WEAR AND SCRATCH RESISTANCE OF SURFACE TREATED COPPER WIRE

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INTRO

As one of the best electrical conductor materials, copper has a long history of being used in electric wiring since the invention of the electromagnet and the telegraph. Thanks to its good corrosion resistance, solderability to components and performance at elevated temperatures up to 150°C, copper wires are applied in a wide range of electronic equipment including, but not limited to panels, meters, computers, business machines, and appliances. The copper for manufacturing electrical wire and cable conductors consumes approximately half of all copper being mined.

IMPORTANCE OF WEAR AND SCRATCH EVALUATION OF COPPER WIRE

The surface quality of copper wire is critical in its service performance and lifetime. The micro defects in the wire surface may lead to excessive wear, crack initiation and propagation, and inadequate solderability. Proper surface treatment can remove surface defects that are generated during wire drawing, and improve the corrosion, wear and scratch resistance of the copper wire. Many applications such as aerospace and commercial airliner require copper wires to behave in a controlled manner to prevent unexpected equipment failure. Quantifiable and reliable measurements are in need in order to quantitatively evaluate the wear and scratch resistance of the copper wire surface.

MEASUREMENT OBJECTIVE

In this application, we simulated the wear process of two copper wires with different surface treatments in a controlled and monitored manner. Micro scratch testing is used to measure the load required to cause cohesive or adhesive failure to the surface treated layer. In this study, we would like to showcase that Nanovea Tribometer and Mechanical Tester are ideal tools for evaluation and quality control of electric wires.

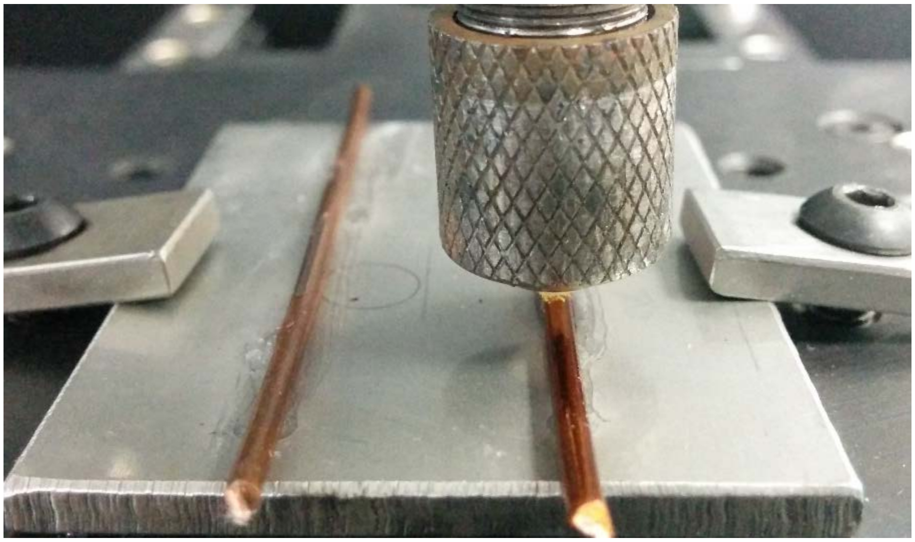


Fig. 1: Setup of the wear test on copper wires.

TEST PROCEDURE

The coefficient of friction, COF, and the wear resistance of two copper wires with different surface treatments (Wire A and Wire B) were evaluated by Nanovea Tribometer using Linear Reciprocating Wear Module. An Al_2O_3 ball (6 mm diameter) was used as the counter material. The wear track was examined using Nanovea 3D non-contact profilometer. The test parameters are summarized in Table 1.

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

Normal force	15 N
Amplitude	10 mm
Speed	60 cycles/min
Duration of test	10 min

Table 1: Test parameters of the wear measurements.

Nanovea Mechanical Tester equipped with a Rockwell C diamond stylus (100 µm radius) was used to perform progressive load scratch tests on the coated wires using Micro Scratch Mode. The scratch test parameters and the tip geometry are shown in Table 2.

Load type	Progressive
Initial Load	0.01 N
Final Load	15 N
Loading rate	15 N/min
Scratch Length	3 mm
Scratching speed, dx/dt	3 mm/min
Indenter geometry	120° conical
Indenter material (tip)	Diamond
Indenter tip radius	100 µm

Table 2: Scratch test parameters.

RESULTS AND DISCUSSION

Wear of copper wire

Fig. 2 shows the evolution of COF of the two copper wires during the wear tests. Wire A shows a stable COF of ~0.4 throughout the wear test. Wire B exhibits a COF of ~0.35 in the first 100 revolutions, and it progressively increases to ~0.4.

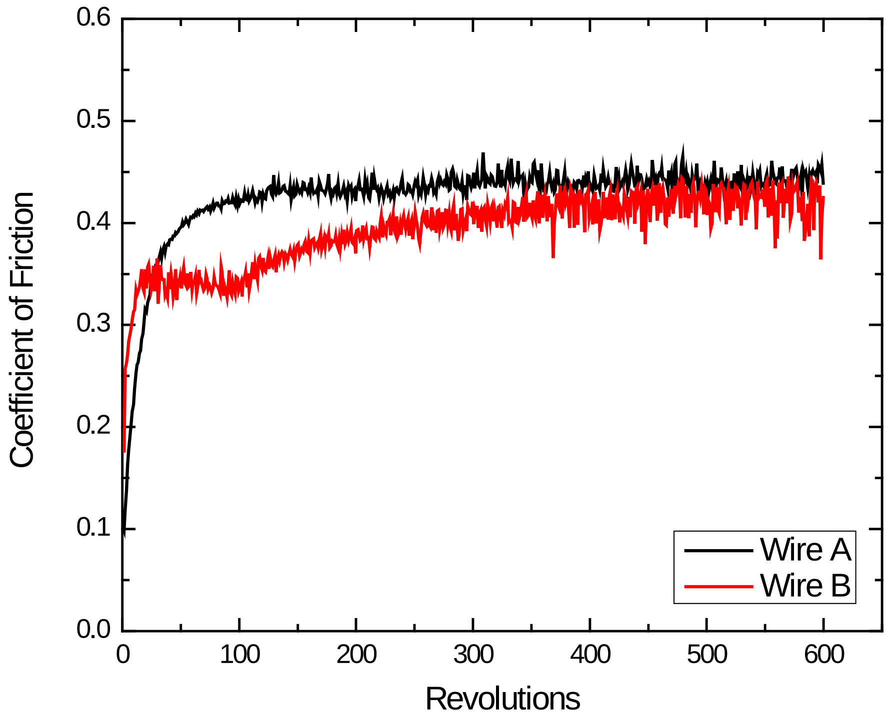


Fig. 2: COF Evolution of the copper wires during the wear tests.

Fig. 3 compares the wear tracks of the two copper wires after the wear tests. Nanovea 3D non-contact profilometer offers a superior tool to analyze the detailed morphology of the wear tracks. It provides more insight in fundamental understanding of wear mechanism and allows direct and accurate determination of the wear track volume. Wire B has a significantly damaged surface in the wear track after a 600-revolution wear test. As shown in the 3D view, the surface treated layer of Wire B has been completed removed and wear process was substantially accelerated, leaving behind a flattened wear track in which the fresh copper substrate is exposed. This could result in significantly shortened lifespan of the electrical equipment in which such copper wires are used in the realistic applications. In comparison, Wire A exhibits a sign of relatively mild wear, which only created a small wear track on the shallow surface. The surface treated layer was not removed by the wear test carried out under the same condition of Wire B.

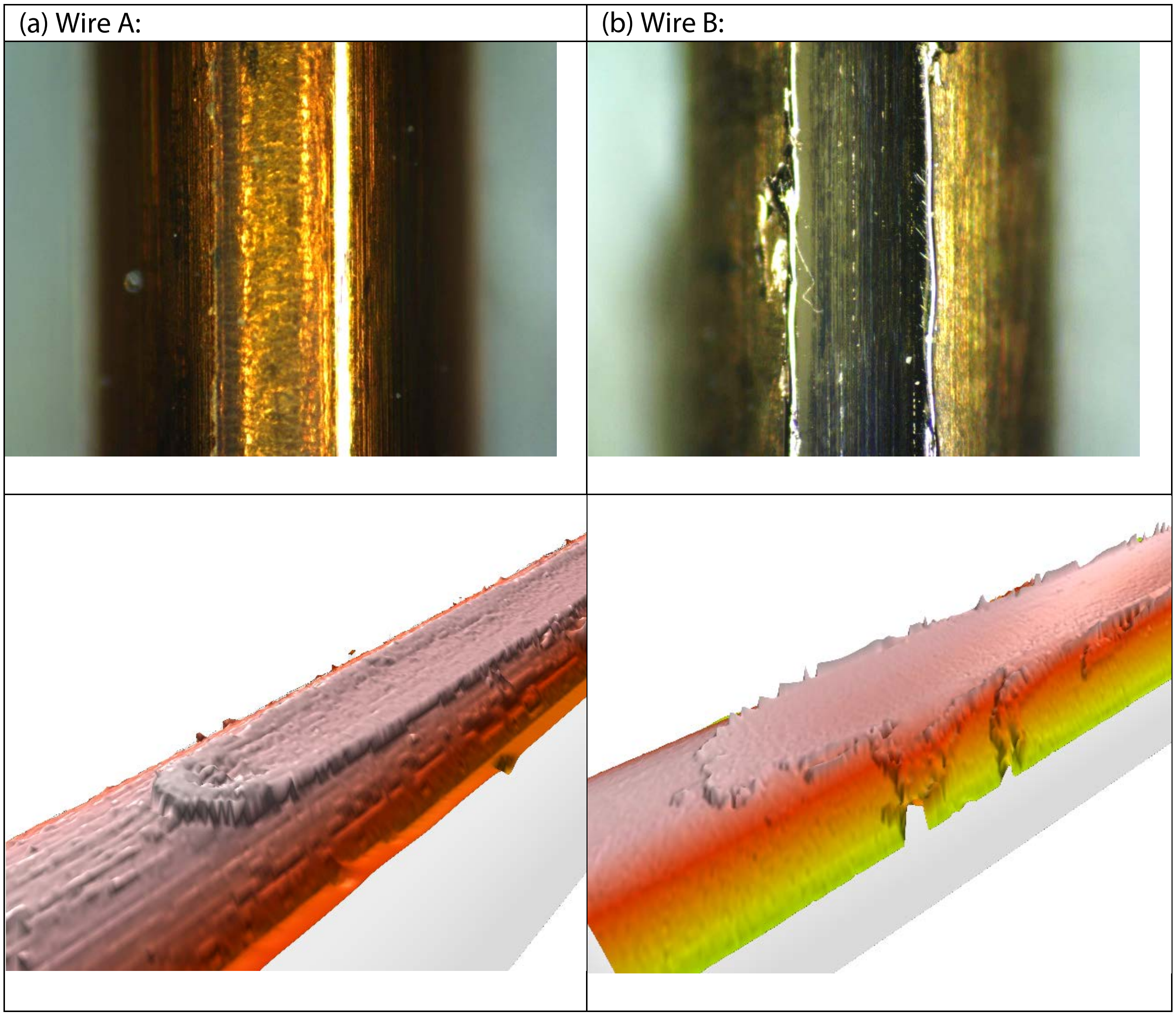
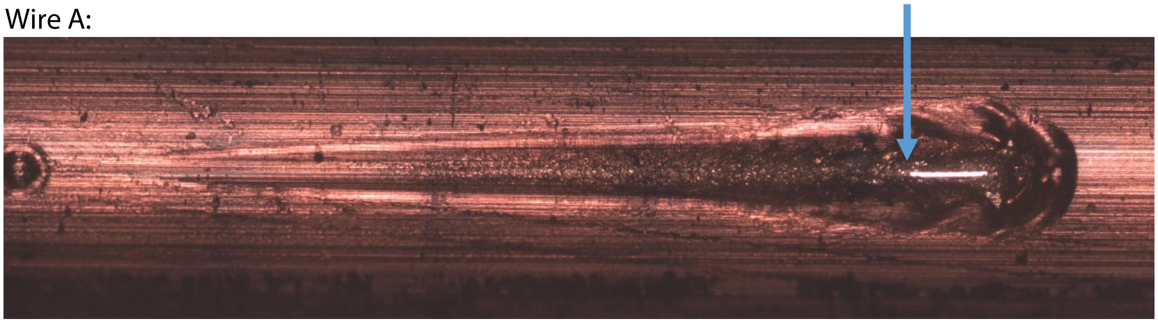


Fig. 3: Wear tracks of Wire A and Wire B under the microscope and 3D scan.

Scratch resistance of the copper wire surface

Fig. 4 shows the scratch tracks on the two wires after the tests. It is clear that the protective layer of Wire A exhibits a very good scratch resistance. It delaminates at a load of ~12.6 N. In comparison, the protective layer of Wire B failed at a load of ~1.0 N. Such a significant difference in scratch resistance for these two wires may contribute to their wear performance, where Wire A possesses substantially enhanced wear resistance. The evolution of Normal force, COF and Depth during the scratch tests as shown in Fig. 5 provides more insight in the failures of the coatings during the test.

(a) Wire A:



(b) Wire B:

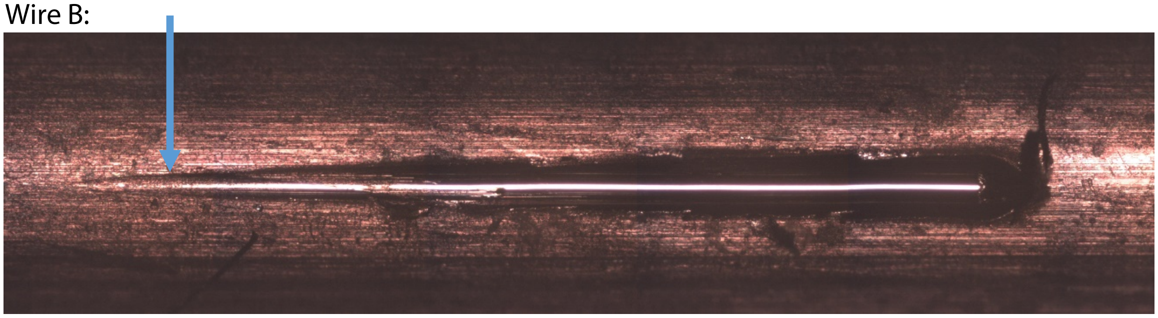
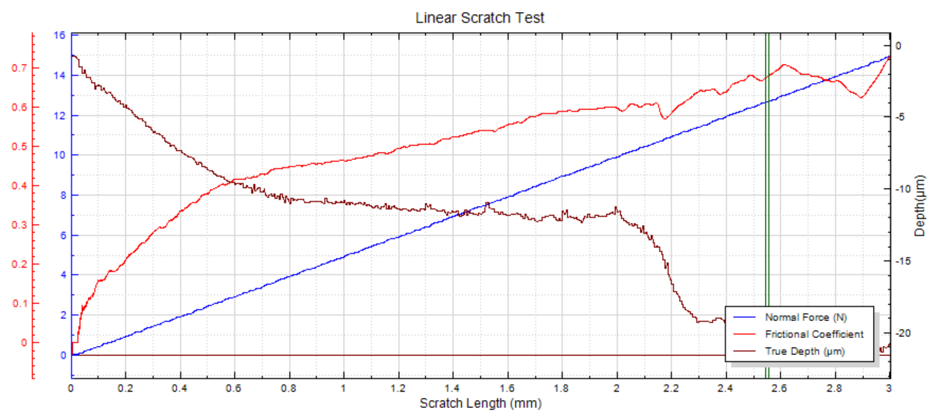


Fig. 4: Scratch tracks on the wires after the tests.

(a) Wire A:



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(b) Wire B:

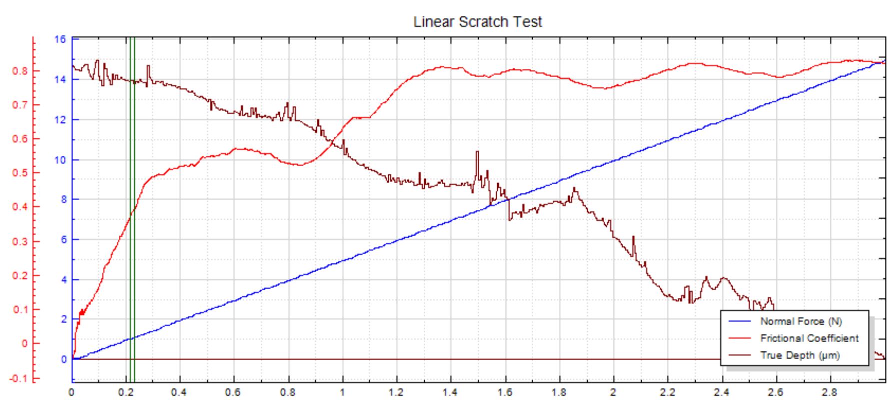


Fig. 5: Evolution of Normal force, COF and Depth during the scratch tests.

CONCLUSION

In this study, we showcased the capacity of Nanovea Tribometer in evaluating the wear resistance of surface treated copper wires in a well-controlled and quantitative manner. Nanovea Mechanical Tester provides reliable assessment of the scratch resistance of the copper wire. The surface treatment plays a critical role in the tribo-mechanical properties of the wires during their service. The proper surface treatment on Wire A significantly enhances its wear and scratch resistance, which is critical in the performance and lifespan of the electrical wires in realistic environment.

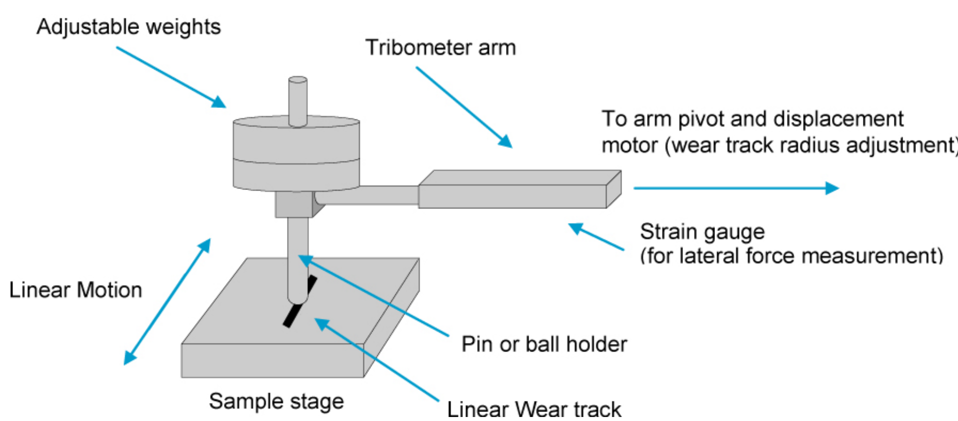
Nanovea Tribometer offers precise and repeatable wear and friction testing using ISO and ASTM compliant rotative and linear modes, with optional high temperature wear, lubrication and tribo-corrosion modules available in one pre-integrated system. Nanovea's unmatched range is an ideal solution for determining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

Learn More about the Nanovea Tribometer, Nanovea Mechanical Tester and Lab Service

APPENDIX: MEASUREMENT PRINCIPLE

Principle of linear wear test

The sample is mounted on a moving stage, while a known force is applied on a pin, or ball, in contact with the sample surface to create the wear. As the sample moves in a linear reciprocating motion, the resulting frictional forces between the pin and the sample are measured using a strain gage sensor on the arm. The wear 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 loss 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. 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.

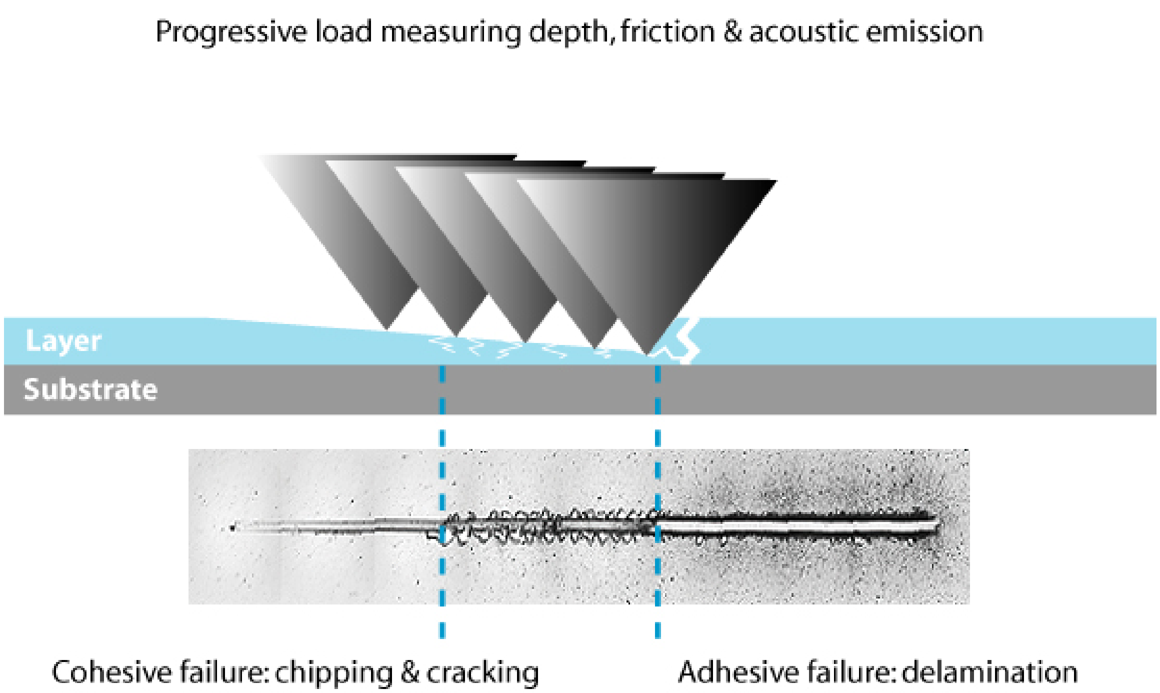


Principle of scratch test

The scratch testing method is a very reproducible quantitative technique. Critical loads at which failures appear are used to compare the cohesive or adhesive properties of coatings or bulk materials. During the test, scratches are made on the sample with a sphero-conical stylus (tip radius ranging from 1 to 200 μm) which is drawn at a constant speed across the sample, under a constant load, or, more commonly, a progressive load with a fixed loading rate. Sphero-conical stylus is available with different radii (which describes the "sharpness" of the stylus). Common radii are from 20 to 200 μm for micro/macro scratch tests, and from 1 to 20 μm for nano scratch tests.

When performing a progressive load test, the critical load is defined as the smallest load at which a recognizable failure occurs. In the case of a constant load test, the critical load corresponds to the load at which a regular occurrence of such failure along the track is observed.

In the case of bulk materials, the critical loads observed are cohesive failures, such as cracking or plastic deformation of the material. In the case of coated samples, the lower load regime results in conformal or tensile cracking of the coating which still remains fully adherent (which usually defines the first critical load). In the higher load regime, further damage usually comes from coating detachment from the substrate by spalling, buckling or chipping.



Comments on the critical load

The scratch test gives reproducible quantitative data that can be used to compare the behavior of various coatings. The critical loads depend on the mechanical strength (adhesion, cohesion) of a coating-substrate composite but also on several other parameters: some of them are directly related to the test itself, while others are related to the coating-substrate system. The parameters that determine the critical loads are summarized in Table 3.

Test specific parameters	Sample specific parameters
Loading rate	Friction coefficient between surface and indenter
Scratching speed	Internal stresses in the material for bulk materials
Indenter tip radius	Material hardness & roughness for coating-substrate systems
Indenter material	Substrate hardness and roughness
	Coating hardness and roughness
	Coating thickness

Table 3: List of parameters that determine the critical loads.

Means for critical load determination

Microscopic observation
This is the most reliable method to detect surface damage. This technique is able to differentiate between cohesive failure within the coating and adhesive failure at the interface of the coating-substrate system.

Tangential (frictional) force recording
This enables the force fluctuations along the scratch to be studied and correlated to the failures observed under the microscope. Typically, a failure in the sample will result in a change (a step, or a change in slope) in coefficient of friction. Frictional responses to failures are very specific to the coating-substrate system in study.

Acoustic emission (AE) detection
Detection of elastic waves generated as a result of the formation and propagation of microcracks. The AE sensor is insensitive to mechanical vibration frequencies of the instrument. This method of critical load determination is mostly adequate for hard coatings that crack with more energy.

Depth Sensing
Sudden change in the depth data can indicate delimitation. Depth information pre and post scratch can also give information on plastic versus elastic deformation during the test. 3D Non-Contact imaging such as white light axial chromatism technique and AFMs can be useful to measure exact depth of scratch after the test.

Other possible measurements by Nanovea Mechanical Tester:

Hardness and Young's Modulus, Stress-Strain & Yield Stress, Fracture Toughness, Compression strength, Fatigue testing and many others.