

# Wood properties

Wood Technology

Matthew Schwarzkopf

# Wood properties

- Learning objectives
  - Describe the function of wood tissues from the tree's standpoint
  - Describe the changes that occur in the anatomical and chemical structure of wood as a force is applied
  - Know **how** and **why** wood properties vary within the location of the ring, stem, and tree

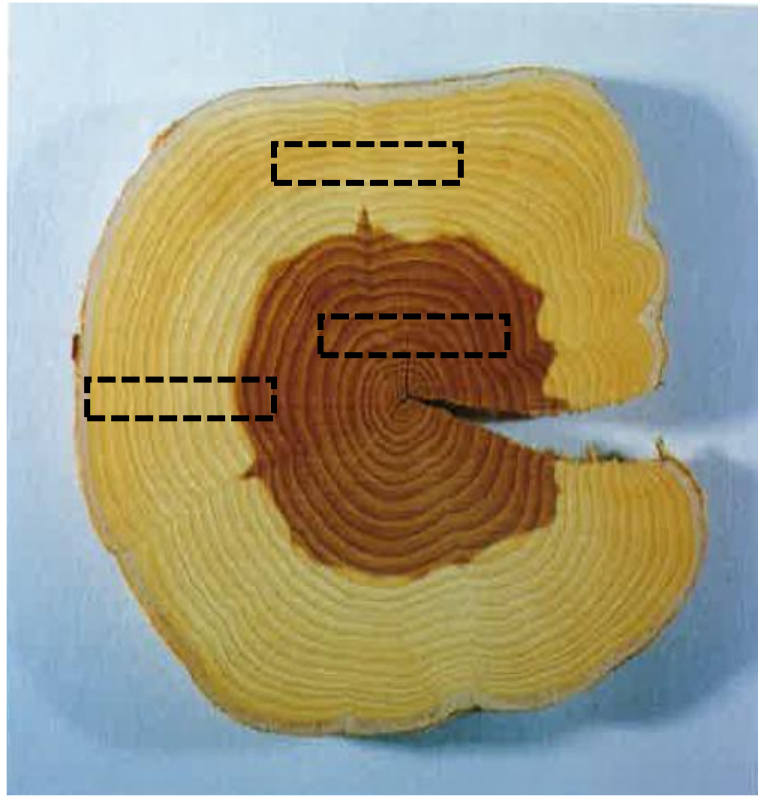
# Function of wood in the tree

- Fluid transport
- Support

- Requirements vary by direction (rays, vessels, pitting, etc.)
- Wood is designed with the tree's needs in mind, not human needs
- Designed to be used in wet conditions and undergo high strain, like the human body (e.g. tendons, skin)

# Cylindrical orthotropicity

- Almost all properties affected
  - Shrinkage
  - Electrical
  - Permeability, diffusion
  - Heat transfer
  - **Strength**



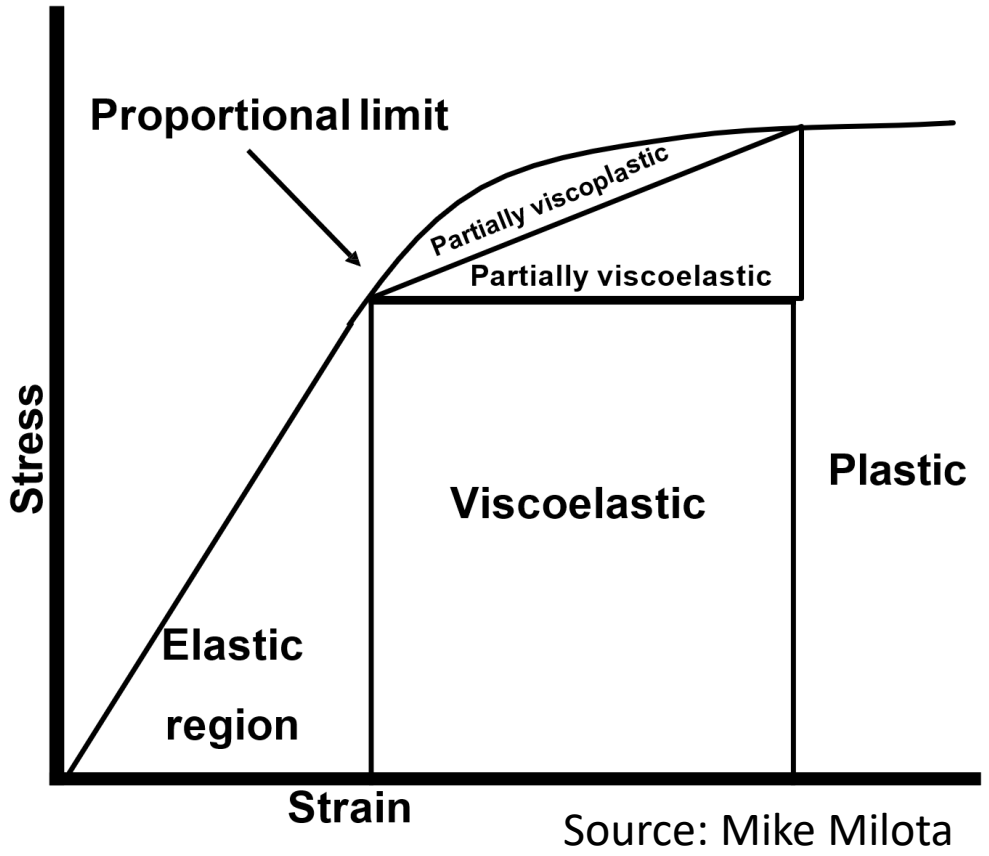
Source: Hoadley

# Strength of wood

- Tension
- Compression
- Shear
- Bending
- Elasticity
- Hardness
- Impact
- Toughness

# Stress-strain curve

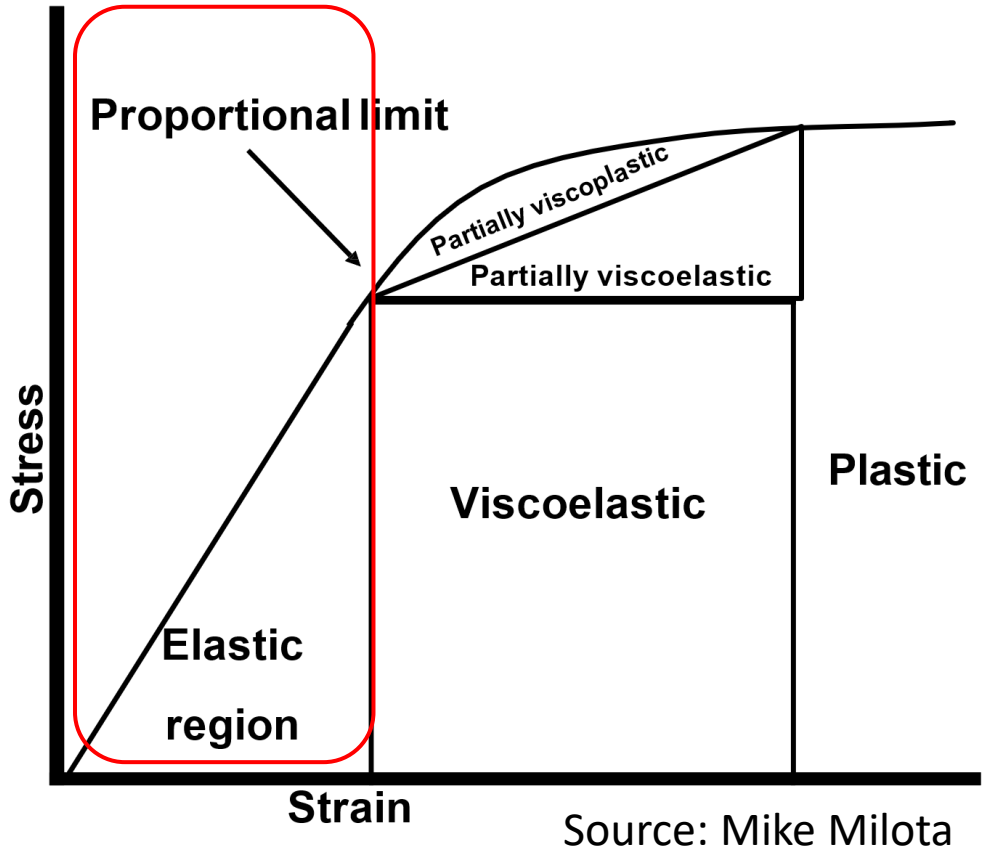
- Elastic, fully recoverable
- Viscoelastic
- Plastic
- Time dependent




Source: Mike Milota

# Elastic region

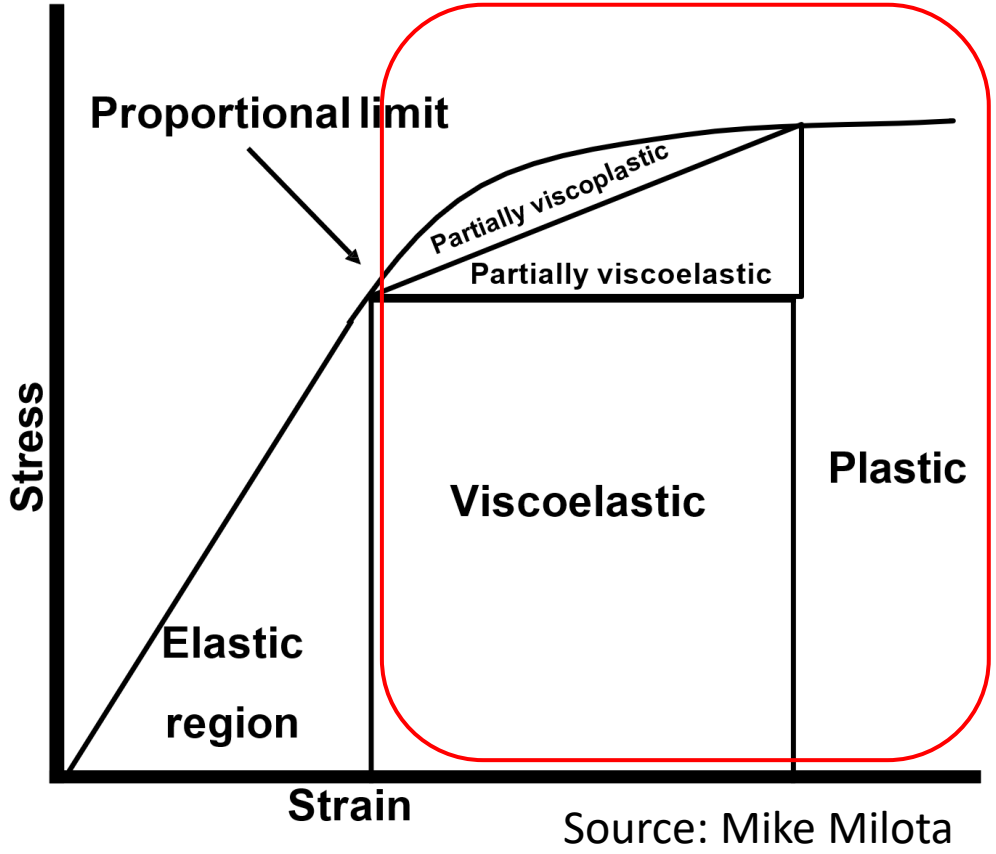
- C-C and C-O bonds distort
- H bonds can break and reform
- Recoverable
- Time dependent
- H bonds allow microfibrils to slide
- Cell wall distortion
- Distortion between cells




Source: Mike Milota

# Above the proportional limit

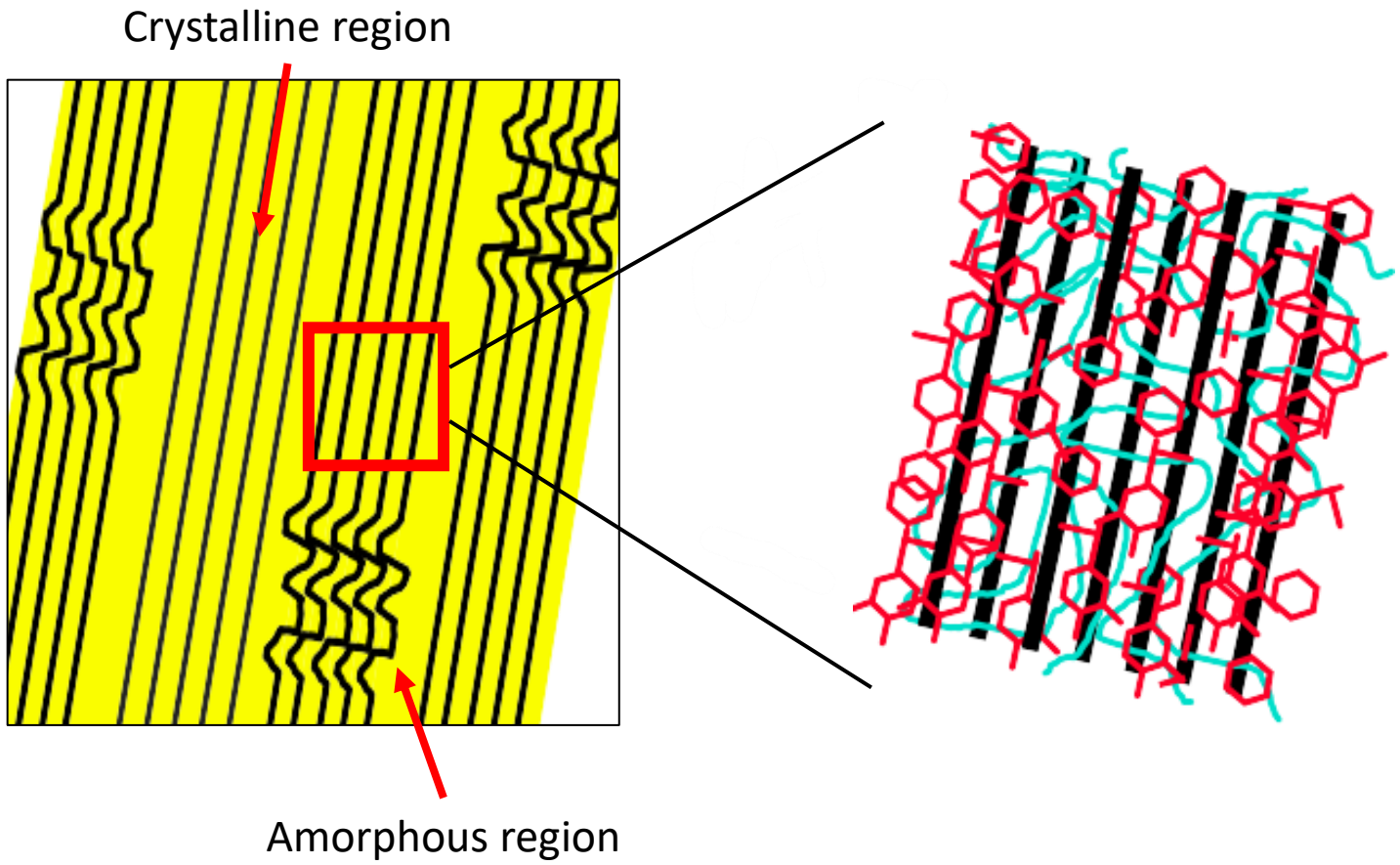
- Additional elastic deformation
- **Covalent** bonds break
  - Big molecules to smaller
  - Not recoverable
- Microfibrils pull apart
- Cracks form in cell wall
- Cellulose failure (brash) or splitting along middle lamella




Source: Mike Milota

# Above the proportional limit

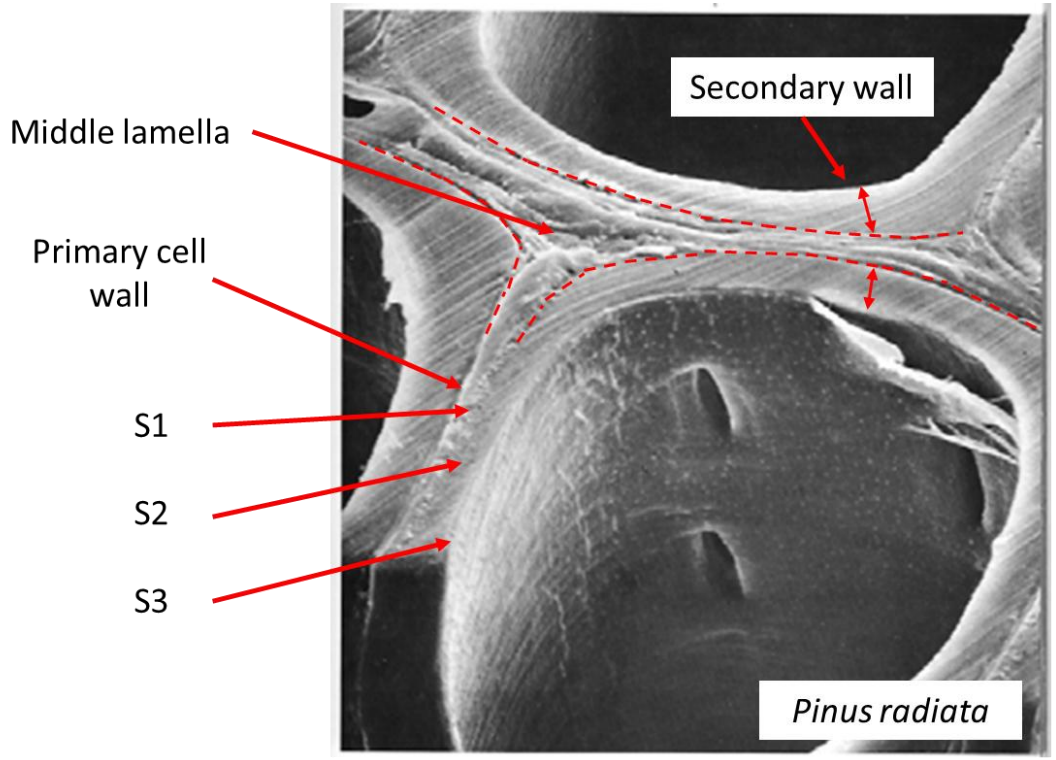
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Source: Adapted from Milota

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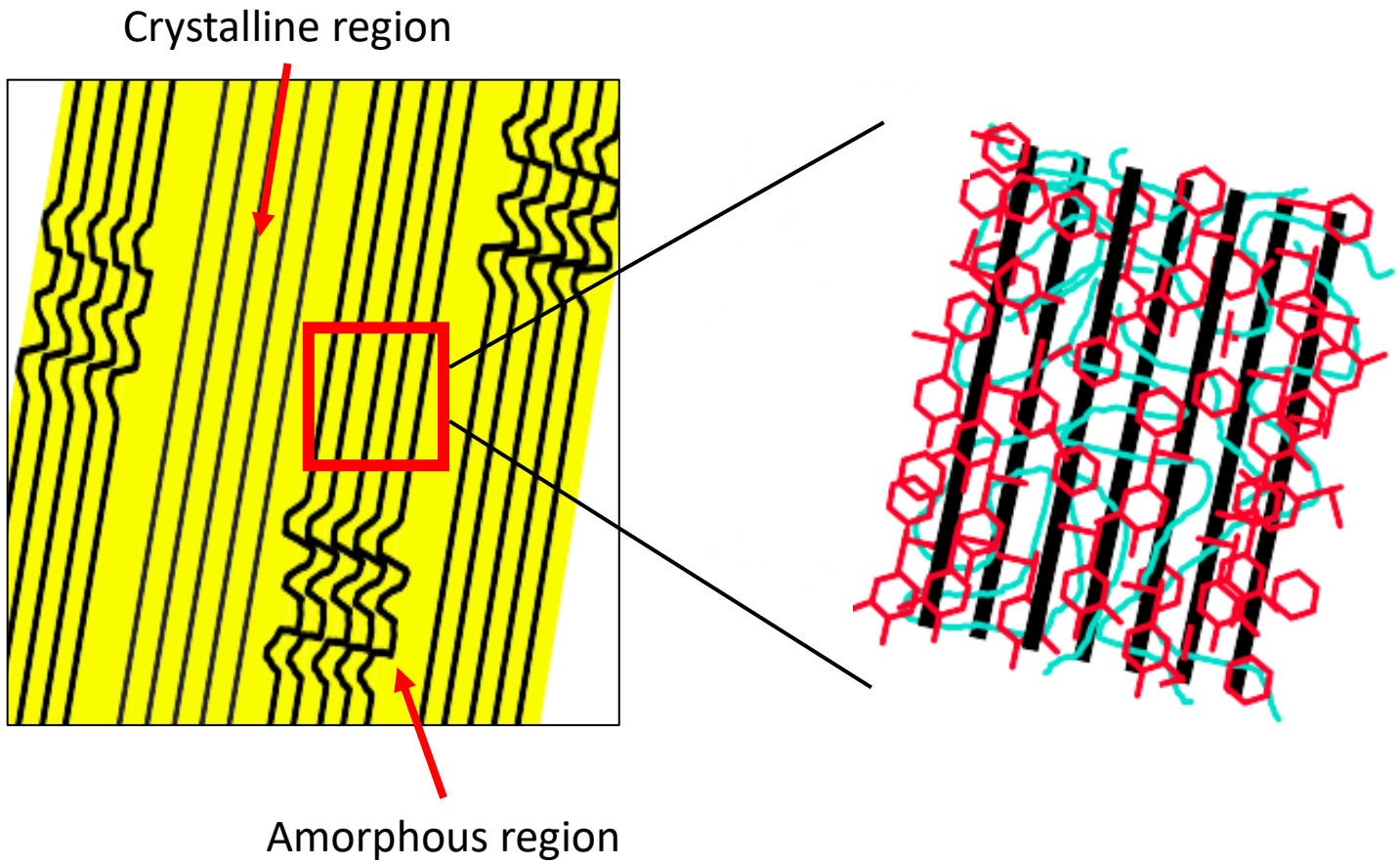
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Source: Meylan and Butterfield

# Lignin is important to strength

- A viral disease in certain types of trees and genetically altered
  - Low lignin
  - Rubbery wood
  - Pulp production (lignin unwanted)
- Delignified wood
  - Dry strength similar to normal wood
  - Wet strength much lower
- Lignin plays a role in keeping water out of fiber




Source: Adapted from Milota

# Variations in properties

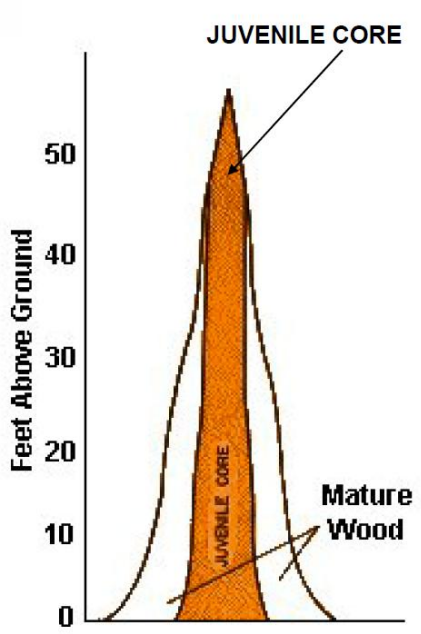
- Affected by everything!
  - Density (cell wall thickness)
  - Microfibril angle
  - Cylindrical orthotropic structure (L, T, R)
  - Cell length
  - Cell types
  - Pits
  - Chemical composition
  - Moisture content
  - Temperature
  - History of growth and also use (e.g., shelving, high compression, long-term loading)

# Variations in properties

- Within tree
  - Juvenile to mature transition
  - Heartwood and sapwood (physical properties)
  - Reaction wood
  - Growth rate (changing site conditions)
  - Anisotropy
  - Earlywood and latewood
  - Branching (knot occlusion and  slope of grain)
- Between trees of same species
  - Genetics
  - Age of the stem
  - Growing site conditions
  - Treatments (fertilization,  pruning, irrigation, etc.)

# Juvenile wood

- Cell length
- High microfibril angle
  - S2 layer
  - Very high shrinkage
  - Cells are shorter, angled, twisted, or bent
- Mechanical properties are poorly understood




Source: Mike Milota

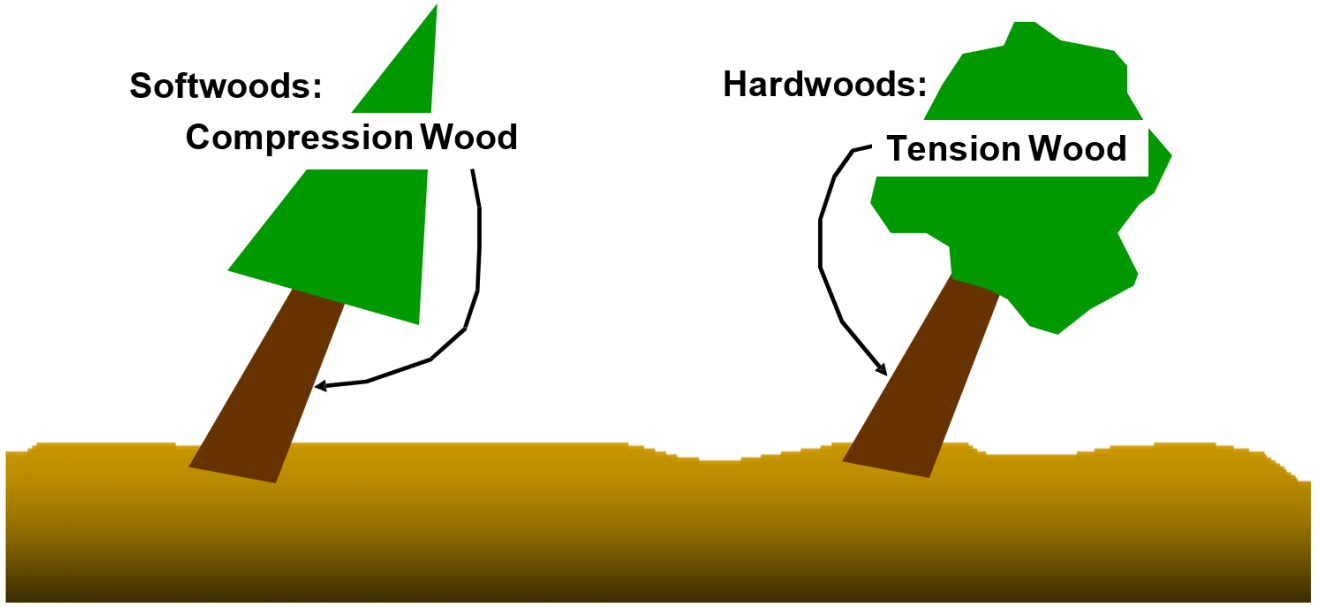
Juvenile wood zone



Source: Hoadley

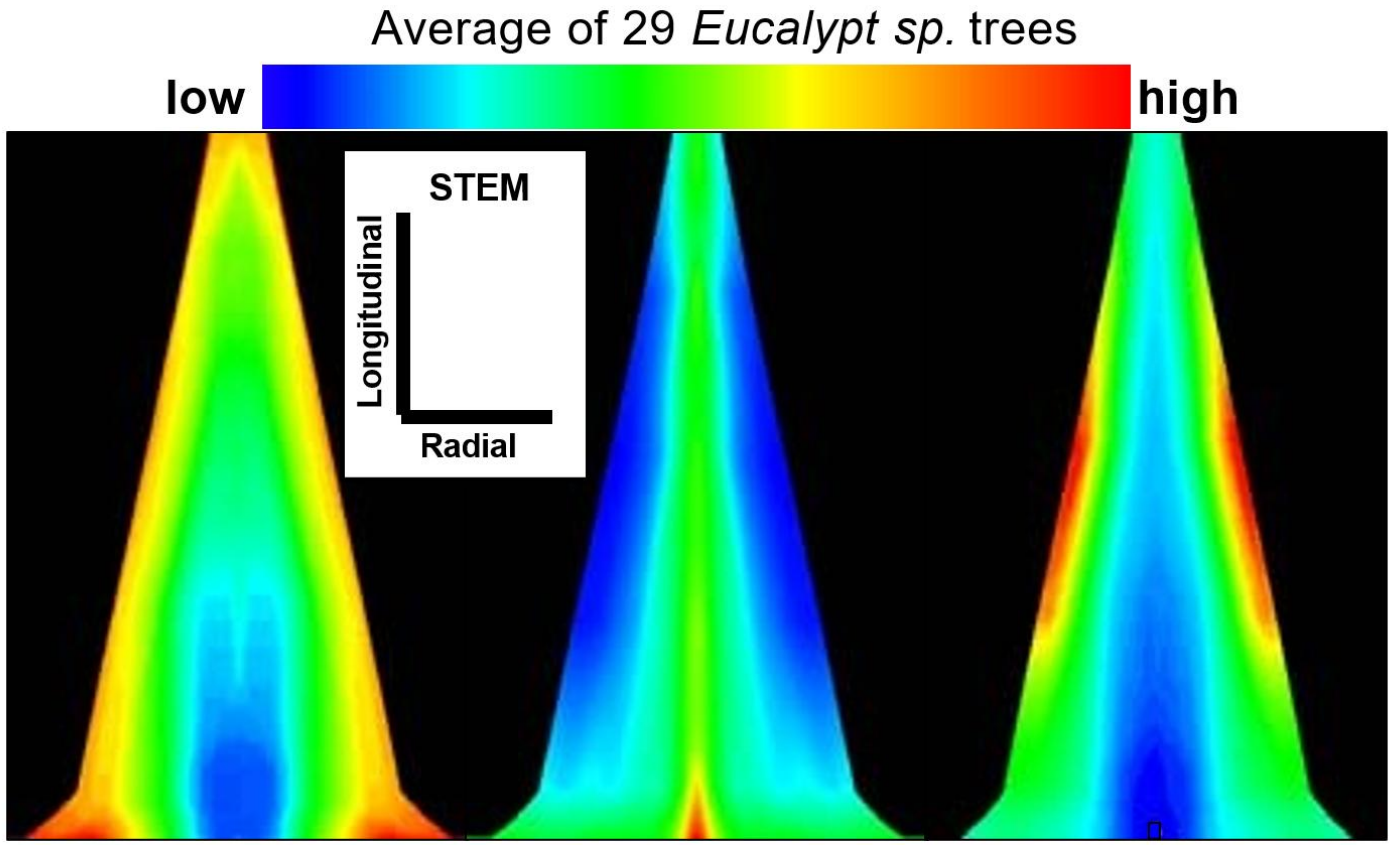
# Reaction wood

- Similar to juvenile wood
- Wood formed by tree in stems and branches that are leaning
- Function is to keep stem vertical or position of branches optimized for exposure to sunlight
- Reaction wood named differently
  - Softwoods: compression wood
  - Hardwoods: tension wood
- Characteristics
  - Cell length shorter
  - Higher microfibril angle in S2
  - Higher lignin content
  - High longitudinal shrinkage
- In tension wood, fibers don't form proper S2 and instead have a highly cellulosic "G-layer", also called the gelatinous layer.



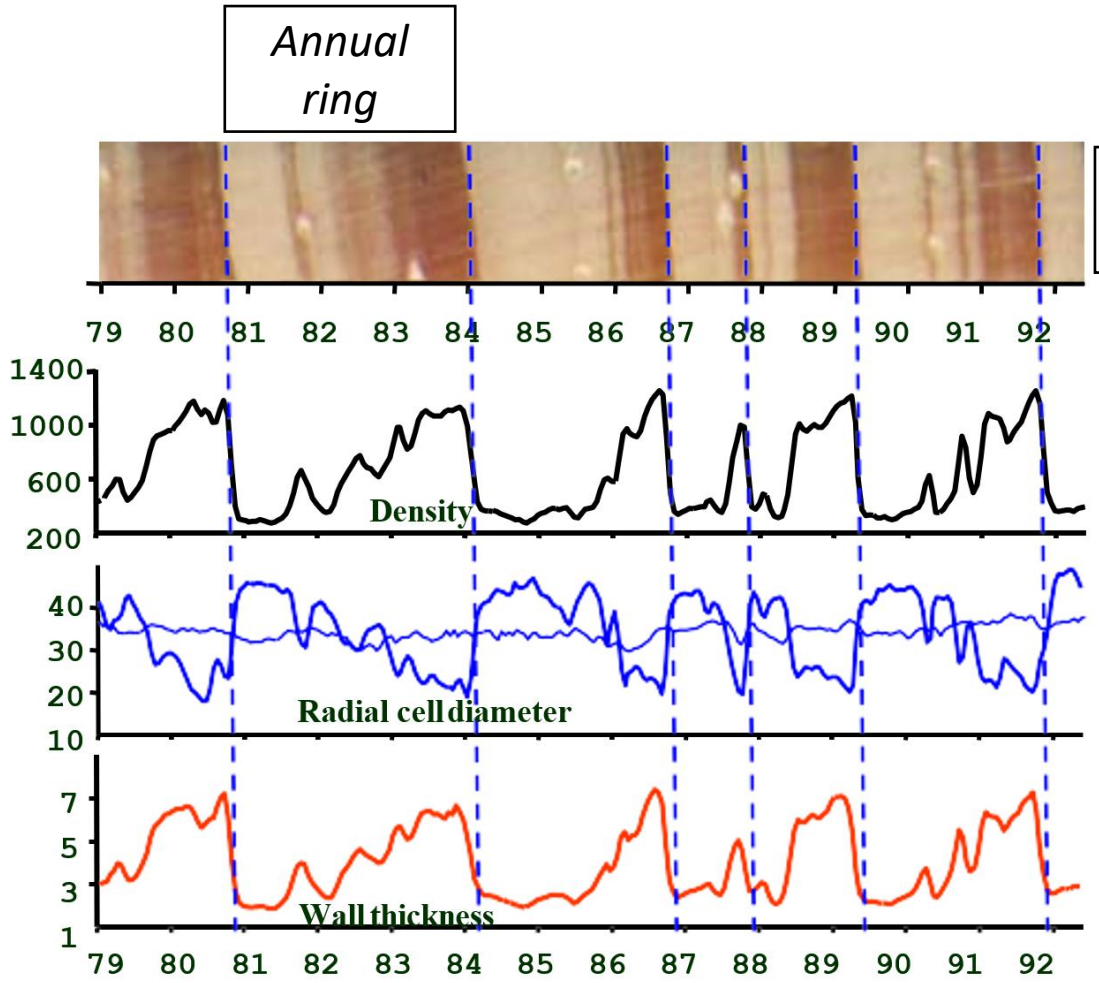

Source: Mike Milota

# Property maps




Source: Mike Milota

# Radial variation




Source: Mike Milota

# Why are these characteristics important for processing and utilization

- Log size
  - Minimize the proportion of juvenile wood and branch effects
- Log form
  - Can be improved through management, pruning, etc.
- % juvenile wood
- Knots (size, abundance)  slope of grain
- % heartwood
- Heartwood decay resistance density
- % latewood  MFA
- Cell length
  - Pulp and paper considerations

# Testing

- Specimen geometry
  - Test configuration and specimen geometry are carefully designed so that material properties can be derived from simple measurements by means of elementary analytical equations
  - The purpose of the test, constraints of the testing apparatus, and known material characteristics are taken into account

# Standardized testing

- Relatively few standard tests aim at generating well defined physical or mechanical characteristics of the material
- Most are designed to **compare specific products or materials** to commonly agreed standard with the purpose to disqualify materials/products of poor quality
- Often they provide a good basis for experimental questions, but do not answer specific questions

# Standardized testing

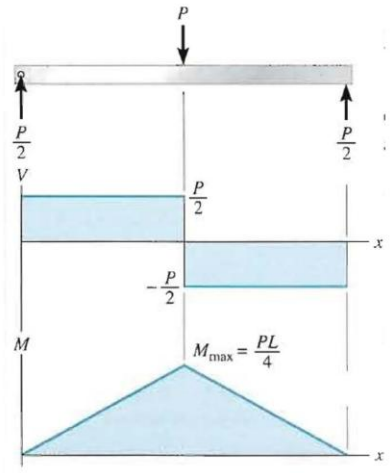
- Some different methods for bending tests
  - Bending is simple to do, but results are often misused

| ASTM # | Specimen type | Test mode | | Outputs |
|---|---|---|---|---|
| | | 3-pt | 4-pt | |
| D143 | Small clear | √ | | *P-Δ* curve, $P_{mx}$ |
| D198 | Lumber in structural sizes | √ | √ | *E, MOE, MOR* |
| D1037 | FB & PB panels | √ | | *MOE, MOR, etc.* |
| D3043 | Structural panels | √ | √ | *MOE, E, MOR,* $M_{mx}$ |
| D3737 | Full size glulam | | √ | *Max shear load* |
| D4761 | Lumber & struct. composites | √ | √ | *E, MOE, MOR* |
| D7341 | Full size glulam | | √ | *MOE, MOR* |

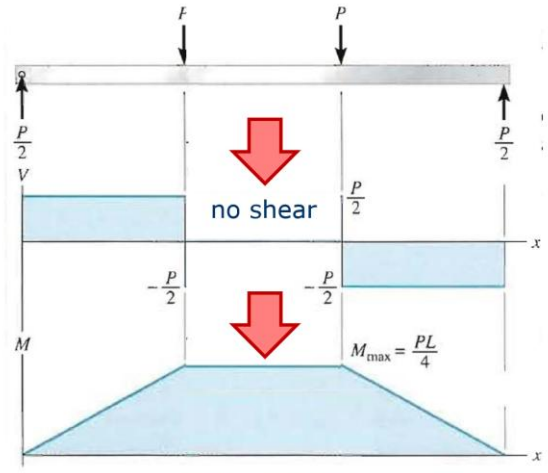
Source: Lech Muszynski

# Test configurations

3 point bending

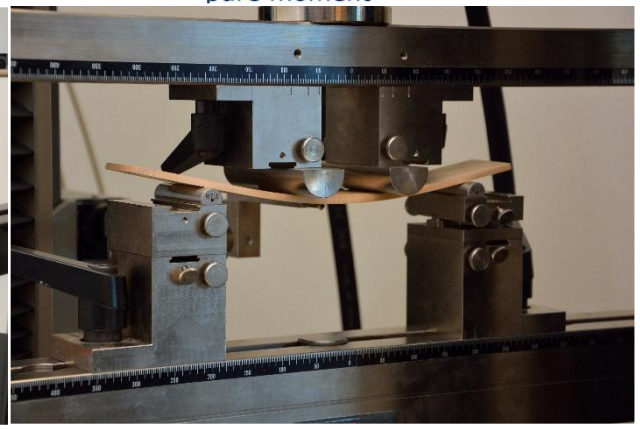



4 point bending
(aka third point bending)




"pure moment"

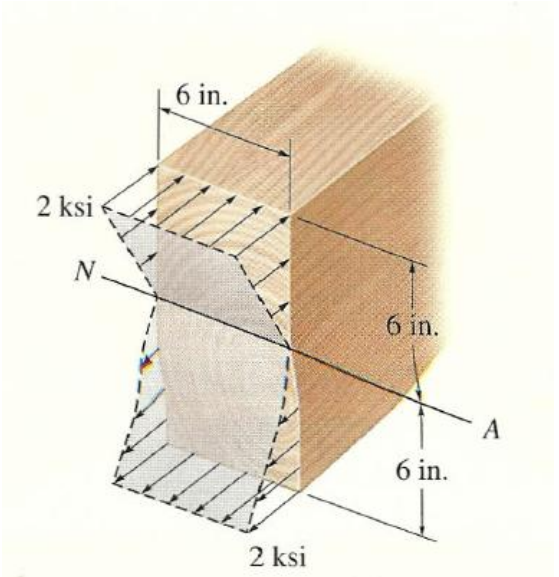


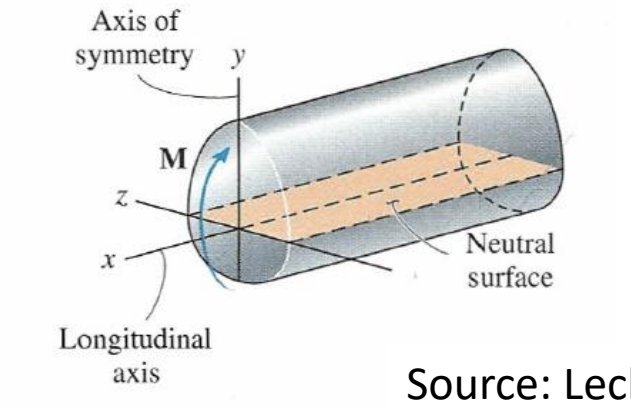


Source: Lech Muszynski

# Stress distribution in beam sections

- The stress in beams is distributed over the cross section
- Part of the section is subjected compressive stress while the other part is subjected to tensile stress
- In between there is part of a section where the normal stress is zero. It is called a **neutral axis** or in a beam segment, a **neutral plane**

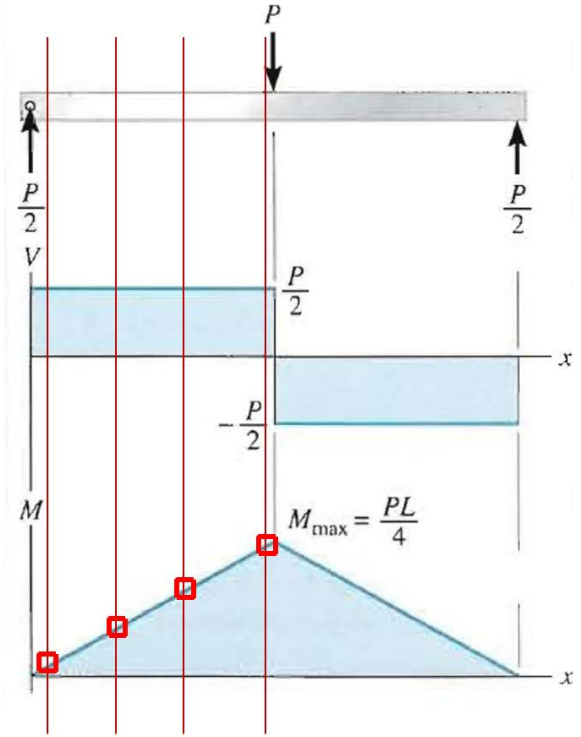



Source: Lech Muszynski

# Normal stress

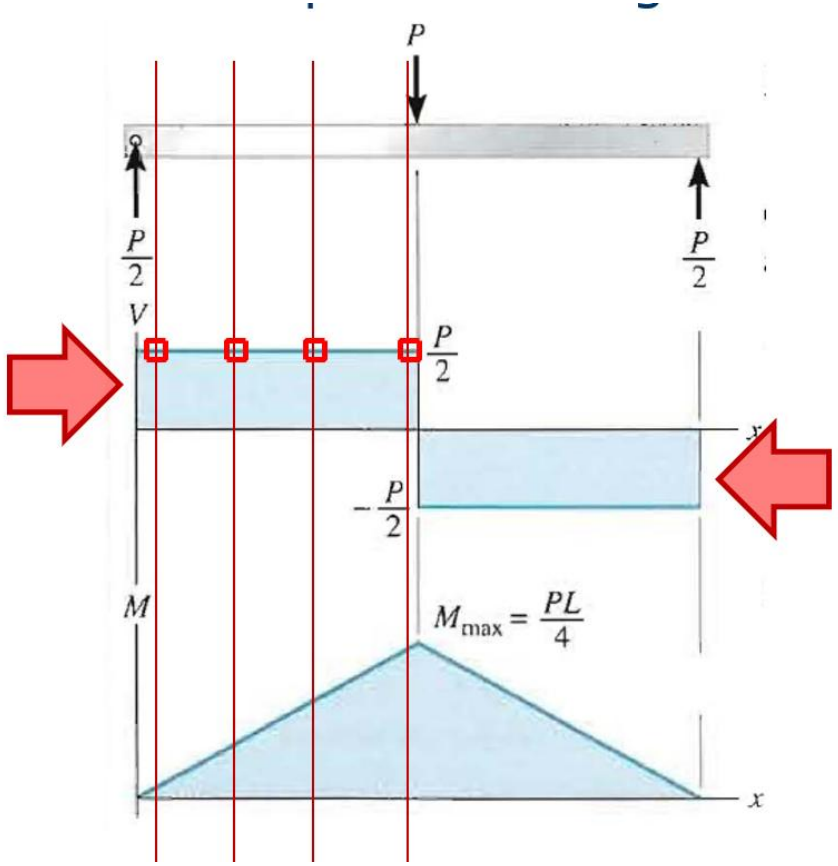
- The magnitude of normal stress in the section depends upon the position of the section in the beam.
- The maximum stress will appear in the extreme fibers of a section loaded with maximum moment




Source: Lech Muszynski

# Shear stress

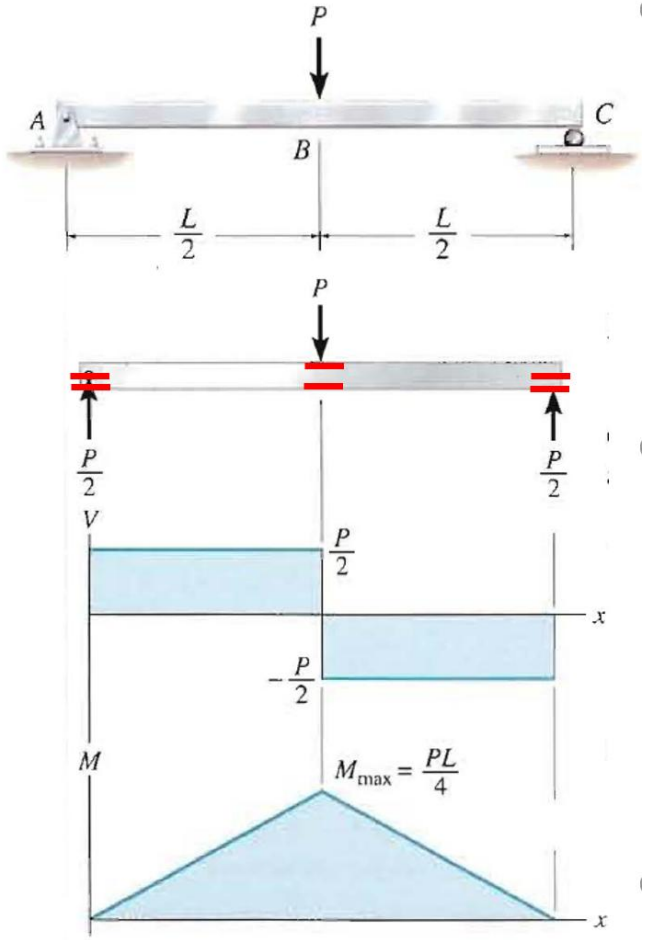
- Maximum shear stress will appear at the neutral axis of a section loaded with maximum shear force




Source: Lech Muszynski

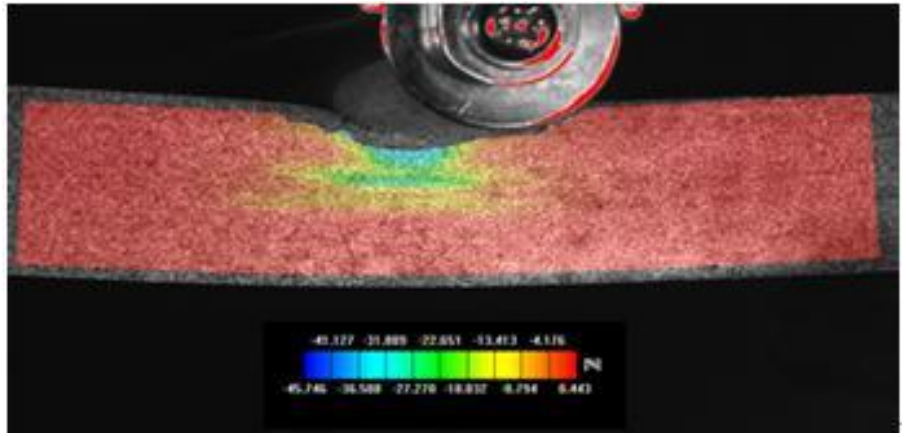
# Complicating factors

- Bending is quite a complex process and beams may fail due to
  - Normal tensile stress in extreme fibers on the tensile side
  - Normal compressive stress in extreme fibers on the compressive side
  - Shear stress ‖ to the grain at the supports
  - A combination of the above
  - Compression perpendicular to the grain at loading points and supports may contribute to a premature failure




Source: Lech Muszynski

# Stress concentration points



Source: Lech Muszynski

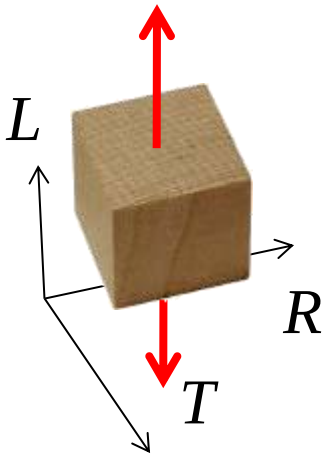


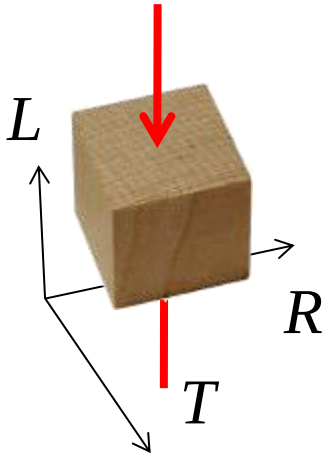
timber.org.au

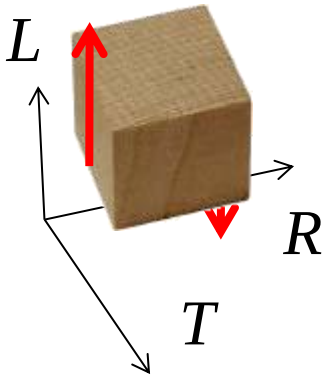
tension

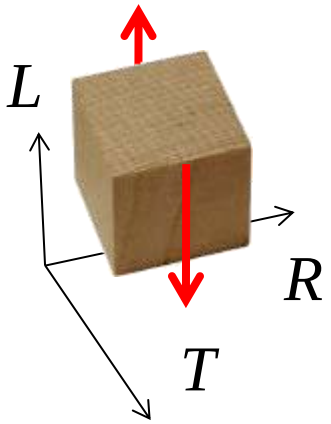
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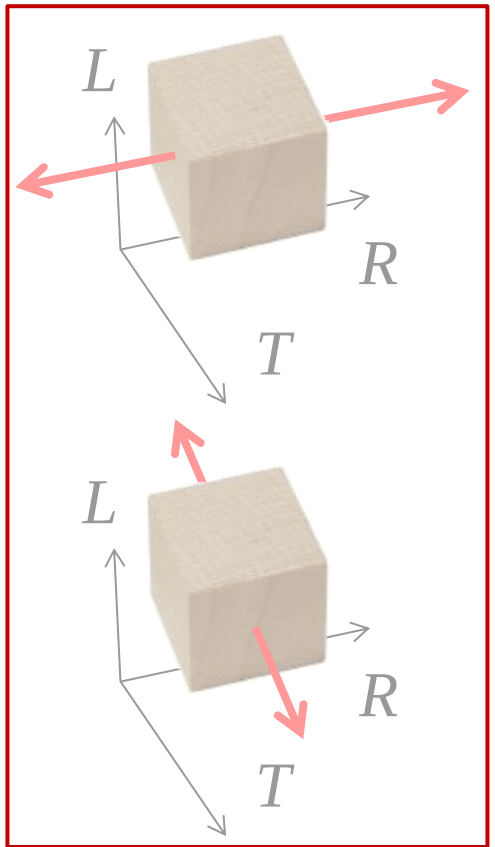
6 possible directions of shear…

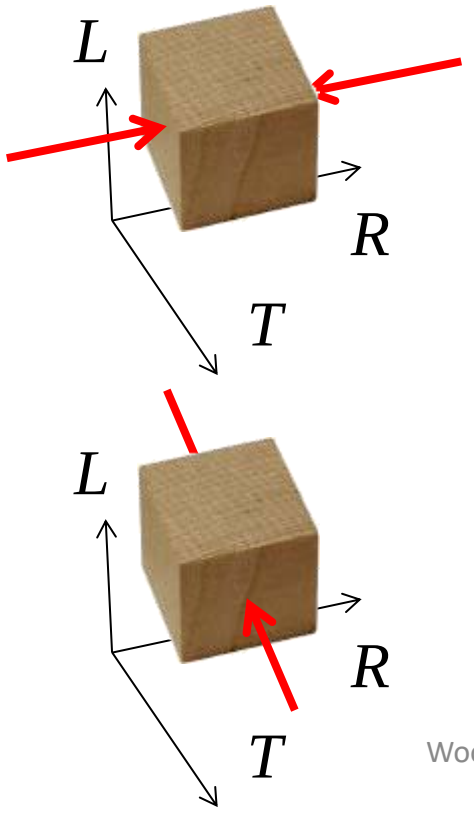


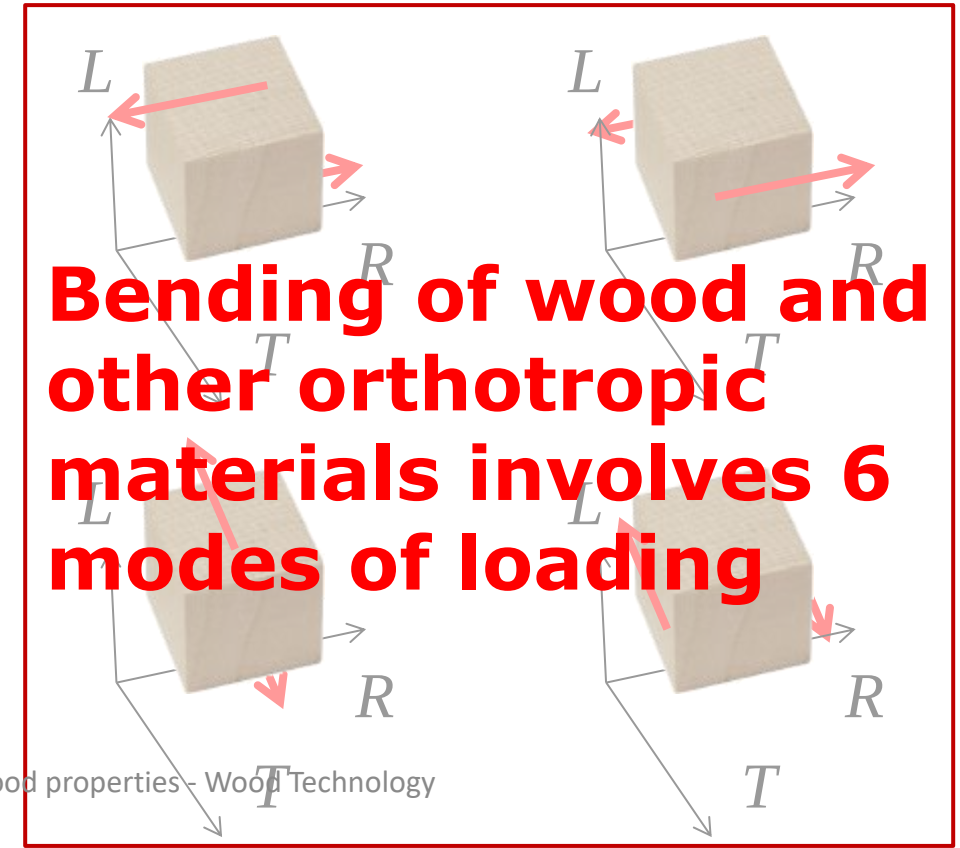




**Bending of wood and other orthotropic materials involves 6 modes of loading**

Source: Lech Muszynski

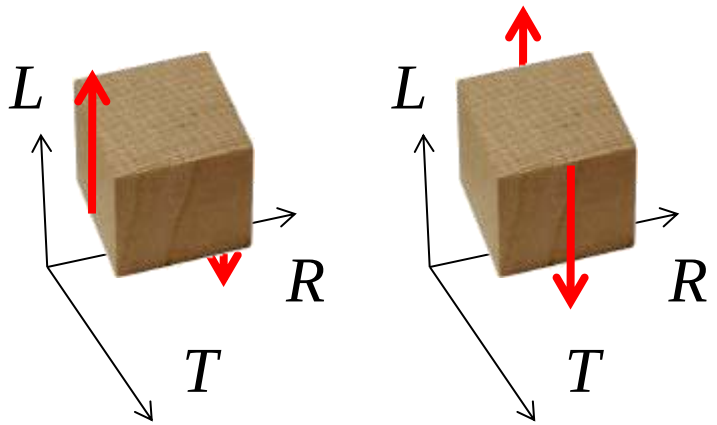
# Summary of stress values

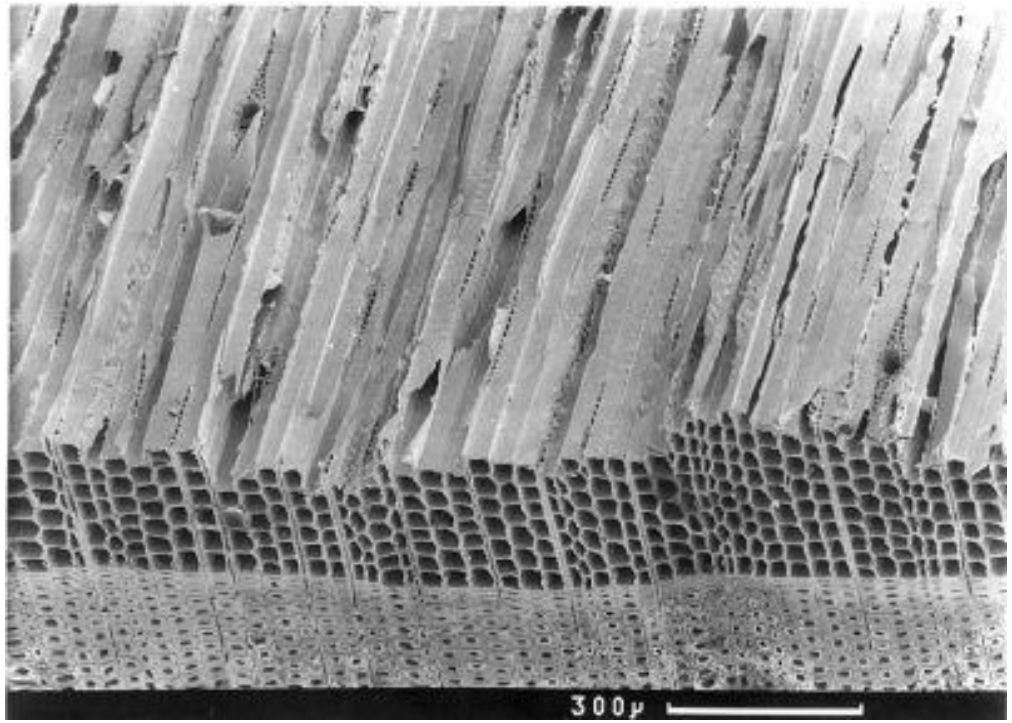
| Strength property | Grain angle | Max stress |
|---|---|---|
| Tension \|\| | 0° | 100 MPa |
| Tension ⊥ | 90° | 3.5 – 5.3 MPa |
| Compression \|\| | 0° | 50 MPa |
| Compression ⊥ | 90° | 5 MPa |
| Shear \|\| | 0° | 10 MPa |
| Shear rolling | 90° | 3.5 – 5.0 MPa |
| MOR | | 75 MPa |

Source: Lech Muszynski

# Shear ∥ to the grain

- Shear ∥ to grain (~10 MPa)
  - Shear plane ∥ to grain
  - Sliding dir. ∥ to grain



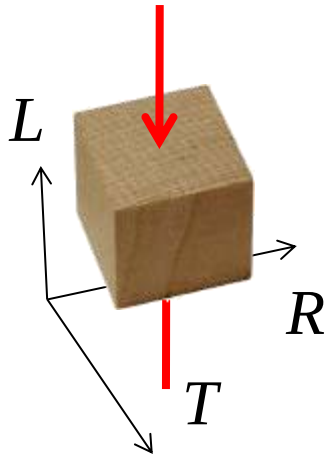

mpa.uni-stuttgart.de

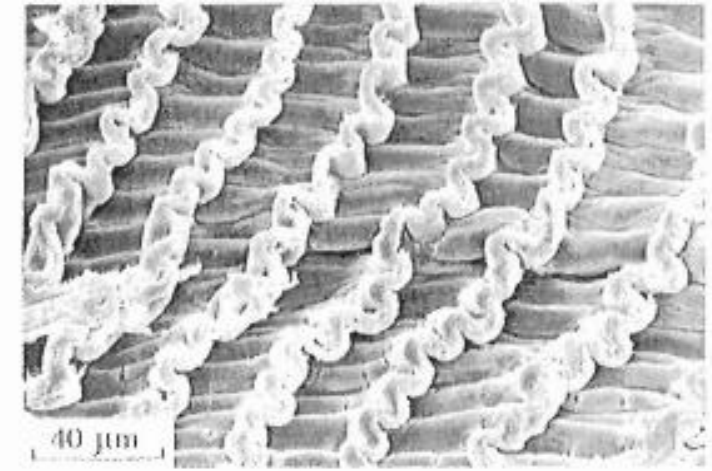
Fractured surface of a specimen (wood species : *Picea spp.*) photographed with a scanning electron microscope (SEM)

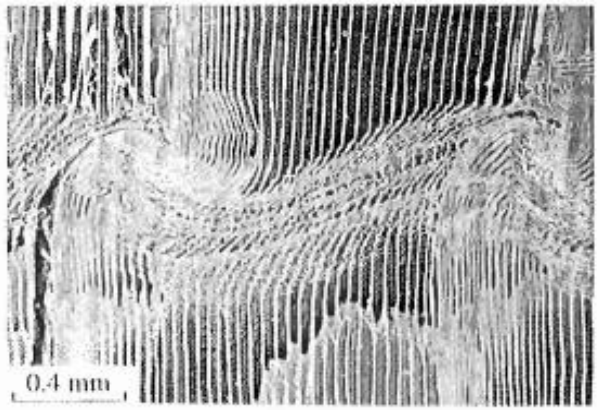
Source: Lech Muszynski

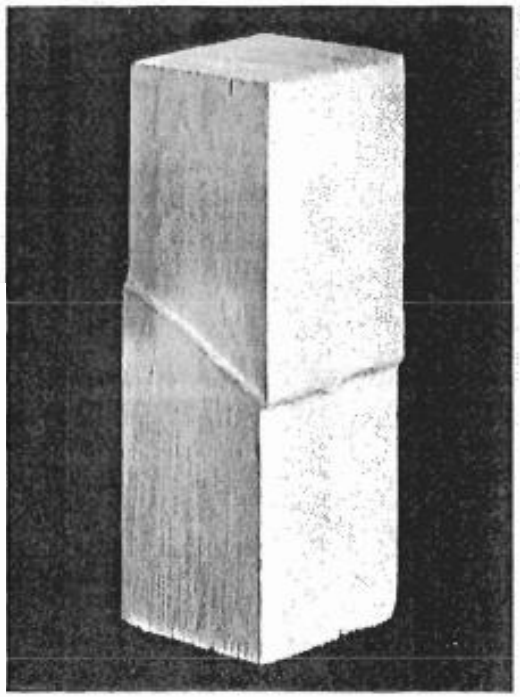
# Compression ∥ to the grain

- ~ 50 MPa (~50% of tension ∥)
- Failure (entirely different from tension):
  - Crumbling, folding (buckling) of cell wall in S shape
  - Eventually wrinkles on L-R and L-T face



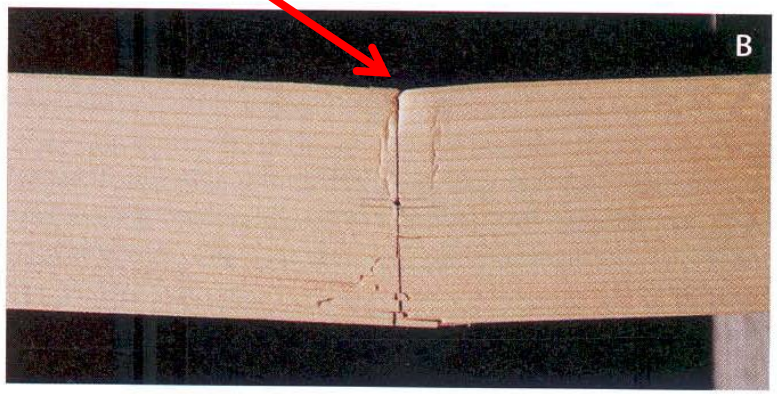



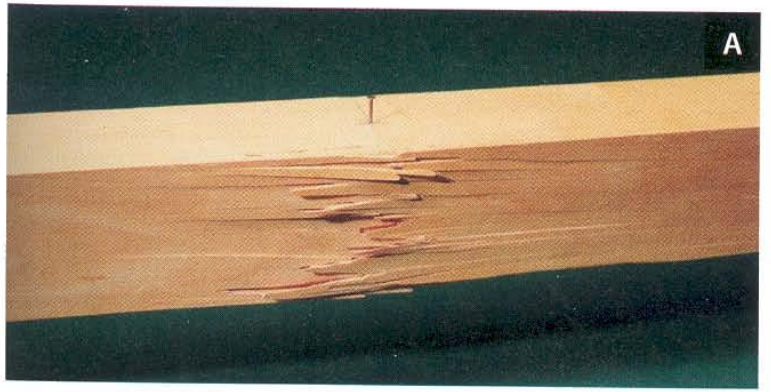
Source: Lech Muszynski

Gibson & Ashby

# Limits of applicability

Typical bending failure begins in compression zone (wrinkles)
but beams finally tend to fail in tension




Understanding Wood by Hoadley (2000)

Source: Lech Muszynski

# Factors influencing mechanical behavior

- Environmental Factors
  - Moisture Content
  - Temperature
  - Time
  - Chemicals
- Natural Characteristics
  - Species (SG/Natural Variability)
  - Slope of Grain
  - Knots, Checks and Shakes
  - Annual Ring Orientation
  - Reaction Wood, Juvenile Wood
  - Pitch Pockets, extractives, others
- Biological
  - fungi, decay, insect, etc.
- Chemical Treatment
  - preservatives

# Effect of knots, slope of grain etc.

- Effect of knots

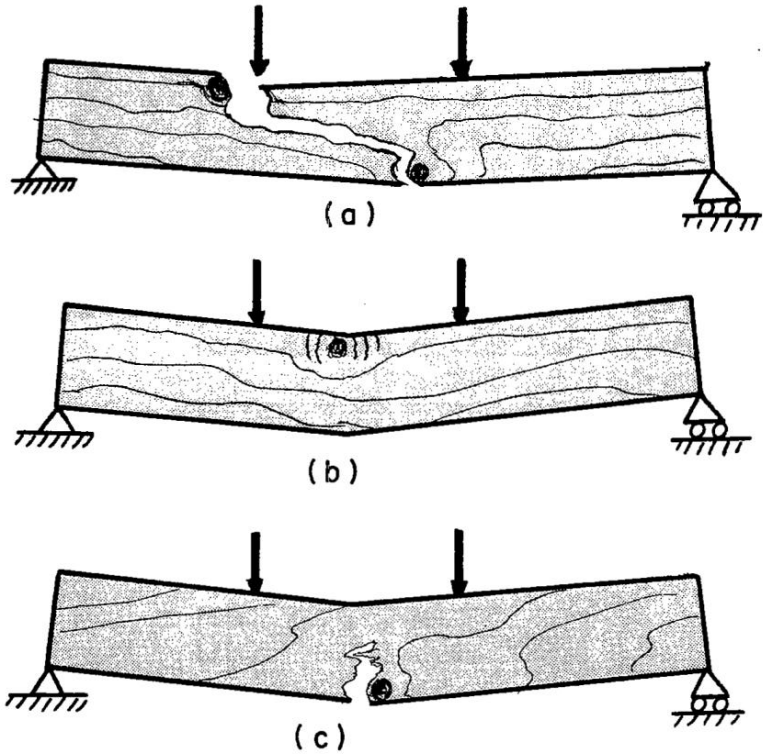



Fig. 7.28. Types of failure of lumber in bending caused by knots: (a) diagonal tension, (b) compression near a knot, (c) localized cross-grain tension.

- Slope of grain

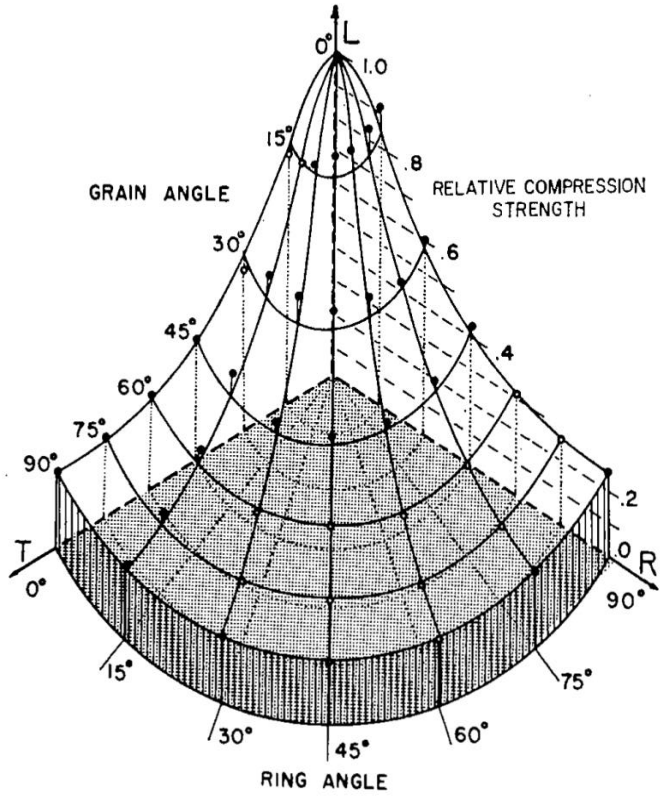



Fig. 7.34. Comparison of experimental data and surface predicted by the three-dimensional Hankinson's formula for oak.

Source: Lech Muszynski

# References


- Hoadley, R. Bruce. 1990. *Identifying Wood: Accurate Results with Simple Tools*. Taunton Press. 240 pp.
- Milota, M. 2010. Oregon State University. Wood Science and Engineering, WSE 521, Wood Science 1, Class Lectures.
- Muszynski, L. 2012. Oregon State University. Wood Science and Engineering, WSE 324, Renewable materials laboratory.