Alternative Measures of Hardwood Flooring Hardness

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New Product Development

Outline

- About Armstrong
- Markets, and Brands
- Background on Wood Hardness Measurements
- Review of Measurement Systems
- Brinell Hardness Test
- Background on Armstrong Macro-Indentation Test
- Test Results
- Conclusions

About Armstrong…

- **Global leader in the design, manufacture and marketing of floors, ceilings and cabinets.**
- **2009 net sales totaled nearly $2.8 billion.**
- **Based in Lancaster, PA, Armstrong operates 36 plants in 9 countries and has approximately 10,800 employees worldwide**
- **Armstrong Flooring Products (AFP) has the leading market position in vinyl sheet, vinyl tile, hardwood flooring, & laminate in the US.**
- **Armstrong has 3 primary business units:**
  - **Floors**
  - **Ceilings & Walls**
  - **Cabinets**

Markets, and Brands

- **Markets – Residential, Commercial, Builder, "Big Box" Retail, Specialty Retail Brands**
  - **Armstrong®**
  - **Bruce®**
  - **HomerWood®**
  - **T-Morton®**

Armstrong® HARDWOOD FLOORING

Bruce® hardwood floors

Armstrong® FLOORING PRODUCTS

HOMERWOOD® PREMIUM HARDWOOD FLOORING

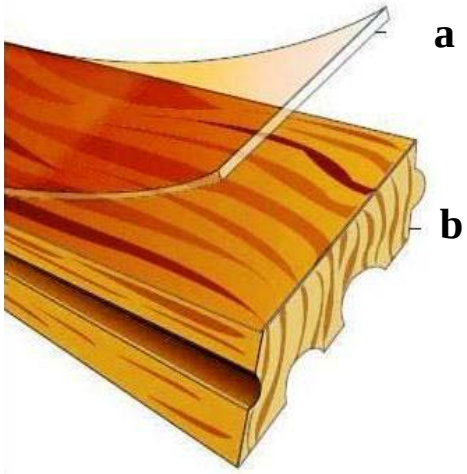
T. MORTON & CO.™ PREMIUM HARDWOOD FLOORS

Background

- The current industry standard for indentation resistance is the Janka Hardness test – ASTM D143 - 09
  - A 0.444" diameter steel ball is forced into the surface of a 2” thick specimen to a depth of 0.222".
  - The load in lbs. at this point is recorded as the hardness of the specimen.

However, a majority of current residential solid wood floors are 5/16” to ¾” thick.

Prefinished Solid Hardwood Flooring



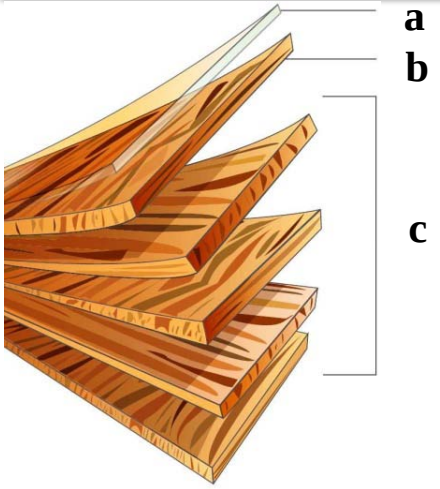
a) Protective coating
b) Solid wood

Engineered wood floors are typically 3/8” thick.

In addition, engineered floors consist of veneers in the core typically composed of softer species.

Sketch source: “Armstrong Flooring Buyers Guide”

Prefinished Engineered Hardwood Flooring



a) Protective coating
b) Face Ply
c) Multiple Ply core

- The 2” thick sample requirement and the 0.222” indent depth make it more appropriate to use the Janka Hardness test to evaluate the raw material (lumber) to manufacture flooring .
- The thickness, indent depth requirement, presence of coatings and multiple species presents a need to develop a universal indentation resistance test for the finished product - wood flooring.

Objective

Objective:

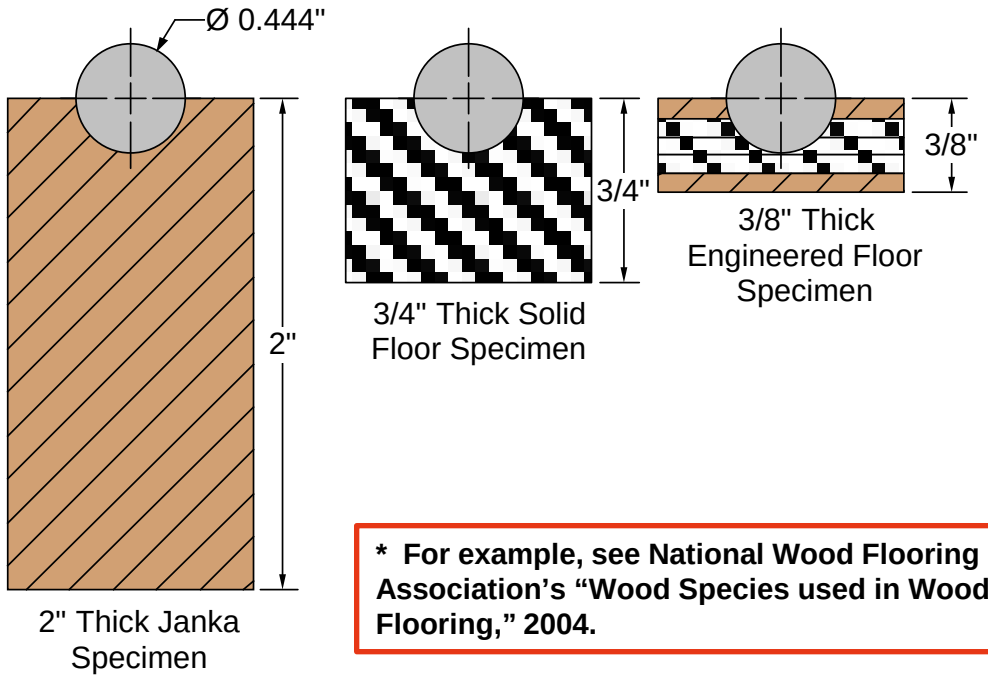
- To evaluate three test methods to characterize the indentation resistance of hardwood flooring.
  - Janka Hardness for species purely from the "Wood Handbook."
  - The Armstrong Balldrop test.
    - This is a simple test that we believe "connects" with our customers.
  - The Armstrong Macro-Indentation test based on a technique similar to nano-indentation.
    - This is a test in which a true measure of hardness is calculated.

Test Materials:

- The materials used in the evaluation were solid and engineered wood flooring with the following species:
  - Brazilian Cherry
  - Maple
  - Red Oak
  - Walnut

- Flooring samples from both Armstrong products and 6 other manufacturers' products were used in the testing.

Janka Hardness Test



*** For example, see National Wood Flooring Association's "Wood Species used in Wood Flooring," 2004.**

Procedure

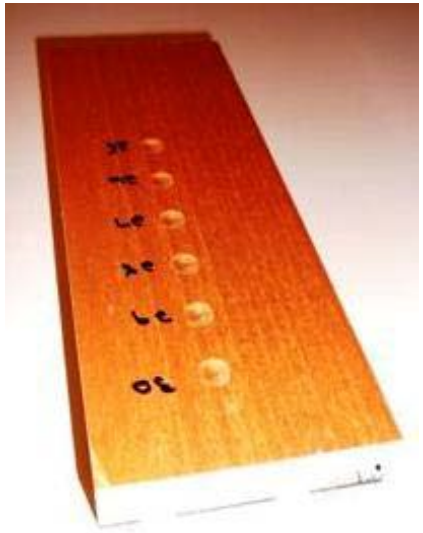
- **Instron Universal Tester.**
- **0.444" diameter hardened steel ball.**
- **Pressed to an indentation depth of 0.222" into a 2" thick piece of wood.**

Measurement

- **Force (in lbs) required to achieve the 0.222" indentation depth is recorded as the Janka Hardness.**

- **Janka Hardness is an industry accepted test for wood*.**
- **However, the specimen thickness (2"), indentation depth (0.222"), and presence of coating on hardwood flooring samples make the Janka test more appropriate for raw material.**
- **Published Janka Hardness is specific to a single species. It does not account for multiple species present in engineered wood floors.**

Armstrong Balldrop Test



Solid Floor Balldrop Sample

Engineered Floor Balldrop Sample

Procedure

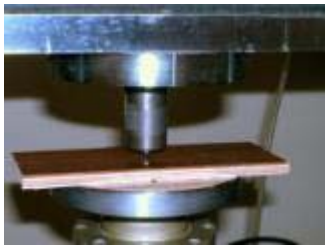
- Custom built Balldrop tester.
- ½" diameter hardened steel ball.
- 12 oz weight ball & holder assembly.
- 15" drop height.

Measurement

- Indentation depth measured on tested samples.

- Armstrong Balldrop test measures final indentation depth after indenter is dropped from 15".
- The final indentation depth is what our customer will see – so we believe this test "connects" better with the customer.
- This is a simple, statistically repeatable and reproducible test. It passed a Gauge R&R test for flooring samples.

Armstrong Macro-Indentation Test



Procedure

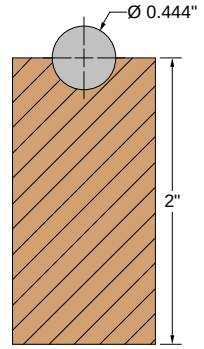
- Instron Universal tester.
- 5/8” diameter hardened steel ball.
- Pressed to a maximum load of 320 lbs. into flooring sample and unloaded.

Measurement

- Indentation depth at maximum load.
- Slope of unloading curve used to calculate Hardness = Load/Indented area.

- Hardness is defined as = Load/Indented area.
- This test calculates true hardness based on calculations adopted from Nano-indentation techniques.

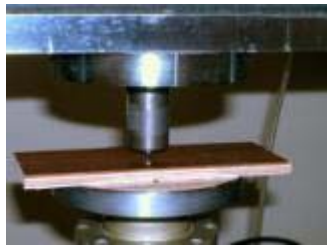
Raw Material vs. Finished Product Tests



2" Thick Janka Specimen

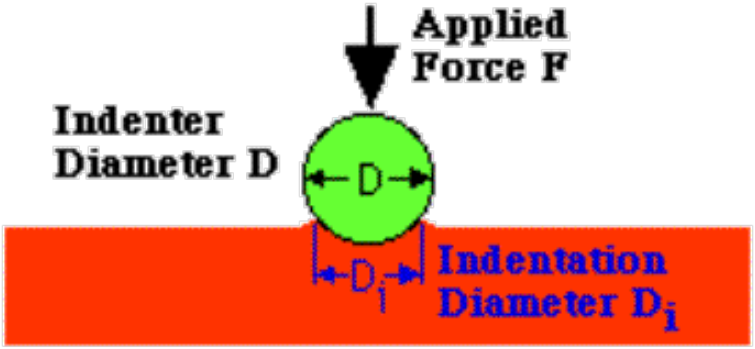
Janka Hardness test for raw materials

Balldrop Test, Macro-Indentation test for finished products



- **The Janka hardness test (ASTM D143-09) can be seen as a raw material test that corresponds to physical and mechanical properties of wood as a raw material.**
- **Both the Armstrong Ball Drop Test and the Armstrong Macro-indentation Test are finished product tests that assess the indent resistance of flooring products relative to consumer expectations.**

Brinell Hardness



$$BHN = \frac{F}{\frac{\pi}{2} D \cdot (D - \sqrt{D^2 - D_i^2})}$$

where
BHN = the Brinell Hardness number
F = the imposed load in kg
D = the diameter of the spherical indenter in mm
D_i = diameter of the resulting indenter impression in mm

Source:
http://www.calce.umd.edu/general/Facilities/Hardness_ad_.htm

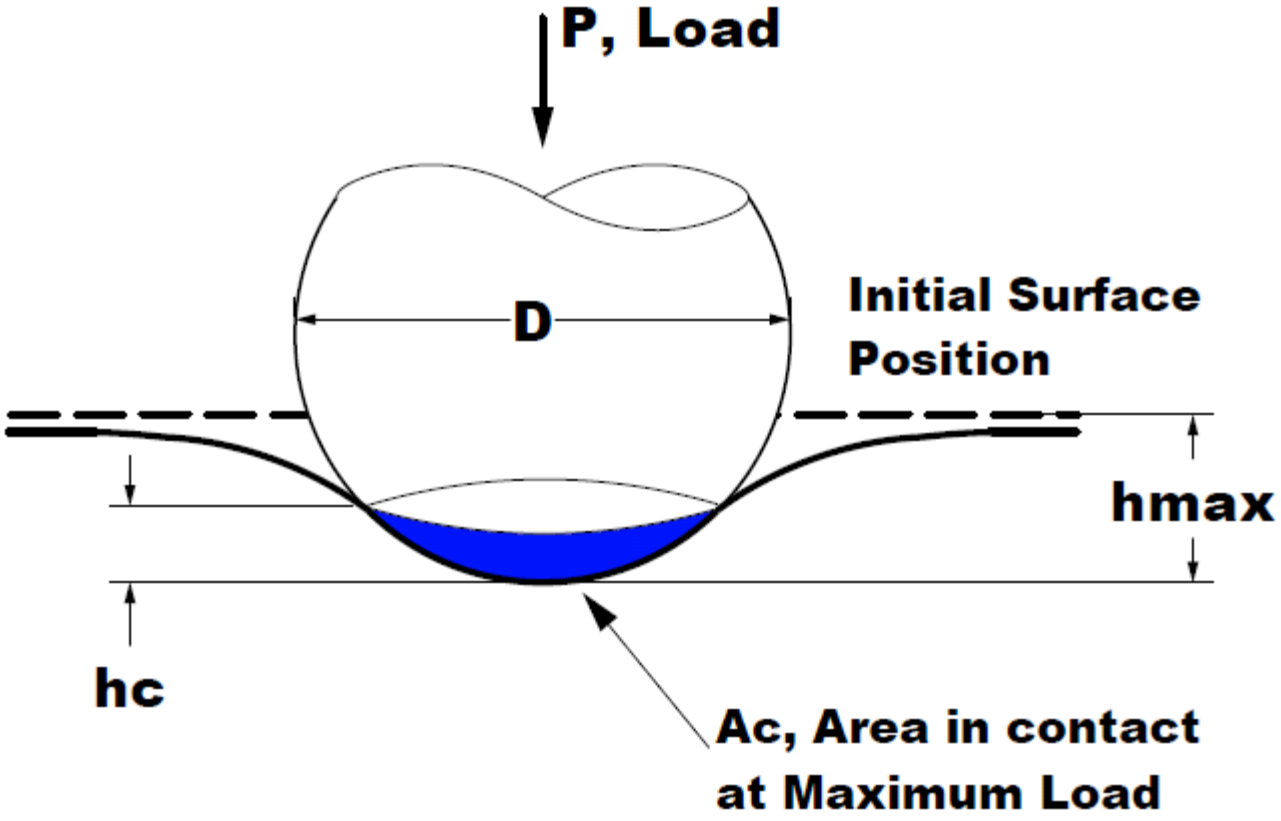
Brinell hardness numbers, HBS	
Material	**Hardness**
Softwood (e.g., pine)	1.6
Hardwood	2.6–7.0
Aluminium	15
Copper	35
Mild steel	120
18-8 (304) stainless steel annealed	200
Glass	1550
Hardened tool steel	1500–1900

Source: http://en.wikipedia.org/wiki/Brinell_hardness_test

- **Brinell Hardness is an industry accepted test for metallic materials.**
- **Also calculates Hardness as = Load/Indented Area.**

Macro-Indentation Terminology

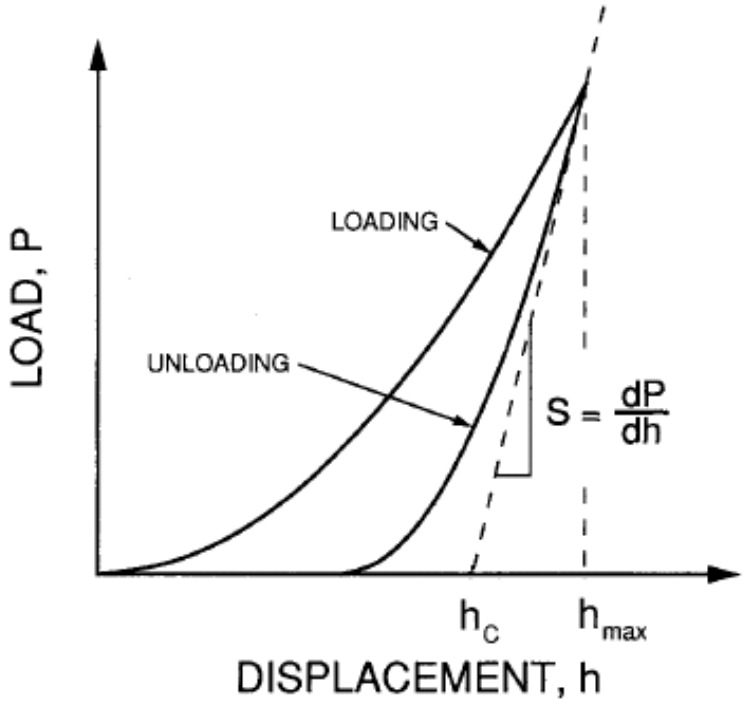
Schematic Sketch of a Ball Indenting a Sample Material



The test material responds as follows:

- **Elastic Deformation – this is recovered at the end of the test.**
- **Plastic Deformation (permanent). This is the final indent depth at the end of the test.**

Loading – Unloading curve



G. M. Pharr et al., "On the generality of the relationship among contact stiffness, contact area, and elastic modulus during indentation", J. Mater. Res., Vol 7, No. 3 March 1992

- The analytical development for nano-indentation shows that the initial slope of the unloading portion of the Load - Displacement curve can be used to calculate the hardness.
- Elastic contact solutions can then be applied when we look at the initial portion of the unloading curve, even though there is plastic deformation as a result of the test.

Equations for Hardness Calculation

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

$$A_c = \pi D h_c$$

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

$$S = \frac{dP}{dh} \mid h = h_{\max}$$

W. C. Oliver et al., "An improved technique for determining hardness and elastic modulus using load displacement sensing indentation experiments", J. Mater. Res., Vol 7, No. 6, June 1992

where,

H - Hardness

P_{max} – Maximum Load

A_c – Area in contact at maximum load

D – Diameter of Indenter

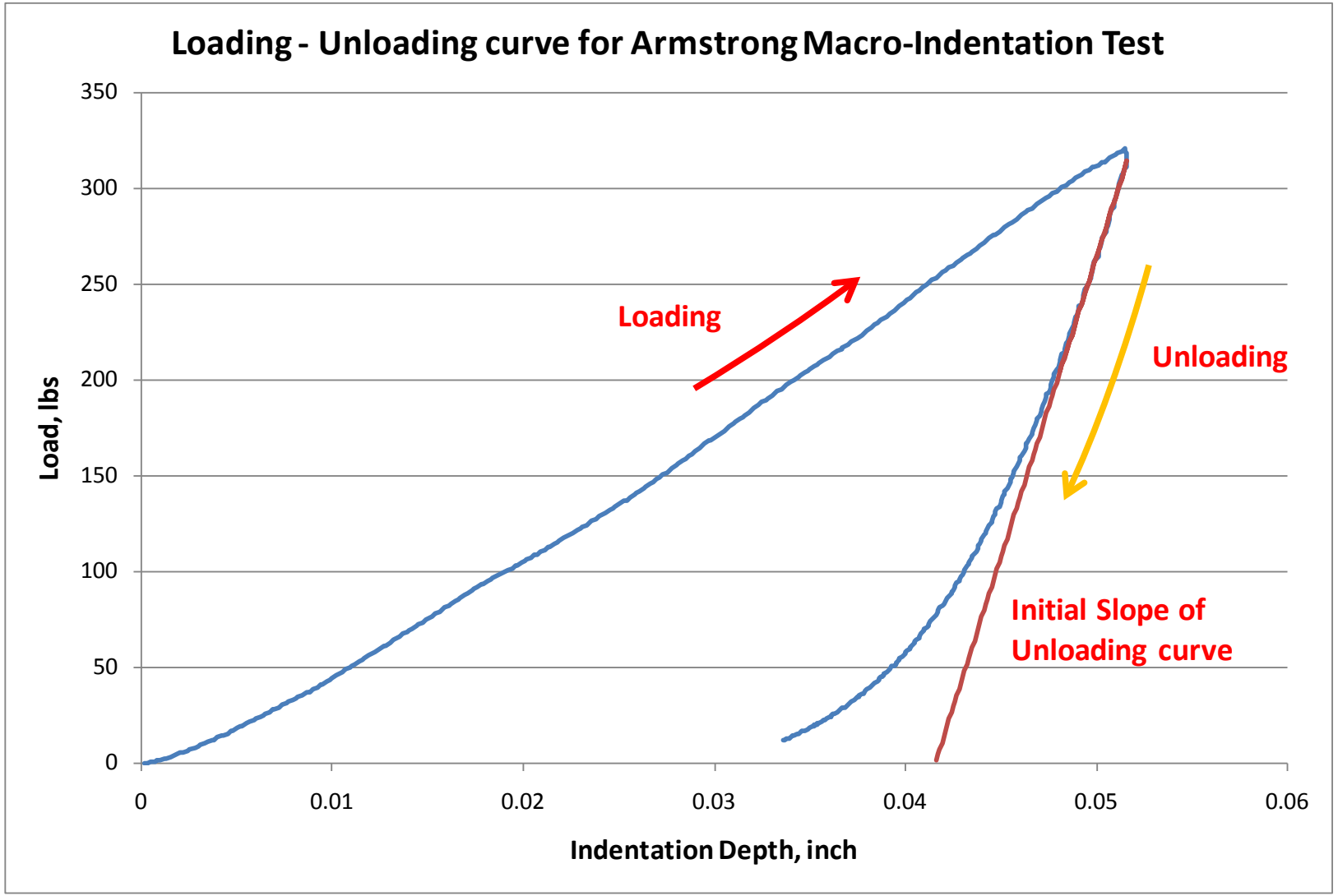
h_{max} – total depth of indent at maximum load

h_c – depth of contact at maximum load

S – Initial slope of unloading curve

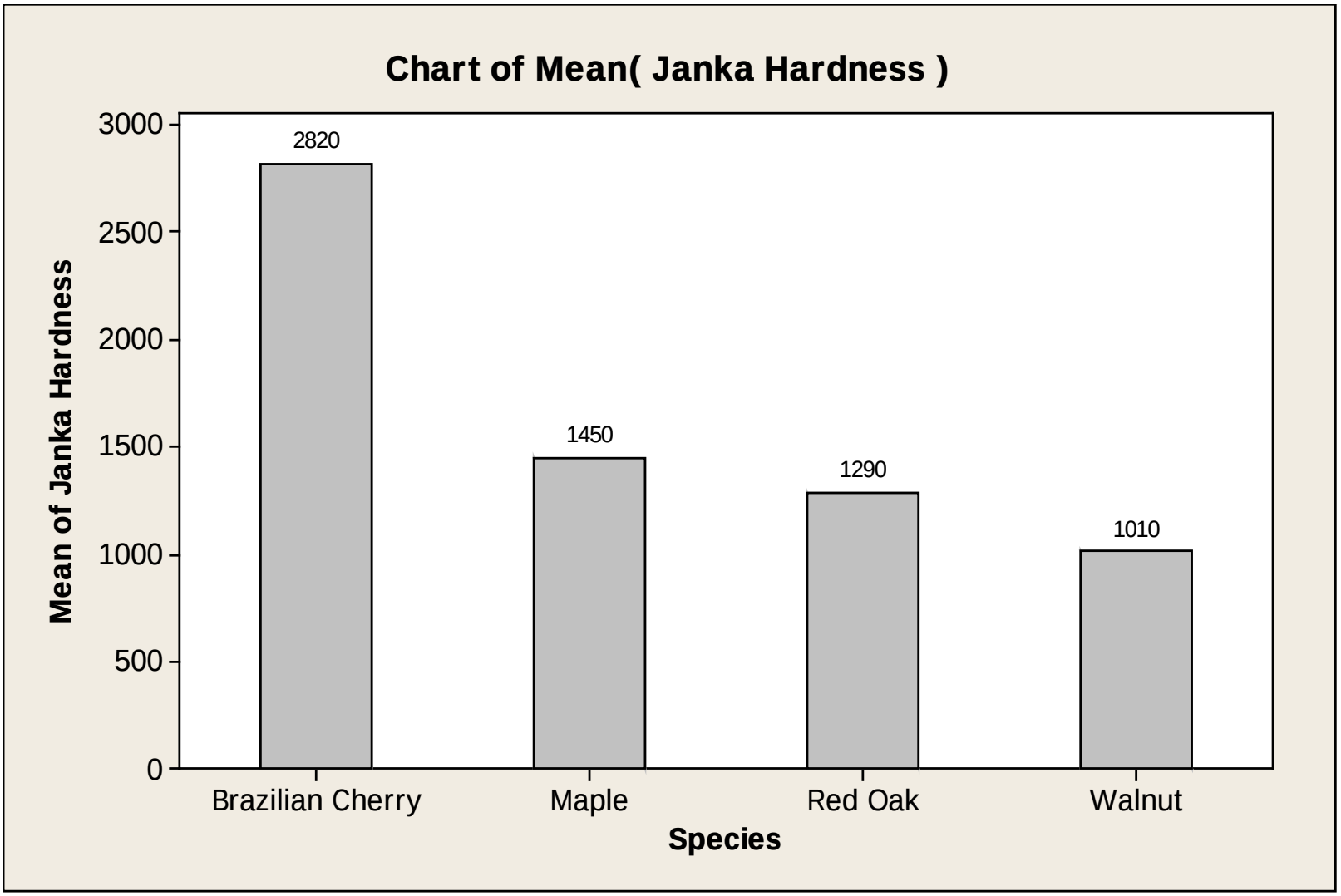
Hardness values were converted to Kg/mm^2 units to compare with Brinell Hardness values

Sample Test Data



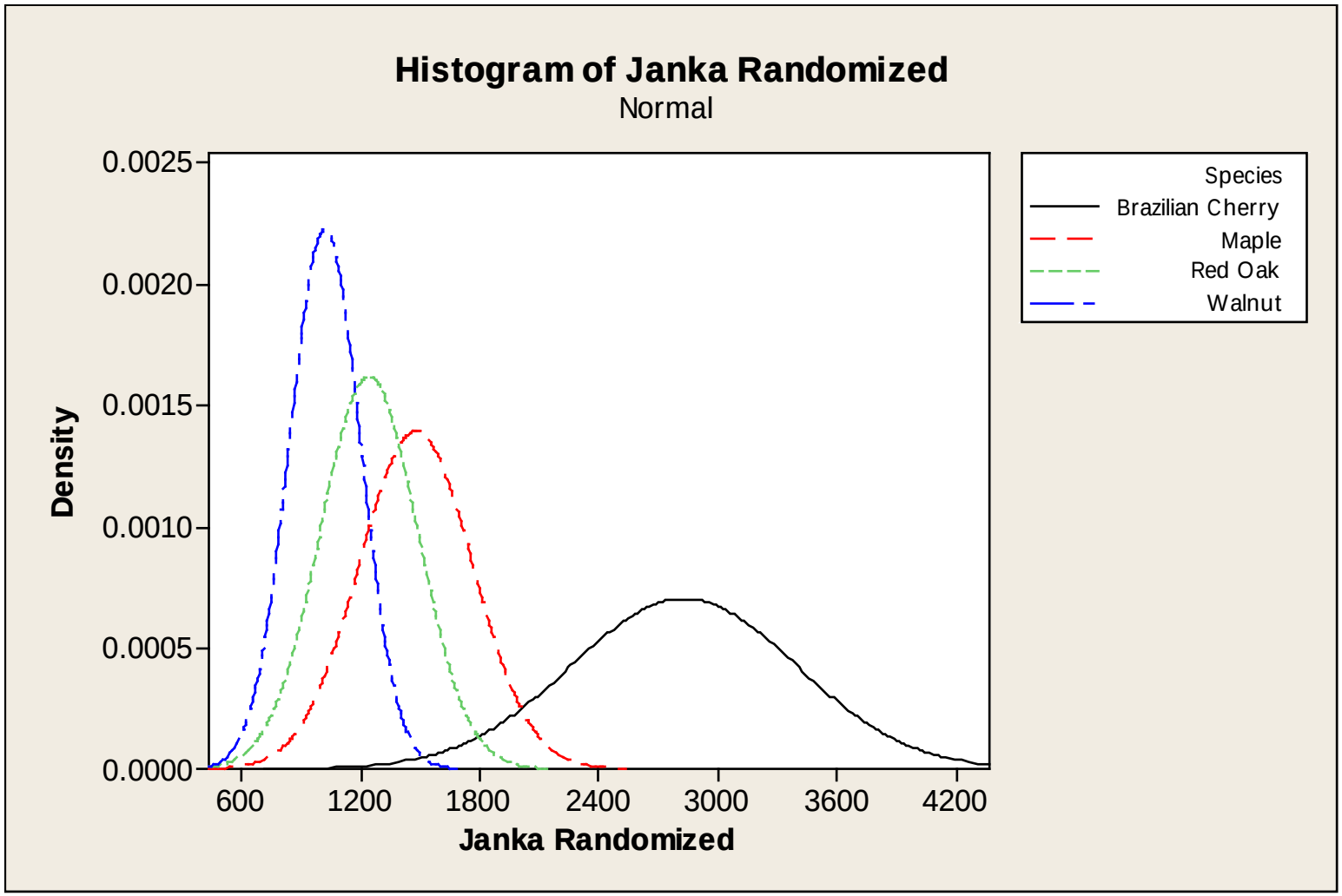
Typical data used in the Macro-Indentation analysis.

Janka Hardness



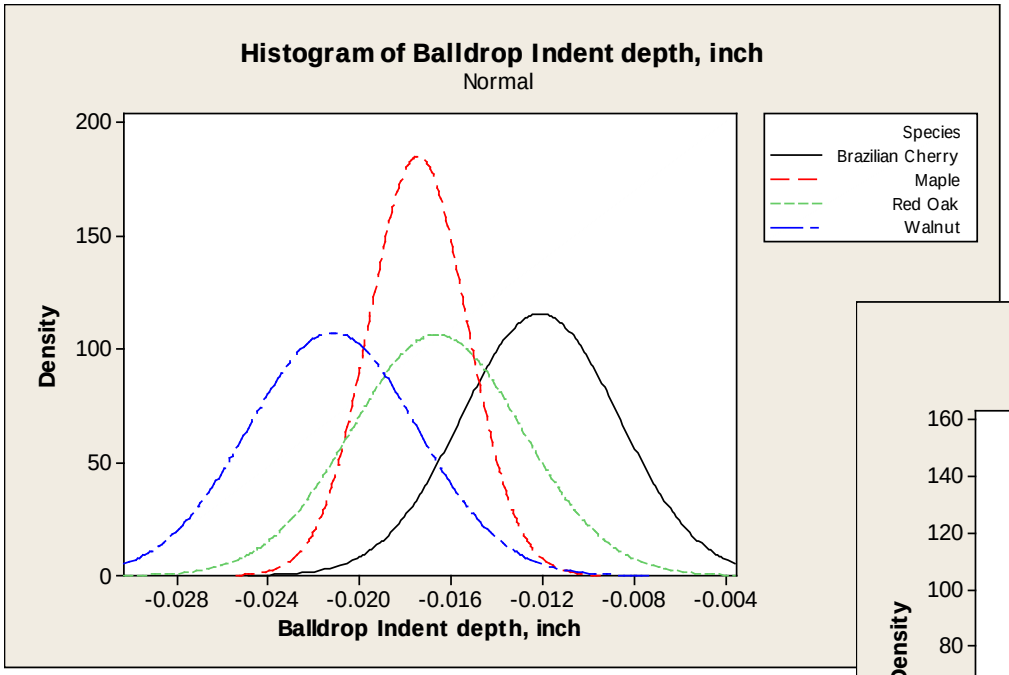
Janka Values Based on Table 4-3b, “Wood Handbook”

Janka Hardness



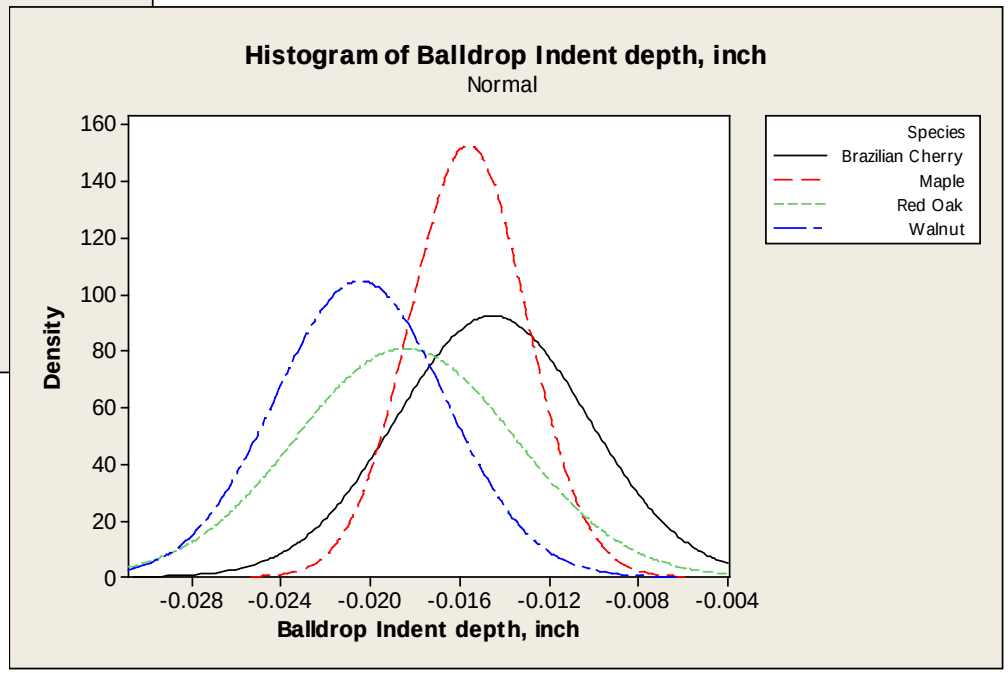
Variation in Janka Hardness with a Coefficient of Variation of 20%.
Random Normal Data generated based on Table 4-6, "Wood Handbook".

Balldrop Indent Depth



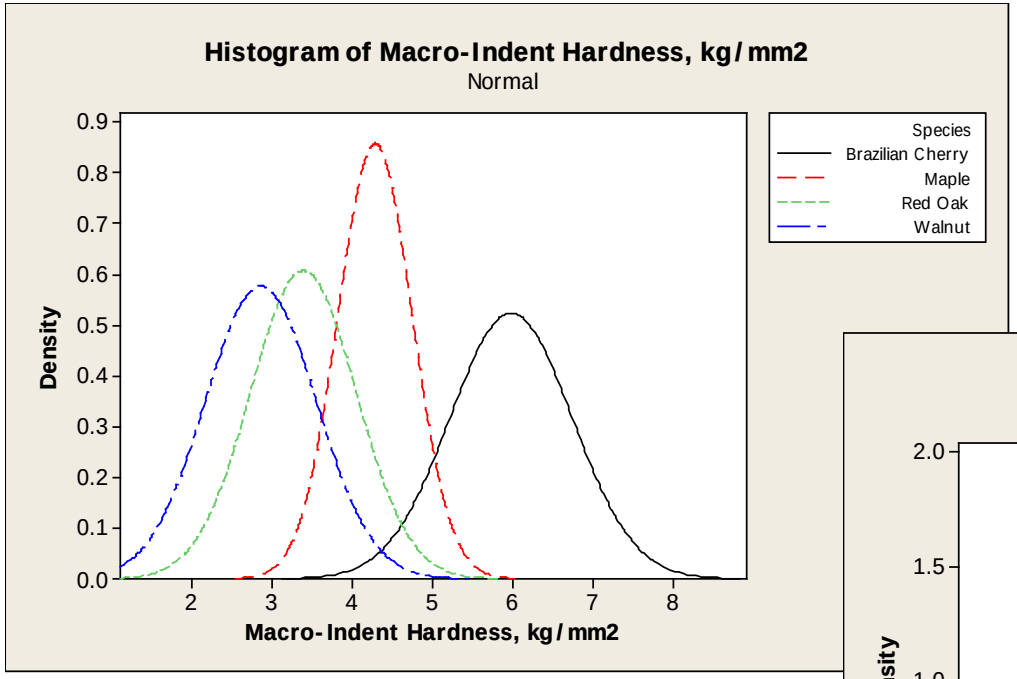
Solid samples

Engineered samples



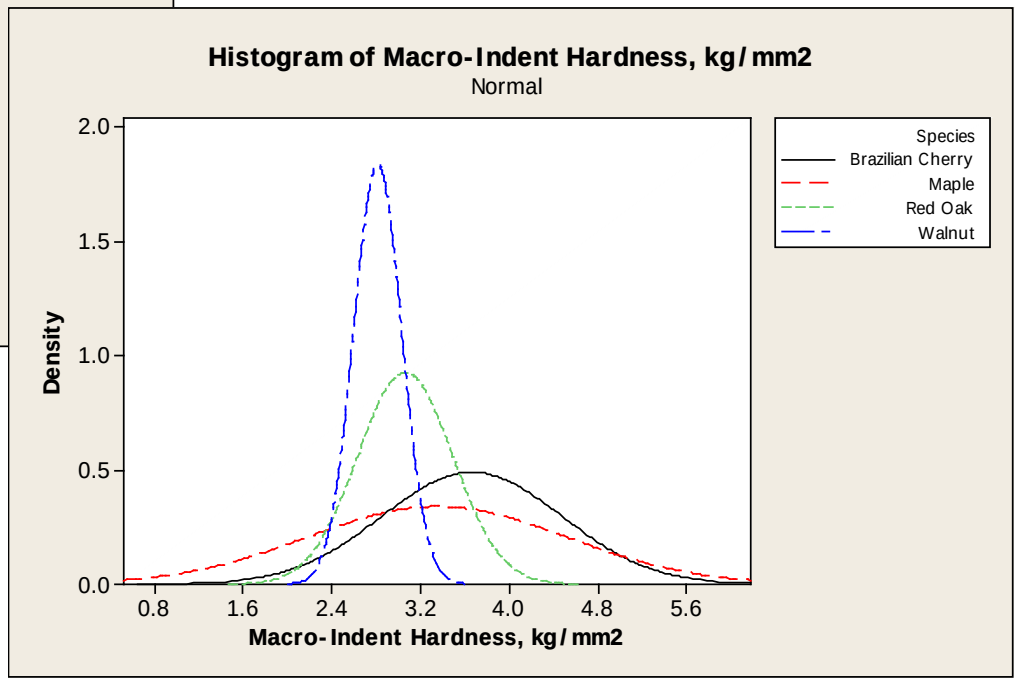
- **Balldrop Indent depth for solid samples generally reflects the trends seen in Janka Hardness.**
- **Data shows a larger difference for solid samples compared to the engineered samples due to the presence of other species in the cores of engineered samples.**
- **We believe this test can be used for standard indentation resistance testing of wood flooring due to its simplicity and statistical repeatability & reproducibility.**

Macro-Indentation Hardness



Solid samples

Engineered samples



- Macro-Indentation Hardness for solid samples also reflects the trends seen in Janka Hardness.
- Data shows an even larger difference for solid samples compared to the engineered samples due to the presence of other species in the cores of engineered samples.
- We believe this test can be used to test the effects of special treatments on wood such as chemical impregnation.

Conclusions

- Existing techniques for hardness measurements include Janka Hardness for wood, Brinell Hardness for metal hardness testing and Nano-indentation for thin film hardness testing.
- Janka Hardness requires a 2” thick sample and a 0.222” indentation depth. We believe the Janka Hardness is more appropriate as a raw material test for single species of wood.
- Solid and engineered wood floor products for residential markets are typically ¾” thick or less. They also have protective coatings on top and in the case of engineered flooring contain multiple species. This presents the need to develop a test that is more appropriate to finished products.
- The Armstrong Balldrop test is simple to use and statistically repeatable and reproducible.
  - The flooring customers typically see the indent crater caused by dropped objects. The Balldrop test is better able to evaluate this attribute that “connects” well with the customer.
  - Data shows a difference for solid Samples compared to the engineered samples due to the presence of other species in the cores of engineered samples.
  - We believe this test can be used for standard indentation resistance testing of wood flooring.
- The Armstrong Macro-Indentation Hardness test is based on analytical techniques developed for Nano-indentation.
  - Macro-Indentation Hardness shows a larger difference for solid Samples compared to the engineered samples.
  - We believe this test can be used to test the effects of special treatments on wood such as chemical impregnation.

Acknowledgements:

- Armstrong Testing & Analytical Lab
- New Product Development
- Product Management
- Administrative Staff

Questions??