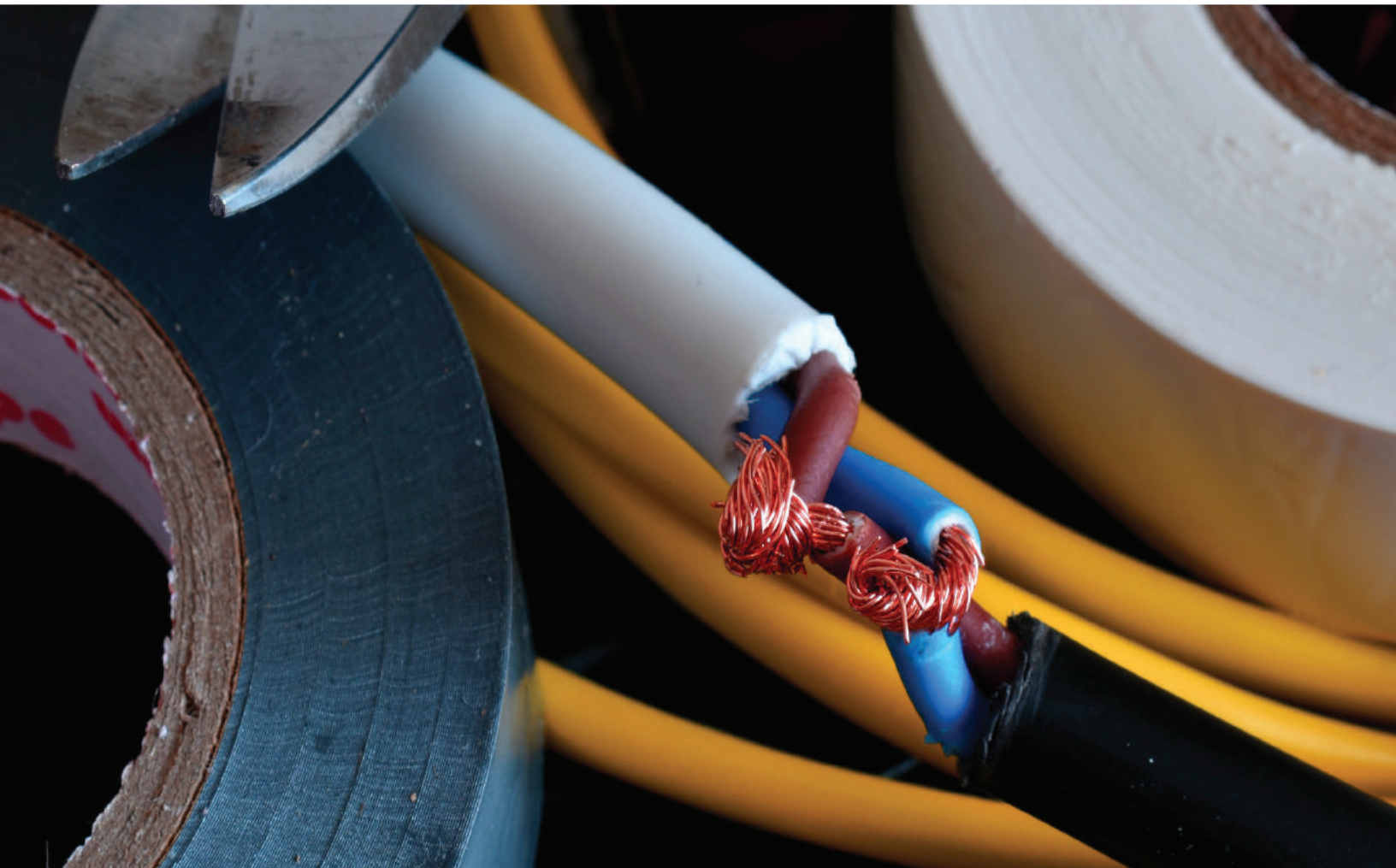
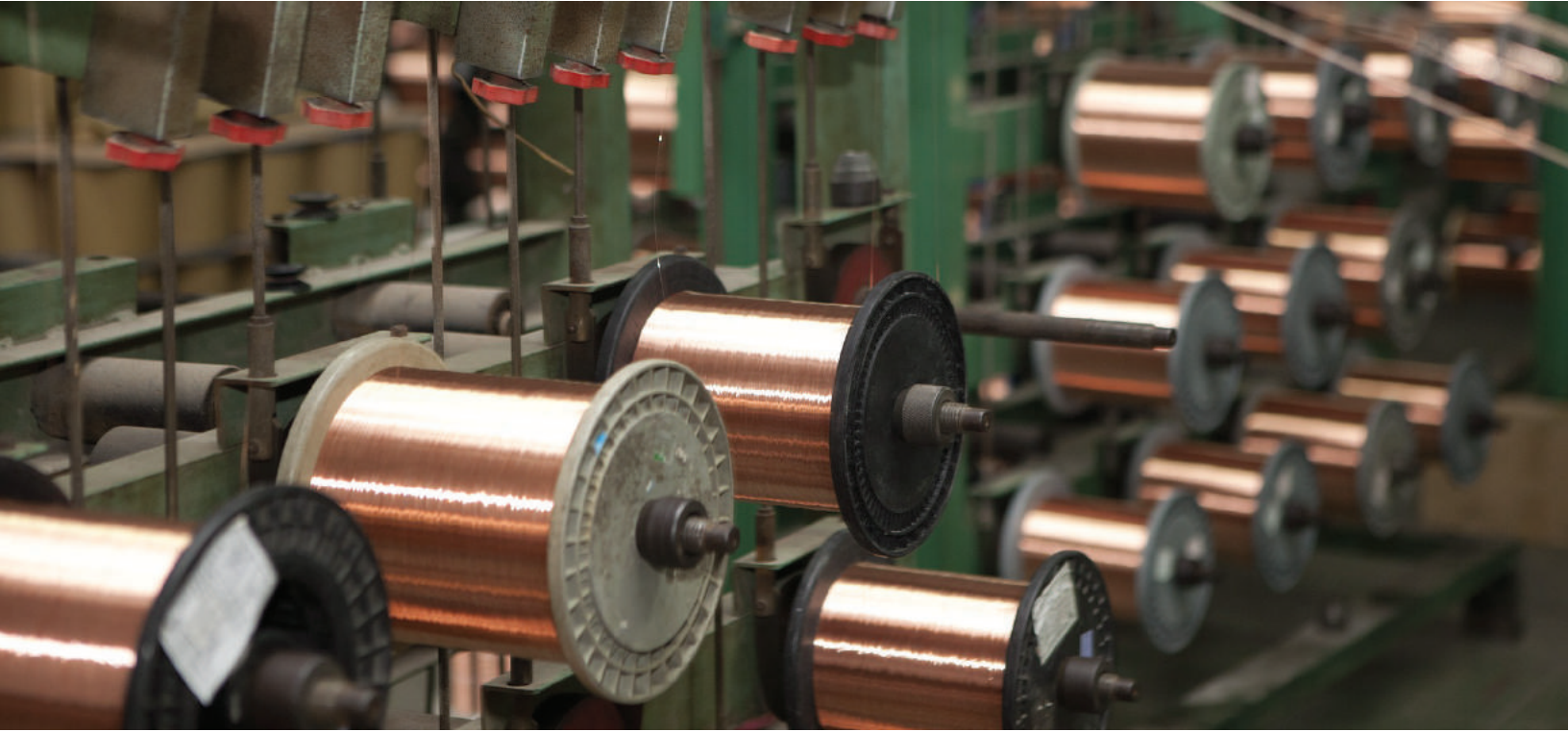


## *WEAR AND SCRATCH EVALUATION* *OF* *SURFACE TREATED COPPER WIRE*



Prepared by  
**Duanjie Li, Ph.D, Jonathan Thomas, and Pierre Leroux**



## Introduction

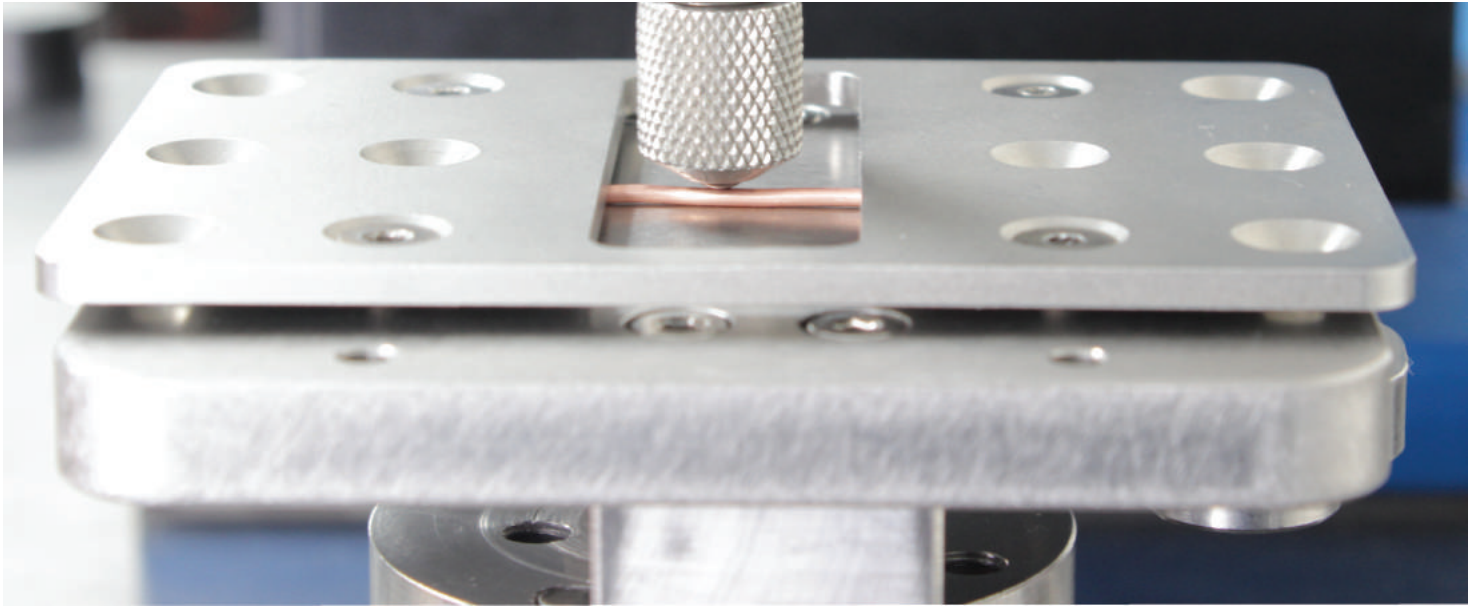
Copper has a long history of use in electric wiring since the invention of the electromagnet and telegraph. Copper wires are applied in a wide range of electronic equipment such as panels, meters, computers, business machines, and appliances thanks to its corrosion resistance, solderability, and performance at elevated temperatures up to 150°C. Approximately half of all mined copper is used for manufacturing electrical wire and cable conductors.

## Importance of Wear and Scratch Evaluation of Copper Wire

Copper wire surface quality is critical to application service performance and lifetime. Micro defects in wires may lead to excessive wear, crack initiation and propagation, decreased conductivity, and inadequate solderability. Proper surface treatment of copper wires removes surface defects generated during wire drawing improving corrosion, scratch, and wear resistance. Many aerospace applications with copper wires require controlled behavior to prevent unexpected equipment failure. Quantifiable and reliable measurements are needed to properly evaluate the wear and scratch resistance of the copper wire surface.

## MEASUREMENT OBJECTIVE

In this application we simulate a controlled wear process of different copper wire surface treatments. Scratch testing measures the load required to cause failure on the treated surface layer. This study showcases the Nanovea Tribometer and Mechanical Tester as ideal tools for evaluation and quality control of electric wires.



**Figure 1: Setup of the wear test on copper wires.**

# TEST CONDITIONS AND PROCEDURES

Coefficient of friction (COF) and wear resistance of two different surface treatments on copper wires (Wire A and Wire B) were evaluated by the Nanovea tribometer using a linear reciprocating wear module. An  $\text{Al}_2\text{O}_3$  ball (6 mm diameter) is the counter material used in this application. The wear track was examined using Nanovea’s 3D non-contact profilometer. Test parameters are summarized in Table 1.

A smooth  $\text{Al}_2\text{O}_3$  ball as a counter material was used as an example in this study. Any solid material with different shape and surface finish can be applied using a custom fixture to simulate the actual application situation.

Wear Parameters	
Normal Force [N]	15
Amplitude [mm]	10
Speed [cycles/min]	60
Duration of Test [min]	10

Table 1: Test parameters of the wear measurements.

Nanovea’s mechanical tester equipped with a Rockwell C diamond stylus (100  $\mu\text{m}$  radius) performed progressive load scratch tests on the coated wires using micro scratch mode. Scratch test parameters and tip geometry are shown in Table 2.

Scratch Parameters	
Load Type	Progressive
Initial Load [N]	0.01
Final Load [N]	15
Loading Rate [N/min]	15
Scratch Length [mm]	3
Scratching Speed [mm/min]	3
Indenter Geometry	120° conical
Indenter Material (tip)	Diamond
Indenter tip radius [ $\mu\text{m}$ ]	100

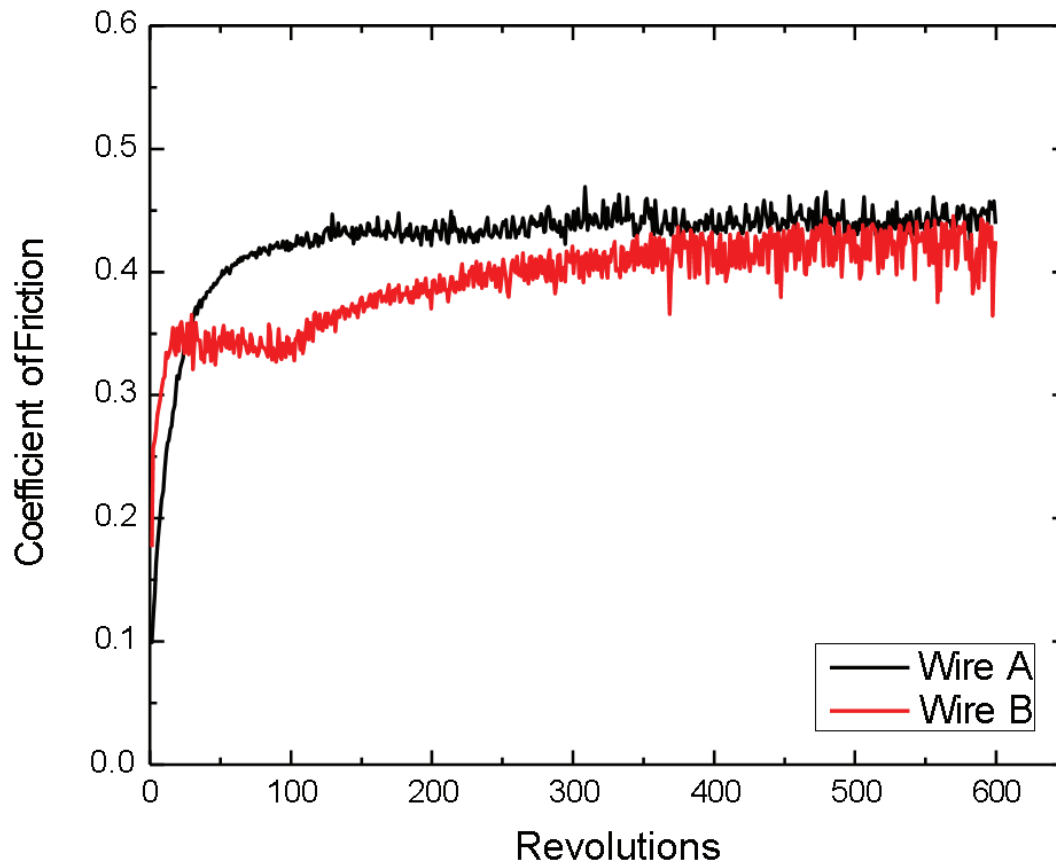
Table 2: Scratch test parameters.



# RESULTS AND DISCUSSION

## Wear of copper wire:

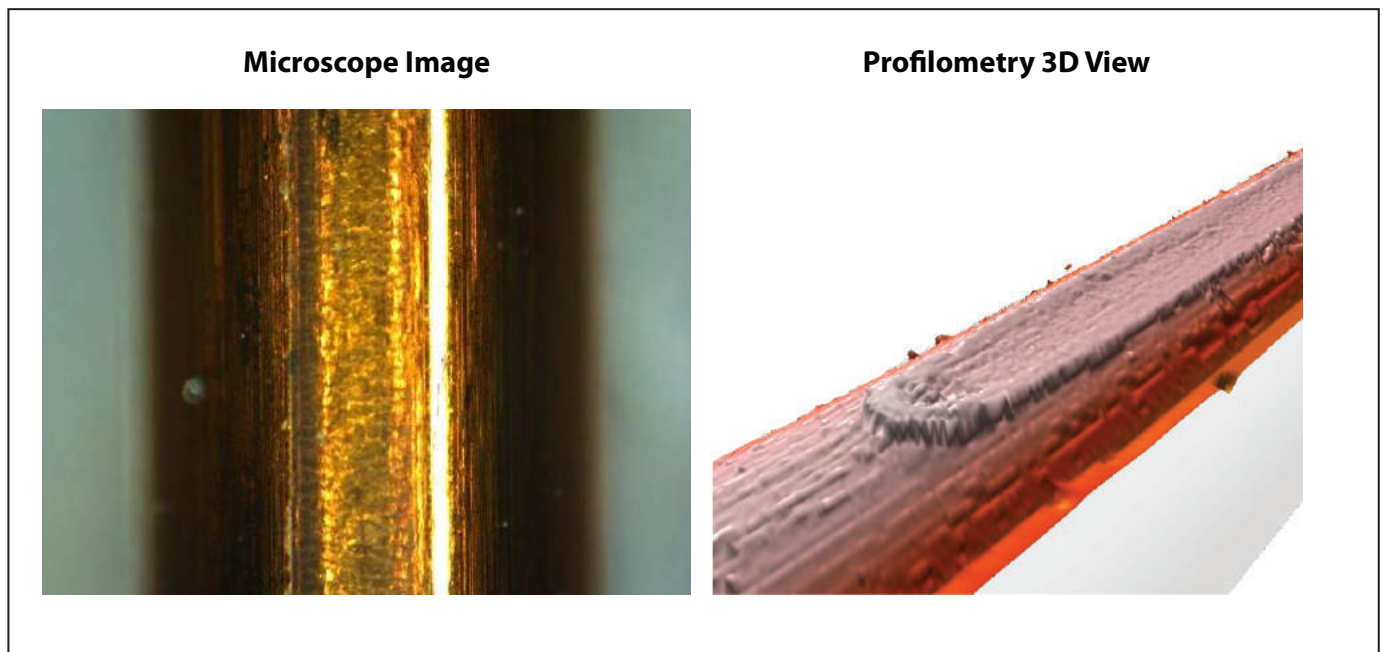
Figure 2 shows COF evolution of the copper wires during wear tests. Wire A shows a stable COF of  $\sim 0.4$  throughout the wear test while wire B exhibits a COF of  $\sim 0.35$  in the first 100 revolutions and progressively increases to  $\sim 0.4$ .



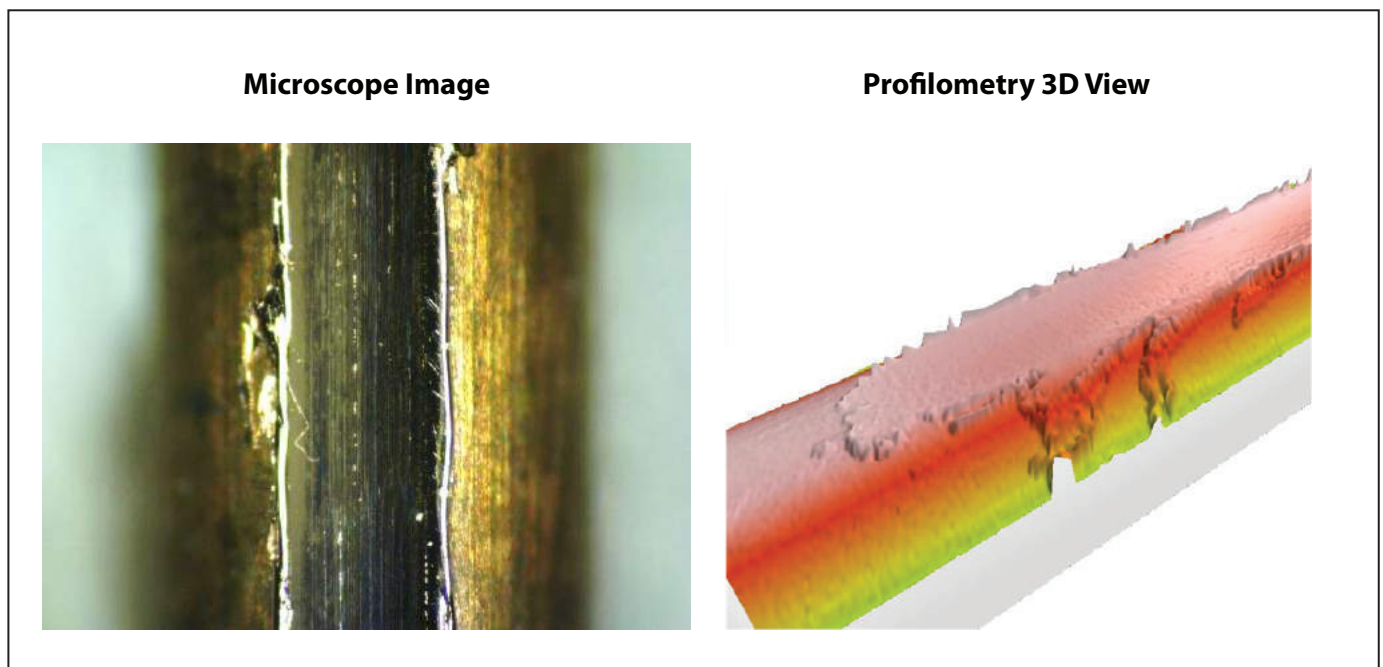
**Figure 2: COF Evolution of copper wires during the wear tests.**

Figure 3 compares wear tracks of the copper wires after tests. Nanovea's 3D non-contact profilometer offered superior analysis of the detailed morphology of wear tracks. It allows direct and accurate determination of the wear track volume by providing a fundamental understanding of the wear mechanism. Wire B's surface has significant wear track damage after a 600-revolution wear test. The profilometer 3D view shows the surface treated layer of Wire B removed completely which substantially accelerated the wear process. This left a flattened wear track on Wire B where copper substrate is exposed. This may result in significantly shortened lifespan of electrical equipment where Wire B is used. In comparison, Wire A exhibits its relatively mild wear shown by a shallow wear track on the surface. The surface treated layer on Wire A did not remove like the layer on Wire B under the same conditions.

(a) Wire A:



(b) Wire B:

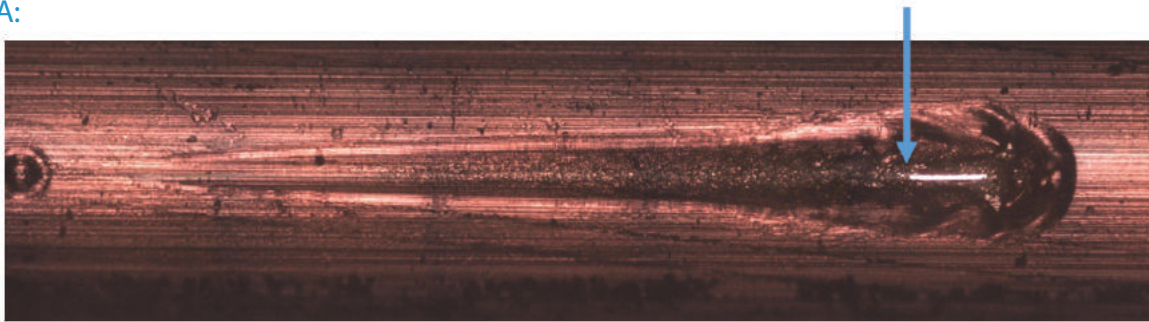


**Figure 3: Wear tracks of Wire A and Wire B under the microscope and 3D scan.**

### **Scratch resistance of the copper wire surface:**

Figure 4 shows the scratch tracks on the wires after testing. The protective layer of Wire A exhibits very good scratch resistance. It delaminates at a load of  $\sim 12.6$  N. In comparison, the protective layer of Wire B failed at a load of  $\sim 1.0$  N. Such a significant difference in scratch resistance for these wires contributes to their wear performance, where Wire A possesses substantially enhanced wear resistance. The evolution of normal force, COF, and depth during the scratch tests shown in Fig. 5 provides more insight on coating failure during tests.

(a) Wire A:



(b) Wire B:

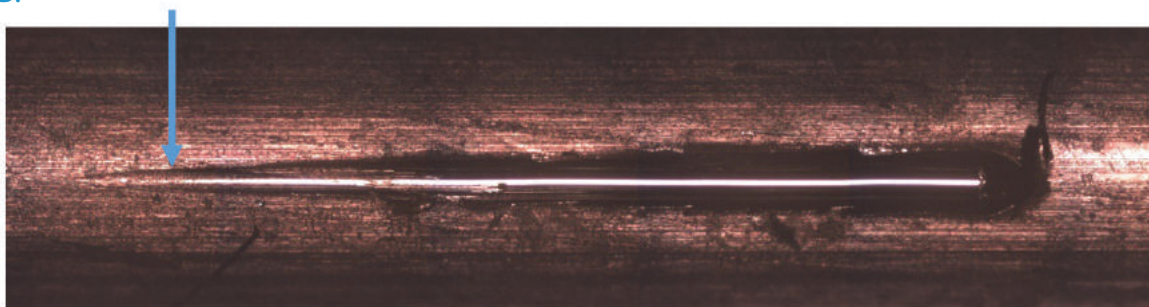
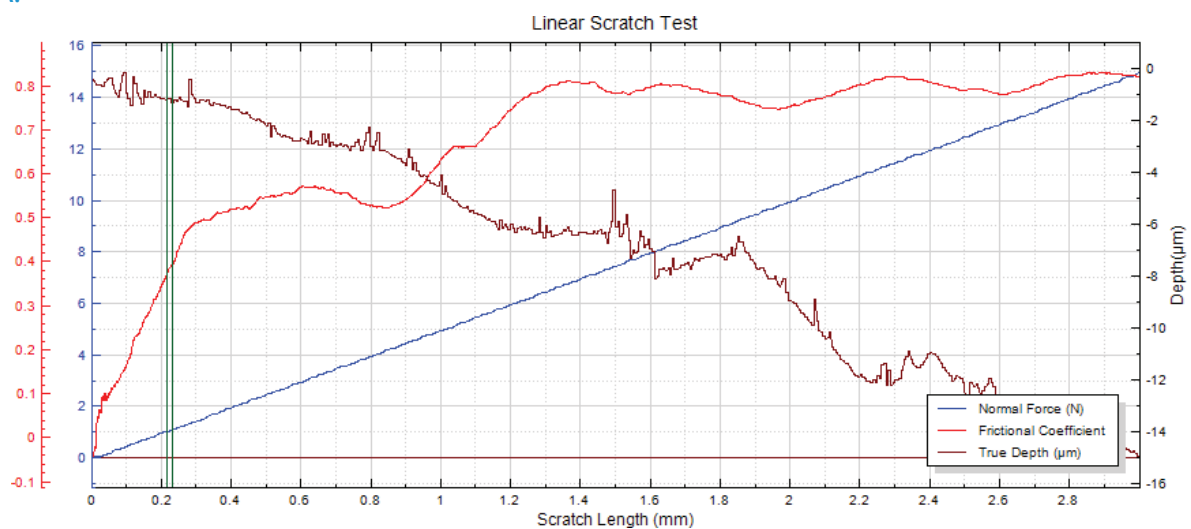


Figure 4: Scratch tracks on the wires after the tests.

(a) Wire A:



(b) Wire B:

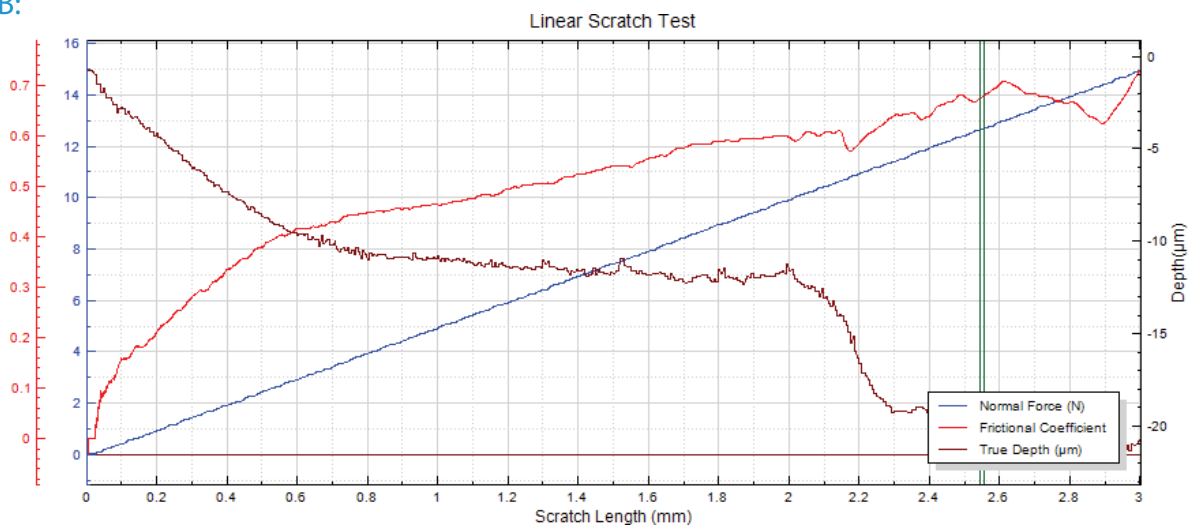


Figure 5: Evolution of Normal force, COF and Depth during the scratch tests.





## Conclusion

In this controlled study we showcased the Nanovea's tribometer conducting quantitative evaluation of wear resistance for surface treated copper wires and Nanovea's mechanical tester providing reliable assessment of copper wire scratch resistance. Wire surface treatment plays a critical role in the tribo-mechanical properties during their lifetime. Proper surface treatment on Wire A significantly enhanced wear and scratch resistance, critical in the performance and lifespan of electrical wires in rough environments.

Nanovea's 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 [Laboratory Services](#).



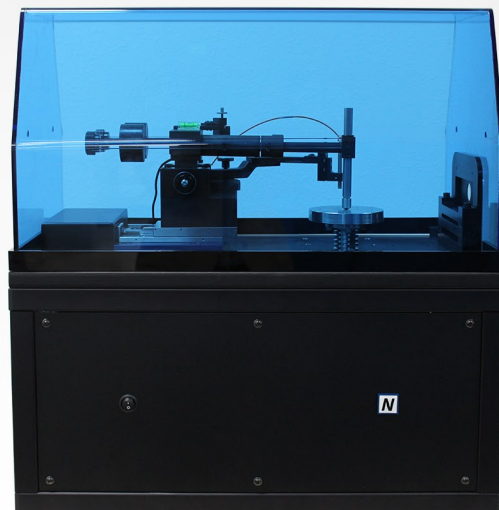
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## **TRIBOMETERS**

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**FOUR BALL**

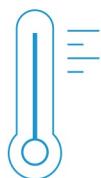


**SCRATCH**

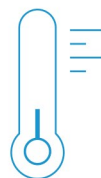
### **ENVIRONMENTAL MODULES**



**CORROSION**



**HIGH TEMP**



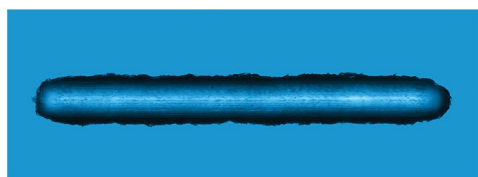
**LOW TEMP**



**LIQUID**



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& GASSES**



**Advanced Pneumatic Technology    Integrated Optical Profiler**  
**Unmatched Speed Control (0.01 to 15000 rpm)**