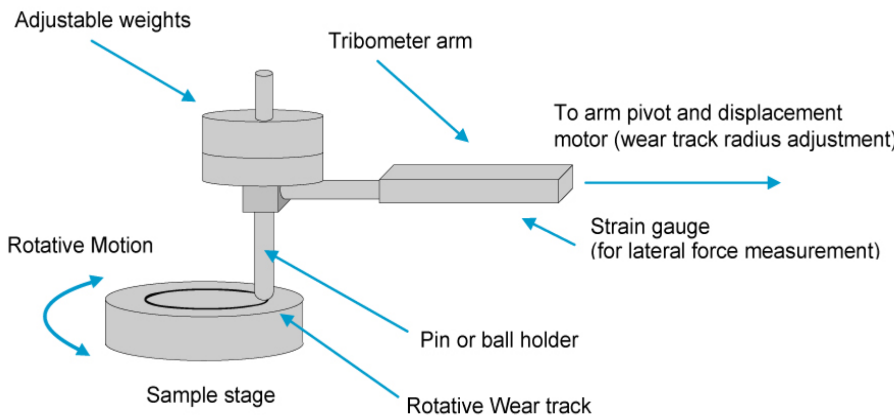
Nanovea Tribometer offers precise and repeatable wear and friction testing using ISO and ASTM compliant rotative and linear modes, with optional high temperature wear, lubrication and tribo-corrosion modules available in one pre-integrated system. Nanovea's unmatched range is an ideal solution for determining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

Learn More about the Nanovea Tribometer, Nanovea Profilometer and Lab Service

APPENDIX: MEASUREMENT PRINCIPLE

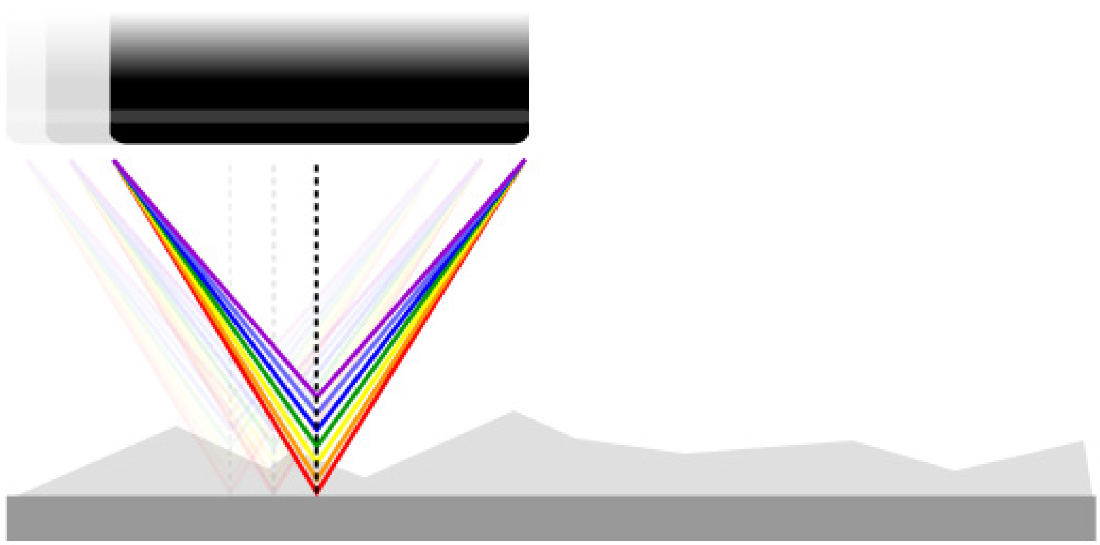
PIN-ON-DISC WEAR PRINCIPLE

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 rotational 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.