WEAR-RESISTANT COATING EVALUATION BY HIGH-LOAD TRIBOMETER

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INTRO

A valve is used to regulates, directs or controls the flow of a fluid such as gases, liquids, fluidized solids, or slurries. Valves are widely applied in virtually every industrial sector including water and sewage processing, upstream oil and gas, downstream and chemical processing, mining and minerals process, nuclear power, hydro power and countless others. Valves are often exposed to high stress level at the contact and extreme application environment combining wear, corrosion, high temperature, etc. Therefore, protective coatings are applied to extend the lifetime of the valves and to cut the cost and time on repairing and replacement.

IMPORTANCE OF WEAR EVALUATION AT HIGH LOADS

A number of techniques has been applied to deposit hard valve coatings, such as high velocity oxygen fuel spraying (HVOF), plasma transferred arc welding (PTA), laser cladding, physical vapor deposition (PVD) and others. These coatings possess superior wear resistance under the conditions of high pressure and stress concentration. Reliable tribological evaluation under a high load is hence critical to simulate and compare the wear behaviors of different valve coatings in a controlled and monitored manner and to select the best candidate for the targeted industry. Conventional pin-on-disc tribometers usually have a load capacity below 100 N, which makes it difficult to simulate the severe service conditions under high pressure. Moreover, it may take days or even weeks to test one sample using a low load tribometer due to the superior wear resistance of the test sample.

MEASUREMENT OBJECTIVE

Nanovea Macro Tribometer is designed with high torque capability for loads up to 500 N. In this study, we simulated and compared the wear behaviors of valve coatings under high loads to showcase the capacity of Nanovea Macro Tribometer in quantitatively evaluating the wear properties of materials such as wear rate and coefficient of friction.

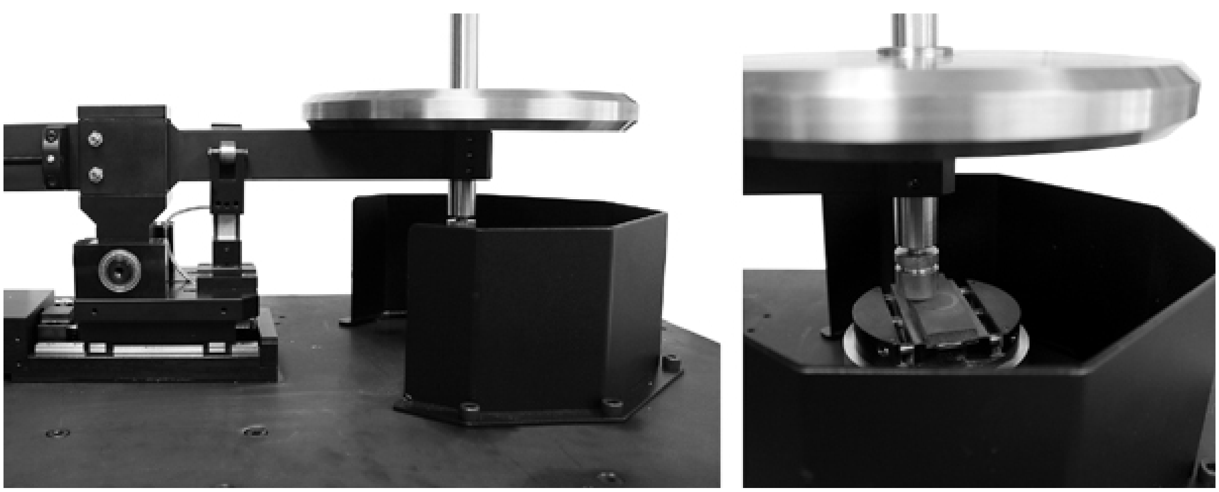


Fig. 1: Setup of the high load wear test.

TEST PROCEDURE

The coefficient of friction, COF, and the wear resistance of two wear resistant valve coatings and the bare metal substrate were evaluated by Nanovea Macro Tribometer. An Al_2O_3 ball (10 mm diameter) was used as the counter material. The wear track and the Al_2O_3 ball were examined using Nanovea 3D non-contact profilometer after the tests. The test parameters are summarized in Table 1.

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 performance of different material coupling under actual application conditions.

Test parameters	Value
Normal force	**100 N**
Rotational speed	100 RPM
Duration of test	30 min (Coating) 3 min (Substrate)
Wear track radius	10 mm
Ball material	Al_2O_3
Ball diameter	10 mm
Lubricant	N/A
Atmosphere	Air
Temperature	24°C (room)
Humidity	40%

Table 1: Test parameters of the wear measurements.

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 and wear scars of the balls were evaluated by the Nanovea Optical Profilometer, and the wear track morphology was examined using optical microscope.

RESULTS AND DISCUSSION

Nanovea Macro Tribometer was employed to measure the COF and wear rate of the valve coatings using a high load of 100 N and a large contact area in order to better simulate the application conditions of the valves. Wear rate is a vital factor for determining the service lifetime of the valves, while a low friction is desirable to improve the equipment performance and efficiency and to avoid damaging issues caused by excessive friction such as galling, deposit formation, or over-tightened packing. Fig. 2 compares the evolution of COF during the tests. Due to the substantial difference in the wear resistance between the test Coatings and Substrate, the Substrate was tested for 3 min, compared to 30 min for the two Coatings. The two valve coatings show a comparable COF of ~0.6 throughout the wear test. The Substrate exhibits a slightly higher average COF of ~0.65 after the run-in period of the first 30 sec.

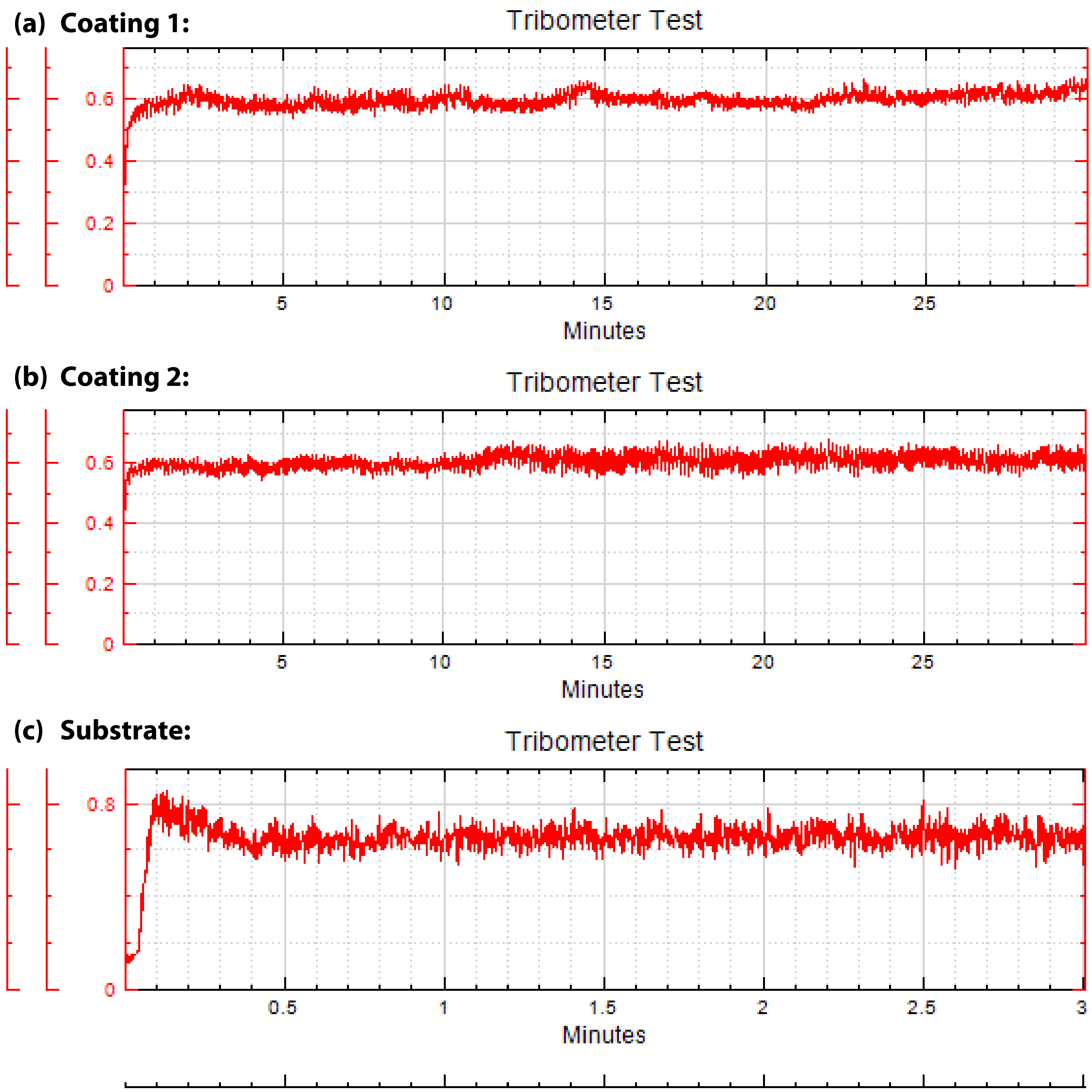


Fig. 2: Evolution of COF during the wear tests. *Note*: The Substrate was tested for 3 min, compared to 30 min for the two Coatings.

Fig. 3 compares the wear track profiles after the tests measured by Nanovea non-contact optical profilometer, and Table 2 summarized the results of the wear track analysis. Fig. 4 shows the wear tracks of the test samples under the optical microscope. It can be observed that Coating 2 exhibits a much larger wear track compared to Coating 1 after the 30 min wear test. The wear rate of Coating 1 is 1.2E-04 mm^3/N m, which is about nine times lower compared to Coating 2. The wear track depth of Coating 1 and Coating 2 are 29 and 160 μm, respectively. Since the Coatings have a thickness of 300 μm, the wear rate calculated here reflects the wear resistance of the coatings. The Substrate has a wide and rough wear track after the three min wear test. The formation of such a peculiar wear track on the Substrate is further analyzed by 3D scan of the wear scar on the counter material – Al_2O_3 ball.

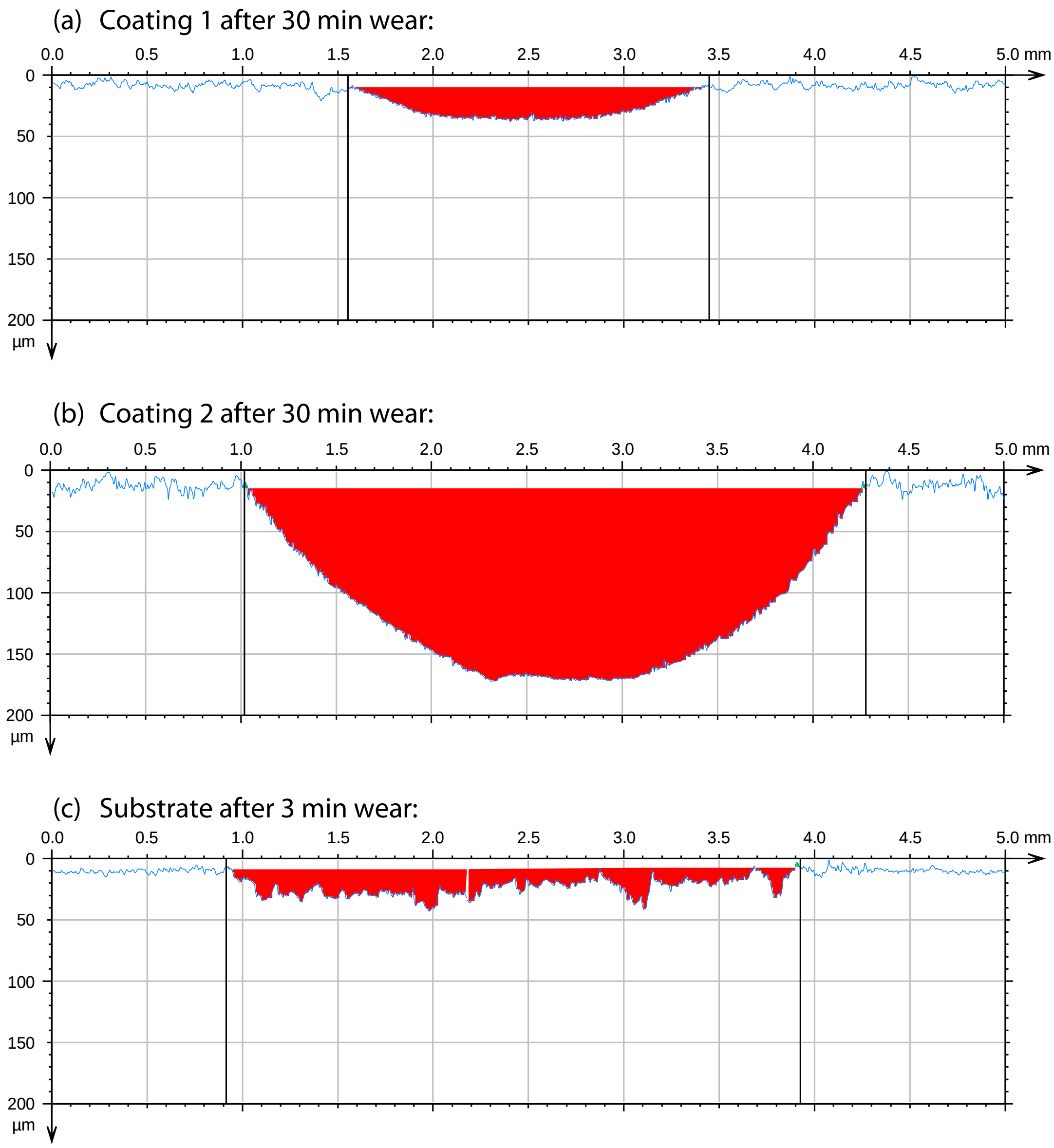
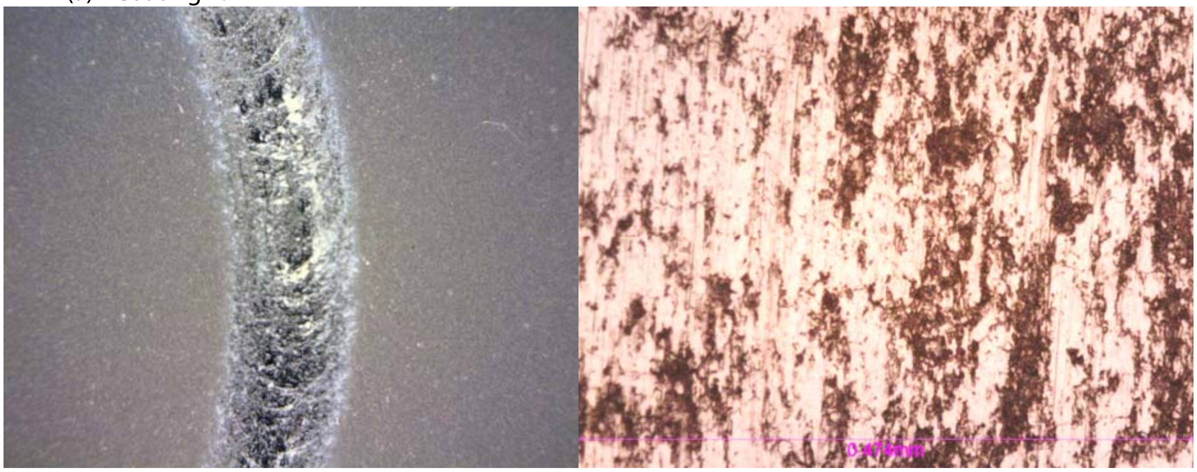


Fig. 3: Wear tracks profiles after the tests.

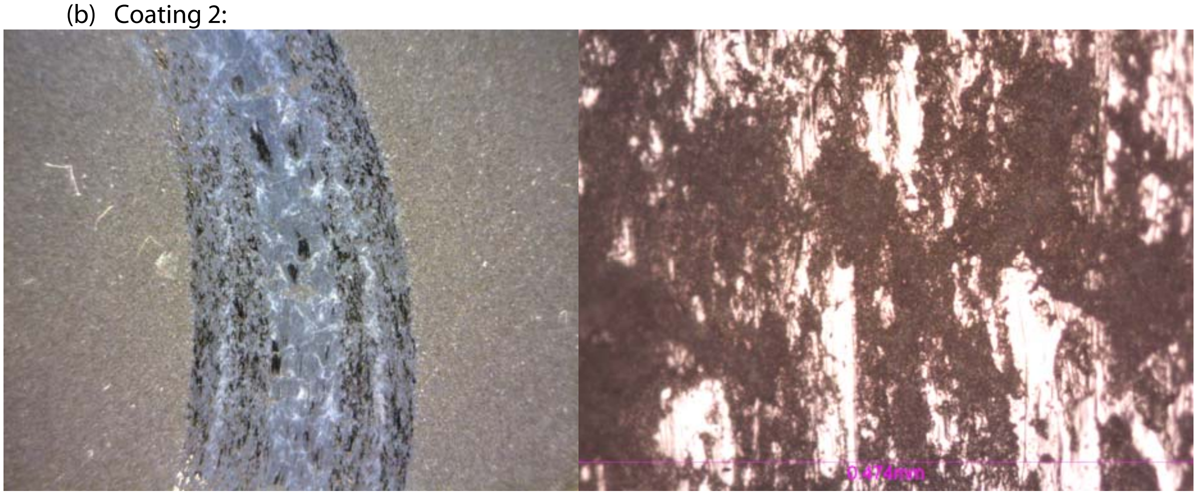
	Maximum depth µm	Area of wear loss $µm^2$	Wear rate mm^3/N m
Coating 1	29	3.6E+04	1.2E-04
Coating 2	160	3.5E+05	1.1E-03
Substrate	36	5.1E+04	1.7E-03

Table 2: Result summary of wear track analysis.

(a) Coating 1:



(b) Coating 2:



(c) Substrate:

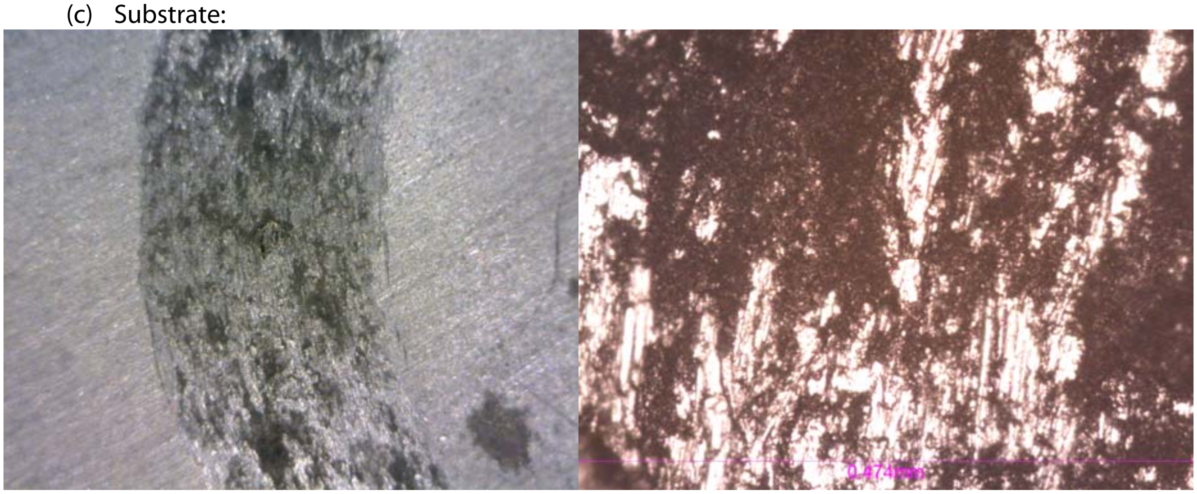
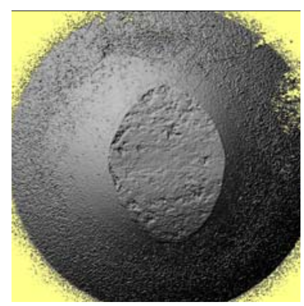


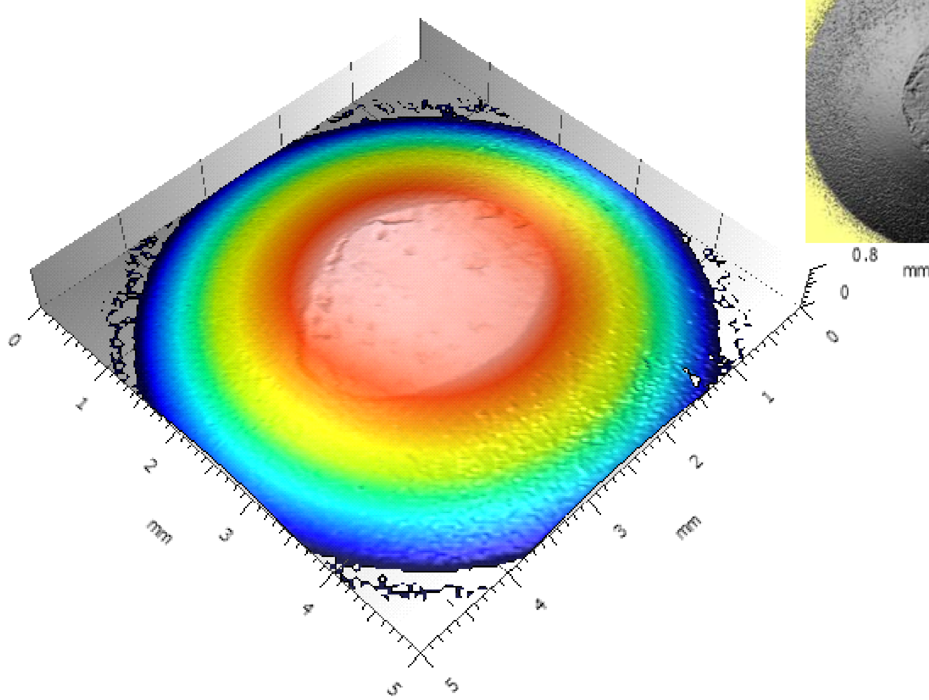
Fig. 4: Wear tracks under optical microscope.

Fig. 5 displays the 3D wear scar morphology on the Al_2O_3 balls against the two Coatings and the Substrate after the wear tests. The volume loss and maximum height loss of the balls are summarized in Table 3 as calculated using Nanovea analysis software. Coating 1 which possesses the best wear resistance among the tested samples creates a wear scar of a volume loss 0.073 mm^3 on the Al_2O_3 ball, compared to 0.149 mm^3 for Coating 2. In comparison, the Al_2O_3 ball against Substrate after only three min wear test exhibits a big flattened wear scar with a volume loss of 1.510 mm^3. This is attributed to the formation of a large amount of abrasive debris removed from the substrate during the wear test, which in turn substantially accelerated the wear rate of both the Substrate and the Al_2O_3 ball. As a consequence, a wide and rough wear track was quickly generated on Substrate in three min.

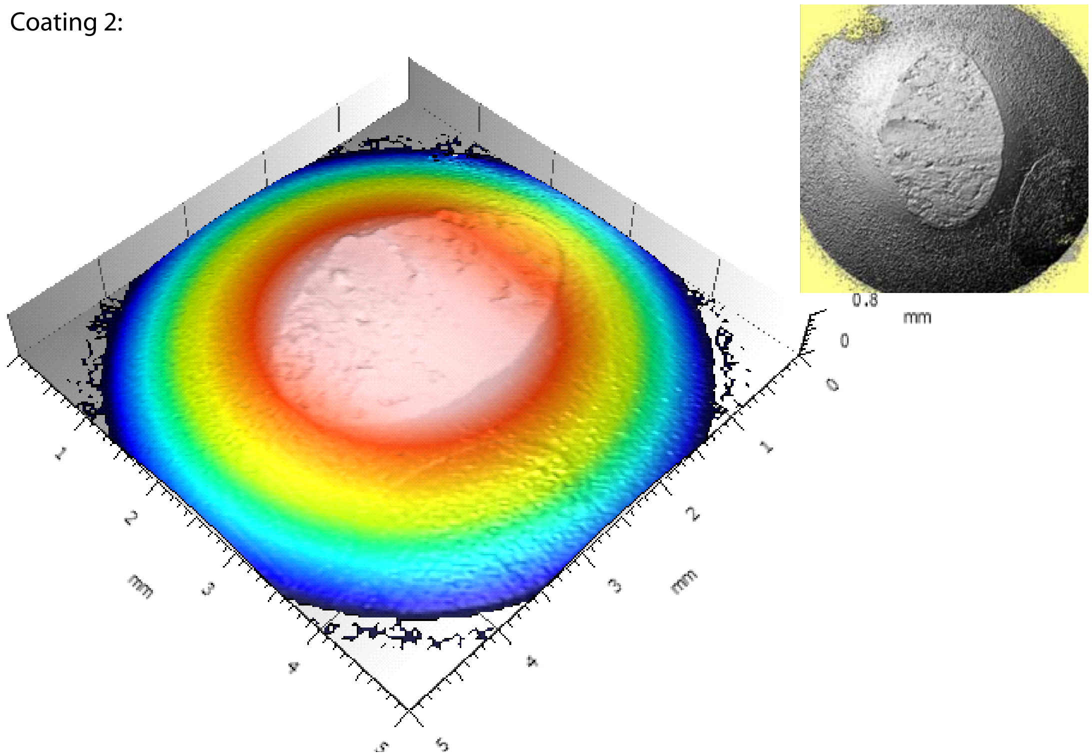
This finding demonstrates the significant enhancement of wear resistance by the valve coatings compared to the metal substrate. The formation of abrasive debris plays an important role in the wear behavior of both the test sample and the counter material. Other materials with different shapes besides the Al_2O_3 ball can also be applied as counter materials to simulate and compare the wear performance of different material coupling under actual application conditions, e.g. high temperature, corrosion, lubrication, etc.

(a) Coating 1:





(b) Coating 2:



(c) Substrate:

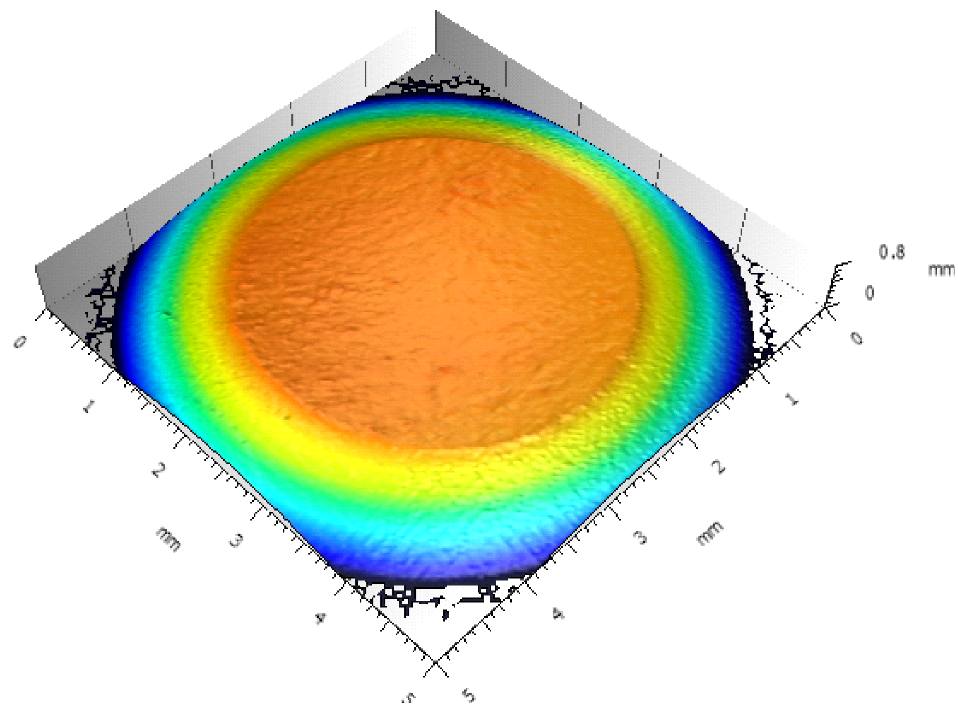


Fig. 5: Wear scar on the Al_2O_3 balls.

	Volume loss mm^3	Max. height loss mm
Ball against Coating 1	0.073	0.078
Ball against Coating 2	0.149	0.104
Ball against Substrate	1.510	0.323

Table 3: Summary of wear scar analysis on the Al_2O_3 balls after the tests.

CONCLUSION

The wear resistance of the valves under a high pressure and concentrated stress plays a vital role in their service performance. Valve coatings can significantly extend the lifetime of the valves under high stress conditions and reduce the time and cost due to valve repairing or replacement.

The Nanovea Macro Tribometer is designed with high torque capability for loads up to 500 N and precise controlled motor of rotational speeds from 0.01 to 2000 rpm. It offers repeatable wear and friction testing using ISO and ASTM compliant rotative and linear modes, with optional high temperature wear and lubrication modules available in one pre-integrated system. This unmatched range allows users to simulate different severe work environment of the valves including high stress, wear and high temperature, etc., and select the best candidate for the targeted industrial applications. It also provides an ideal tool to quantitatively assess the tribological behaviors of superior wear resistant materials under high loads.

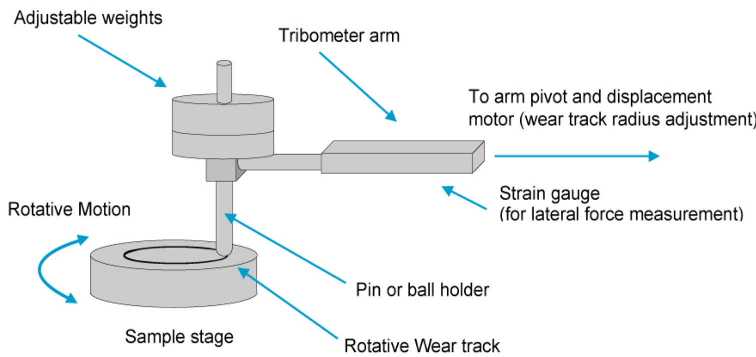
Nanovea 3D non-contact profilometer enables precise wear volume measurement and offers a tool to analyze the detailed morphology of the wear tracks, providing more insight in fundamental understanding of wear mechanism.

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

APPENDIX: MEASUREMENT PRINCIPLE

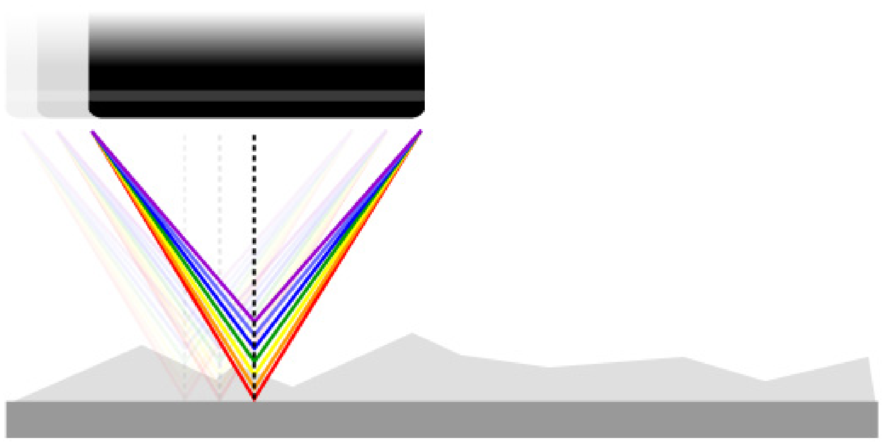
PIN-ON-DISC WEAR PRINCIPLE

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.