Lecture 17:
Design of paper and board packaging
Mechanosorptive creep

Wood packages, flexible packaging, bags and sacks
Glass and metal packaging

After lecture 17 you should be able to

• discuss the time-dependent behaviour of paper
• describe the effect of varying humidity on creep, i.e. mechanosorptive creep.
• illustrate some examples of wood packaging
• describe manufacturing of paper sacks and flexible packaging
• discuss the most important properties of paper for bags and flexible packaging applications
• describe some important features of metals and glass for packaging applications
• briefly describe manufacturing of typical metal and glass packages
• briefly account for some trends in future packaging
Literature

- *Fundamentals of packaging technology*, Chapters 7, 8, p. 505-509, 514-516
- *Metal Packaging*

Time-dependent behaviour of paper

Adapted from
Johan Alfthan
Innventia AB
Important application

Packages deform and will eventually collapse – a very rapid process if they are exposed to varying humidity.

Lifetime

<table>
<thead>
<tr>
<th>Force on the corrugated box, % of BCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days of loading</td>
</tr>
</tbody>
</table>

Kellicut and Landt 1951

Time-dependent behaviour

- Creep and relaxation
  - Time dependent deformation
- Mechanosorptive creep
  - Creep and varying humidity
Creep and relaxation

- Same material behaviour, different experiments.
- Creep:
  - Constant stress ...
  - ... time dependent strain.
- Relaxation:
  - Constant strain ...
  - ... time dependent stress.

Isochronous curves for material characterization

- Stress-strain curves at different times.

Linear for small stresses and strains, slope is “creep stiffness”.
Mechanosorptive creep

- Varying humidity makes problems worse:

- Rapid collapse of packages
- Converting problems for paper rolls

Mechanosorptive creep

- Creep of paper is accelerated during humidity cycling
Isocyclic curves for material characterization

- Stress-strain curves after different number of cycles

Mechanosorptive creep in different materials

- Wood (Armstrong et al. 1960, 1961)
  - Paper (Byrd 1972)
- Concrete (Pickett 1942)
- Wool (Mackay & Downes 1959, Nordon 1962)
- Synthetic fibres (Wang et al. 1990, 1993)
Paper

• Byrd 1972:
  – Tensile creep of handsheets
  – Compressive creep of corrugated board.

Modelling of mechanosorptive creep
Different length scales

Box
Corrugated board, liner
Fibre network
Fibres, fibrils
Molecules

Rheological models
Mechanical models
Hydrogen bond models
Free volume models
Mechanical model
Basic mechanisms according to Gudmundson & Alfthan

1. Heterogeneous hygroexpansion produces a transient redistribution of stresses.
   - Average stress state not changed
2. Creep is non-linear.
   - Regions with increased stress deforms more than regions with decreased stress
⇒ Accelerated creep is produced by changes in moisture content.

Example

![Diagram of mechanical model example]
Non-linear creep

Creep rate
Example (Continued)

Example (Continued)
Creep rate

average creep rate

Creep
Modelling results
Network model

(Continued)

• Anisotropic hygroexpansion produces heterogeneous stresses at the bonds.
Network model
(Continued)

- Anisotropic hygroexpansion produces heterogeneous stresses at the bonds.

Creep of network model
Compression and tension

• Söremark & Fellers 1993

Creep deformation and hygroexpansion are larger in compression.

Possible mechanisms

Anisotropic hygroexpansion leads to straightening of kinks and curl of fibres.

1. 

2. 

3. 

$L_0$

$L > L_0$
Possible mechanisms

The amount of kinks and curl increases in compression and decreases in tension.

1.  

2a.  

2b.  

Result from evaluation of mechanism

Tension  Compression  Difference

The difference is proportional to curvature

High moisture  Low moisture
Comparison to bending

Most deformation at low moisture content.

The mechanism captures the behaviour.

Finite element model

Box
Corrugated board, liner
Fibre network
Fibres, fibrils
Molecules

Finite element model
Continuum model
Network model
Finite element model

- For small applied loads it is possible to derive a continuum model for paper, which can be used in finite element models.
Applications for wood packages
Upscale and novelty packaging

• Small amounts
  – Mainly chosen for aesthetic properties

Manufacture of pallets, skids (stödbalkar), boxes and crates (packkorgar, backar, spjällårar)

– Structural properties such as stiffness and fastener-holding ability are most important
Wood packages
Pallets, boxes and crates

Important considerations for wood packaging materials

- Wood packages are typically decorated using screen printing
- Design for
  - wind and seismic conditions
  - structural glued laminated timber
  - structural-use panels
  - shear walls and diaphragms
  - structural composite lumber
  - structural connections (nails, bolts, screws, fasteners)
  - metal plate connected wood trusses
  - pre-engineered metal connectors
Other important considerations for wood packaging materials

• Different types of timber pest, plant disinfects, germs and bugs
• International Plant Protection Convention (IPPC) standards calls for most wood packaging materials to be either heat treated or fumigated (to subject to smoke or fumes in order to exterminate pests or disinfect) with methyl bromide

Flexible packaging, sacks

Bag
A flexible container that open or fill at one end that may subsequently stay open or be sealed

Sack
Heavy-duty bag
Major paper bag markets

• Cement and other minerals
• Grain products
• Pet food
• Industrial chemicals
• Polymer resins
• Consumer products
  – Sugar
  – Salt
  – Flour
  – Cookies etc.

• Paper bags have a price and weight advantage over plastic bags, but plastic-based laminates more easily offer weather resistance and specific high-barrier properties.

Sack manufacturing and filling
## Sack paper
### Important properties

<table>
<thead>
<tr>
<th>CUSTOMER DEMAND</th>
<th>CUSTOMER VOCABULARY</th>
<th>PAPER PROPERTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Trouble-free sack manufacturing</td>
<td>• Runnability</td>
<td>• No “slack” areas” or “long edges”, CD profile</td>
</tr>
<tr>
<td>• Rapid filling</td>
<td>• Porosity</td>
<td>• Gurley number</td>
</tr>
<tr>
<td>• Handling strength</td>
<td>• Drop test</td>
<td>• Tensile Energy Absorption (TEA)</td>
</tr>
<tr>
<td>• Stacking stability</td>
<td>• Friction</td>
<td>• Slide angle</td>
</tr>
<tr>
<td>• Good print image (consumer goods)</td>
<td>• Printability</td>
<td>• Surface roughness</td>
</tr>
</tbody>
</table>

A Gurley number is the time in seconds it takes for 100 cm² of air to pass through one-square inch of membrane when a constant pressure of 4.88 inches of water is applied.

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## Important paper properties

- **Tensile energy absorption**
  
  - Combining strength and elongation properties increases the bag’s ability to absorb shocks during filling and handling

- **Porosity**
  
  - In general a high porosity paper would be preferred to avoid problems during filling

- **Drop tests**
  
  - Both butt drops (circumferential failure) and flat-face drops (stressed in the length direction)

- **Friction properties**
  
  - Avoid handling problems on for example pallets

- **Water vapour barriers**
  
  - Achieved by extrusion coating of paper by low- or high-density polyethylene or polypropylene
Tensile Energy Absorption
“Area under the load-elongation curve”

MG = machine glazed (one side only)
MF = machine glazed

Production of extensible paper

The Clupak unit

The Expanda unit

Moving rubber blanket
Nip bar, non rotating
Rubber roll
Steel roll
Paper
Steel roll
Paper
The Clupak unit - I

• The extensible unit is normally installed in the dryer section of a paper machine where the dry content of the web is between 60 - 65% depending on the pulp furnish.

• The rubber blanket is pressure-loaded by a "nip bar" so that the gap in the nip becomes less than the thickness of the rubber blanket.

• The rubber then acts like a fluid passing through a venturi - it accelerates so that the volume flowing remains constant.

The Clupak unit - II

• When the stressed rubber and the moist web have passed through the centre of the nip, the outer surface of the rubber begins to recoil (return to resting position). The paper is subjected to a longitudinal compressive force by the frictional effect of the recoiling rubber.

• A significant feature of the compaction process is that it is entirely mechanical. No chemical changes are made to the furnish or the paper.
Sack paper also in for example flexible packaging for medical applications

Flexible packaging
Important properties

CUSTOMER DEMAND
• Good print image
• Trouble-free converting
• Special requirements, e.g. PE and heat seal adhesion, "no fibre tear", smooth back side, controlled porosity and pore size.

PAPER PROPERTIES
• Surface roughness, formation, ink absorbency
• No “slack areas” or “long edges”, CD profile, etc.
• Bending stiffness
• Customised testing, paper chemistry, beating, calendering, etc.
Flexible packaging paper grades

MG papers
(Machine Glazed - A type of paper that has a glossy finish on one side produced by a Yankee cylinder dryer.)
- Traditional
- Good stiffness
- Good one side smoothness
- Low production capacity, high cost
- High back side roughness, needs calandering

MF papers
(Machine Finished - A type of paper, which is calendared on the paper machine to impart smoothness and gloss.)
- High production capacity, lower cost
- More modern machines, better control
- Lower stiffness

Metal packaging
Performance containers

- are required to be liquid tight
- are made by three-piece welding or precision two-piece forming systems and fall into ranges of standard container sizes
- also containers for industrial use as well as those for the carriage of dangerous goods
- are used as primary packaging

The volumetric capacity of this family of containers ranges from 30 ml to 25 litres.

Non-performance containers

- are not required to be liquid tight
- are either made-up containers using a simple lock seam for the body or non-precision two-piece drawn container
  - do not fall into standard size ranges
- are typically highly decorated containers, many of which are secondary packaging and used for promotional purposes.
- are in addition to being used for promotional purposes also serving specific end markets such as:
  - Wines & Spirits
  - Tobacco – cigars
  - Dry foods – biscuits
  - Beverages – tea
  - Confectionery – sweets, chocolates
  - Health & Beauty – toiletries
  - Giftware – pencil boxes, candle holders, money boxes
Materials
Typical thicknesses

- Steel
  - Thin metal plates (tin) with thin layers of tin electro-deposited onto both sides (bleckplåt)
  - Tin-free steel sheets

<table>
<thead>
<tr>
<th></th>
<th>STEEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>drinks cans</td>
<td>from 0.24 mm to 0.27 mm</td>
</tr>
<tr>
<td>processed food cans</td>
<td>from 0.14 mm to 0.30 mm</td>
</tr>
<tr>
<td>aerosols</td>
<td>from 0.17 mm to 0.23 mm</td>
</tr>
<tr>
<td>non-food tins</td>
<td>from 0.20 mm to 0.30 mm</td>
</tr>
<tr>
<td>vacuum closures</td>
<td>from 0.15 mm to 0.18 mm</td>
</tr>
</tbody>
</table>

- Aluminium

<table>
<thead>
<tr>
<th></th>
<th>ALUMINIUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>drinks cans</td>
<td>from 0.28 mm to 0.34 mm</td>
</tr>
<tr>
<td>health &amp; beauty</td>
<td>from 0.30 mm to 0.45 mm</td>
</tr>
<tr>
<td>roll-on pilfer-proof closures</td>
<td>from 0.21 mm to 0.23 mm</td>
</tr>
</tbody>
</table>

Decorations

- Printing or paper labelled
- Screen printing and varnishing
- Forming into complex shapes

Recycling rates

- “Currently” approximately 51 % (70-80 %) for all steel packaging and 34 % (85 %) for aluminium drinks cans in U.K. (Sweden).
Example of metal package manufacturing:
How a two-piece drawn and wall-ironed drinks can is made

Presentation Created by MPMA

1. Aluminium or steel strip arrives at the can manufacturing plant in large coils.
2. The strip is lubricated with a thin film of liquid and then fed continuously through a cupping press, which blanks and draws thousands of shallow cups every minute.

3. Each cup is rammed through a series of tungsten carbide rings. This drawing and ironing process redraws the cup to a smaller diameter and thins the walls, whilst increasing the height.
4. Trimmers remove the surplus irregular edge and cut each can to a precise specified height.

5. The trimmed can bodies are passed through highly efficient washers and then dried. This removes all traces of lubricant in preparation for coating internally and externally.
6. The clean cans are coated externally with a clear or pigmented base coat which forms a good surface for the printing inks.

7. The cans pass through a hot air oven to dry the lacquer.
8. The next step is a printer/decorator which applies the print design in up to six colours, plus a varnish.

9. A coat of varnish is applied to the base of each can by the rim-coater.
10. The cans pass through a second oven which dries the ink and varnish.

11. The inside of each can is sprayed with lacquer. This special lacquer is to protect the can itself from corrosion and from any possibility of interaction between the contents and the metal.
12. Lacquered internal surfaces are dried in an oven.

13. The cans are passed through a necker/flanger, where the diameter of the wall is reduced (necked-in). The tops of the cans are flanged outwards to accept the ends after the cans have been filled.
14. Every can is tested at each stage of manufacture. At the final stage they pass through a light tester which automatically rejects any cans with pinholes or fractures.

15. The finished can bodies are then transferred to the warehouse to be automatically palletised before despatch to the filling plant.
How ring pull can ends are made

Presentation Created by MPMA

1. Pre-coated aluminium or steel strip arrives at the can manufacturing plant in large coils or sheets.
2. The sheet is fed through a press which stamps out thousands of ends every minute.

3. At the same stage the edges are curled.
4. The newly formed ends are passed through a lining machine which applies a very precise bead of compound sealant around the inside of the curl.

5. A video inspection system checks the ends to ensure they are perfect.
6. The TAB. The pull tabs are made from a narrow coil of aluminium or steel. The strip is first pierced and cut. Then the tab is formed in two further stages before being joined to the can end.

7. The ends pass through a series of dies which score them and attach the tabs, which are fed in from a separate source.
8. The final product is the ring pull end.

Food can end
(full aperture)

Drinks can end
(small aperture)

Metals
Properties

• Large strains to failure
  – Formability
• Corrosion resistance
  – Material should not contaminate the contents inside or affect the taste.
• Recycling
  – Not as well-developed as for example paper and glass
Glass packaging

What is glass?

- Inorganic substance fused at high temperatures and cooled quickly so that it solidifies in a non-crystalline structure
- No distinct melting or solidifying temperature
- All commercial glass based on silica (quartz)-SiO₂
- Glass production relies on many formulations
- Soda-lime-silica glass is the type used for most commercial bottles and jars (see next slide)
Soda-lime-silica glass

- The composition is normally 68-73 % Silica sand (silicone oxide), 10-13 % Soda ash (sodium carbonate), and 10-13 % Limestone (calcium carbonate). A low percentage of other materials can be added for specific properties such as colouring.
- It has a smooth and nonporous surface that allows glass bottles and packaging glass to be easily cleaned.
- Soda-lime glass containers are virtually inert, resistant to chemical attack from aqueous solutions so they will not contaminate the contents inside or affect the taste.
- Whereas pure glass SiO$_2$ does not absorb UV light, soda-lime glass does not allow light at a wavelength of lower than 400 nm (UV light) to pass.
- The disadvantages of soda-lime glass is that is not resistant to sudden thermal changes.

Advantages of glass as packaging material

- It is inert to most chemicals
- Foods do not attack glass, nor do glass leach out materials that might alter taste and smell
- It is impermeable (c.f. wine bottles, does not let air into the bottle)
- Clarity allows product visibility
- Perceived as having upscale image
- Rigidity
- Stable at “high” temperatures
Example of manufacturing of glass bottle
Blow-and-blow bottle manufacture - I

1. The gob (temperature about 985 °C) is dropped into the blank mould.
2. Air is blown into the mould to force glass into the finish section.
3. The parison bottomer is replaced by a bottom plate and air is counter blown to expand the glass upwards.

Example of manufacturing of glass bottle
Blow-and-blow bottle manufacture - II

4. Parison is removed and a gripping fixture rotate the bottle to right-side up orientation in the blow mould.
5. Air forces the glass to conform to the shape of the blow mould.
6. Bottle is cooled and taken to annealing oven (to reduce residual stresses in the glass bottle)
Post-blowing operations

- Surface coating for reduction of the coefficient of friction and strengthening of the glass surface
- Inspection for blisters, contaminating grain or grit, etc.
- Inspection for tolerances (glass shrinks, like for example paper, during manufacturing)

Some personal reflections on trends in future packaging

- Bio-plastics
- Paper and board with high failure strains to enable forming of complex structures
- Sheet materials based on nano-cellulose (MFC=microfibrillar cellulose) as part of sandwich structures
- Foam materials made of cellulose
- Artistic design parameters increasingly important
- Environmental issues increasingly important
- Improved logistics using printed electronics, RFID etc.
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