

**Nano Puncture Resistance
Using Nanoindentation**



Prepared by
Jorge Ramirez

INTRO

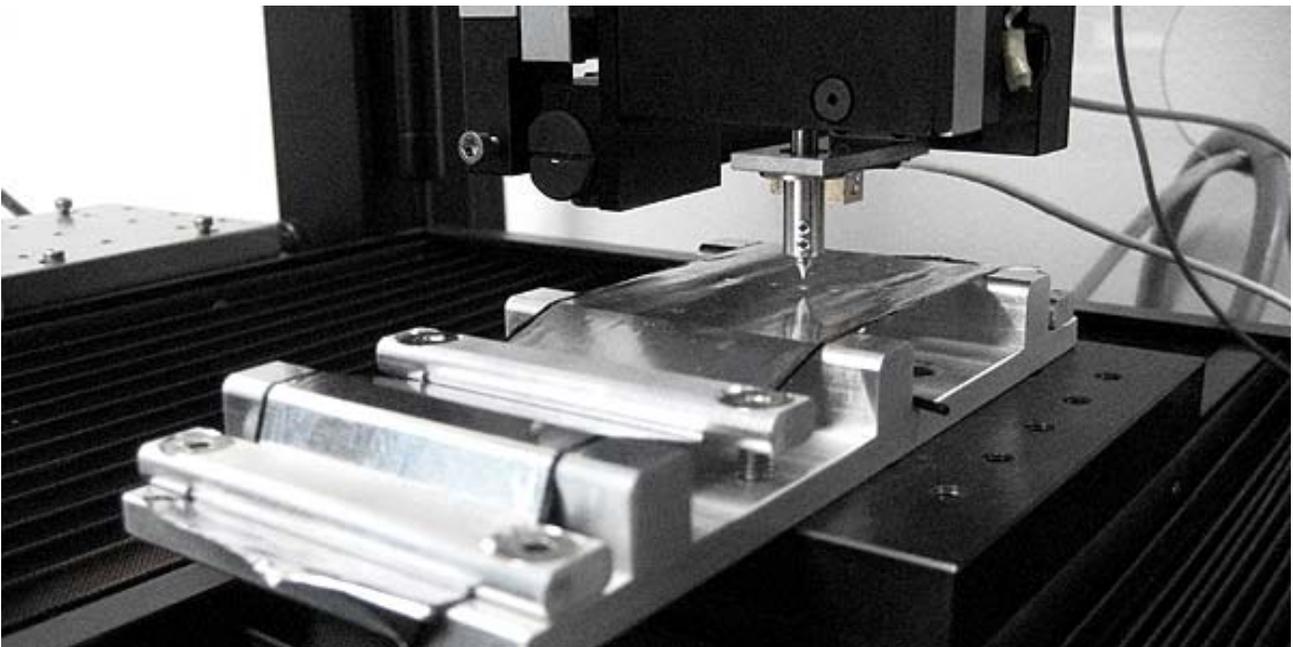
Traditional Puncture Tests are typically used to determine the penetration characteristics of a wide range of protective material such as films, foils or membrane. It is widely used in food and medical industries on applications ranging from food packaging to rubber gloves and needles. The test is performed like that of a compressive test. A probe, with multiple tip selection, uses increasing load until material is penetrated and load is recorded at failure. These traditional tests were typically performed at higher loads, Newton and above, with poor load control and resolution.

IMPORTANCE OF NANOINDENTATION PUNCTURE TEST

With many traditional mechanical tests (Puncture, Hardness, Compression, Yield Strength etc.), today's quality control environments with advanced sensitive materials now requires greater precision and reliability. Traditional mechanical instrumentation fails to provide the sensitive load control and resolution required. In addition multiple instruments are needed to perform various mechanical tests which can now be performed on a single system. Puncture Tests, among many others, can now be tested with precise resolution at Nano through Macro controlled loads with a single instrument.

MEASUREMENT OBJECTIVE

In this application, the Nanovea Mechanical Tester, in Nanoindentation mode is used to study the puncture resistance of an aluminum foil sample using a cylindrical flat tip indenter. A custom sample holder was designed to secure thin film and foil samples.



MEASUREMENT PRINCIPLE

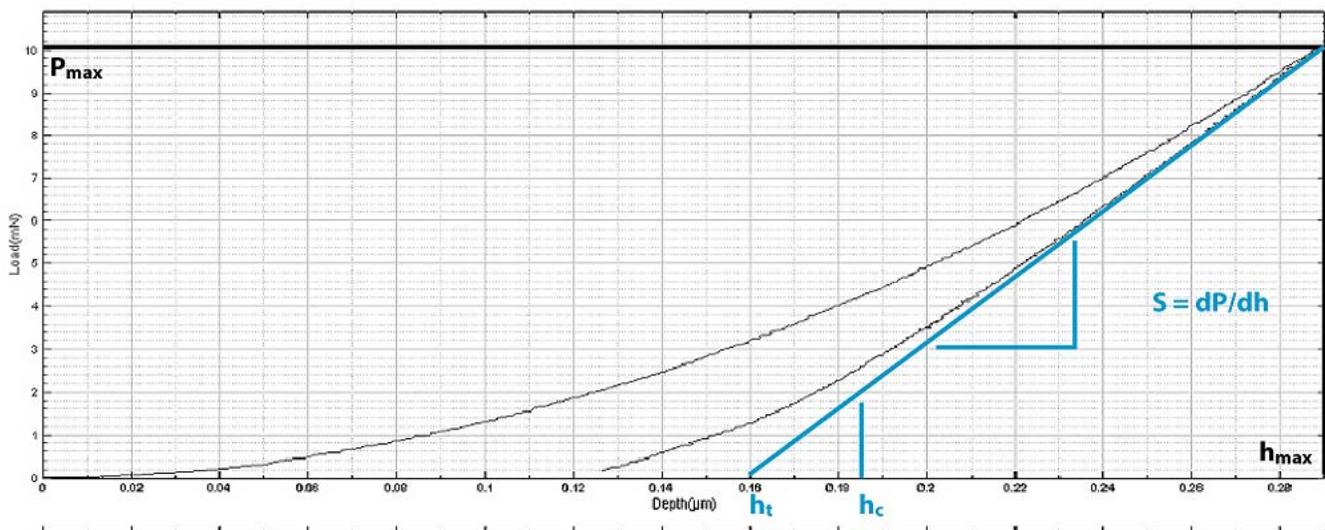
Nanoindentation is based on the standards for instrumented indentation, ASTM E2546 and ISO 14577. It uses an already established method where an indenter tip with a known geometry is driven into a specific site of the material to be tested, by applying an increasing normal load. When reaching a pre-set maximum value, the normal load is reduced until complete relaxation occurs. The load is applied by a piezo actuator and the load is measured in a controlled loop with a high sensitivity load cell. During the experiment the position of the indenter relative to the sample surface is precisely monitored with high precision capacitive sensor.

The resulting load/displacement curves provide data specific to the mechanical nature of the material under examination. Established models are used to calculate quantitative hardness and modulus values for such data. Nanoindentation is especially suited to load and penetration depth measurements at nanometer scales and has the following specifications:

Maximum displacement (Dual Range)	: 50 μm or 250 μm
Depth Resolution (Theoretical)	: 0.003 nm
Depth Resolution (Noise Level)	: 0.05 nm
Maximum force	: 400 mN
Load Resolution (Theoretical)	: 0.03 μN
Load Resolution (Noise Floor)	: 1.5 μN

Analysis of Indentation Curve

Following the ASTM E2546 (ISO 14577), hardness and elastic modulus are determined through load/displacement curve as for the example below.



Hardness

The hardness is determined from the maximum load, P_{max} , divided by the projected contact area, A_c :

$$H = \frac{P_{\max}}{A_c}$$

Young's Modulus

The reduced modulus, E_r , is given by:

$$E_r = \frac{\sqrt{\pi}}{2} \frac{S}{\sqrt{A_c}}$$

Which can be calculated having derived S and A_c from the indentation curve using the area function, A_c being the projected contact area. The Young's modulus, E , can then be obtained from:

$$\frac{1}{E_r} = \frac{1-\nu^2}{E} + \frac{1-\nu_i^2}{E_i}$$

Where E_i and ν_i are the Young's modulus and Poisson coefficient of the indenter and ν the Poisson coefficient of the tested sample.

How are these calculated?

A power-law fit through the upper 1/3 to 1/2 of the unloading data intersects the depth axis at h_t . The stiffness, S , is given by the slope of this line. The contact depth, h_c , is then calculated as:

$$h_c = h_{\max} - \frac{3P_{\max}}{4S}$$

The contact Area A_c is calculated by evaluating the indenter area function. This function will depend on the diamond geometry and at low loads by an area correction.

For a perfect Berkovich and Vickers indenters, the area function is $A_c=24.5h_c^2$ For Cube Corner indenter, the area function is $A_c=2.60h_c^2$ For Spherical indenter, the area function is $A_c=2\pi Rh_c$ where R is the radius of the indenter. The elastic components, as previously mentioned, can be modeled as springs of elastic constant E , given the formula: $\sigma = E\varepsilon$ where σ is the stress, E is the elastic modulus of the material, and ε is the strain that occurs under the given stress, similar to Hooke's Law. The viscous components can be modeled as dashpots such that the stress-strain rate

relationship can be given as,
$$\sigma = \eta \frac{d\varepsilon}{dt}$$
 where σ is the stress, η is the viscosity of the material, and $d\varepsilon/dt$ is the time derivative of strain.

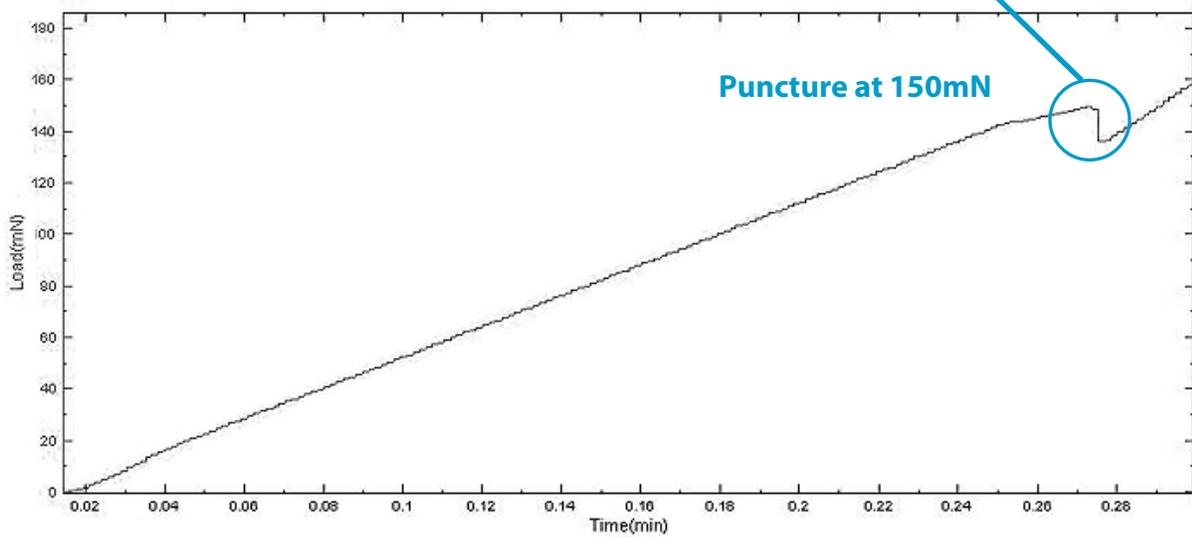
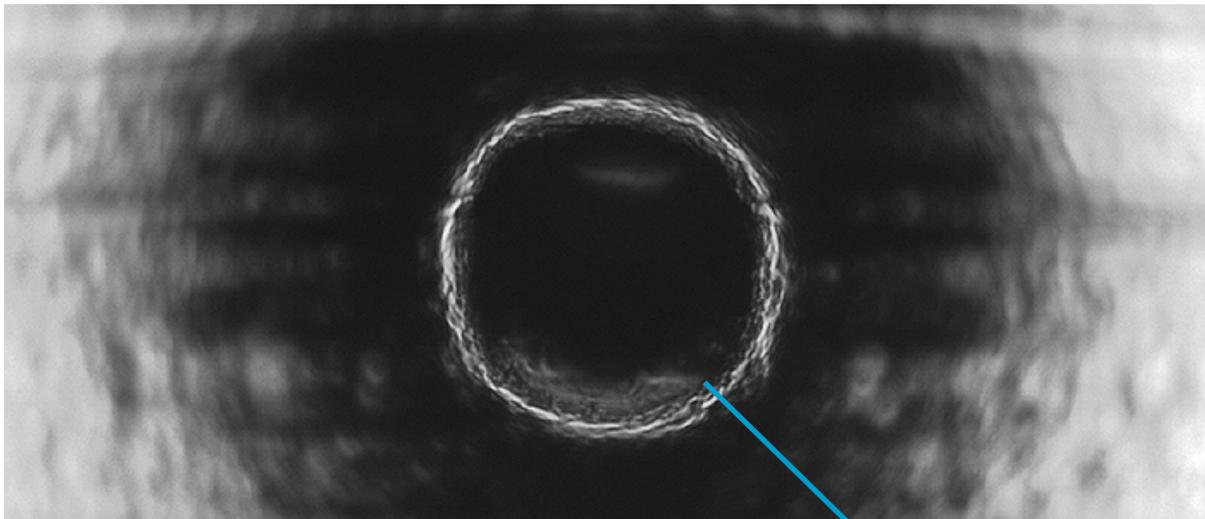
Since the analysis is very dependent on the model that is chosen. Nanovea provides the tool to gather the data of displacement versus depth during the creep time. The maximum creep displacement versus the maximum depth of indent and the average speed of creep in nm/s is given by the software. Creep may be best studied when loading is quicker. Spherical tip might be a better choice.

Other tests possible includes the following:

Puncture Resistance, Stress-Strain & Yield Stress, Fracture Toughness, Compression Strength, Fatigue testing and many others.

TEST CONDITIONS

Applied Force (mN)	400
Loading rate (mN/min)	600
Unloading rate (mN/min)	600
Indenter type	Cylindrical Flat



CONCLUSION

In conclusion, we have shown how the Nanovea Mechanical Tester, in Nanoindentation mode, provides precise measurement of puncture resistance and has a superior advantage compared to traditional instruments. Other tests possible with the same system, for example, depth versus load also allow hardness, elastic modulus and creep to be tested with a sharp Berkovich diamond or during a more compressive test with a sphere or flat indenter. Fatigue could be tested with multiple cycle loading and yield strength can be tested with increasing load multiple cycles. With the controlled XY stage, the same instrument can be used to measure scratch and marring properties or to measure coefficient of friction of these film samples. Multi-pass wear is also a common test as it provides important information on the long term viability. Studying the coatings on films and foils could also be done using the lower load range of the nano module. To learn more about [Nanovea Nanoindentation](#).