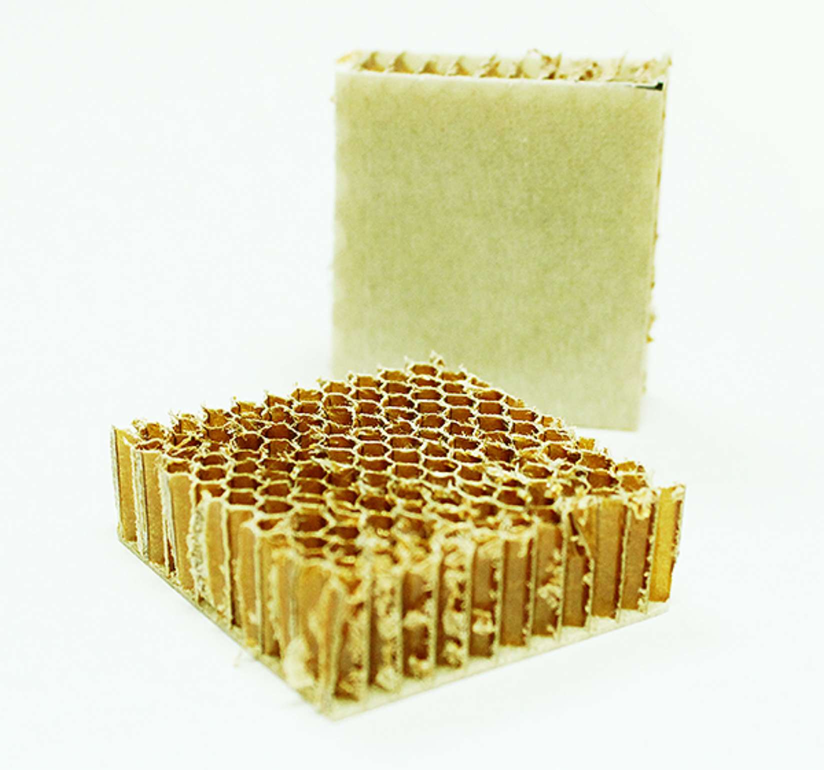
HONEYCOMB MECHANICAL BEHAVIOR USING MACROINDENTATION



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INTRODUCTION

Honeycomb-structured panels consist of honeycomb cores layered between two stiff thin sheets to form a sandwich-structured composite. Honeycomb panels can be manufactured using a variety of materials, such as paper, thermoplastics, aluminum and fiber-reinforced plastics. They are widely used in different industries, from aerospace industries, automotive and furniture to packaging and logistics.

IMPORTANCE OF MACROINDENTATION TEST ON HONEYCOMB STRUCTURE

The strength of honeycomb panels depends on several factors, such as the panel size, facing material and the density of the honeycomb cells within it. Mechanical integrity of the honeycomb structure is a key factor in manufacturing failure free product. Different ASTM standards have been developed to evaluate the overall compressive strength and tensile strength of panels, lamination strength of bond between facings and core of sandwich structure, as well as beam coefficients, such as bending stiffness, deflection and facing stress.

In aerospace industry where the honeycomb panels are most widely used, mechanical structure of minimal weight and excellent strength and durability is desirable. The thinner vertical walls in the core and facing fiber-reinforced plastic sheets demand high-precision local mechanical integrity inspection. Indentation is widely applied to measure the mechanical behaviors of materials at small scales[i]. In order to accurately evaluate the local mechanical properties of the honeycomb structure, indentation location control of high precision is critical.

MEASUREMENT OBJECTIVE

In this application, the Nanovea Mechanical Tester, in Macroindentation mode is used to measure the local mechanical properties of different locations on a honeycomb panel. We showcase the capacity of Nanovea Mechanical Tester in performing high load indentation measurement on a honeycomb panel with high precision and user friendliness using *Broadview Map Selection Tool* (Patent Pending).

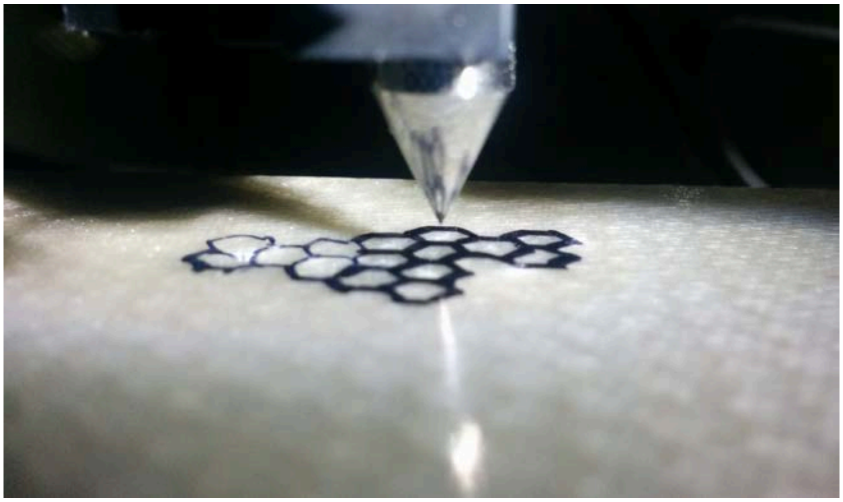


Fig. 1: Macroindentation tip on the Honeycomb panel.

TEST CONDITIONS

Broadview Map Selection Tool provides a user-friendly tool to observe and precisely select the intended area for mechanical testing. In this particular study, a map of 20×20 images were taken by the optical microscope integrated in the Nanovea Mechanical Tester as shown in Fig. 3a, in order to obtain a better observation of the overall honeycomb panel surface for indentation. Four representative areas on the honeycomb panel were directly selected on the image for macro indentation as numbered. The four macro indentation test were performed in one shot under the test conditions summarized in Table 1. The geometry of the 100 µm flat tip is displayed in Fig. 2.

The procedure set up by *Broadview Map Selection Tool* can be saved and reapplied on other samples of the same geometry, so that the indentations at the same load and location will be automatically performed. This function substantially facilitates quality control of large batches of samples of the same geometry.

Maximum force (N)	150
Loading rate (N /min)	300
Unloading rate (N /min)	300
Indenter type	100 µm flat tip

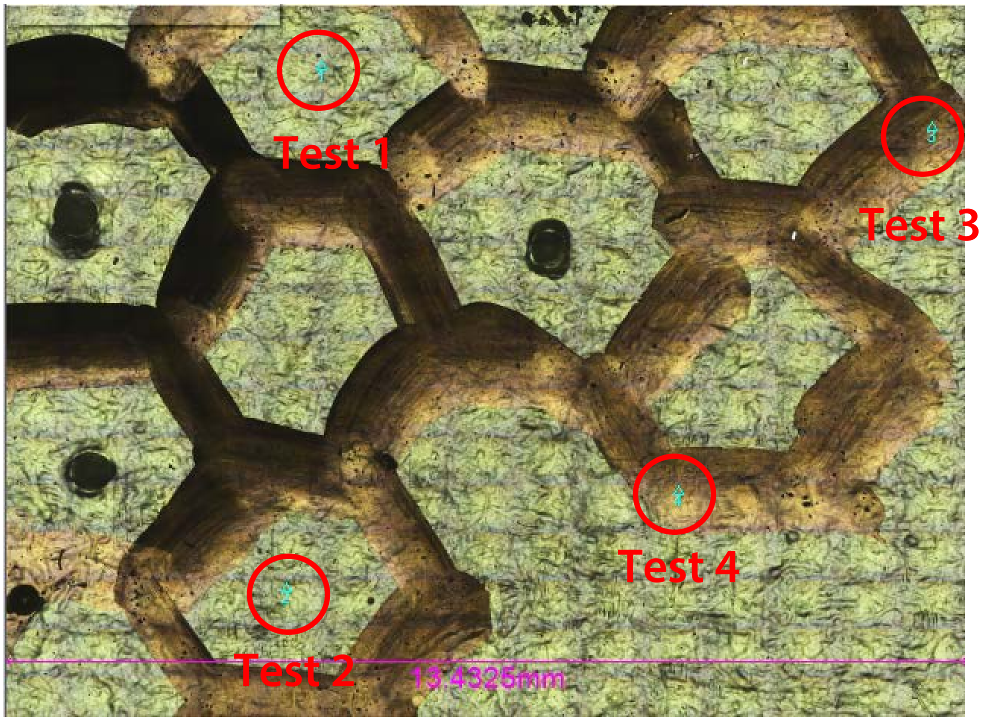
Table 1: Test conditions of the Macroindentation.

Fig. 2: 100 µm flat tip geometry.

RESULTS AND DISCUSSION

The images of the indentations at the four selected locations before and after the indentation tests are displayed in Fig. 3. We demonstrate that the excellent position control of the sample stage in Nanovea Mechanical Tester allows users to precisely pinpoint the target areas on this image map for mechanical properties testing. This makes measurement of the local mechanical properties substantially less time-consuming and more user friendly.

(a) Before indentation:



(b) After indentation:

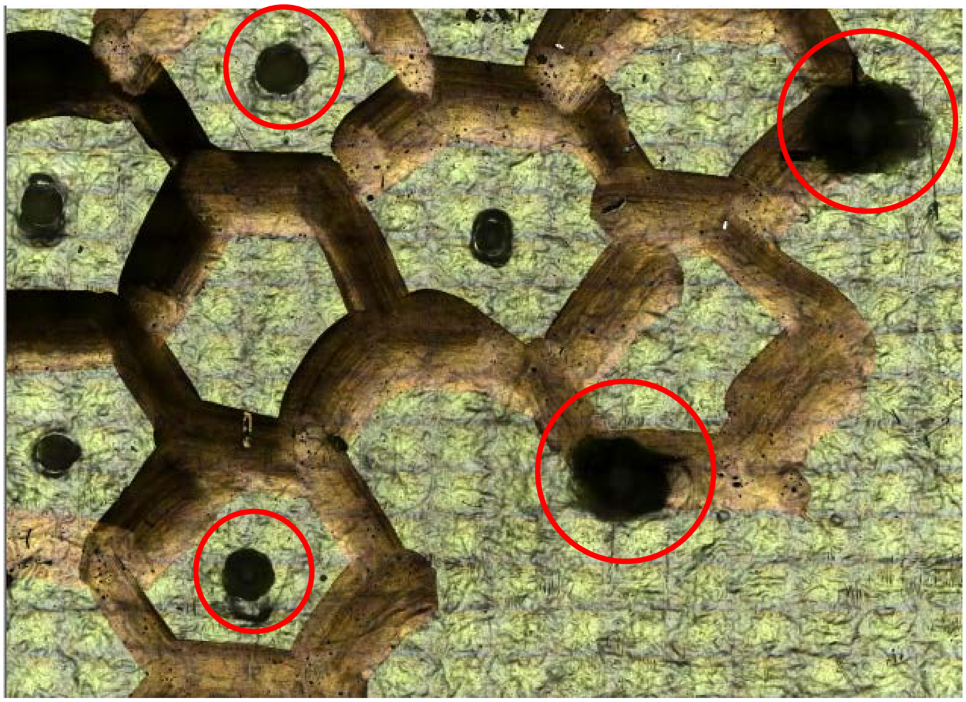


Fig. 3: Broadview Map of the indentations on the honeycomb panel before and after the test.

It can be observed in Fig. 3 that surprisingly the faceplate above the hollow cell center (Tests 1 and 2) exhibits stronger strength compared to that above the joint of the vertical walls (Tests 3 and 4). Indents of much smaller size is created at the center of the hollow cell. Such observation is in agreement with the load-displacement curves of the indentations recorded in situ as shown in Fig. 4. In a counterintuitive manner, the indenter on the joint region reaches a much larger depth above 1200 μm, compared to ~800 μm for that on the hollow cell center. As highlighted by a red dashed box in Fig. 4, accelerated depth penetration starts to take place at the depth of ~300 μm. This might be related to the piercing of the faceplate. When the indentation is performed above the hollow cell center, more deformation of the faceplate is allowed as the normal force is applied. This leads to increased contact area between the side face of the indenter and the deformed faceplate surface, which results in reduction of the concentrated pressure. In comparison, the supporting wall joint does not allow much elastic deformation of the faceplate during the indentation test. It therefore limits the increase of contact area between the side face of the indenter and the faceplate surface, leading to significantly higher concentrated pressure at the tip of the indenter.

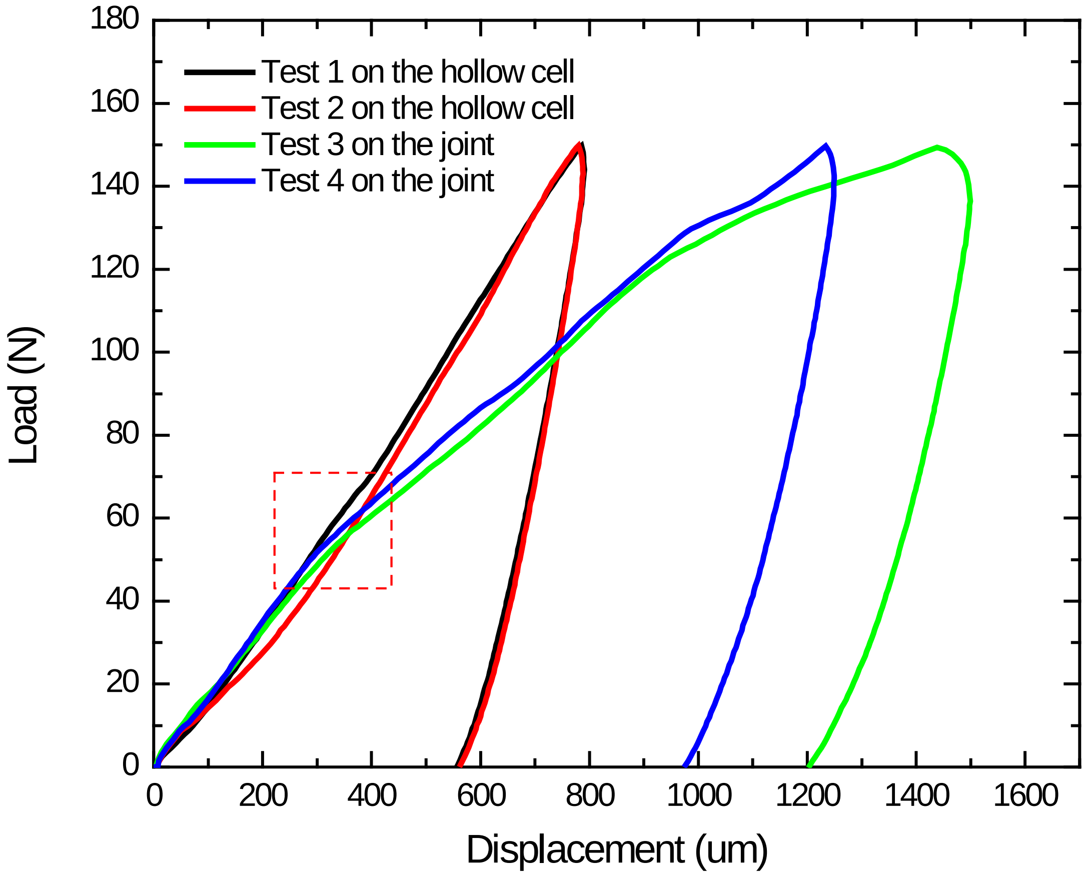


Fig. 4: Load-displacement curves of the indentations.

The resistance to repeated loading cycles is further investigated as shown in Fig. 5 and Fig. 6. Both tests were performed on the faceplate above the hollow cell center. When multiple loading and unloading cycles are applied during the indentation test, the indenter progressively penetrates through the top faceplate, leaving behind a much larger indentation mark on the faceplate as shown in Fig. 6. It should be noted that the pattern of the multiple loading and unloading cycles can be changed to better simulate the realistic application conditions.

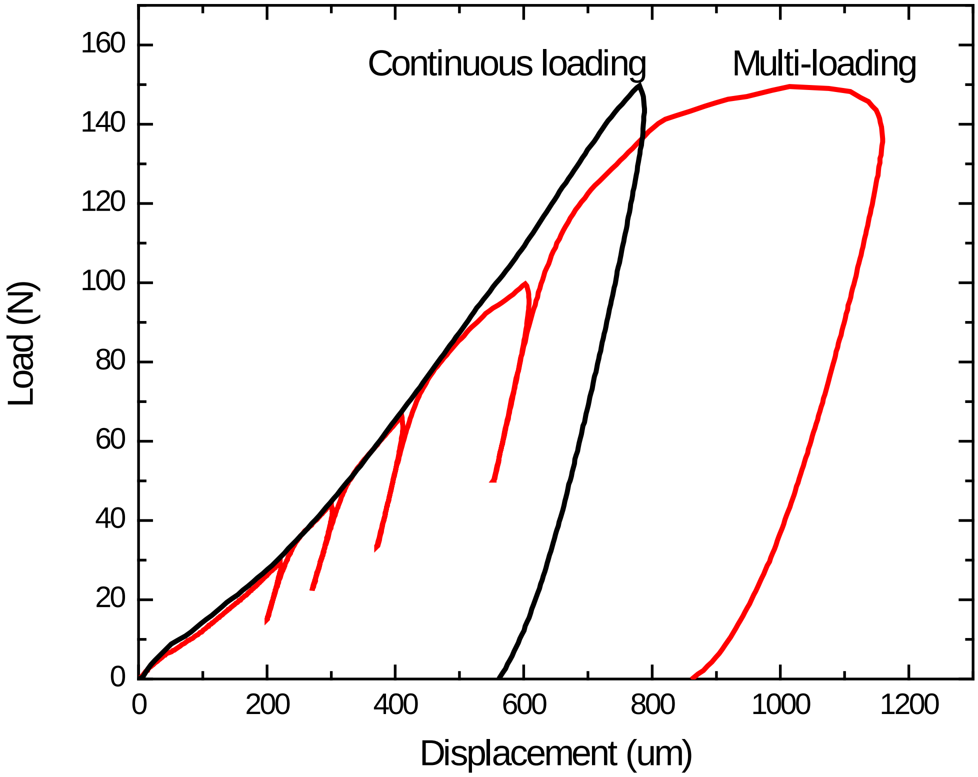


Fig. 5: Load-displacement curves of the honeycomb panel under continuous loading and multi-loading indentation tests.

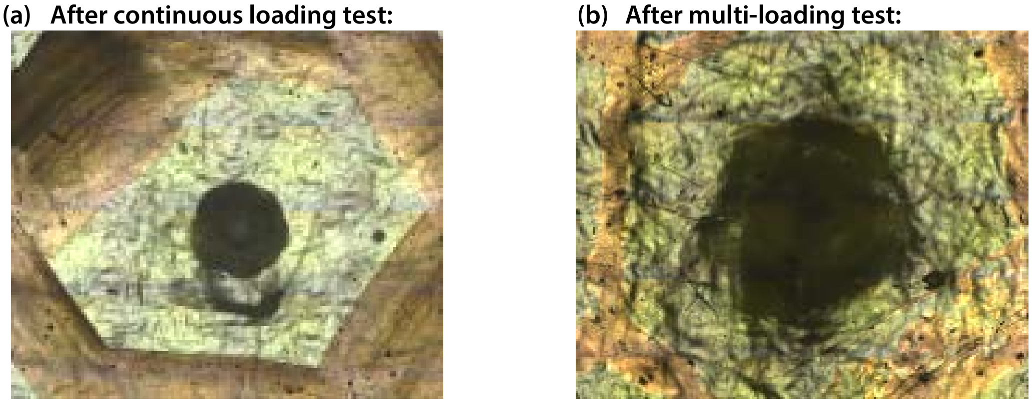


Fig. 6: Indentations on the honeycomb panel after continuous loading and multi-loading indentation tests.

CONCLUSION

In this study, we showcased the capacity of Nanovea Mechanical Tester in performing Macroindentation mapping on target areas of a honeycomb panel using patent pending

Broadview Map Selection Tool. The precise position control allows users to directly select the areas of interest for indentation on a large optical image array and perform accurate mechanical property measurements. We discover that interestingly, the faceplate above the hollow cell of the honeycomb structure exhibits stronger resistance to piercing compared to that above the joint of the vertical walls. Moreover, multi-loading process can pierce through the faceplate where continuous loading is not capable of.

The Nano, Micro or Macro modules of the Nanovea Mechanical Tester all include ISO and ASTM compliant indentation, scratch and wear tester modes, providing the widest and most user friendly range of testing available in a single system. Nanovea's unmatched range is an ideal solution for determining the full range of mechanical properties of thin or thick, soft or hard coatings, films and substrates, including hardness, Young's modulus, fracture toughness, adhesion, wear resistance and many others.

In addition, optional 3D non-contact profiler and AFM Module are available for high resolution 3D imaging of indentation, scratch and wear track in addition to other surface measurements such as roughness.

To learn more about Nanovea Mechanical Tester or Lab Services.

APPENDIX: MEASUREMENT PRINCIPLE

Nanoindentation 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 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)	: 0.15 nm
Maximum force	: 400 mN
Load Resolution (Theoretical)	: 0.03 μN
Load Resolution (Noise Floor)	: 0.3 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.

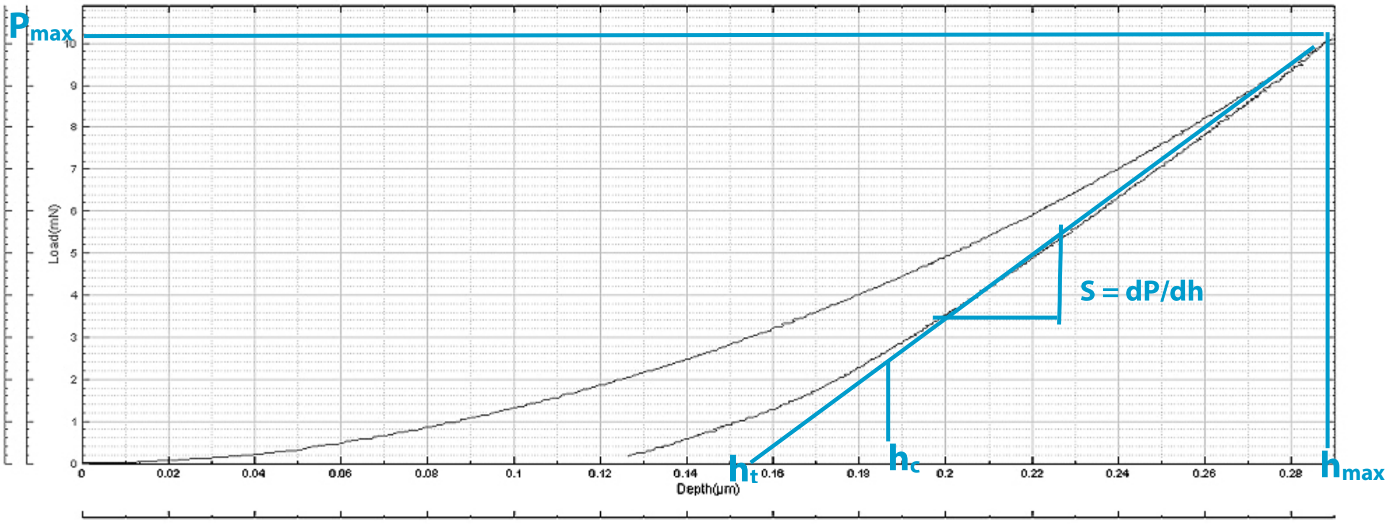


Fig. 7: Load-displacement curve of nanoindentation.

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's ratio of the indenter and ν the Poisson's ratio of the tested sample.

How are these calculated?

A power-law fit through the upper 1/3 to1/2 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:

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

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 is a better choice.

Other possible measurements by Nanovea Mechanical Tester:

Stress-Strain & Yield Stress, Fracture Toughness, Compression strength, Fatigue testing and many others.

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[i] **Schuh, C.A., Materials Today, Volume 9, Issue 5, May 2006, pp. 32–40**