Suncoast Woodcrafters Guild

Presentation & Demo on Steam Bending of Wood

by Roy Mitton 11 March 2008

1. Structure of Trees and Wood

Angiospermae	Gymnospermae
Broadleaf - Hardwoods	Conifers - Softwoods
About 9500 species on earth	About 500 species on earth
Vessels (pores) conduct sap vertically and hardwoods are called porous	Sap transferred vertically through cells called tracheids and softwoods are called nonporous
Vessels are long tubes cemented together by a thin layer called the middle lamella	Walls of the tracheids form the bulk of the wood and middle lamella is between the cell units
Many thin fiber cells provide the wood strength	Tracheids give the wood strength

Question – What is generally easier to bend, hardwood or softwood?

2. Make-up of Wood

Cellulose	40-50%	Principal chemical component of cell walls. A complex carbohydrate with very long polymer chains. Hard crystalline structure
Hemicellulose	20-35%	Also a carbohydrate but a smaller and shorter molecule. Surrounds the cellulose. Contributes to the bonding between the cellulose and lignin
Lignin	15-35%	Complex and high weight polymer built up of phenylpropane units. Occurs between cell walls as a binding agent to hold the cells together. Occurs within the cell walls to provide rigidity.
Ash & Other	1-2%	

- "Lignin" is from the Latin term Lignum, which means wood.
- Wood without lignin is cotton.
- Lignin and hemicellulose are key to wood bending
- A pulp mill mainly delignifies ligin by treating wood chips with sodium sulfide and sodium hydroxide at high temp of about 170 deg C for 2 hours. The lignin polymer fragments into smaller alkali and water soluble fragments
- Old newspaper yellows because of residue lignin

3. The Various Bending Processes

<table>
<tr><td rowspan="11">Wood Bending</td><td colspan="5">Laminated Bending</td></tr>
<tr><td rowspan="10">Solid Wood Bending</td><td colspan="4">Kerfing</td></tr>
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<tr><td colspan="2">Boiling method</td></tr>
<tr><td rowspan="2">Steaming method</td><td>High pressure method</td></tr>
<tr><td>Low pressure method</td></tr>
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- The two easiest methods for the small shop are laminated bending and low pressure steaming.
- Kerfing is also easy in a small shop but limited in application.
- Cold bending also easy but very limited in radius of bend. Wood is presoaked in water

4. Moisture Content Knowledge – Fundamental for Effective Bending (and for everything else in working with wood!)

Moisture Content is the ratio of the weight of water in wood to the oven dry weight of that wood,

%MC = (weight of water in sample / oven dry weight of the sample) x 100% or,

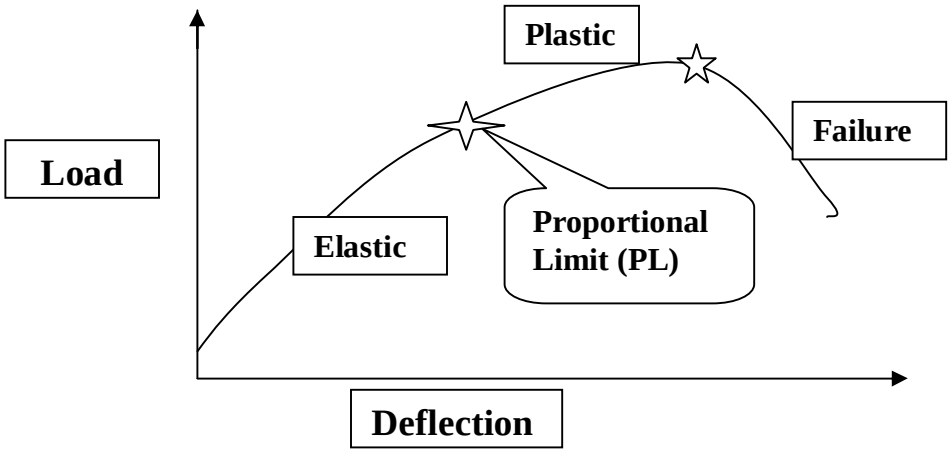
%MC = ((weight of sample / oven dry weight of sample) – 1) x 100%

% MC		
100 +	Fully saturated	All cavities filled with free water. Cell walls saturated
30 to 100	Green wood	Some free water in cell cavities. Cell walls saturated with absorbed or bound water
30	Fiber Saturation Point (FSP)	Point at which all free water has evaporated. Below this point the wood gains strength and shrinks as the bound water evaporates.
20 to 30		Desired range for bending
20	Typical air dried value	
8 to 15	Typical Equilibrium Moisture Content (EMC) range	EMC is when the MC is relatively stable and in balance with the Relative Humidity
6 to 10	Kiln dried	
0	Oven dried	All bound water evaporated

- Above table typical – variation of a few % with species
- Bending very green wood can rupture the wood due to the excessive water within the cells (the water will not compress)
- Kiln dried wood will absorb water but you will not get it back to FSP.
- EMC will vary with the relative humidity (RH). Rule of thumb is EMC approximately equal to 20% RH. Actual relation is a curve and varies species to species.

5. Basic Wood Stretching/Bending Characteristic

This is the a load curve for any typical material:



- For a permanent bend, the wood must be in the PLASTIC range
- When wood is steamed (high moisture and heat), the plastic range is extended although there is some loss of strength
- What would this curve look like for
  - Copper wire?
  - Spring steel?
  - Non steamed wood?
  - Steamed wood?

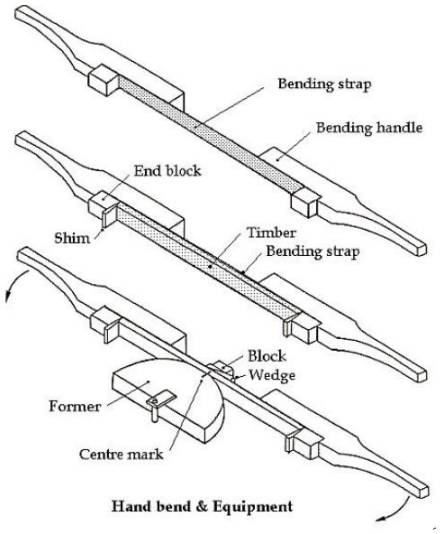
6. Tension and Compression

- Wood is very weak in tension and can only be stretched 1 or 2 % before it fractures or tears. Low pl and short plastic range
- Stronger in compression, up to about 10% before failure. Moderate proportional limit (PL) and a longer plastic range.
- When the lignin is heated, it is plasticized and the walls of the cells compress into smaller cells (as long as the free water is gone). The plasticized lignin allows the cells to slide alongside each other as compression occurs. This greatly increases the plastic range of the wood for compression, however, the tension range is essentially unchanged.
- Controlling the tension side of a bend is the critical element.

7. Tohnet's Method of Steaming and Bending

Michael Tohnet (1796-1871) was an Austrian chair maker who developed a method of chair manufacture around 1830 using glue and laminate strips. Later he experimented with a steel strap on the tension side of solid steamed wood and was successful in producing chairs that were stronger and lighter than was possible previously. His chair:

was first release in 1859 and since its release, more than 200 million have been sold. His technique with the steel strap is essentially unchanged for the last 150 years.



Hand bend & Equipment

The steel band is adjusted to the same length as the wood strip and hence the tension stress is transferred to the steel and the outside radius of the wood stays the original length. That's all there is too it – control and reduce the tension side of the bend.

Steaming – this is simply a method of transferring heat to the core of the wood, ie the lignin. The moisture in the wood acts as a conductor of the heat. Some points:

- Presoaking for a day or so should aid heat transfer
- Broadleaf woods are in general easier to bend than conifers
- Rule of thumb is 1 hour steaming (at full 100 deg C) for each inch of thickness. Width does not matter.

- Oversteaming can cause compression wrinkles due to excessive breakdown or weakening of the lignin

8. Which Woods are the Best/Easiest to Bend?

Some woods in order of easiest to hardest to bend are:

Species	Min radius in inches	Species	Min radius in inches	Species	Min radius in inches
White Oak	1.0	Sweet Chestnut	3.0	Douglas Fir	15.0
Elm	1.5	Hornbeam	4.0	Greenheart	18.0
Beech	2.0	American Ash	4.5	Hemlock	18.0
European Cherry	2.0	Yew	8.5	Teak	18.0
Hickory	2.0	Ebony	10.0	Western Red Cedar	35.0
Red Oak	2.0	American Mahogany	12.0	African Mahogany	36.0
Sycamore	2.0	Larch	12.0	Pine	36.0
Walnut	2.0	Olive	12.0	Spruce	36.0
European Ash	2.5	Alder	14.0	Maple	40.0
Birch	3.0	Lime	14.0		

- Above table is typical but minimum values are approximate
- Minimum radius stated is for wood 1 inch thick. Half inch thick would be half the stated value and 2 inch thick, double
- Assumes properly steamed and bent with good procedure and a steel supporting strap on the tension side.
- Assumes blemish free wood, straight grain with little run-out
- Without steaming, a rule of thumb is a minimum bending radius of about 30 times the thickness. Note some woods in the above table exceed that even when steamed.

9. Causes of Failure in Bending

Expect about 20% failures for average bends, much higher failure rates if you try to approach the minimum limits. The most frequent causes of failure are:

- Poor material selection
- Improper band length setting
- Improper moisture content

10. Spring Back

Spring back can be expected to be about 1% of the curve length assuming:

- Work was moved from the steamer to the bending jig and clamped onto the form within a minute or so
- Work was left on the form for 2 or 3 days. Recommended to cover the work with a sheet to slow down evaporation for the first day. This does not affect spring back but can prevent surface checking from drying too fast before the internal stresses stabilize.

11. References

Following are a number of references and much of the above detail has come from these sources.

1. http://www.tai-workshop.com/english/tech-2(b)-e **–** Great paper and gives some detail on all the other bending methods as well.
2. http://www.woodweb.com/knowledge_base/Rx_For_Bending_Wood.html
3. http://www.woodweb.com/KnowledgeBase/KBMISCEL.html **–** An amazing site if you haven't browsed it before. Lists numerous other articles of woodworking interest, not just bending.
4. http://images.lulu.com/items/volume_1/55000/55471/1/print/55471.pdf
5. http://www.fpl.fs.fed.us/documnts/usda/ah125.pdf - This is an excellent treaties on the subject by the US Department of Agriculture Forest Service written in 1957 It is 40 pages!
6. http://www.wcha.org/tidbits/steamfaq.html
7. Veritas Steam-Bending Instruction Booklet – Lee valley No. 05F15.01. Free and an excellent introduction to the subject with focus on the bending strap.