Summary of Workshop

- Overview and terminology of paper and board grades that are extrusion coated
- Properties of paper and board used for extrusion coating
- Paper and board manufacturing variables that impact extrusion coating
- Trends and developments
- General group discussion
Extrusion Coated Grades

- Extrusion coating is applied to a wide variety of paper and board grades depending on the properties sought.
- Extrusion coating/lamination can be used to bond foil to paper or paperboard for enhanced barrier properties.
## Extrusion Coated Grades

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Property Sought</th>
<th>End Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bag and wrapping paper</td>
<td>MVTR, OGR, liquid resistance</td>
<td>QSR, bakery, carry-out, multiwall sacks</td>
</tr>
<tr>
<td>Bleached board</td>
<td>Liquid resistance</td>
<td>Cups, milk cartons</td>
</tr>
<tr>
<td>Linerboard</td>
<td>MVTR, OGR, liquid resistance, release</td>
<td>Frozen food &amp; other packaging</td>
</tr>
</tbody>
</table>
Variability of Paper

- Paper is not a homogeneous material.
- Varies in the machine direction (MD), cross-direction (CD), Z-direction, and over time.
- It is also reactive to changes in its environment. Shrinks and expands and usually not uniformly.
- Its structure depends on the process that produced it and even the location across the width of the paper machine.
Variability of Paper
Components of Wood

- Cellulose – 45%
- Lignin – 25%
- Hemicelluloses – 25%
- Extractives – 5%
Cellulose \((\text{C}_6\text{H}_{10}\text{O}_5)_n\)
Fiber Structure
Fiber Structure

- Like a drinking straw
- 1/32” (0.75mm) to 1/4” (6mm) long
- Length to width ratio of 50 to 140
Fiber Structure

Pine sheet

Eucalyptus sheet
Fiber Structure

- Softwoods for strength and runnability
- Hardwoods for uniformity, smoothness, formation, and printability
- Inherent strength requirement of the converting process dictates the amount of softwood that is included in the furnish
Pulping and Bleaching

- 65% of the pulp produced in the world is made by the kraft process.
- Chemical pulping removes most of the lignin and hemicelluloses and all of the extractives.
- However, chemical pulping results in dark brown pulp that must be bleached.
- Nearly all extrusion coated paper and board is made from kraft pulp.
Cellulose molecule is aligned more or less parallel to the long axis of the fiber.

Fibers are hydrophilic.

Fibers expand and shrink based on the water content in the fiber walls.

Fibers can swell up to 25% in width but only slightly in length.

Hydrolysis results in fiber swelling, greater fiber flexibility, and fiber collapse.
Paper Structure

Side view

More fiber collapse

Less fiber collapse

Top view
Paper Structure

Fiber collapse depends on:

- Thickness of the cell walls
- Ratio between fiber wall thickness and fiber width
- Amount of lignin left in the fiber wall
- Amount of mechanical action
- Pressure on the paper machine
Paper Structure

Microcompressions

Fiber A

Fiber B
Fiber orientation means that paper is stronger in the machine direction than in the cross machine direction.
Paper Structure

Tensile Stiffness Tester

Polar Graph
More fiber alignment in the MD is called anisotropy.

Sonic modulus relates to tensile stiffness index (TSI).

TSI relates to fiber orientation.
Paper Structure

- TSO is the angle of max TSI.
- Might not be in the exact MD.
- Varies across the sheet.
- Called asymmetrical anisotropy.
Fibers swell in width, but not in length.

Humidity changes affect the CD more than the MD.

Same problem if top and bottom of the sheet is different.

Paper curls.
Summary of Papermaking

- Paper is a record of all the processes that have occurred in its production, and those processes are inherently unstable.
- The physical properties of paper are based on the structure of the cellulose molecule, the type of fiber, and how that fiber was separated from the other components of the wood.
- The way the fibers are reassembled strongly affects how the paper reacts to further converting operations and other changes in its environment.
Base Stock Questions

- End use requirements?
- Is the base stock made to be coated?
- Are you making or buying?
- Can you specify or must you adapt?
Roll Quality for Off-Machine Coating

- Clean slit edges
- No edge cracks
- Uniform tension - no wrinkles
- No holes
- Splices
  - Minimal number
  - Properly made and marked
Specifying Base Stock
Physical Properties

- Basis weight
- Moisture
- Caliper
- Strength
  - Tensile
  - Tear
  - Internal bond
  - Folding endurance
- Porosity
- Smoothness/roughness
- Coefficient of Friction (COF)
- Scoring and bending properties
Specifying Base Stock
Optical Properties

- Brightness
- Shade
- Gloss
Paper and Board Testing

Strength Properties

- Folding Endurance
- Scott Bond (Internal Bond)
- Stiffness
  - Bending Resistance of Paper – Gurley Method
  - Stiffness of Paperboard – Taber Method
- Tearing Resistance
- Tensile Strength
Folding Endurance

- Folding endurance is tested using the MIT tester
  - A strip of paper is mounted under tension in the tester
  - The tester rotates back and forth through 270°
  - The number of double folds is reported – either as raw data or $\log_{10}$
- ISO 5626 and TAPPI T 511 are the folding endurance test methods
Scott Internal Bond

- Measures the internal bond strength
- Very critical for offset printing – especially sheet fed offset with high tack inks
- Resistance to fiber picking
- TAPPI T 569
Bending resistance is important for sheet fed offset.

Sample is clamped and used to deflect a pendulum with weight.

Data is reported in Gurley stiffness unit.

TAPPI T 543
Taber Stiffness for Paperboard

- Determines the bending moment in gram centimeters required to deflect the free end of a 38-mm wide sample 15° from its centerline with a load applied 50 mm away from the clamp
- TAPPI T 489
Elmendorf Tear Tester

- Paper sample is torn through a fixed distance by means of a pendulum.
- The work done in tearing is the loss in potential energy of the pendulum.
- Data reported in grams force.
- TAPPI T 414
Tensile Strength

- Tensile strength is the maximum stress developed in a sample before rupture.
- Sample is clamped in a tensile tester and force applied to separate the jaws.
- Tensile strength is reported in Kn/m.
- Breaking length is the calculated limiting length of a hanging strip of paper that would break it.
- Tensile Index is tensile strength in N/m divided by grammage.
- ISO TC6 and TAPPI T 494.
Paper Surface Property Testing

- Coefficient of Friction
- Porosity
  - Air Resistance – Gurley Method
- Roughness
  - Sheffield Method
  - Parker Print Surf Method
- Wax Pick
- Wet Rub
Coefficient of Friction

- Static Coefficient of Friction by slide angle
  - Slide angle correlates to COF
  - TAPPI T 548
- Static and Kinetic COF by horizontal plane
  - Calculate COF by forces required to move
  - TAPPI T 549
Air Permeability – Gurley Test

- Gurley tester consists of an outer cylinder partially filled with liquid and an inner cylinder with a 6.4 cm² orifice and clamp.
- Paper sample is mounted in the clamp and the inner cylinder released to force air through the sheet.
- Time required for 100 ml of air to pass through the paper is recorded as Gurley seconds density.
- TAPPI T 460
Sheffield Smoothness/Roughness

- Measures air flow between the sample – backed by a smooth glass – and two pressurized, concentric annular rings impressed into the sample from the top side.
- Lower number means smoother paper.
- Reported in Sheffield units.
- TAPPI T 538.
Parker Print Surf Roughness

- More precise air leak measurement
- Clamping pressure can be varied
  - 10 Kg is standard
- Annulus is 0.051 mm
- Air flow gives an indication of surface roughness is reported as µm with pressure, e.g. $PPS_{10} = 1.2 \, \mu m$
- Developed for gravure but widely used for many types of paper and paperboard
Wax Pick Test

- Measures surface strength
- Calibrated sealing waxes with increasing adhesive power are pulled from the paper surface
- Highest number that does not tear fibers from the surface is recorded
- TAPPI T 459
Wet Rub Test – Adams Wet Rub

- Measures the resistance of the paper surface to wet abrasive action
- Key test for offset papers
- Sample is mounted on wheel and rubbed with wet roll
- Material abraded from surface is washed into bottle with water
- Turbidity of water correlates to material rubbed off and is reported as wet rub value
Paper Testing
Optical Properties

- Brightness
- Whiteness
- Color
- Dirt Count
- Fading
- Fluorescence
- Gloss
- Opacity
Contact of light and paper

Specular reflection → gloss
Scattered reflection → brightness
Permeance → opacity
Absorption → color
Brightness

- Brightness is percentage reflectance of light at wavelength 457 nm
- ISO and TAPPI (GE Brightness) methods differ
- TAPPI T 452 measures through a 457-nm filter and is based on magnesium oxide being 100%
- ISO2469/2470 measures over a range of wavelengths
- TAPPI (GE) brightness values are usually a point or two lower than ISO brightness values
Brightness With and Without UV Fluorescence

- Brightness is measured with and without a UV filter to determine fluorescence and the effect of optical brighteners.
- Modern brightness testers are all equipped with UV filters and also measure color in terms of L,a,b values and also measure whiteness.
Color

TAPPI Test Methods for color are T 442, T 524 and T 527
Whiteness

- Whiteness is measure of reflectance at all visible wavelengths of light.
- Measurements are made using a standard D65 light source to get color coordinates.
  - UV component of the D65 source is controlled to adjust for effect of fluorescent dyes.
- Calculation of whiteness is based on these measurements.
- ISO 11475:2004 is used for papers without OBA.
- ISO 2469 is used for papers made with OBA.
Gloss

- Gloss describes the mirror-like property of coated paper.
- Gloss is defined as the percentage reflectance at an angle equal to the angle of incidence compared with a standard surface.
- TAPPI T 480 measures at 75° and is the standard test.
- TAPPI T 653 measures at 20° and is commonly referred to as “Low Angle Gloss.”
Opacity

- Opacity is a measure of the amount of light transmitted through paper.
- 100% opacity means no transmitted light.
- Measurement is made by comparing the reflectance of a single sheet over a black background to an opaque stack of sheets.
- Opacity test methods are ISO 2471 and TAPPI T 425.
## Where Grades Are Produced

### Regional % of U. S. Production

<table>
<thead>
<tr>
<th>Grade</th>
<th>South</th>
<th>NE/NC</th>
<th>West</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncoated Free</td>
<td>65</td>
<td>26</td>
<td>9</td>
</tr>
<tr>
<td>Coated Paper</td>
<td>23</td>
<td>73</td>
<td>4</td>
</tr>
<tr>
<td>Coated SBS</td>
<td>95</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Coated SUS</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Kraft Linerboard</td>
<td>83</td>
<td>0</td>
<td>17</td>
</tr>
</tbody>
</table>
## U. S. Pulpwood Fiber Characteristics

<table>
<thead>
<tr>
<th>Species</th>
<th>Specific Gravity</th>
<th>Fiber Dimensions</th>
<th>Wall Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loblolly P.</td>
<td>0.47</td>
<td>3.5-4.5</td>
<td>4-11</td>
</tr>
<tr>
<td>Doug. Fir</td>
<td>0.43</td>
<td>3.5-4.5</td>
<td>3-8</td>
</tr>
<tr>
<td>W. Hemlock</td>
<td>0.38</td>
<td>2.5-4.2</td>
<td>2-5</td>
</tr>
<tr>
<td>Spruce</td>
<td>0.37</td>
<td>2.5-4.2</td>
<td>2-3</td>
</tr>
<tr>
<td>White Oak</td>
<td>0.59</td>
<td>1.4</td>
<td>5</td>
</tr>
<tr>
<td>Sweet Gum</td>
<td>0.44</td>
<td>1.7</td>
<td>8</td>
</tr>
<tr>
<td>Birch</td>
<td>0.48</td>
<td>0.8-2.7</td>
<td>2-3</td>
</tr>
<tr>
<td>Aspen</td>
<td>0.35</td>
<td>0.4-1.9</td>
<td>2-3</td>
</tr>
</tbody>
</table>
## Properties of Kraft Pulps by Species

<table>
<thead>
<tr>
<th>Species</th>
<th>Coarseness ( \mu g/m )</th>
<th>Tensile Index ( N \cdot m/g )</th>
<th>Maximum Tear Index ( mN \cdot m^2/g )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spruce</td>
<td>140</td>
<td>135</td>
<td>20</td>
</tr>
<tr>
<td>W. Hemlock</td>
<td>190</td>
<td>120</td>
<td>18</td>
</tr>
<tr>
<td>Doug. Fir</td>
<td>264</td>
<td>90</td>
<td>30</td>
</tr>
<tr>
<td>Southern Pine</td>
<td>280</td>
<td>85</td>
<td>28</td>
</tr>
<tr>
<td>Oak</td>
<td>143</td>
<td>67</td>
<td>11</td>
</tr>
<tr>
<td>Gum</td>
<td>266</td>
<td>96</td>
<td>13</td>
</tr>
<tr>
<td>Birch</td>
<td>116</td>
<td>101</td>
<td>10</td>
</tr>
<tr>
<td>Aspen</td>
<td>129</td>
<td>103</td>
<td>8</td>
</tr>
</tbody>
</table>
## Structural Properties by Species

<table>
<thead>
<tr>
<th>Species</th>
<th>Maximum Bulk cm³/g</th>
<th>Elastic Modulus kN·m/g</th>
<th>Edgewise Compr. Index N·m/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spruce</td>
<td>1.7</td>
<td>8.1-9.0</td>
<td>40-43</td>
</tr>
<tr>
<td>W. Hemlock</td>
<td>2.0</td>
<td>8.2</td>
<td>37-41</td>
</tr>
<tr>
<td>Doug. Fir</td>
<td>2.1</td>
<td>6.5-8.5</td>
<td>31-33</td>
</tr>
<tr>
<td>Southern Pine</td>
<td>2.1</td>
<td>8.7</td>
<td>36</td>
</tr>
<tr>
<td>Oak</td>
<td>2.4</td>
<td>6.4</td>
<td>28</td>
</tr>
<tr>
<td>Gum</td>
<td>1.8</td>
<td>8.6</td>
<td>30-40</td>
</tr>
<tr>
<td>Birch</td>
<td>1.5</td>
<td>6.1</td>
<td>36.5</td>
</tr>
<tr>
<td>Aspen</td>
<td>1.5</td>
<td></td>
<td>43</td>
</tr>
</tbody>
</table>
Bending Stiffness

\[ S = kEc^3 \]

Where:
- \( S \) = Stiffness
- \( E \) = Young’s modulus of elasticity
- \( c \) = Caliper
Paper Surface Properties

- Surface pore structure is important to get extrudate adhesion
- Overall structure performance is importance
  - Resistance to penetration by liquid or gas
- Measures that tighten the base sheet structure can adversely affect adhesion
- May require a pretreatment
Recycled Fiber Base Stock

Potential Problems and Concerns

- Dirt
- Blade scratches and streaks
- Shade variation
- Spots and shiners
- “Bloom up” of stickies under infrared dryers
- Brightness reversion and/or yellowing
- Strength loss
Papermaking Additives

- Most extrusion coated grades are used for packaging – requiring strength
- Fillers are not commonly used
- Measures to improve sheet density
  - Refining to increase density
  - Surface sizing
- Internal sizing
- Calender sizing on paperboard
Base Stock for Extrusion Coating

- Fillers seldom used
- Starch or strength additives
- Retention aids
- “Cycle-up” potential with recycled fiber, especially in tightly closed systems
- Internal sizing
- Wet strength
Wet End Operations
Base Stock for Extrusion Coating

- CD profile - from the headbox or former
- Formation and microcontour
- Fourdrinier board
  - Dandy roll
  - Top former
- Cylinder board
  - Uniflow top liner vat
Pressing

- Minimize open draws for paper
- Effect on bulk and stiffness
- Double sided dewatering for paper
- Flow controlled nip
- Split top felt on cylinder machines
- Felts - stratified batt
- Felt conditioning
Paper Structure
Drying

- Slalom felt run desirable, especially for paper
- Conventional cylinders
  - Warm up dryer temperatures
  - Picking/fiber lifting - streaks
- Yankee dryers
  - Machine glazed surface
- Breaker stacks - bulk loss
Surface Sizing Chemicals

- Starch
- Film formers other than starch
  - CMC
  - Polyvinyl alcohol
  - Alginate
- Other specialty surface sizes
- Pigments
- Latex and other binders
Size Press

Simultaneous application, metering and distribution
Transfer Roll Coaters

- Premeter and distribute - then apply
- Similar to a printing press

Gate Roll Coater

Metering Size Press
Calender Sizing

- Pickup dependent on moisture profile
- Crushes and compacts sheet
- Reduces bulk and stiffness
Calender Box
Calender Sizing Pickup Variables

Incoming Sheet
- Moisture
- Sizing
- Roughness
- Formation
- Porosity

• Speed
• Loading
• Material applied
  – Viscosity
  – Solids
  – Temperature
Troubleshooting Calendar Sizing

- Foam: Non-uniform application
- Too tight film: Gluability problem
- Excessive ZDT: No fiber tear
- Soft binder: Back side picking
Calendering Techniques

- Hard nip gives uniform caliper but can cause localized density variations and mottle
- Soft nip gives uniform density
- Both improve smoothness
Effects of Hard vs. Soft Nip

Calendering
Open coating structure is desirable to promote extrudate adhesion

Coating pigments
- Calcium carbonate
- High aspect ratio clay

Coating binders
- Latex
  - Acrylics and acetates
  - Biopolymer nanoparticle latex
- Soy protein polymer
Promoting Adhesion and Developing Chemical Resistance

- Oxidation of the substrate
  - Corona treatment
  - Flame treatment

- Chemical primer
  - Surface modifier
    - increases energy
    - adds reactive sites
  - Facilitates extrudate wet out
Treatment vs. Wetability

- **Treatment**
  - Oxidizes the surface
    - makes chemical sites for bonding
  - Burns off contaminants
  - Improves wet out of the primer

- **Wetability**
  - Improving wetability in terms of contact angle doesn’t always provide adequate adhesion
Primer on Paper Base Stock

Extrudate
Primer
Paper
Chemical Primers

- Surface modifier
  - increases energy
  - adds reactive sites
- Facilitates extrudate wet out
- Provides adhesion between substrate and extrudate
- Contributes to the chemical resistance of a structure
Primers for Paper

- Ethylene Acrylic Acid
- Crosslinked Polyethylenimine
- Vinyl Acetate/Ethylene
- Polyester
- Amine
  - Melamine
  - Others
Pigments in Primer

- Addition of pigment to the primer can improve performance and reduce cost
- Kaolin clay pigments
  - High aspect ratio clay opens pore structure
- Calcium carbonate
  - Ground calcium carbonate
  - Precipitated calcium carbonate - aragonite
Primer Application Methods

- Gravure, Direct/Reverse
- Offset Gravure, Direct/Reverse
- Flexographic
- Smooth Transfer Roll, Direct/Reverse
- Wire Wound or Grooved Rod Coater
Smooth Roll Applicator
Transfer Roll Coaters

Hydrophilic Transfer Roll Coater - LAS
Transfer Roll Coaters

REVERSE ROLL COATER
Gravure Applicator
With Enclosed Doctor Blade

Backup Roll

Web

Chambered Doctor Blade

Etched Pickup Roll

Primer

Web
WIRE WOUND ROD
WIRE WOUND ROD COATER

- Applies excess of coating to the web with an applicator roll
- “Deckles” wipe the coating off the roll at the edges.
- The substrate can be run with a dry edge for cleanliness.

Figure 1
The main difference between the coaters shown in Figure 1 and 2 occurs after the web leaves the applicator roll. Air-loaded rod coaters support the web with a backing roll.
GROOVED ROD
Trends and Developments

- **Sustainability focus**
  - Wal-Mart packaging scorecard

- **Desire for paper-based packaging to be:**
  - Recyclable
  - Biodegradable

- “Plastic Coated” paper and board considered problematic

- **New biodegradable resins**
  - PLA
Recyclability of Extrusion Coated Paper and Paperboard

- Dedicated de-poly systems have been used for decades
- Work is progressing toward processing extrusion coated paper products in OCC and tissue systems
- Global Green Initiatives
  - Starbucks cup program
  - CORR – Coalition for Resource Recovery
Recyclability of Extrusion Coated Paper and Paperboard

- Not just driven by environmental groups
- OCC supply crisis
- Chinese mills have state-of-the-art systems and can handle single side extrusion coated waste paper
OCC Shortage Due to Increased Chinese Demand

Thousand of Metric Tons

Data from RISI 15 Year Forecasts
## Potential New Sources of Secondary Fiber

<table>
<thead>
<tr>
<th>Potential Fiber Source</th>
<th>2007 Discarded Tons*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper Plates and Cups</td>
<td>1,310,000</td>
</tr>
<tr>
<td>Folding Cartons</td>
<td>4,020,000</td>
</tr>
<tr>
<td>Bags and Sacks</td>
<td>720,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6,050,000</strong></td>
</tr>
</tbody>
</table>

* According to the EPA Municipal Solid Waste Report
Alternatives to Extrusion Coating

- Recyclable barrier coatings
- Gaining market acceptance – but progress is slow
- Initial successes are in replacement of waxed corrugated
  - Would add ~1.5 million tons/year of OCC
- Development of aqueous dispersions of Olefins
  - PLA
Outlook

- Major consumer goods marketers have active programs to replace plastic packaging with biodegradable or recyclable paper based packaging.
- Progress will be slow.
- Extrusion coating is not likely to be replaced in the short or medium term.
- Continued research on recyclable extrusion coating materials.
Thank you for your attention!