Making Effective Use of Technological Advances:

Joinery and Adhesives

Daniel Hindman
Assistant Professor
Wood Science and Forest Products
Virginia Tech
Schedule

- Successful joints
- Adhesives
  - Theory
  - Wood Structure
  - Types of Adhesives
- Joinery
  - Theory
  - Types of Joinery
- Testing
Successful Joints

- Provide adequate strength and stiffness for the required loadings
- Minimize cost and effort
- Conform to acceptable health and safety standards
Characteristics of a Successful Joint

- No Gaps!
- Materials in close contact
  - A good bondline is between 0.003” to 0.006”
  - A good fitting wood-wood joint has a gap of 0.005”
- Correct size and alignment of wood parts
ADHESION

Mechanics
- Stress Transfer

Chemistry
- Wetting
- Interlock

Materials
- Flow
- Penetration
- Distribution
Bond Formation

Adhesive Applied To One Surface

Wetting and penetration of one surface

As surfaces meet, the adhesive is transferred to the other surface and flow begins

Flow occurs along bondline. Penetration occurs into wood cells

As pressure increases, penetration potential increases

Wetting continues on internal surfaces

Pressure holds wood in place until all flow and penetration have stopped

Solidification stops all penetration and flow
How Much Flow and Penetration?

**Enough To Get An Adequate Bond To Meet Performance At Minimal Cost**

- Reduce stress concentrations around bonds
- Encapsulate fractured cells near the bondline
- End grain difficult to bond, consumes more adhesive
- Low density wood has more void space to fill, consumes more adhesive
Wood Structure

- outer bark
- phloem
- heartwood
- sapwood
- pith
- an annual ring

**SECTION OF TRUNK OF A PINE TREE**

- cambium produces phloem (bark tissue) and xylem (wood tissue)
- Wood is made up of annual rings, each composed of thin-walled earlywood cells and thick-walled latewood cells.
Softwoods and Hardwoods

- earlywood tracheids
- latewood tracheids
- ray cells
- vessel
- fibre
- ray cells
Wood Structure Conclusions

- Softwoods are relatively simple structure
- Hardwoods show more diversity of cell structures and arrangements
- Moisture (and adhesive) flow in wood is in lumens (cell cavities) and through pits
All Wood Is Not Created Equal

- Annual growth
- Late wood
- Early wood

- Annual growth

- Annual growth
  - No distinction between late wood and early wood

- Narrow annual growth (weak)
- Wide annual growth (strong)

- Annual growth
  - Late wood
  - Early wood
Chemistry

- Wetting of Surface to Form Chemical Bonds
- Mechanical Interlock
Wetting

- *Wetting* is the ability of the adhesive to develop contact with the substrates.

> Good wetting does not assure good bonding...
> But poor wetting assures bad bonding.

> Consolidation: Voids and stress concentration.

> Consolidation: No Voids, sound bondline.
Mechanical Interlock

- Even smooth wood surfaces have a series of small irregularities, broken cells and microcracks.
- Adhesives which penetrate into these areas create an ability to interlock, creating joint strength.
Mechanics – Stress Transfer

- Penetration of adhesive into wood helps distribute load from the bond to the wood material.
This Seems To Be A Good Bond
Good Joint / Bad Joint?

3”

1”
Good Joint / Bad Joint ? (2)
ADHESIVE SELECTIONS
<table>
<thead>
<tr>
<th>Adhesive</th>
<th>Moisture Durability</th>
<th>Temperature Sensitivity</th>
<th>Flexibility</th>
<th>Color</th>
<th>Staining of Wood</th>
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<td>Others</td>
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<td>• Hot Melt</td>
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<td>• Neoprene</td>
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<td>---</td>
<td>Black (over time)</td>
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Adhesives

• Natural Adhesives
  ◦ Animal
  ◦ Vegetable
  ◦ Casein

• Usually low strength and low durability

• Traditional uses

• Activation with heat helps with forming delicate parts
Adhesives II

- Thermoset adhesives –
  - Urea / Urea Formaldehyde
  - Phenol (resorcinol)
  - Melamine

- Used for wood composite manufacture

- Some of these adhesives have concerns about formaldehyde emissions (especially urea formaldehyde)
VOCS and Formaldehyde

- Many green building certification systems are requesting reduced or eliminated formaldehyde emissions

- What’s In a Name?
  - Urea Formaldehyde – offgas over life of product
  - Phenol Formaldehyde – offgas immediately after pressing

- New formulations of water-based and PVA are becoming stronger and exterior rated!
Adhesives III

- Other Adhesives
  - Epoxy
  - Hot Melt
  - PVA
  - Crosslinked PVA
  - PVA - X
  - Polyurethane – moisture cured
New Adhesives
Joinery

- Dovetail
- Mortise and Tenon
- Dowels
- Biscuits
- Pocket hole Screws
Introduction to Joinery

- Interaction of materials and connections
- Concept of stress, or load/area
  - Higher stress materials require *less* area of contact to carry the load (steel screws, plates)
  - Lower stress materials require *more* area of contact to carry the load (dovetail, mortise and tenon, dowels)
- Stress also governs the number and spacing of fasteners needed
What’s New In Joinery?

• Several new connectors

• Think about traditional joinery in terms of your CNC operations . . .
Forces in Joints

Shear
- Force applied parallel to glueline

Tensile
- Force applied perpendicular to glueline
Forces In Joints

- Peeling
- Cleavage
Dovetails

- Beautiful joints
- Very strong
- Require specialized tools and precision
- Mostly used in solid wood
- High level of time and skill needed
Mortise and Tenon

- Beautiful Joints
- Have good moment resistance (i.e. frames)
- Difficult to construct (Can use CNC equipment)
- Can use wedges or dowels to attach joint
Standard Dowels

- Produce good joints
- No visible fasteners
- Special jigs / fixtures are available
- Alignment of holes is crucial!
Stepped Dowels

- Since wood absorbs moisture readily through end grain, this dowel swells to lock the joint very tightly
- Requires special drill bit
- Dowels made in domestic and tropical hardwoods
Biscuits

- Biscuits expand in slots when covered with adhesive
- Combination of adhesive and swollen biscuit lock joint
- Can be used with composites
- Need special hole cutter
Pocket Hole Screws

- Angled holes drilled into connections
- Create strong joints
- Very good for 90 degree joints (end grain to side grain)
- Many products and inexpensive jigs available
JOINERY OF WOOD COMPOSITES
# TYPICAL CARCASE JOINTS

## Corner Joint

### Key to Chart

- **Suitability and Relative Strength**
  - Excellent
  - Good
  - Fair
  - Poor
  - Unsuitable

- **Suitable Method of Making**
  - Hand-cut (Using hand tools)
  - Hand-cut/jig (Using hand tools with jigs)
  - Machine-cut (Using hand-held power tools)*
  - Machine-cut (Using machine tools)*
  - Jigs may also be used

- **Relative Difficulty of Making**
  - Difficult
  - Simple

### Corner-Joint Options

<table>
<thead>
<tr>
<th>Corner-Joint Options</th>
<th>suitability and relative strength</th>
<th>suitable method of making</th>
<th>relative difficulty of making</th>
<th>comments</th>
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<tbody>
<tr>
<td>Butt</td>
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<tr>
<td>Mitered Butt</td>
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<td>Splined Miter</td>
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<td>Loose-Tongued Miter</td>
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<td>Rabbet</td>
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<td>Mitered Rabbet</td>
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<td>Barefaced Housing</td>
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### Comments

- Butt: Has exposed core. May be reinforced by screw or block reinforcement. Improves strength.
- Mitered Butt: Core is hidden. Has similar strength to plain butt. Good for veneering.
- Splined Miter: Stronger than plain miter. Can be used as decorative joint.
- Loose-Tongued Miter: A strong miter joint. Core is hidden. Good for veneering.
- Rabbet: Neater and stronger than a plain butt. Shows little core at corner.
- Mitered Rabbet: Core is hidden. Better appearance than other butt. But more difficult to make.
- Barefaced Housing: Has exposed core. Has greater strength than plain butt.
### Typical Carcase Joints

**Corner Joint**

![Diagram of Corner Joint]

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**Key to Chart**

#### Suitability and Relative Strength
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- Hand-cut (Using hand tools)
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*Jigs may also be used*

#### Relative Difficulty of Making
- Difficult
- Simple

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<table>
<thead>
<tr>
<th>Joint</th>
<th>Plywood</th>
<th>Blockboard</th>
<th>Chipboard</th>
<th>plywood</th>
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<th>Chipboard</th>
<th>Hand-Cut</th>
<th>Hand-Cut/Jig</th>
<th>Machine-Cut</th>
<th>Machine-Cut</th>
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<tr>
<td>Mitered Dowel</td>
<td>![Diagram of Mitered Dowel]</td>
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<td>![Diagram of Mitered Dowel]</td>
<td>![Diagram of Mitered Dowel]</td>
<td>![Diagram of Mitered Dowel]</td>
<td>- Similar to loose-temper miter in strength and appearance, cut welling.</td>
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<tr>
<td>T-JOINT OPTIONS</td>
<td>SUITABILITY AND RELATIVE STRENGTH</td>
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</table>

**KEY TO CHART**

Suitability and relative strength

- Excellent
- Good
- Fair
- Poor
- Unsuitable

Suitable method of making

- Hand-cut (Using hand tools)
- Hand-cut/jig (Using hand tools with jigs)
- Machine-cut (Using hand-held power tools)*
- Machine-cut (Using machine tools)*

*Jigs may also be used

Relative difficulty of making

- Difficult
- Simple

**COMMENTS**

- Relatively weak. Nail or screw reinforcement improves strength.
- Has greater strength than plain butt. Reinforcement not required.
- As above but neater at front edge.
- Similar to plain dado.
- Greater strength than plain dado but more difficult to cut.
- Strong, simple to cut with aid of a dowel jig.
- Strong machine-made joint.
## Edge-to-edge Joint Options

### Key to Chart
- **Suitability and relative strength**
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  - Good
  - Fair
  - Poor
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- **Suitable method of making**
  - Hand-cut (Using hand tools)
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  - Machine-cut (Using machine tools)*
  - Jigs may also be used
- **Relative difficulty of making**
  - Difficult
  - Simple

### Comments
- **Simple to cut. Use modern synthetic glues for improved strength.**
- **Greater strength than plain butt. Tongue helps locate the edges.**
- **As above.**
- **As above.**

### Edge-to-Edge Joint Options

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Testing Connections

• When something goes wrong
• Trial of new methods or processes
• Examining new products or markets
• Certification or validation needs (ICC or others)
• Litigation / Expert Witness
What is the Goal of Testing?

- Predict performance
- Quality Control
- Effect of Environmental Factors (temperature, moisture)
- Realism in Testing
- Use a sampled population
Sample Size Determination

\[ n = \left( \frac{t}{0.05 \cdot COV} \right)^2 \]

- \( n = \) number of specimens
- \( COV = \) coefficient of variation = mean / std. dev.
- \( t = \) t-statistic depending upon confidence interval and specimen number
Testing Advice

• Different types of testing
  • Certified labs – need for ICC and others, litigation
  • Non-certified labs – used to solve internal problems, litigation
• Realism in Testing – Use correct loadings
• Adequate sample size
Take Home Message

- Consider how adhesives and joinery interact to create the joints you need
- Many different systems for adhesives and joinery depending upon:
  - Use
  - Amount of Strength Needed
  - Price Point (Costs)
  - Experience / Skill of Workers
- Green building has inspired development of water-based and PVA type adhesives with greater strength, safer products
- Testing services are available depending upon your needs
Resources

- Wood Handbook
  (http://www.fpl.fs.fed.us/products/publications/several_pubs.php?grouping_id=100&header_id=p)

- WOODWEB
  (http://www.woodweb.com/)

- Wood Based Composites Center
  (http://www.wbc.vt.edu/)
Thanks!

Daniel Hindman
(540) 231-9442
dhindman@vt.edu