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Introduction to Wood Properties and Wood Products

Wood-based panels

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Today

- To provide an **overview** of the manufacture of dry-formed wood-based panels (particleboard, MDF, OSB), using **particleboard** as an example
- To introduce how the parts of the process affect the panel board properties
- To explain the hot-pressing process, particularly with regard to how the process affects the development of the structure and the properties of the panel
  - Although the focus is on particleboard, similar reasoning applies to other panel products and engineered wood products
Structure of PB

- Particles of mm dimensions
- Typically 3 layers – surface or face material of fine particles
- Core material of coarser material (larger chips)
- Density profile developed during manufacture
  - Improved properties in bending
  - Harder surface
Some factors that affect the properties of a panel board:

The development of the final properties are dependent upon either the raw material or the manufacturing process!

(Source: Maloney, 1993)
Properties

• Importance of property depends on application:
• Range of differing physical, mechanical & other properties, including:
  – Strength (bending, transverse tensile, shear)
  – Stiffness (bending)
  – Density
  – Surface hardness
  – Screw holding
  – Colour
  – Surface “finish” (roughness)
  – Moisture resistance
  – Creep (long term deformation under a sustained load)
  – VOC emissions
Panel properties affected by

- Raw material characteristics
  - Strength, chemical composition, density
- Interaction between particles
  - Particle to particle bonding
- Structural organisation of constituents
  - Size and shape of the particles
  - Orientation of particles
  - Packing
  - Relative proportions of the constituents
Some factors that affect the properties of a panel board...

(Source: Maloney, 1993)
Basics steps in the process

1. Raw material prepared
2. Converted into particles
3. Particles dried
4. Particles classified
5. Blended with a resin and additives
6. Particle/resin/additive blend ("furnish") is formed into a mattress
7. Hot pressed to compact the particles together and cure the resin
8. Cooled and finished
The particleboard process

(Product)

Wood-raw material

(Source Diffenbacher: http://www.dieffenbacher.de/index2.html)
Raw materials

(Particles, adhesive & additives)
Particle

• Raw material properties influence many board properties, including board density, strength and stiffness etc.
• Can also influence the manufacturing process....
• Wood:
  – Virgin wood, mainly softwood, but other species can be used
    • Round wood
    • Co-products (sawdust, slabs, etc.)
    • Short rotation coppice (poplar)
  – Recovered/recycled wood (“urban forest”)
    • Pallet wood, packaging etc.
    • Management can be problematic due to difficulties in identifying contaminants (polymeric – paints and varnishes; preservatives - CCA).
• Non-wood:
  – Agricultural by-products
    • Wheat straw, bagasse, hemp, rice straw
• Basically any fibrous lignocellulosic material!
Wood raw material

• Species:
  – Density (affects the “compaction ratio” and the way the chip deforms under compression during pressing), strength and stiffness
  – Chemistry: pH, buffering capacity, affect resin cure
  – Extractives: may “interfere” with the bonding process or lead to emissions problems

• Recovered wood:
  – Contaminants:
    • Metallic (large! Easily dealt with, but in preservatives more problematic (CCA)
    • Inorganic (grit, sand, cement...)
    • Organic (e.g. paints/varnishes - problems with pressing; creosote)
  – Identification of contaminants (materials management)
Non-wood raw material

• Basically any lignocellulosic material!
• E.g. wheat straw:
  – High inorganic content
  – Waxes

• See, for example, CS Process Engineering website
Raw material for particleboard
(Koskisen Oy)

• By-products
• Spruce - 80 %
• Birch - 15 %
• Pine - 5 %
• Saw dust
• Mini chips
• Cutter chips
• Chips/board
• 4,5 m$^3$ / m$^3$

(Courtesy: Koskisen Oy)
Adhesives

• Primarily thermosetting resins
  – Main type (90%) is Urea formaldehyde (UF)
    • Low cost
    • Rapid cure
    • Adequate properties for many applications (brittle and susceptible to hydrolysis)
    • “Low” formaldehyde emissions “E0”, E1 (E1 Classification <8m g HCHO/100g oven-dried board)
  – “Fortified” UF (melamine urea formaldehyde)
  – Phenol formaldehyde (PF)
  – MDI (methylene diphenyl diisocyanate) and pMDI. Zero formaldehyde release, but careful handling needed
• Other adhesives
  – Inorganic (cement bonded)
  – Thermoplastics
• Renewable resource-based adhesives
  – Tannin-based adhesives
  – Lignin-based adhesives
  – Glues based on vegetable oils
  – Soy flour-based adhesives
  – Furan polymer-based adhesives
• Binder-less boards using “activated” chips/particles (enzymatic or chemical)
Additives

- Waxes (reduction in moisture uptake)
  - Emulsion
  - Molten wax
- Fungicides
- Flame retardants
The Process
Process steps

1. Raw material preparation
2. Converted into particles
3. Particle drying
4. Particle classification
5. Blended with a resin and additives
6. Particle/resin/blend ("furnish") is formed into a mattress
7. Hot pressing to compact the particles together and cure the resin
8. Cooled and finished
1. Raw material preparation

- Debarking undertaken to remove bark which can reduce the properties of particleboard if present in quantities more than a few per cent
  - Rotary debarker
  - Drum debarker
- Sorting classification of waste wood for further processing
- Removal of metallic and other contaminants
- Problems in identifying some treatments that have previously been applied to wood. In particular, polymeric substances can cause problems in processing, for example

(Source: Andritz)
Process steps

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2. Conversion to particles (chipping)

- Aim to manufacture a homogeneous product
- Need therefore to produce chips of a suitable size & shape to form the furnish for the board
Chipping

(Courtesy: Koskisen Oy)
Particles (chips)

• Depends on raw material. For example, if the raw material is in log form or is already reduced in size, e.g. shavings

• Reduction may therefore be a two stage process. For example, primary reduction of debarked logs to give large, coarse chips, followed by further milling to produce more “engineered” chips

• Different equipment may be used to prepare chip of the required type
Types of equipment

• Knife systems
  – Use knives cut or slice chips form the raw material
  – Disc/drum chippers

• Hammer mill systems
  – Use hammers to grind, break, tear shred raw materials into smaller particles

• Attrition systems
  – Grind the wood raw material into fibre – similar to TMP pulp
Particle engineering

• Each particle reduction (milling) process will produce a range of particle sizes
• Different chip size/type used for surface and core layers – fine chips or particles on the surface (good finish), coarser chips in the core
• Important to produce chip surfaces with as little damage as possible to improve particle-particle bonding:
  – A mechanically weak surface layer will lead to possible break-down of the glue-line, resulting in degraded board properties
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3. Particle drying

• Why?
• High MC of chips from green wood too high (>100%) for pressing – can lead to the development of high vapour pressure in boards leading to delamination or “blows”
• Ensure that the “furnish” has a homogeneous MC
  – Core and surface layers may have different MC
• Some moisture is necessary to assist in heat transfer during the pressing process (see later lecture)
  – Remember: most commonly used commercial resins (e.g. UF/MUF) are water-based and this needs to be taken into account when determining the final moisture content of the particles..... Typically for UF around 65% solids content
  – Also wax emulsions contain water!
• Typically final MC of chips in the region of 2.5% after drying, but before resin blending
• Drying is a BIG consumer of energy!
Particle drying

- Optimisation of MC important: too much and this will cause problems with board blows, too little will lead to poor heat transfer in the press and incomplete resin cure, resulting in poor mechanical properties.
- Driers work on the principle of passing the particles through a stream of hot air (180-200°C).
Dryer types

Various types of dryer e.g.

- Drum type (rotary/fixed)
- Belt dryers
- Paddle trough dryers
- Suspension-type
- “Flash” driers (high temperature)
- See for example, Diffenbacher
Process steps

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4. Classification

• Why?
• Control particle size distribution – important so as to optimise the position and size of the particles relative to their position in the board – small particles on the surface, bigger particles in the core
• Need to ensure that the board is “balanced”, i.e. the same amount of surface particles on both faces of the board (c.f. plywood). Otherwise may result in distortion of the board
• Note: very small particles (fines) will consume more resin (high surface area to weight ratio)
Classification systems

- **Sieving** – pass particle through different sized sieves, larger particles are retained, smaller particles pass through to the next size down.

- **Air classification** – suspended in an air stream; the smaller, lighter, particles are carried away in the air stream, leaving the larger heavier particles (lower surface area to weight ratio).
  - Can form part of the drying process – simultaneous drying and classification.
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5. Gluing/blending

- An adhesive or glue needs to be applied to the surface of the particles to bind the particles together
- Different resins have different performance characteristics:
  - UF; brittle and subject to hydrolysis
  - MUF; better moisture resistance than standard UF
  - PF; more resilient and less subject to hydrolysis
  - MDI; highly reactive and bonds well
- The resins are generally applied as liquids in the form of an atomised spray
  - Note: can also be applied in solid (powder) form that forms a liquid on heating, before reverting to an insoluble, infusible, solid form (e.g. PF)
- Additional mechanical blending can enhance the coverage of the resin over the particle
Glue factors influencing board properties....

- **Amount of resin**
  - Generally, more resin, better properties (but more expensive!), therefore a balance...
  - Varies from resin type to resin type and is typically 8% (solids on oven dry wood) for UF in PB (or MDF), but can be as low as 2% (for MDI in MDF)

- **Resin properties**
  - Viscosity (depends on resin itself and “solids content”)
  - Solids content (weight of solid resin to total weight of resin)
  - pH and buffering capacity

- **Distribution of resin**
  - Droplet size (spray type and nozzle design)
  - Generally smaller droplets preferred, giving better resin distribution (see e.g. Kelly, 1977)

- **Cure characteristics**
  - Heat and/or catalyst needed to cure resin
  - Gel time/cure time depends on several factors
More on glues & additives

• Resins frequently manufactured on site, particularly UF and MUF. Storage conditions and duration important to prevent degradation (short shelf-life)
• Other additives (e.g. waxes, fungicides, flame retardants) may be blended in at the same time
• Typically, wax is added at around 0.5-1.0% (solid on OD wood)
Process steps

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Forming

• Laying up the “furnish” prior to pre-pressing and hot pressing (consolidation)
• Important process in the formation of the structure of the board and therefore strongly affects the board properties:
  – Improved bending properties
  – Good surface finish
  – Optimised density
• Boards may be “single layer”, “multi-layer” (3,5), or “graduated”
• Must always be a “balanced” structure to prevent distortion or poor properties (i.e. 2 or 4 layer no good)
• Surface layers of “fine” particles, “core” of coarser particles
• MC of surface layers 8-15%; core 4-8%
• Resin content of surface layers may also be higher to give improved strength
Forming

3 layer  Homogeneous  2 layer - unbalanced

Surface  Core  Surface

Forming
Process steps

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6. Particle/resin/blend (“furnish”) is formed into a mattress
7. Pre-pressing & hot pressed to compact the particles together and cure the resin
8. Cooled and finished
Pre-pressing & hot pressing

- Pre-pressing of the furnish to reduce the bulk and give some mechanical strength to the mattress
- Hot-pressing, to finally consolidate the board and cure the adhesive. Density profile generated during hot-pressing
- Various types of press, the most common being a continuous press.
Pre-pressing

- Part of the consolidation process
- Pre-pressing undertaken to:
  - Reduce the thickness of the mattress (i.e. increase the bulk density of the mattress)
  - Give the mattress some mechanical strength for handling
  - Speed up the hot press process, reduce pre-cure
- Important that the mattress has some “tack” (slightly sticky), provided by the glue
- Pre-pressing may be cold or hot, important not to pre-cure the resin, but can help in getting heat energy into the mattress
Hot-pressing

- Main mechanism for consolidation of the mattress, the development of the board internal structure (in combination with forming etc...) and curing the adhesive binding the particles together
- Pressing may be batch-wise in a single or multi-opening press, or in a continuous press (“conti-press”)
- Press control vital in the development of board properties and much research directed towards understanding what is going on in press and in modelling this behaviour
Press types

• Opening presses:
  – Single-
  – Multi- daylight presses

• Continuous presses

(Source: Siempelkamp.com: http://www.siempelkamp.com/Products.552.0.html)
What is going on in the pressing process?

- Heat transfer and flow of gasses
- Phase change of water
- Densification of material
- Adhesive cure
- Development of internal stresses
Basic steps

• Board (mattress) fed to the press
• “Daylight” closes
• Press closure to target (thickness, pressure) – pressure increase
• Pressure/thickness maintained: resin cure
• Daylight opens: pressure reduced
  – May be done in stages
• Boards removed
**Hot-pressing**

- Press closes
- Pressure applied

**Mattress**
**Heated platen (circa 140 – 180°C)**
**(Target thickness reached & held)**

Progression in pressing process
What happens to:

- Mat thickness
- Counter pressure
- Surface temperature
- Core temperature
- Core vapour pressure

During the pressing process?
Pressing physics

(Source: Kavvouras, 1977)
Press control/monitoring

Output from PressMan control unit
(Source: Alberta Research Council)
Factors that affect the pressing process and influence the final board properties
Raw material

• Particle type and geometry – whether it is “granular” (chips), flakes or strands
  – Internal structure and ability of gasses to move around the interior of the mat: easier if it is granular, less so if it is composed of flakes

• Mat moisture content
  – Overall
  – Distribution
    • Higher on surfaces
  – Heat transfer, plasticisation of chips, but...
  – ...higher internal vapour pressure, possible delamination
Heat transfer mechanisms

• Conduction
• Convection
  – Change of phase: liquid-vapour-liquid
• Radiation
  – Negligible
Development of adhesive strength

• Gel time: liquid to solid....
• Time to reach full cure
Densification, internal stresses and spring-back

• Wood undergoes both instantaneous and time-dependent deformation when load is applied:
  – Elastic
  – Delayed elastic
  – Viscous
  – Plastic/microstructural failure

• “Trapped” elastic and delayed elastic stresses lead to internal stresses
Development of density profile

- Higher face moisture content will favour relaxation of the chips and so lead to higher face densities
- Faster press closure times will tend to result in higher density surfaces
- Higher density surfaces:
  - Increased bending properties and strength parallel to the board surface ....
  - ... but reduced internal bond strength (transverse tensile strength), inter-laminar shear strength and screw holding characteristics
Edge effects

- Vapour/gasses in the mat during pressing will tend to escape from the edges (not sealed)
- Leads to a lower gas pressure at the edges
  - Difficulty of scaling: e.g. simulating processes on a laboratory press
Limitations

• Thick panels
• Low density panels

• How to overcome these:
• External heating sources....
  – Steam injection
  – Radio Frequency (RF) and microwave heating
Cooling and finishing

• At exit from press, adhesive cured sufficiently to retain board integrity
• Some further “curing” may take place (used to be common to “hot stack” finished panels to cure the resin further)
• Panels need to be cooled before finishing (e.g. sanding) as if done too soon, board properties may be affected and tools will become clogged
• On exit boards trimmed before cooling
Cooing & finishing

- Cooled in e.g. “star cooler”
- After cooling the boards are sanded to the final thickness and to give good surface finish, especially if subsequent processing takes place, for example, lamination
Adding value

• Frequently the “raw boards” undergo further processing to add value
• Example is lamination or overlaying a decorative finish to the board
• Speciality boards (“moisture resistant”, “flame proof”)
References and further reading

- Philip E. Humphrey (undated) Temperature and Reactant Injection Effects on the Bonding Kinetics of Thermosetting adhesives
Further information

• Manufacturers:
  – Egger (www.egger.com)
  – Kronospan (http://www.kronospan.co.uk/)
  – Norboard (http://www.norbord.com/)