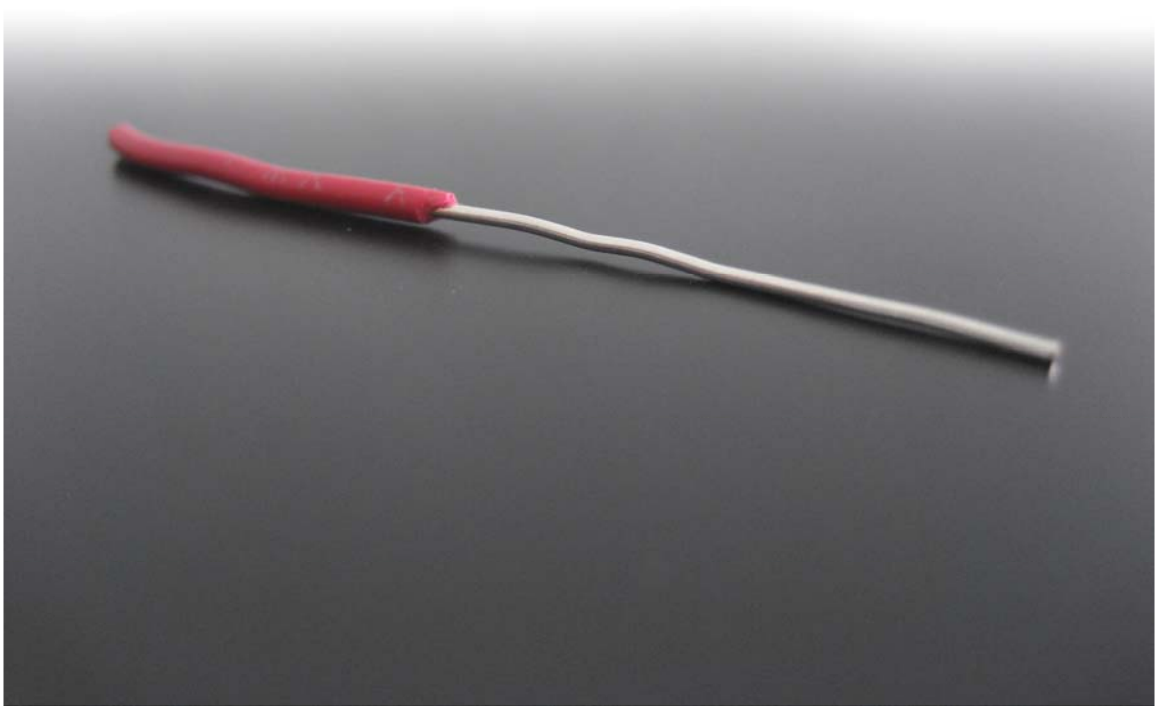
NANO SCRATCH TESTING
OF SOLID TINNED COATED COPPER WIRE



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INTRO

Hookup wires are used in a wide range of electronic equipment that uses a low current and low voltage in its applications. These include, but are not limited to panels, meters, computers, business machines, and appliances. Typically hookup wire is made of a metal conductor with a thin metal coating and insulated by a thermoplastic and rubber material to prevent the leakage of current. The conductors are made from such metals as aluminum, aluminum alloys, aluminum clad-steel, copper, copper alloys or copper-clad steel. Copper conductors with a thin Tin coating are the most widely used hookup wire configuration and are used because of its good corrosion resistance, ability to be soldered to components and its performance when operated at temperatures exceeding 100°C up to 150°C.

TINNING OF HOOKUP WIRE PROCESS CONCERNS

The process in witch the Copper conductor is coated with the Tin is known as Tinning. This process allows a thin layer of Tin to coat the entire surface of the Copper. There are two standard methods of Tinning a surface, hot dripping and electroplating. The most common technique, electroplating, has limitation to how uniform a coating can be applied along with controlling the thickness of the coating. Many applications such as aerospace and commercial airliner require hookup wire to behave in a controlled manner to prevent the failure of equipment. To insure the Tin coating does not unexpectedly fail during use, the max force required to damage the coatings becomes important information. One method to obtain this critical value is through scratch testing.

MEASUREMENT OBJECTIVE

We must simulate the process of scratching in a controlled and monitored manner to observe sample behavior effects. In this application, the Nanovea Mechanical Tester, in nano scratch tester mode, is used to measure the load required to cause the failure of the Tin coating on the Copper conductor. A standard 22 gauge solid hookup wire with a 1μm Tin coating was tested. The thick protected sleeve was first stripped away to reveal the tin coating. A 5μm diamond tipped stylus was used at a progressive load ranging from 0.05 mN to 200.00 mN to scratch the coating. The point where the Tin coating fails and the Copper conductor is revealed is taken as the point of failure. Five tests where done the sample of hookup wire in order to determine the exact failure critical loads.

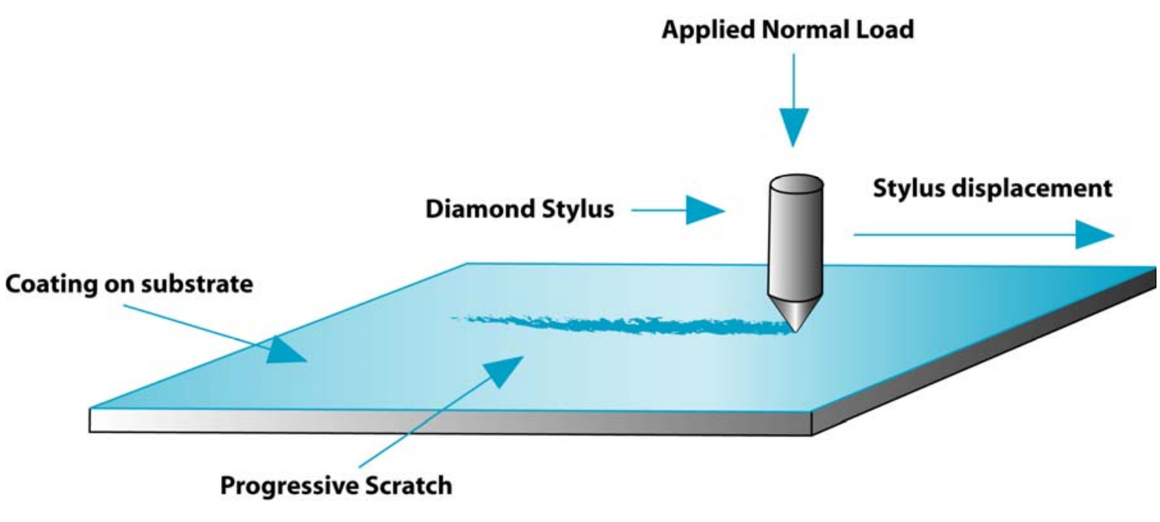
MEASUREMENT PRINCIPLE:

The scratch testing method is a very reproducible quantitative technique in which 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 20μm) 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 200μm for micro/macro scratch tests, and 1 to 20μm 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 or 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.

Figure 1 : Principle of Scratch Testing



Comments on the critical load

The scratch test gives very 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 test specific parameters include:	The sample specific parameters include:
• Loading rate • Scratching speed • Indenter tip radius • Indenter material	• Friction coefficient between surface and indenter • Internal stresses in the material For bulk materials • Material hardness and roughness for coating-substrate systems • Substrate hardness and roughness • Coating hardness and roughness • Coating thickness

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.

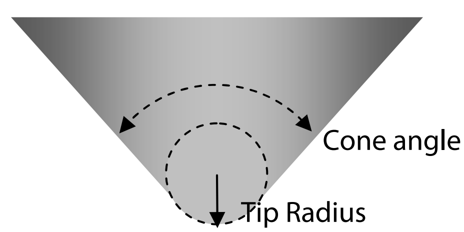
Tangential (frictional) force recording
This enables the force fluctuations along the scratch to be studied and correlated to the failures observed under the microscope. Typically, a failure in the sample will result in a change (a step, or a change in slope) in coefficient of friction. Frictional responses 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 AFM's can be useful to measure exact depth of scratch after the test.

Test parameters

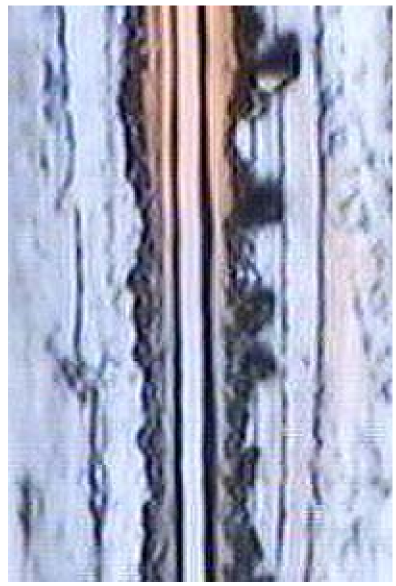
Load type	Progressive
Initial Load	0.050 mN
Final Load	200.00 mN
Loading rate	200.00 mN/min
Scratch Length	1.5 mm
Scratching speed, dx/dt	1.5 mm/min
Indenter geometry	60° conical
Indenter material (tip)	Diamond
Indenter tip radius	5 µm



Results

This section presents the data collected on the failures during the scratch test. The first section describes the failures observed in the scratch and defines the critical loads that were reported. The next part contains a summary table of the critical loads for all samples, and a graphical representation. The last part presents detailed results for each sample: the critical loads for each scratch, micrographs of each failure, and the graph of the test.

Failures observed and definition of critical loads

Critical failure	Micrograph of failure
Failure is the point where the Tin coating fails and the Copper conductor is visible for the remainder of the scratch track.	

Summary table of main numerical results

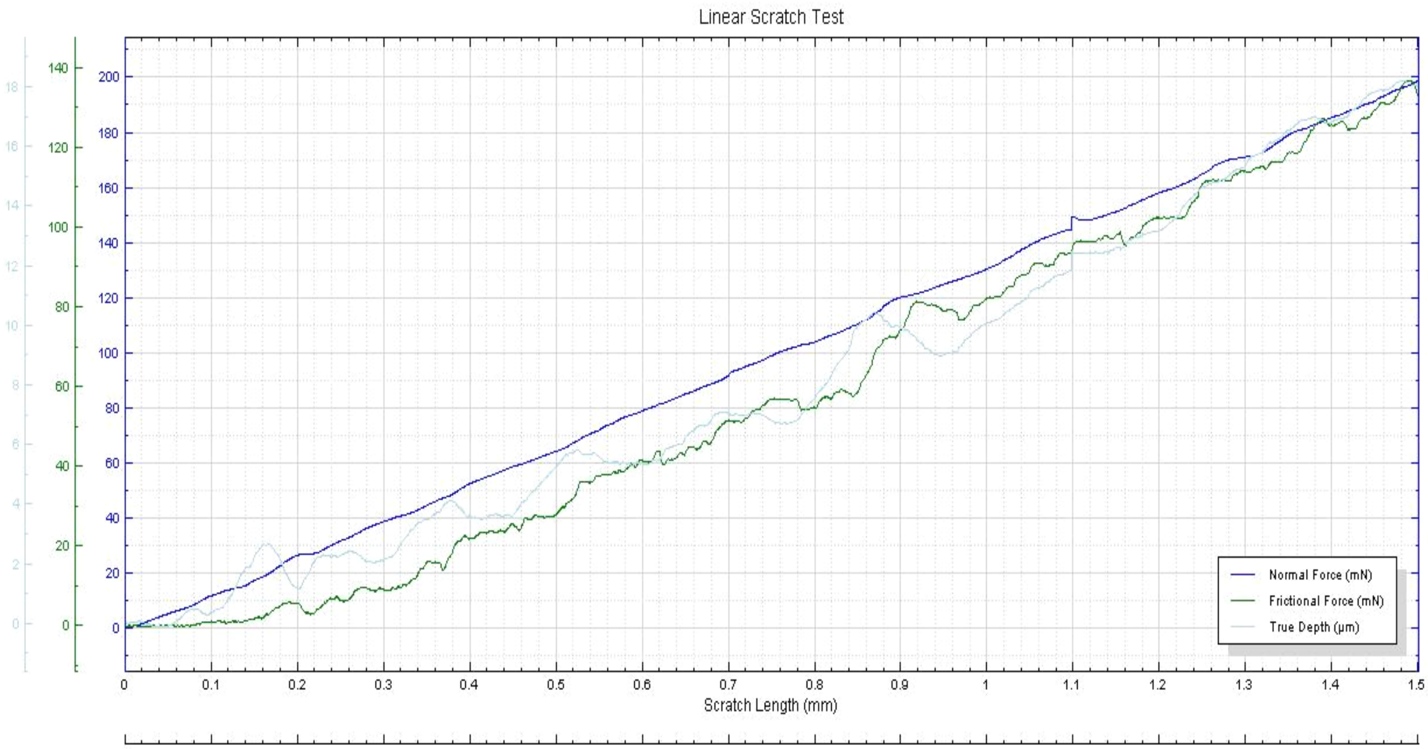
Sample	Failure [mN]		
	Value		Std Deviation
Tin Coating	41.379	±	0.882

Detailed results –Tin Coating

Critical loads – Tin Coating	
Scratch	**Failure [mN]**
1	40.152
2	42.242
3	42.217
4	41.293
5	40.992
Average	**41.379**
Std dev	**0.882**

Figure 2 : Micrograph of Failure – Tin Coating
500x magnification (image width 0.0615mm)

Figure 3 : Friction graph – Tin Coating



Conclusion

It has been shown that by applying loads in a controlled and closely monitored fashion, the Nanovea Mechanical Tester, during Nano Scratch Tester Mode, is a superior tool to quantify the scratch resistance of Tin coating on copper wire application. A clear force required to fail is observed between several tests and the small standard deviations reflect the reproducibility of the technique/instrument. This information can help manufactures improve the quality of their thin films including those found on small diameter wire apllications. Other parameters that could be measured include friction coefficient, hardness and elastic modulus of the coating.