

COMPRESSION MEASUREMENT OF FOAM
WITH MICROINDENTATION



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INTRO

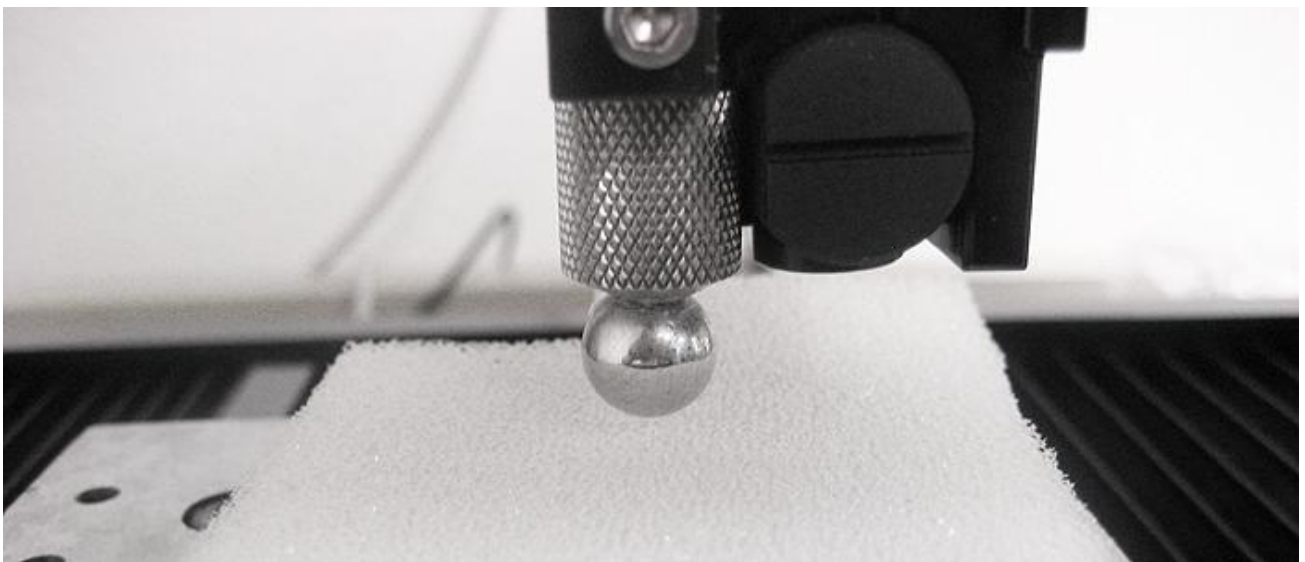
Vital throughout many industries, solid foam is a lightweight cellular material classified into two types based on pore structure: open and closed cell. Open cell structured foam is soft due to broken pores connected to each other forming an open interconnected network. Closed cell foam is dense with intact pores and no interconnectivity. Closed cell foam has a higher compressive strength due to its structure. It is this variance in density that can determine foam type, its intended use and its ultimate success.

IMPORTANCE OF DEPTH VERSUS LOAD COMPRESSIVITY OF FOAMS

Standard compressive measurement instruments are not capable of low loads and fail to provide adequate depth data for soft foam materials. Therefore Nanovea Nano or Microindentation mode provides the ability to precisely measure the compressivity of soft foam materials. Measuring depth versus load during the compression and decompression allows calculation of both hardness and elastic modulus.

MEASUREMENT OBJECTIVE

In this application, the Nanovea Mechanical Tester, in Microindentation mode (seen below), is used to measure the Compressive Measurement of various foams to show a range of compression data. A spherical tip was used in our study, although a flat wide tip could have been used to analyze the compression property of the foam which can be a different approach to this study. This would be very useful in cases where the material would have a distinct texture (such as honeycomb) on the surface. This was not the case with the samples tested in this study.



MICROINDENTATION MEASUREMENT (MHT)

Principle

Microindentation test is based on the standards for instrumented indentation, ASTM E2546 and ISO 14577. It uses an 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 partial or complete relaxation occurs. This procedure is performed repetitively; at each stage of the experiment the position of the indenter relative to the sample surface is precisely monitored with an optical non-contact depth sensor.

For each loading/unloading cycle, the applied load value is plotted with respect to the corresponding position of the indenter. 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.

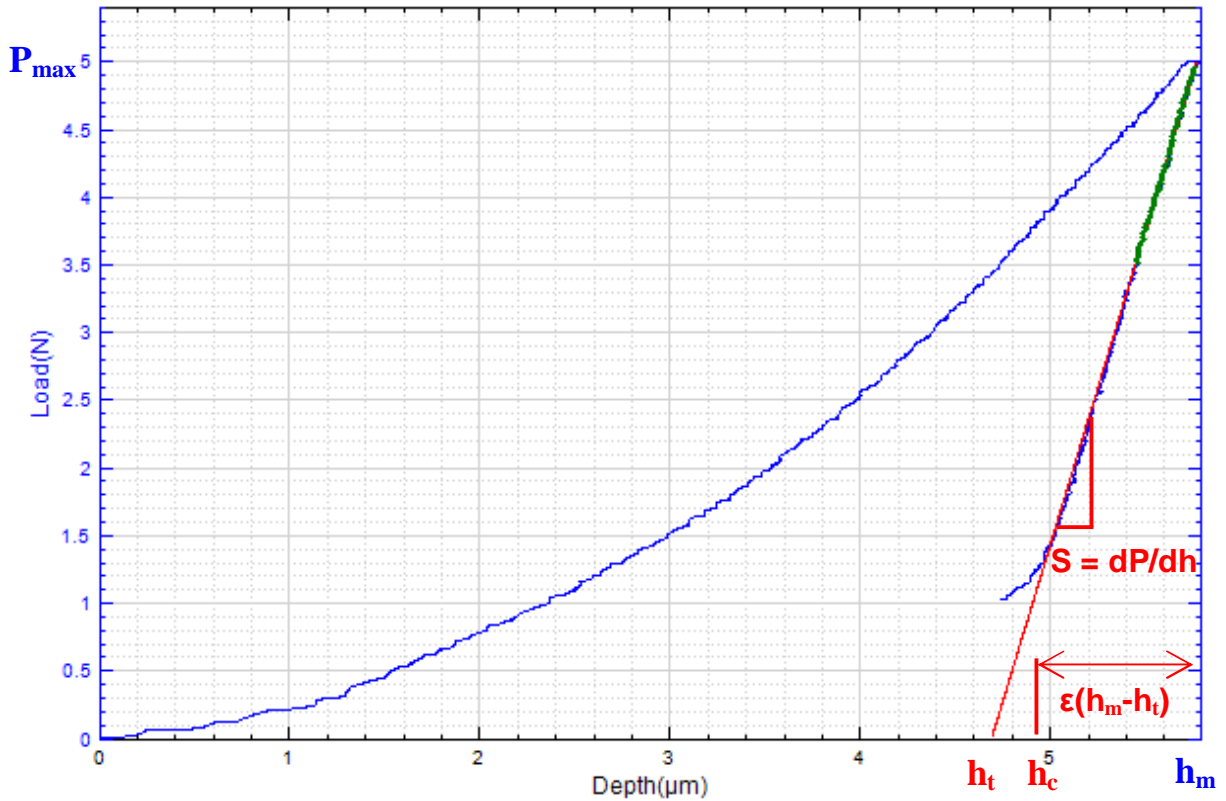
Microindentation is especially suited to perform tests of penetration depths in the micrometer scale and has the following specifications:

Specifications

- Maximum indenter range: 50mm
- Displacement resolution: 10 nm
- Load application: Z motor controlled with force feedback loop
- Normal load noise floor resolution: 1.5mN
- Minimum load: 10 mN
- Maximum load: 30 N
- Contact force hold time: Unlimited

Analysis of Indentation Curve

A typical load/displacement curve is shown below, from which the compliance $C = 1/S$ (which is the inverse of the contact stiffness) and the contact depth h_c are determined after correction for thermal drift.



A simple linear fit through the upper 1/3 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:

$$h_c = h_m - \varepsilon(h_m - h_t)$$

where ε depends on the investigated material.

In practice, a more meticulous approach is used where a power law function is used to describe the upper 80% of the unloading data:

$$P = P_{\max} \left(\frac{h - h_0}{h_m - h_0} \right)^m$$

where the constants m and h_0 are determined by a least squares fitting procedure. The contact stiffness $S (=1/C)$ is given by the derivative at peak load:

$$S = \left(\frac{dP}{dh} \right)_{\max} = mP_{\max} \left[\frac{(h_m - h_0)^{m-1}}{(h_m - h_0)^m} \right] = mP_{\max} (h_m - h_0)^{-1}$$

and the tangent depth, h_t , is thus given by:

$$h_t = h_m - \frac{P_m}{S}$$

The contact depth, h_c , is then:

$$h_c = h_m - \varepsilon(h_m - h_t)$$

where ε now depends on the power law exponent, m . Such an exponent can be summarized for different indenter geometries:

Elastic indentation Behavior (indenter geometry)	m (power law exponent)	ε
Flat	1	1
Paraboloid	1.5	0.75
Conical	2	0.72

Calculation of Young's Modulus and Hardness

Young's Modulus:

The reduced modulus, E_r , is given by:

$$E_r = \frac{\sqrt{\pi}}{2} \frac{S}{\sqrt{A_c}} = \frac{\sqrt{\pi}}{2} \frac{1}{C} \frac{1}{\sqrt{A_c}}$$

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.

Hardness:

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

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

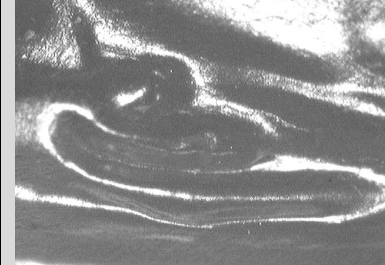
TEST CONDITIONS AND PROCEDURE

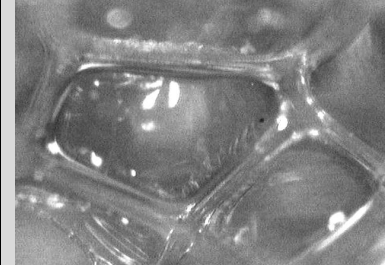
The following indentation parameters were used:


	Soft	Medium	Hard
Maximum force (N)	0.20	3.00	5.00
Loading rate (N/min)	0.05	0.40	2.00
Unloading rate (N/min)	0.05	0.40	2.00
Creep (s)	15		
Computation Method	Oliver & Pharr		
Indenter type	Spherical (10mm diameter)		

RESULTS

These full results present the measured values of Hardness/Compressibility and Elastic modulus as well as the penetration depth (d).

	H [MPa]	E [MPa]	Δd [mm]
	Soft	0.0038	0.016

	H [MPa]	E [MPa]	Δd [mm]
	Medium	0.0545	0.177

	H [MPa]	E [MPa]	Δd [mm]
	HARD	0.1249	1.628

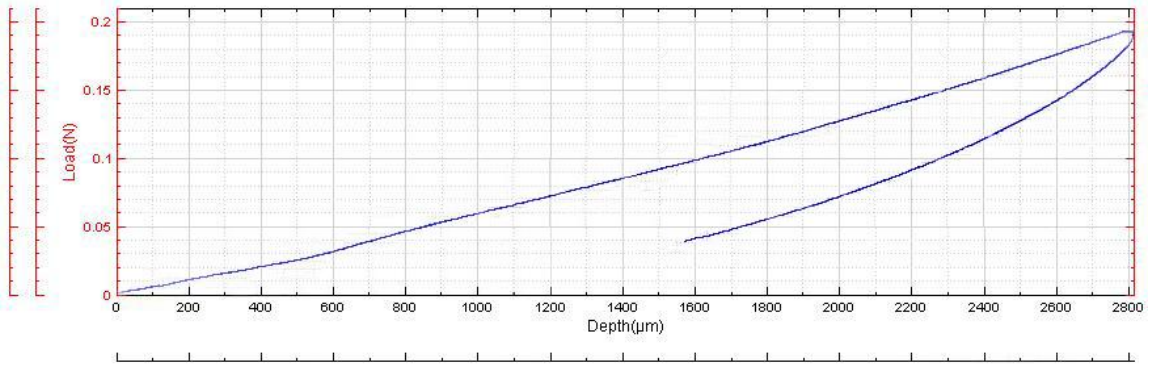


Figure 1: Loading Curve – Soft Foam

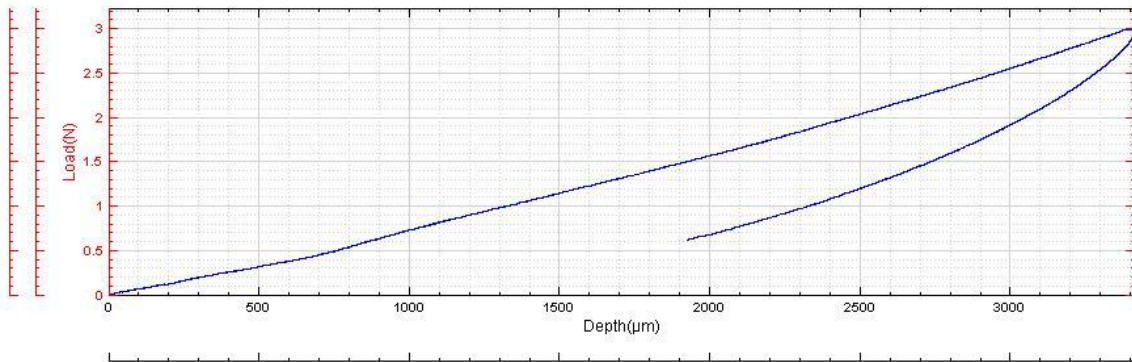


Figure 2: Loading Curve – Medium Foam

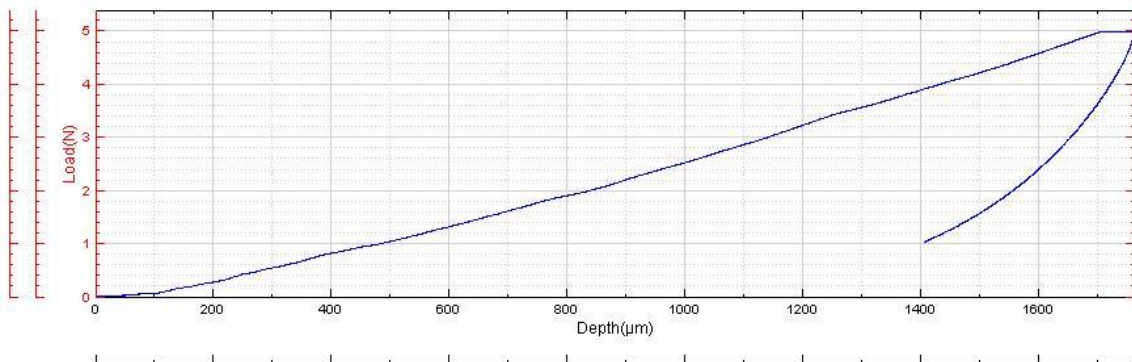


Figure 3: Loading Curve - Hard

CONCLUSION:

In conclusion, we have shown that the Nanovea Mechanical Tester, in Microindentation mode, can provide hardness/compressibility and elastic modulus data of foam material. The use of the large Z range allows test with displacement up to 50mm at load from the 0.1N to 200N. Lower loads down to 0.1mN, is possible for extremely sensitive compression tests using the nano module. Displacement of the same order makes the use of this technique possible on very soft sponges or even bio materials. Additionally studies could include compressibility of food (such as fruits) and fracture when testing materials such as pills. Multi-cycling of the load can also be used to study the fatigue properties of materials tested. AFM or optical profiler integration is also an option to measure the residual surface deformation or damages. The optical profiler is an ideal non contact option to study 3D measurements of the foam surface.