Lecture 2:
**Paper and paperboard based packaging**
Overview of different types of materials

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After Lecture 2 you should be able to

- Describe different types of wood fibre based packaging materials and their basic usage in different applications
- Describe and define different types of paperboard and some of their basic end-use properties
- Describe and define different types of corrugated board (corrugated packaging) and some of their basic end-use properties
Literature

- Lecture notes
- *Cartons, Crates and Corrugated Board – Handbook of Paper and Wood Packaging Technology* - Chapter 7.
- *Pulp and Paper Chemistry and Technology* - Volume 4, Paper Products Physics and Technology - Chapters 1, 3, 10.

Paper, Paperboard and Paperboard Composites Packaging
Wood fibre based packaging

Consumers like paper, survey shows, 2010-04-30

• Paperboard and paper are environment-friendly and safe packaging materials, and the environmental image of paperboard and paper is superior to that of other packaging materials.
  • These are the findings of a Finnish survey, conducted by the Association of Packaging Technology and Research, PTR, that examined consumer attitudes and preferences on packaging, as well as how these had developed over the last decade.

• According to the survey, consumers feel that paper packaging is nowadays more frequently an indication of a high-quality, valuable product.
  • The young and adults under 30 years of age consider paper and paperboard a more ordinary and less trendy material than other respondents.
World paper and board production in millions of tonnes

- Graphic 89.3 M (30%)
- Newsprint 36 M (12%)
- Other 9.9 M (3%)
- Packaging 145.1 M (49%)
- Tissue 18.6 M (6%)

CEPI, 1998

Paper and Paperboard Packaging

- Exists at all levels of packaging
  - Sales or primary packaging
  - Grouped or secondary packaging
  - Transport or tertiary packaging
Some important paper and board properties for packages

- Stiffness
- Delamination resistance
- Fracture properties
- Stack strength and creep

Moisture

- Curl
- Misregister
- Swelling
Paper

Definition

• Matted or felted sheet usually composed of plant fibres
• Paper has been commercially made from such fibre sources as
  – rags (linen)
  – bagasse (sugar cane)
  – cotton
  – straw
• Modern paper is almost exclusively made from “cellulose fibres” derived from wood

Terminology

Introduction

• Paperboard = boxboard = cardboard = carton board describes a heavier paper stock
• Paper and paperboard are non-specific terms that can be related to either material thickness (caliper) or grammage (basis weight)
• ISO (International Standards Organisation)
  – Paperboard = paper with a grammage > 250 g/m²
• General U.S. practice
  – Paperboard = paper with thickness > 300 μm
Representative paper machines

• Twin-wire Machines

Representative paper machines

• Fourdrinier Machines
Typical dryness and moisture ratio (mr) in a paper machine

Most important factors affecting the mechanical properties of paper

- **Botanical factors:** The structure, length distribution, fibre wall thickness and proportion of lumen in the fibres.
- **Chemical factors:** The degree of delignification, the degree of polymerisation of cellulose DP, the content and type of hemicellulose.
- **Papermaking factors:** Beating, forming, pressing, drying and calendering.
- **Chemical environment:** The presence of electrolytes, polyelectrolytes and surfactant substances.
Final paper properties affected by

- Beating of the pulp
- Forming of the fibre network
- Wet-pressing
- Addition of chemicals
- Drying and drying constraints
- Post-drying operations such as
  - Size pressing (starch solution)
  - Surface coating
  - Calendering

Fibre sources

- Spruce fibre – long and flat
- Birch fibre – short and cylindrical
- Pine fibre – long and flat
- Mixed fibres of spruce, pine and birch
Fibre source and length

- Most important fibre characteristics is fibre length

<table>
<thead>
<tr>
<th>Fiber Source</th>
<th>Typical Fiber Length</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Sources</strong></td>
<td></td>
</tr>
<tr>
<td>Hardwood (e.g., poplar, aspen, maple)</td>
<td>2 mm</td>
</tr>
<tr>
<td>Hardwood (eucalyptus)</td>
<td>1-1.5 mm</td>
</tr>
<tr>
<td>Softwood (e.g., pine, spruce, hemlock)</td>
<td>4 mm</td>
</tr>
<tr>
<td><strong>Other Sources</strong></td>
<td></td>
</tr>
<tr>
<td>Straw, bagasse</td>
<td>&lt; 2 mm</td>
</tr>
<tr>
<td>Bast (e.g., linen, cotton)</td>
<td>&gt; 2 mm</td>
</tr>
<tr>
<td>Recycled paper</td>
<td>varies depending on source</td>
</tr>
</tbody>
</table>

Long fibres produces paper with

- proportionately higher
  - tensile strength
    - tear strength
    - fold strength
    - puncture strength
- a rougher surface texture
- variations in density due to poor formation that can lead to
  - uneven ink adsorption during printing
  - erratic adhesive bonding
Short fibres produces paper with

- a smoother surface, and
- significantly reduced mechanical properties compared to long fibres

Recycled fibres will have properties

- inherited from the original fibres source, but
- with the provision that every re-pulping process degrades and reduces fibre length, thus
- significantly reduced physical properties compared to long fibres, and
- affected by extraneous contaminants such as
  - water insoluble adhesives
  - plastic debris
  - non-removable printing inks
Pulping methods

- Mechanical pulping
  - mechanical separation of fibres in refiners
- Chemical pulping
  - chemical separation of fibres
  - alkali sulphate extraction (kraft pulp)
- Combined processes
  - semi-chemical (chemicals before refining, NSSC)
  - thermo-mechanical (wood softened by heating before mechanical refining)
  - chemical-thermo-mechanical pulp (CTMP)

Pulp characteristics

Mechanical pulp

- High yield from the timber
- The presence of lignin makes the fibres hard and rigid.
- Limited degree of consolidation
  - Paper with high bulk (low density), bending stiffness and dimensional stability
- A sheet made solely of mechanical pulp is relatively weak but also relatively stiff.
**Pulp characteristics**

Chemical pulp

- Preserves fibre length
- Develops a high degree of consolidation
  - High density
- Flexible and soft fibres
  - Good creasing, embossing and cutting properties
- High whiteness, brightness and light stability properties
- High purity yields good odour and taint protection

**Bonds between two well-beaten fibres in a paper**
Freely dried paper (left) and paper dried under restraint (right)

Coated cartonboard

The fibres and structure is chosen mainly to give bending stiffness, good converting properties and surface properties.
Linerboard

Material directions

Depositing a fibre-water suspension onto a moving wire belt tends to align fibres in the direction of the web travel.

Paper can to a good approximation be considered as an orthotropic material.

- Three mutually perpendicular symmetry planes

⇒ Three perpendicular principal material directions
Why only orthotropic to a good approximation?

- Principal directions do not necessarily coincide with MD, CD and ZD everywhere in the web. WHY?

### Tensile stiffness index vs. shrinkage

![Graph showing the relationship between tensile stiffness index and shrinkage.](image)

Tensile stiffness index vs. shrinkage,

\[ \text{Tensile stiffness index (MN/m²kg)} \]

\[ \varepsilon_1 / \% \]

-4 -3 -2 -1 0 1 2 3 4

c.f. LJU Chapter 3

### Stiffness in the sheet at different drying strategies

![Graph showing shrinkage in CD for different drying strategies.](image)

Stiffness in the sheet at different drying strategies

- **Shrinkage in CD**

- Double-tier dryer

- Single-tier dryer

Position across the paper web, CD / m

![Figure 3.46](image)
To summarize:
Different shrinkage at the edges will make the sheet only approximately orthotropic across the web

Why bother?

- Non-uniform effects are typically located at the edges of the web, but streaks can also occur in the interior of the web.
- Edge effects create runnability problems in converting and end-use, particularly in
  - printing operations, and
  - manufacturing of paper bags and sacks
Large deformation bending of plates and its influence on deflection of paper and board

Unstable at large deflection

Stable at large deflection

(Nordström et al. 1998)

- Large deflection is typically larger than the sheet thickness!
- Double-curved surfaces in general possible only for very small deflections!
The paperboard manufacturing process

How to choose paperboard
Some related properties and features
How to choose paperboard
Promotion of products

- Physical protection needs
- Possibilities and contradictions
- Limitations due to the laws of nature
- Competitive economy
- **Consistency in manufacturing**
## To select paperboard - I

<table>
<thead>
<tr>
<th>Paperboard manufacturing</th>
<th>Paperboard properties</th>
<th>From paperboard to product</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Marketing</strong></td>
<td></td>
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<tr>
<td>Shape</td>
<td>Primary fibre</td>
<td>Strength and toughness</td>
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<tr>
<td></td>
<td>Multiply forming</td>
<td>Stiffness</td>
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<td></td>
<td>Coating components</td>
<td>Creasability and foldability</td>
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<td></td>
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<td>Gluability and sealability</td>
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<tr>
<td><strong>Graphical reproducibility</strong></td>
<td>Primary fibre</td>
<td>Design</td>
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<td></td>
<td>Pigment coating</td>
<td>Die-cutting and creasing</td>
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<td>Surface finishing</td>
<td>Gluing and sealing</td>
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<td>Deep drawing</td>
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## To select paperboard - II

<table>
<thead>
<tr>
<th>Paperboard manufacturing</th>
<th>Paperboard properties</th>
<th>From paperboard to product</th>
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</thead>
<tbody>
<tr>
<td><strong>Protection</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical protection</td>
<td>Primary fibre</td>
<td>Strength and toughness</td>
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<td></td>
<td>Multiply forming</td>
<td>Stiffness</td>
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<td></td>
<td>Box compression strength</td>
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<td></td>
<td></td>
<td>Design</td>
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<td>Extrusion coating</td>
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<td></td>
<td></td>
<td>and lamination</td>
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<td></td>
<td></td>
<td>Die-cutting and creasing</td>
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<td></td>
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</tr>
<tr>
<td>Product safety</td>
<td>Primary fibre</td>
<td>Taint and odour neutrality</td>
</tr>
<tr>
<td></td>
<td>Coating components</td>
<td>Design</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
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<td>and lamination</td>
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<td>Printing and varnishing</td>
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</table>
To select paperboard - III

<table>
<thead>
<tr>
<th>Paperboard manufacturing</th>
<th>Paperboard properties</th>
<th>From paperboard to product</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Converting and recycling properties</strong></td>
<td>Runna-ility</td>
<td>Primary fibre</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multiply forming</td>
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<td></td>
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<td>Coating components</td>
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<tr>
<td><strong>Distribution and end-use</strong></td>
<td>Primary fibre</td>
<td>Strength and toughness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stiffness</td>
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<tr>
<td></td>
<td></td>
<td>Rub resistance</td>
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Single-ply and multi-ply paperboard

**ply = layer**

Multi-ply paperboard is a LAMINATE structure
Solid Box Board (SBB)

Solid Bleached Board
(aroma and flavour sensitive products)

Solid Unbleached Board
(carrier sleeves, liquid packaging)

Folding Box Board (FBB)

Low density material with high stiffness

The I-beam principle
White Lined Chipboard (WLC)

- Wide range of different qualities
- Used in general packaging

Carton terminology and placement of the working creases and manufacturers joint

Gable-top carton blank and erected gable-top carton
CORRUGATED BOARD

- Corrugated containers are by far the most common form of transport packaging.
- Corrugated board packaging was not very many years ago not considered (and accepted) as a transport packaging giving sufficient product protection.
  - Conveyance of goods was carried out in non-covered trucks and goods wagons exhibiting the packaging to severe climates.

Price per unit area as function of specific stiffness

Corrugated board boxes
Main features

• Versatility
  – materials possessing a wide range of properties
  – flat sheets with a large range of structural and decorative properties
  – minimum space before erected
• High strength and low weight characteristics
  – structural sandwich with a low density core
    (long before it was introduced in the fibre reinforced plastics industry)
• Ready adaptation
  – suitable for a wide range of production techniques
• Production containment and protection features
  – contains and protects from producer to customer
• Low set up and tooling costs
  – many styles of boxes can be made by conventional converting equipment

Corrugated board boxes
Main features continued

• Low storage and handling costs
• Quick change characteristics
  – changes in style, graphics etc. can readily be made to suit changes in need
• “Suitable” for graphics design
  – “smooth” easily printed surface
• Use of renewable resources and suitability for recycling
  – made of wood fibres
• Contribution to the effectiveness of all handling and storage operations
  • closely tolerance dimensions
  • secure closure methods
  • easy design modification
Corrugated board - a sandwich structure

- Strong relatively high density facings
- Low density core
- Honeycomb core
- Facing density 0.7 g/cm³
- Core density 0.07 g/cm³
- Reboard

Notation used for corrugated board
Definitions of different types of corrugated board

<table>
<thead>
<tr>
<th>Flute type</th>
<th>Flute spacing (mm)</th>
<th>Flutes per meter</th>
<th>Flute height (mm)</th>
<th>Take-up factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>8.3–10</td>
<td>110 ± 10</td>
<td>4.67</td>
<td>1.54</td>
</tr>
<tr>
<td>C</td>
<td>7.1–8.3</td>
<td>130 ± 10</td>
<td>3.61</td>
<td>1.43</td>
</tr>
<tr>
<td>B</td>
<td>6.1–6.9</td>
<td>165 ± 10</td>
<td>2.46</td>
<td>1.32</td>
</tr>
<tr>
<td>E</td>
<td>3.2–3.6</td>
<td>295 ± 15</td>
<td>1.15</td>
<td>1.27</td>
</tr>
</tbody>
</table>

Usage of different types of liner and fluting in corrugated board

- **Natural kraft linerboard**
  - Mainly unbleached kraft fibre, some recycled content allowed

- **White top linerboard**
  - Bleached top layer on an unbleached base layer

- **Testliner**
  - Top layer and base layer made from 100% recycled fibres

- **Other recycled liner**
  - Mainly kraft top layer, which is a natural kraft layer on a recycled base layer

- **Recycled medium**
  - 100% recycled fibre furnish

- **Semi-chemical medium**
  - Contains mostly NSSC hardwood and/or softwood (NSSC= Neutral Sulphite Semi-Chemical pulp. Produced by defibration in a disc refiner.)

European market 1999
Testing of corrugated board packaging

- Testing of corrugated board packaging structures and materials can be carried out at different structural levels.
- Today, typically, component testing is carried out by paper “people” and box testing by “packaging” people. This should be changed since box and components properties of course are STRONGLY linked.

Different types of containers
Regular Slotted Container (RSC)

Special purpose packaging
Special purpose packaging

Die cut box

Wrap around box (IKEA)
Stacking of boxes on pallets

- Column stack
- Interlocking layers of boxes
- Interlocking 2 top layers only

Interlock stack patterns has 37% less potential strength than column stacks.

P. G. Wright, P.R. McKinlay, E.Y.N. Shaw

Influence of stacking pattern on strength of pallets

- 3 Tier vertically aligned, no overhang
- 3 Tier vertically aligned, no overhang

- 2 Tier vertically aligned, no overhang
- 2 Tier vertically aligned, no overhang

-45% -32%

Securing the pallet

- angular corner pieces with twine or strap
- tension net
- shrink and stretch film
- adhesive tapes ties

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