# Material Properties of Wood

In this activity, participants will measure the stiffness per unit weight of various wood samples. Students will develop an understanding of material properties such as the modulus of elasticity and the moment of inertia. This exercise will allow an opportunity for students to give thought to the industry processes that ultimately lead to appropriate material choices for a product or application. For our purposes, the electric guitar will serve as the application!

## Learning Objectives:

1. Accurately measure the dimensions of various wood samples.
2. Accurately measure deflections of cantilevered wood samples.
3. Calculate the modulus of elasticity for various wood samples.
4. Calculate the stiffness/weight ratio for various wood samples.

## Standards:

**HS-PS2-6 Molecular-Level Structure of Designed Materials**

Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

**CCSS.Math.Content.HSG.MG.A.3** Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios).

## Materials Required:

1. Wood samples approximately 610mm x 32mm x 4mm (approx. 24" x 1.25" x 0.16")
2. A dial or digital caliper
3. A ruler or printed scale
4. An electronic scale capable of measuring 200gm
5. A weight of approximately 100gm (no need to calibrate it, as it will be weighed)
6. Two clamps (Quick Grips or C-clamps work well)
7. Masking tape
8. A mechanical pencil
9. A bench with a squared edge
10. A sandwich bag
11. A paper clip

## Safety:

Be sure to keep feet from beneath the weight in case the wood sample breaks, and as in all lab settings, wear closed-toe shoes.

Wear protective eyewear, in case the wood sample breaks.

## References:

Bergman, et al, Forest Products Lab (2010) Wood Handbook, Wood as an Engineering Material, FPL-GTR-190, www.fpl.fs.fed.us/products/publications.

Mott, R (2007) Applied Strength of Materials, 5th ed. Prentice Hall.

**Activity:**

The object is to calculate the material stiffness of several species of wood and to compare the stiffness to weight ratios. The stiffness of a structure (like a small wood beam) is determined by its geometry and the material stiffness. All the beams should be the same length and cross-sectional shape, so any differences in stiffness are due to the material properties. The material stiffness is called the modulus of elasticity. The stiffness due to the cross-sectional shape of the beam is called the area moment of inertia.

Procedure:

1. Using a caliper, determine the width and thickness of two specimens. It is a good idea to write dimensions right on the specimens. If you want to speed up the activity, provide the specimens with the dimensions already labeled:


Units: To be consistent with international standards, it makes sense to perform all measurements and calculations in metric units. All forces should be in Newtons, all masses should be in kilograms and all lengths should be in meters.

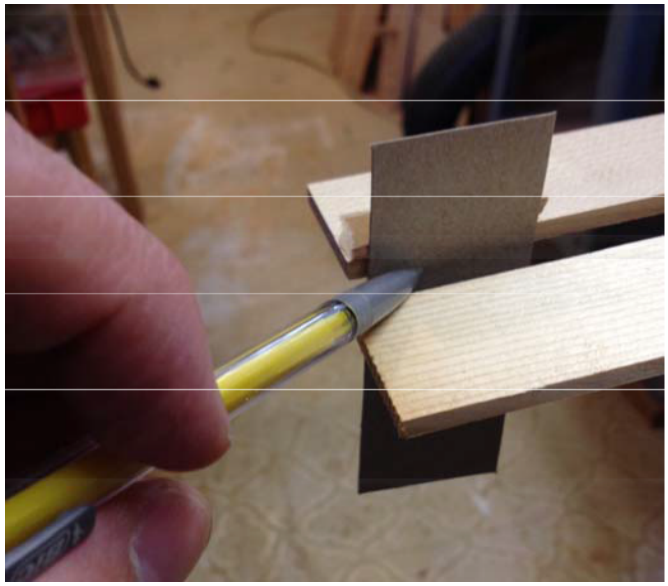
2. Using the electronic scale, weigh each of your specimens. You'll need to keep track of the specimens, so you should number or label them. Record the weights in kilograms (which is actually mass, not weight).

3. You'll need to know the density of each of the wood specimens. Calculate the volume in $m^3$ for each specimen. Divide the mass by the volume to determine mass density, and record the density for each specimen.

4. The most complicated measurement is recording displacement due to a load. The first step is to cantilever the two specimens. Clamp the two specimens to the table so they a parallel to each other and closely separated (less than 25.4mm or 1 inch). Also make sure that they have the same free length from the table. If possible, clamp them so that at least 559mm (about 22 inches) extends out from the table. Be sure that the edge of the table is a 90 degree corner to form a good boundary condition. Don't use a table edge that has been rounded.

5. The ends of the two beams should be as close to the same height as possible. It is typical for one or both of the sticks to have a slight curve, so arrange them to have as little difference as possible. Select one of them to be your reference beam (The one that isn't loaded) and one to be your test beam (the one that is loaded). Tape a small piece of cardboard or a printed scale to your reference beam as shown.

6. Put a light pencil mark on the cardboard that matches the height of the test beam. This will serve as a reference point.

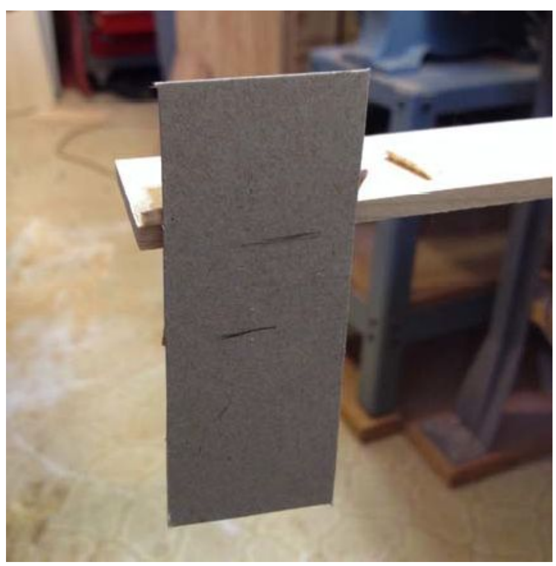


7. You will need a weight to load your specimens. A socket works very well. If sockets are not available, you can use sealable sandwich bags containing coins, screws or other heavy materials. Weigh the bag or the weight and record the mass in kilograms. Multiply by the acceleration of gravity to determine weight in Newtons.

8. Put your weight on the test specimen. If you are using a bag, you can use a paperclip to form a hook and suspend it from the end of the beam. When the beam has stopped vibrating, use the mechanical pencil to put a second mark on the cardboard showing how far the test specimen has deflected due to the load. Perform this test for each specimen and record the deflections in meters.

Aside: Wood displays a property known as *creep*, which means that a sample will continues to deflect slowly after a load is applied.  The beams used in this experiment may creep when loaded, so you may notice that your test beam continues to move just a little.  Rather than try to wait until it stops creeping, record the deflection right after applying the load.

9. The difference between the two marks is the deflection due to the weight.  Once you have a deflection number for one test specimen, make it the reference beam and make the other the test beam.  Then, repeat the test.



10. Once you have the displacements, you can calculate the modulus of elasticity for each beam. To accomplish this, you'll need to use the equation for the displacement of a cantilevered beam:

$$\Delta y=\frac{FL^3}{3IE}$$

Some Definitions:

$F$ = Force applied – weight in this case. Force is in Newtons
$L$ = Length of beam starting from the edge of the table, L is in meters
$I$ = Area moment of inertia of the cross-section of the beam. This number describes the stiffness of the beam due to its cross-sectional shape

$$I=\frac{1}{12}bh^3$$

Where b is the width of the beam and h is the thickness of the beam. Both dimensions should be in meters. The units for I are $m^4$.

$E$ = Elastic modulus. This is stiffness due to the material

The displacement equation can be rearranged:

$$E=\frac{F^3}{3I\Delta y}$$

We can measure or calculate everything on the right hand side of the equation. Note that elastic modulus is likely to be a very big number. For example, the elastic modulus of hard maple (often used for necks) is listed as approximately 12 $\times 10^9$ Pa or 12 GPa.

11. The last step is to calculate the ratio of stiffness to weight. For each specimen, divide the elastic modulus in GPa by the density. Record the resulting values and put them in order from the highest to the lowest.

In Closing:

The woods most favored for acoustic guitars are often the ones with the highest stiffness to weight ratio. In particular, Sitka spruce is favored for the soundboards of acoustic guitars. Electric guitars can be made with a wider range of woods. It is typical to use hard maple or mahogany for the neck and something less dense for the body. Alder and Basswood are typical choices for body wood, though soft maple is sometimes used.

Name ______________________________

**Assessment**
**Wood for Guitars**

1. What is the best tool for getting the most accurate dimension of your wood specimens?

   A. Ruler

   B. Tape measure

   C. Micrometer

   D. Calipers

2. Which term is used to specify the distance the beam moves once weight is applied?

   A. Deflection

   B. Gravity

   C. Compression

   D. Tension

3. To have consistent data, it is important to have each of your beam specimens exactly the same size.

   True -or- False

4. After clamping the wood to the table. Which items need to be checked to make sure they are completed? (select all that apply)

   A. Both specimens (measured and reference) are clamped with the same length of wood on the table

   B. Both specimens (measured and reference) are level to each other

   C. The clamping table does not have a rounded edge

   D. The beams (measured and reference) should be far apart - more than 3"

5. When measuring displacement due to load, the two wood specimens must be clamped to the table so they a parallel to each other and have the same free length from the table.

True -or- False

6. What is wood creep?

A. Wood that has a knot in it

B. Wood continues to move due to the fibrous nature of it once a force is applied

C. The creak that is made when wood is stressed

D. The surface discoloration that results from too much moisture in the wood

7. The wood specimen must be weighed.

True -or- False

8. An acoustic guitar top requires a higher stiffness-to-weight ratio than than the body of an acoustic guitar.

True -or- False

9. Match up the equation terms with their meanings in this activity.

| | | | |
|---|---|---|---|
| ____ | Area of moment of inertia | A. | The change in distance an object moves once a force is applied |
| ____ | Elastic Modulus | B. | Stiffness due to the material |
| ____ | Force | C. | Beam overall size distance |
| ____ | Displacement | D. | Weight applied to wood beam |
| ____ | Length | E. | Stiffness due to the shape of the cross section |

Assessment Key:

1. D - Calipers
2. A - Deflection
3. True
4. A, B and C - Both specimens (measured and reference) are clamped with the same length of wood on the table, Both specimens (measured and reference) are level to each other, The clamping table does not have a rounded edge
5. True
6. B - Wood continues to move due to the fibrous nature of it once a force is applied
7. True
8. False
9. E, B, D, A, C

**Reviewing Faculty Cohort Members:**

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