WOOD HARDNESS & ELASTIC MODULUS USING MICROINDENTATION

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INTRODUCTION

Wood has a long history of being used as an important construction material for building houses, furniture, shelters, boats and many others, thanks to its structural strength, beautiful natural patterns, relatively low cost and ease of construction. As a naturally grown material, the individual cellular and fiber structure of the wood makes it a heterogeneous and anisotropic material of infinite variation of details. The same type of wood may possess different mechanical properties when the trees are subjected to the altered environmental influences such as growing areas, climate, soil conditions, and growing space[i].

Hardness and Young's modulus are two of the most important mechanical properties of wood. A precise and reliable measurement of these wood properties is critical in determining their level of durability and suitability for different uses. The high-precision load-displacement curves from the micro indentation measurement directly provide the physic-mechanical properties including hardness, Young's modulus, and creeping. Compared to conventional hardness measurements, the micro indentation tests by Nanovea Mechanical Tester avoid user errors during observing the imprint and determining its edge and size under the microscope. In addition, the elasticoplastic properties such as Young's modulus and creeping are measured at the same time, which are essential in selecting the wood of the best mechanical properties for targeted applications.

MEASUREMENT OBJECTIVE

In this application, the Nanovea Mechanical Tester, in microindentation mode is used to compare the mechanical properties of three different types of wood. We would like to showcase the capacity of Nanovea Mechanical Tester in performing hardness and Young's modulus on wood samples with high precision and reproducibility.

Fig. 1: Microindentation on a wood sample.

TEST CONDITIONS

The Micro Module of the Nanovea Mechanical Tester was applied to perform microindentation on three wood samples (Cherry, Maple and Walnut) using a Vickers indenter. All indentations were performed to a maximum load of 5 N. The test conditions are summarized in Table 1. Six tests were carried out on each sample to ensure result reproducibility.

As an orthotropic material, the mechanical properties of wood is independent in three directions, namely, longitudinal, tangential and radial. Moreover, the irregular grains such as knots, burls, and “crotch” wood or porosity and cracks may also cause variation in the measured values of hardness and Young’s modulus. In this study, we located the areas for measurements on a smooth wood surface with regular wood patterns. This is followed by measuring the side hardness and Young’s modulus on the plank surface perpendicular to the wood grain, in order to achieve better repeatability and tighter standard deviation.

Maximum force (N)	5
Loading rate (mN /min)	10
Unloading rate (mN /min)	10
Creep (s)	5
Indenter type	Vickers

Table 1: Test conditions of the microindentation test.

RESULTS AND DISCUSSION

The representative load-displacement curves of the indentations on the three wood samples are shown in Fig. 2 below. The Maple sample shows a penetration depth of ~90 µm, compared to that below 60 µm for Cherry and Walnut, indicating its relatively soft characteristics. The values of hardness and Young’s Modulus calculated using Oliver and Pharr Method [ii] are summarized and compared in Fig. 4. The Cherry sample possesses a high hardness of 0.095 GPa, compared to 0.031 and 0.078 GPa, respectively, for Maple and Walnut. The Young’s modulus values of the Cherry, Maple and Walnut samples are 1.63, 0.88 and 2.28 GPa, respectively.

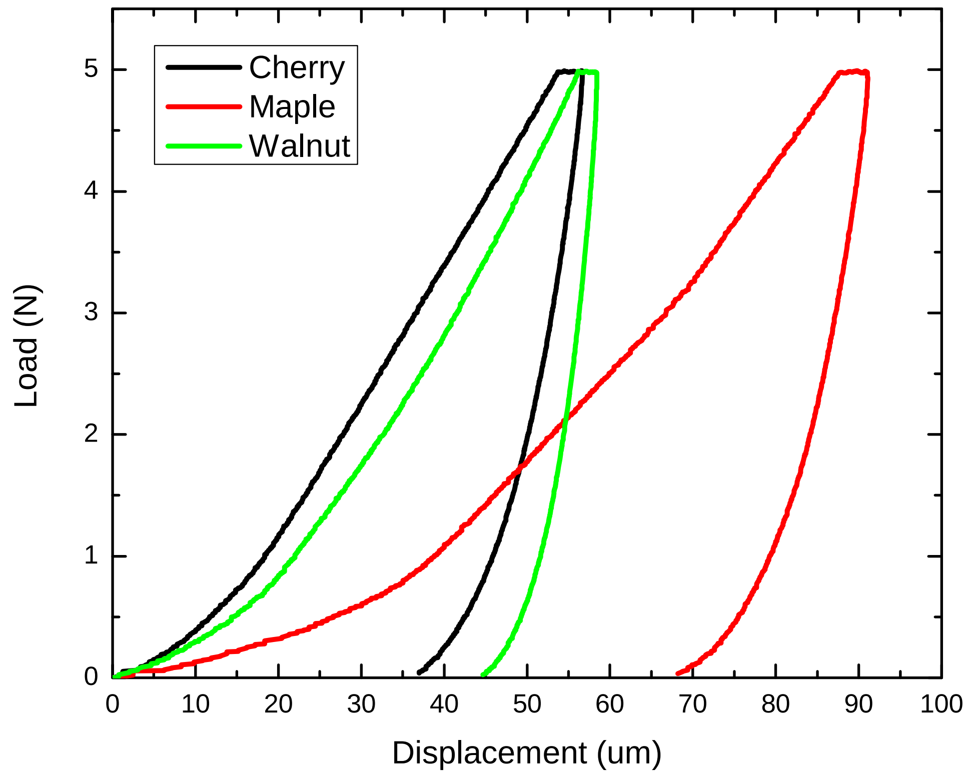

Fig. 2: Load-displacement curves of the indentations.

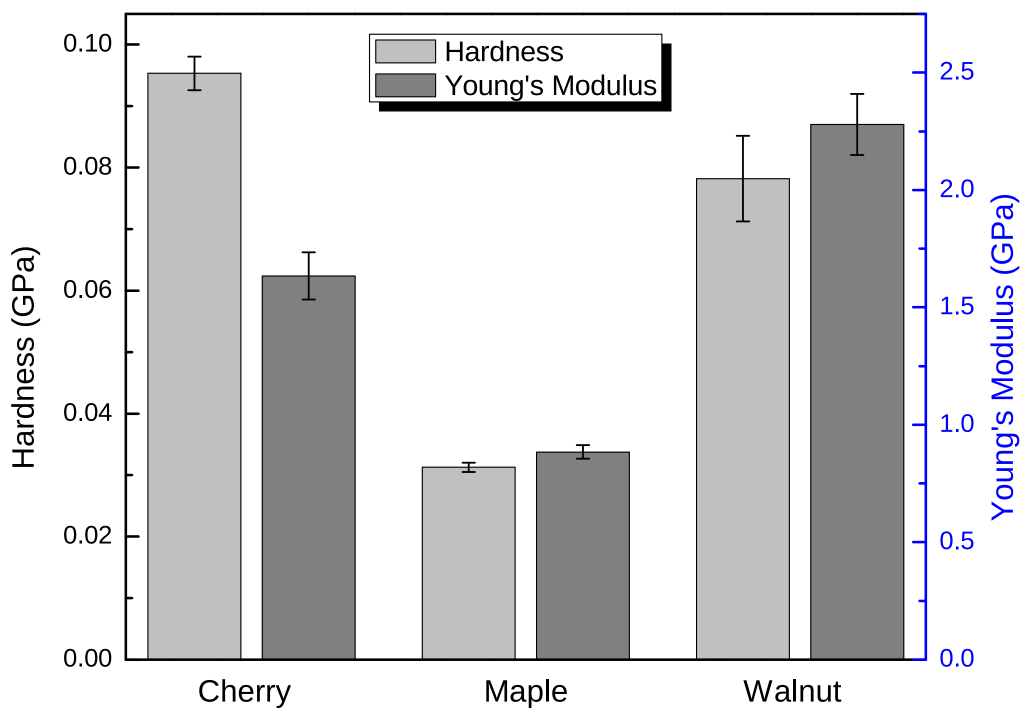

Fig. 3: Hardness and Young's Modulus of the wood samples.

CONCLUSION

In this study, we showcased the capacity of Nanovea Mechanical Tester in performing micro hardness tests on wood samples. It is an ideal tool for measuring the mechanical properties such as hardness and Young's modulus of different types of wood. The cherry sample shows the highest hardness of 0.095 GPa, compared to 0.031 and 0.078 GPa, respectively, for Maple and Walnut. The Young's modulus values of the Cherry, Maple and Walnut samples are 1.63, 0.88 and 2.28 GPa, respectively.

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

Microindentation 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.

Analysis of Indentation Curve

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

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=2πRh_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 dε/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] **http://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr113/ch04.pdf**

[ii] **Oliver, W. C.; Pharr, G. M., Journal of Materials Research, Volume 7, Issue 6, June 1992, pp.1564-1583**