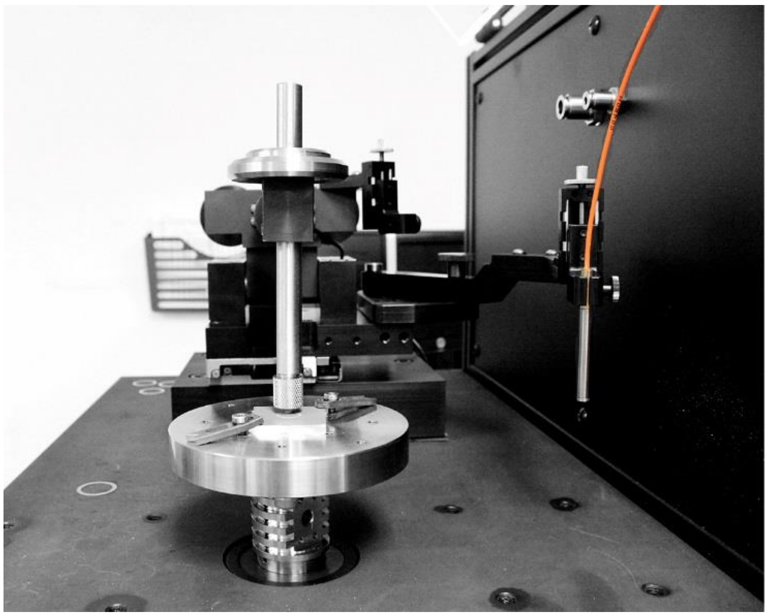
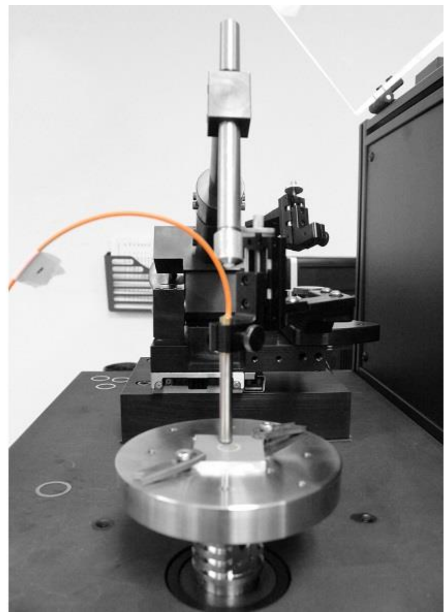
NANOVEA
A Better Measure.

IN SITU NON-CONTACT MEASUREMENT OF WEAR RATE EVOLUTION





Prepared by
Duanjie Li, PhD

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

INTRO

Anodizing process is widely applied on aluminum to modify the texture of the surface and change the microstructure of the metal near the surface. The formation of such an anodized aluminum oxide layer can enhance corrosion and wear resistance and improve cosmetic effects. Anodized aluminum is widely used on electronic devices, such as mp3 players, flashlights and cameras.

IMPORTANCE OF WEAR TESTING FOR SELECTION AND QUALITY CONTROL OF ANODIC FILMS

Anodic films are generally much stronger and more adherent than most types of paint and metal plating. The anodized aluminum coatings grown on different types of aluminum alloy substrates possess significantly different wear resistance. Taber abrasion tests were conventionally used to evaluate the wear resistance of the anodized aluminum coatings according to ASTM D4060 Standard. However, as mentioned in the ASTM D4060 standard, "For some materials, abrasion tests utilizing the Taber Abraser may be subject to variation due to changes in the abrasive characteristics of the wheel during testing."[i] Moreover, the aggressive abrasion process by Taber Abraser can quickly wear through anodized aluminum coatings and create mass loss to the substrate, which leads to substantial errors in the calculation of the coating weight loss.

A more reliable and repeatable technique for wear evaluation is in need – In this study, we developed a tribometer implemented with a non-contact profilometer that allows us to closely monitor the evolution of the wear process of anodized aluminum coatings, determine the failure mode of the different anodized aluminum layers, and select the best candidate for real-life applications involving wear protection.

MEASUREMENT OBJECTIVE

The wear process of an anodized Al2036 coating is simulated in a controlled and monitored manner using the Nanovea Tribometer equipped with a non-contact profilometer. We would like to showcase that Nanovea Tribometer is an ideal tool for evaluation and quality control of various protective coatings including anodized aluminum.

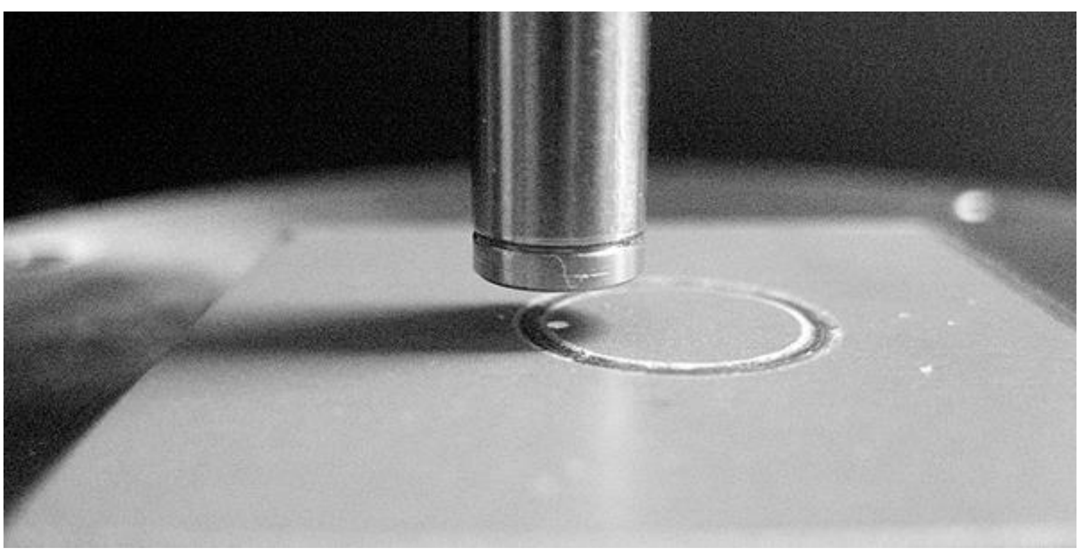


Fig. 1: Wear track profile scan with a non-contact profilometer.

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.

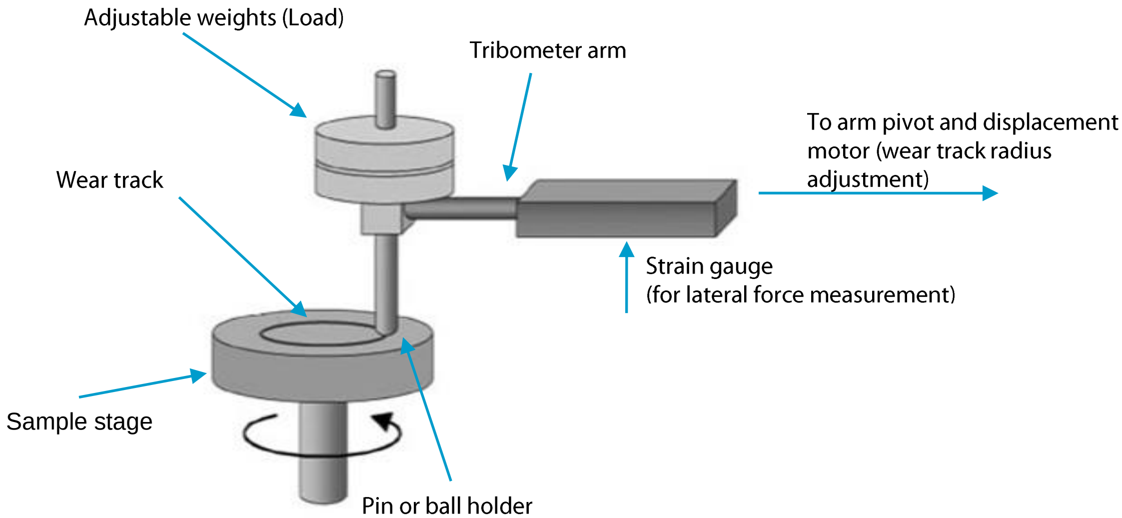


Fig. 2: Schematic of the pin-on-disk test.

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.

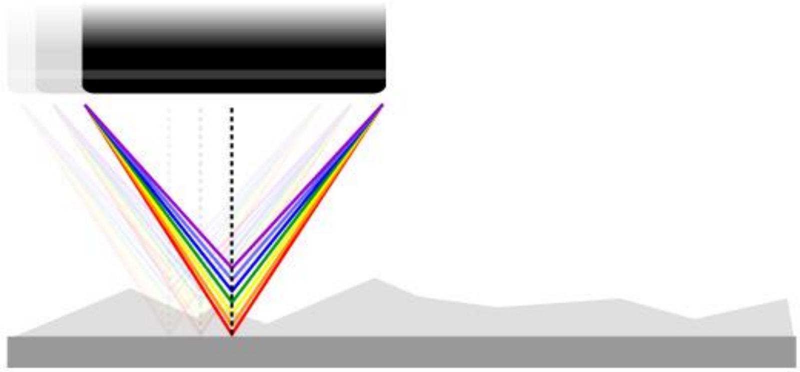


Fig. 3: Schematic of axial chromatism technique.

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

Nanovea Tribometer equipped with a non-contact profilometer was applied to evaluate the tribological behavior, e.g. coefficient of friction, COF, and wear resistance of an anodized Al2036 sample. A normal load of 10 N was applied by an Al_2O_3 ball tip (6 mm dia.) against the sample. The COF was recorded in situ. Wear track profiles were measured and the wear track morphology was examined using optical microscope every 2000 revolutions. The test parameters are summarized in Table 1.

Test parameters	Value
Normal force	10 N
Rotational speed	400 RPM
Duration of test	80 min
Radius	5 mm
Revolutions	32000
Ball Diameter	6 mm
Ball Material	Al_2O_3
Atmosphere	Air
Temperature	24°C (room)

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

RESULTS AND DISCUSSION

The COF recorded in situ during the wear test is shown in Fig. 4. The COF exhibits a high value above 0.75 at the beginning of the wear process. It gradually decreases in the first 8000 cycles and then maintains a relatively constant value of ~0.6 throughout a long sliding distance until close to 30000 revolutions. This is followed by an abrupt decrease of COF to ~0.35, indicating a change of the tribological behavior at the contact surface taking place at this point.

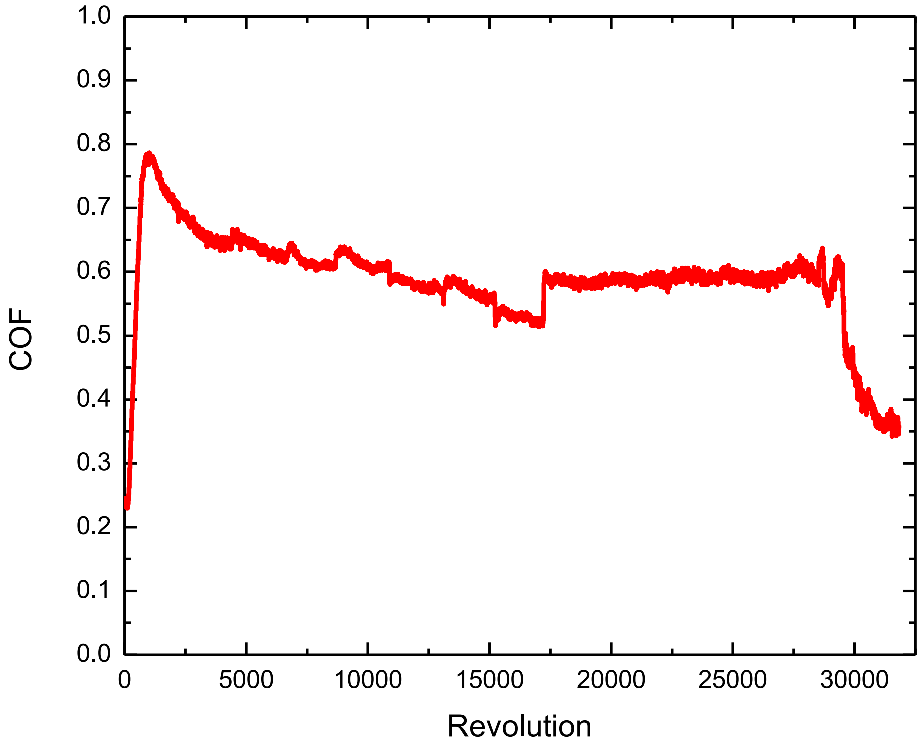


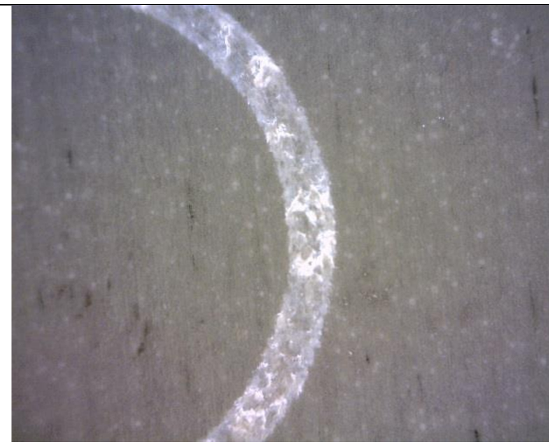
Fig. 4: Coefficient of friction during the pin-on-disk test.

Fig. 5 displaces the images of the wear tracks and Fig. 6 presents the cross section profiles after 2000, 4000, 8000, 16000, 24000 and 32000 cycles under the optical microscope. These results are in agreement with the evolution of the COF during the wear test. The initial spike of COF at the beginning of the wear process is primarily attributed to the rough morphology of the anodized surface layer. As the asperities at the surface get removed progressively in the first 8000 revolutions as shown in Fig. 5a-c, the COF gradually decreases to a value of ~0.6. At this stage, the tested anodized Al sample shows a relatively high wear rate, as reflected by the fast increase of wear volume from 2000 to 8000 cycles shown in the cross section profiles of wear tracks in Fig. 6.

As the wear process continues through ~8000 to ~30000 revolutions, the wear track maintains a fairly smooth surface feature (see Fig. 5d-e), while the wear volume does not show any significant change as indicated in Fig. 6. Such an observation demonstrates that the anodized Al surface layer possesses very different wear resistance at different distances to the top surface – the shallow surface has a poorer wear performance due to its porous feature, while the dense layer at the depth of ~30 to 50 μm exhibits a significantly enhanced wear resistance.

When the Al_2O_3 ball tip wears through the anodized Al protective layer at ~30000 revolutions, the wear process dramatically accelerates as indicated by the large wear track and exposure of the metal substrate after 32000 cycles (see Fig. 5f and Fig. 6). This also leads to a decrease of COF as shown in Fig. 4.

(a) 2000 Rev.



(b) 4000 Rev.

(c) 8000 Rev.

(d) 16000 Rev.

(e) 24000 Rev.

(f) 32000 Rev.

Fig. 5: Wear tracks after 2000, 4000, 8000, 16000, 24000 and 32000 revolutions.

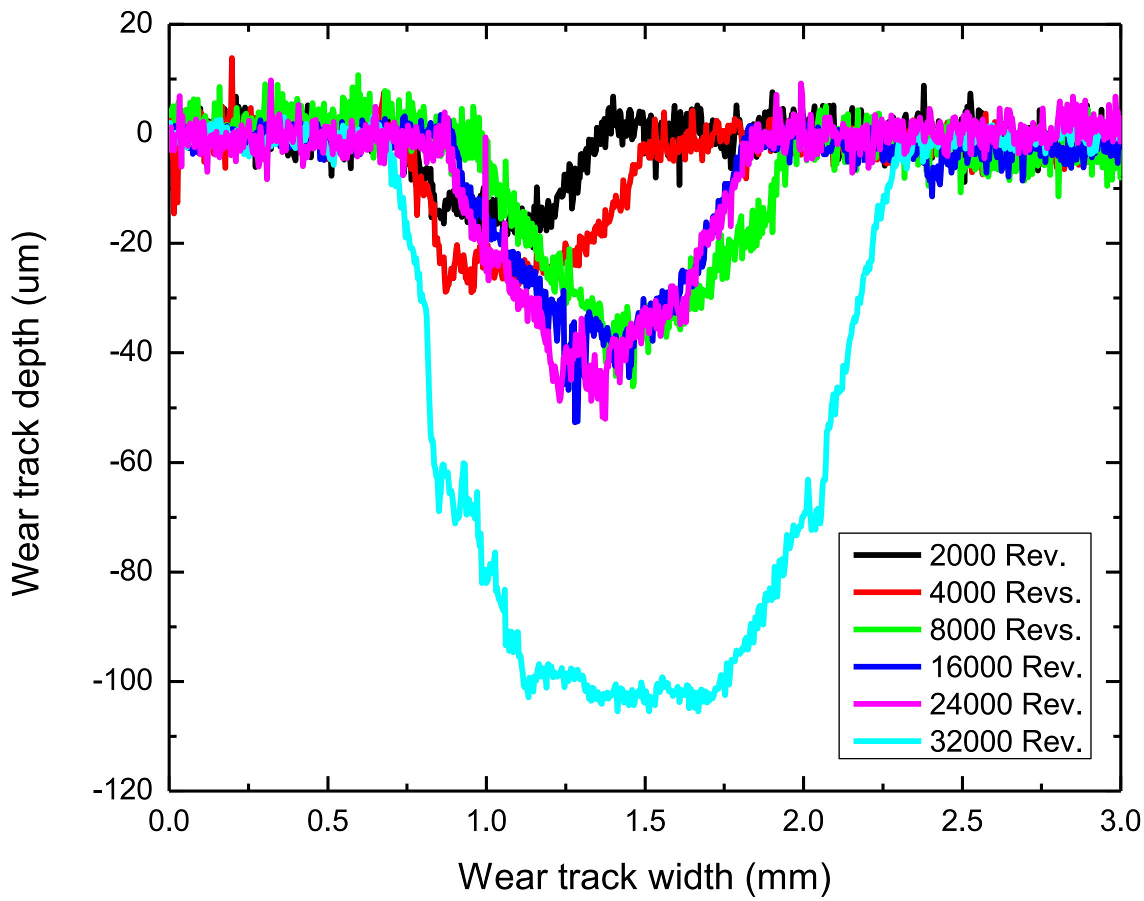


Fig. 6: Cross section profiles of wear tracks after 2000, 4000, 8000, 16000, 24000 and 32000 cycles.

The evolution of average wear rates after different number of revolutions is shown in Fig. 7. It is calculated using the formula $K=V/(F\times s)=A/(F\times n)$, where V is the total worn volume, F is the normal load, s is the sliding distance, A is the cross-section area of the wear track as displayed in Fig. 6, and n is the number of revolutions. It is evident from Fig. 7 that the calculated wear rate of a material strongly depends on the number of revolutions, which is directly related to the different stages of the wear mechanism. In this particular study, the wear resistance of the tested sample (anodized Al2036) varies along the thickness of the coating, resulting in significantly different wear rate calculated after different number of revolutions.

Therefore, it is extremely important to be cautious in comparing the wear rate measured using different test parameters or reported from different labs. This study also demonstrates that Nanovea Tribometer with the integration of a non-contact profilometer is an ideal tool for monitoring and studying the evolution of the wear process at different stages. It cuts the cost and time for the preparation of multiple samples, and eliminates the possibility of test result fluctuation due to the property variation from different samples. Moreover, compared to conventional pin-on-disc or Taber testers, it considerably facilitates the initial investigation of the test parameters, which in many cases is the most energy and time consuming process. For example, Taber tester is widely used to study the wear resistance of the anodized coatings. However, because of the aggressive wear nature of the Taber abraser, the coatings could be worn out in a short time. However, if the test time is too short, the more wear resistant sub layer will not be reached, resulting in an underestimated calculation of the wear rate.

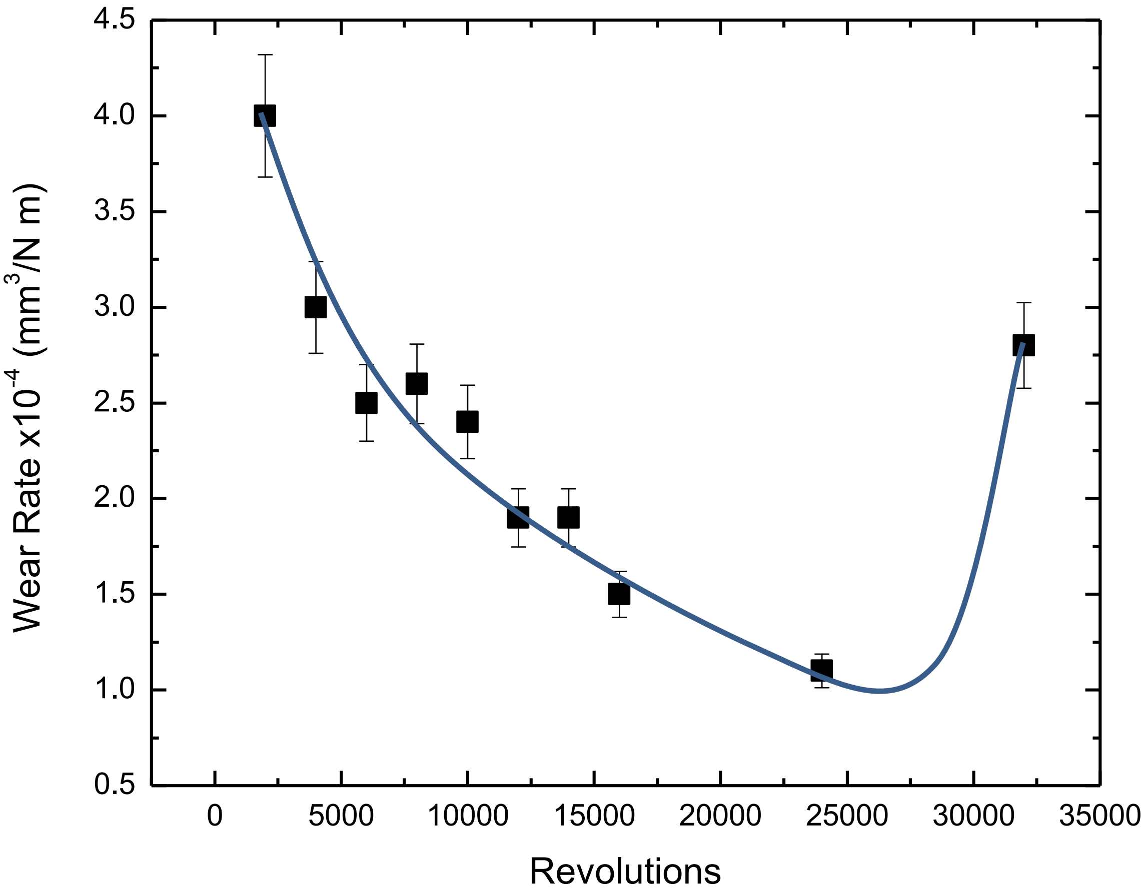


Fig. 7: Evolution of the wear rates calculated at different number of revolutions.

CONCLUSION

In this study, we showcased that Nanovea Tribometer equipped with a non-contact profilometer is a superior tool for wear evaluation. Compared to the conventional Taber abrasion measurements, Nanovea Tribometer provides well-controlled quantifiable and reliable wear assessment that can ensure reproducible evaluation and quality control of the anodized Al coatings. Moreover, the capacity of in-situ COF and wear rate measurements allow users to correlate different stages of wear process with the evolution of COF and wear rate, which is critical in improving fundamental understanding of the wear mechanism.

Based on the comprehensive tribological analyses, we show that anodized Al2036 possesses different wear resistance along the thickness of the coating. This assessment allows us to evaluate and select the best candidate that serves in environments that involve wear. Moreover, the capacity of evaluating the wear rates after different number of revolutions substantially facilitate the initial test parameter setup.

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.

Learn More about the Nanovea Tribometer and Lab Services

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[i] ASTM D4060 - 10: Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser.