Discussion Topics

- Equipment and Purpose
- Chill Water System Design and Control
- Basics of Process
- Calculations
- Troubleshooting
Extrusion Coating & Laminating

The goal in extrusion coating and/or laminating is to form a continuous, inclusion free polymer layer of uniform thickness, that adheres to the desired substrate(s).

Extrusion Coating Uses

- Milk Cartons
- Ream Wrap
- Juice Cartons
- Snack Food Packaging
- Photo Paper
- Bakery Trays
- Sugar Pouch
- Cheese Wrap
- Snacks
- Dry Mixes
- Lidding Stock
- Multiwall Bags
- Medical Packaging
Nip Roll

- What: Water cooled (generally double shell) roll with a rubber covering
- Function:
  - To combine the substrate(s) and molten polymer together at the chill roll with even pressure
  - It removes air from the product
  - It facilitates cooling

Nip Roll

- Operation
  - Opens and closes with either pneumatic air cylinders or air bags.
  - Pressure is changed by adjusting air pressure to cylinders or bags.
  - Typical pressure is 150 pli but can be higher.
  - Both rolls open for threading and safety
Nip Roll Coverings

- Hypalon (Chlorosulfonated Polyethylene)
  - Shore hardness range: 40-90
  - Good release, temp resistance, ozone resistance and easily reground
- Neoprene (Polychloroprene)
  - Shore hardness range: 15-80
  - Regrindable, not as durable, good release, inexpensive
- Silicone (Polymethylsiloxane)
  - Shore hardness range: 40-70
  - Soft, very good release, temp resistance, good for porous substances

Nip Roll Release Options

- Why do the edges need more release than center?
- Teflon® Tape
  - Change for different widths
- Teflon® Belts
  - Adjustable but difficult to use
- Teflon® Sleeves
  - Costly
Nip Roll Deflection

- Bending of the roll due to gravity, tension and pressure
  - Backing roll helps the deflection
  - Function of roll diameter and construction
  - Can be measured by nip impression tape
  - OR…

- Corrected by crowning the roll
  - Caution: improper crowning will generate wrinkles in the nip

Backing Roll

- What: Water Cooled
  - Chrome plated double shell
  - Increases the life of the nip roll covering

- Function:
  - Cools surface of nip roll to reduce sticking
  - Reduces bowing/deflection of the nip roll
Stripping Roll

- **What:**
  - Steel, aluminum or rubber covered idler roll
  - Opened and closed with pneumatic cylinders
- **Function:**
  - Initiate even removal of product from chill roll
- **Location:**
  - Metal roll is 1” or less from chill roll
  - Rubber roll contacts chill roll
- **Opens for threading and safety**
  - Is adjustable if a wide variety of products is to be made

Chill Roll Function

- Quench molten polymer to strippable temperature
- Set extrusion line speed – Lead section
- Impart surface texture to final product (extrusion coating only)
Chill Roll Construction

- Diameter range: 18-50 inches
- Mono flow
  - In one end, out other
- Single shell design
  - Small Rolls only – not Recommended!!
- Double shell design
  - Small amount of water, next to outer shell
- Double shell spiral fluted
  - Most common design
  - Lowest delta T

Chill Roll Finish

- Surface roughness is a measure of the smoothness or texture of the roll surface
  - Ra – “Average Roughness”
  - RMS – “Root Mean Square”
  - 10 Ra = 11 RMS
- Surface roughness determines how easily the polymer can be removed from the roll and the surface finish of an extrusion coated product.
Chill Roll Finishes

- Matte – 30-125 Ra typical
  - Grit blasted, plated with dull finish and good release
- Gloss – 4-10 Ra typical
  - Precision ground and polished with good surface finish and release
- Mirror – 2-4 Ra typical
  - Belt or stone polish with high gloss and poor release
- Optical Mirror – 1 Ra or less

Material Considerations

- Heat Conductivity (k) – Steady state heat transfer rate within solid or liquid materials
- Thermal Expansion – Fractional change in length or volume of material for unit temperature change
- Durability – resistance to dents, scratches or deformation
- Weight
- Cost of raw materials and fabrication
# Material Selection

<table>
<thead>
<tr>
<th>Material</th>
<th>Coefficient of Thermal Expansion*</th>
<th>Heat Conductivity**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>12.8</td>
<td>1460</td>
</tr>
<tr>
<td>Brass</td>
<td>11.4</td>
<td>833</td>
</tr>
<tr>
<td>Chromium</td>
<td>3.4</td>
<td>480</td>
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<tr>
<td>Copper</td>
<td>9.8</td>
<td>2670</td>
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<tr>
<td>Gold</td>
<td>7.9</td>
<td>2090</td>
</tr>
<tr>
<td>Iron(pure)</td>
<td>6.6</td>
<td>529</td>
</tr>
<tr>
<td>Nickel</td>
<td>7.2</td>
<td>421</td>
</tr>
<tr>
<td>Silver</td>
<td>10.5</td>
<td>2910</td>
</tr>
<tr>
<td>Steel(SAE 1020)</td>
<td>6.6</td>
<td>360</td>
</tr>
<tr>
<td>Steel(SAE 1095)</td>
<td>5.7</td>
<td>360</td>
</tr>
<tr>
<td>Steel 285 Grade B</td>
<td>6.5</td>
<td>-</td>
</tr>
<tr>
<td>Stainless Steel(18-8)</td>
<td>9.5</td>
<td>-</td>
</tr>
</tbody>
</table>

*10e-6 in/in *°F  
**BTU-in /(/°F –ft2 –hr)

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## Chill Roll Temperature

- What do I need?
- The ideal chill roll temperature is cool enough to allow the coating to release cleanly, but warm enough so the polymer does not cool before having a chance to wet the substrate adequately.
**Water Recirculation System**

- Usually a closed loop system
  - Same water is chilled and re-circulated
- Cooling can be varied
  - Based on extruder output
  - By changing temperature of rolls
- Water temperature is controlled
  - Usually runs at 50-85°F
Chill System Fouling

- What: Any layer or deposit of extraneous material on a heat-transfer surface. This reduces thermal conductivity of surface.

- Causes
  - Scale or mineral deposits
  - Algae
  - Rust

- Prevention
  - Initial system treatment
  - Maintenance program

- Removal of build-up is either chemical or mechanical

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Chill Roll Temperature

- 600°F Melt Temp.
- Contact time 0.24 sec
- Shell = 12mm (0.5”)
- 1.0 mil coating
- 70°F in 73°F out
- 450°F
- 340°F
- 230°F
- 120°F
- Line Speed 1000 ft/min
- Substrate
Extrusion Process Variables

- Polymer Melt Temperature
- Linespeed
- Air Gap/Drawdown
- Die Position Lead
- Die Gap (not discussed)
- Chill Roll Temperature
- Nip Roll Pressure
- Nip Roll Hardness
Oxidation (melt temperature)

- All substances are either organic or inorganic
- Organic materials will burn
- High temperatures promote faster oxidation rates
  - At some temperature the ignition point will be reached.

Bond / Adhesion

- All organic materials have a surface skin
  - This is an oxidized layer of itself (rust)
- Some materials resist oxidation such as stainless steel
- **TO OBTAIN ADHESION BETWEEN TWO MATERIALS, ONE MUST BE LIQUID!!!**
- Too much oxidation destroys adhesion as does too little.
**Air Gap**

- The amount of time the molten polymer is in contact with air effects its adhesion to the substrate.
  - The longer the polymer is exposed to air, the cooler it becomes and tends to decrease adhesion.
  - If the melt temperature is high enough, increased time will increase oxidation and will improve adhesion.
  - Therefore, an optimum air gap permitting maximum adhesion exists for each set of circumstances.

**Bond versus Air gap**

![Graph showing the relationship between bond strength and air gap](image)
**Melt Curtain Air Gap**

- Determined by linespeed

- Raising Die
  - Time in air gap increases
  - 100ms for LDPE
  - TIAG=60 x gap(mm) / linespeed (m/min)

- Neck-In increases

- Melt temperature drops

- 1” increase in gap = 10°F increase in melt temperature

<table>
<thead>
<tr>
<th>Air Gap (in)</th>
<th>Line Speed (fpm)</th>
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<tbody>
<tr>
<td>7.0</td>
<td>up to 700</td>
</tr>
<tr>
<td>8.5</td>
<td>700 – 1,200</td>
</tr>
<tr>
<td>10.0</td>
<td>1,200 – 1,800</td>
</tr>
<tr>
<td>12.0</td>
<td>1,800 and up</td>
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</tbody>
</table>

**Neck-In**

- Determined by:
  - Resin properties such as molecular weight and molecular weight distribution
  - Extrusion conditions such as melt temperature, line speed, output rate and die pressure
  - Equipment geometry such as screw design, air gap and die lip gap
Die Position Lead

- Lead onto either substrate for improved adhesion
- Substrate burn through coatweights
- Web contraction on heavy coatweights
- Linespeed will effect
- Work needs to be done to optimize location
Chill Roll Temperature Setting

- Too Cold produces rapid quench rate
  - Reduced adhesion
  - Roll may sweat in high humidity
- Too Warm produces slower quench rate
  - Polymer may stick to roll
  - Bond issues or tearing with substrate
  - Can wrap chill roll
- Uneven Temperature
  - Poor or uneven strippability
  - Flow marks in product
  - Indication that chill roll may be fouling

Chill Roll Strip Position

If Roll to High…
…Chill Roll Surface Cannot Recover

If Roll to Low…
…Poor Stripability Resulting in Quality Defects

A misaligned or Worn Roll Can Result in Wrinkles in the Product
The Chill Roll needs time and distance to recover cooling of its surface (A to B). The amount of impression is determined by:

- Roll Hardness
- Roll Diameter
- Nip Pressure
- Wider nip
- Improved adhesion
- For heavier substrates
- Can create pinholes

Even nip across the roll is important!!
Quick Calculation for Chill Water GPM

\[ m_w \times C_{pw} \times \Delta T_w = m_p (C_{pp} \times \Delta T_p + h_{fp}) \times \text{Eff} \]

- \( m_w \): Mass Flow Water, lb/hr
- \( C_{pw} \): Specific Heat Water, BTU/lb-°F
- \( \Delta T_w \): Temperature Rise Water, °F
- \( m_p \): Extruder Output, lb/hr
- \( C_{pp} \): Specific Heat Polymer, BTU/lb-°F
- \( \Delta T_p \): Temperature Change Polymer, °F
- \( h_{fp} \): heat of Fusion Polymer, BTU/lb
- \( \text{Eff} \): Efficiency of System

\[ \text{GPM} = \left[\left( \frac{m_p \times 0.75 \times \Delta T_p}{\Delta T_w \times 500} \right) \times 1.2 \right] \]

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How much water do we need to pump through our chill roll if we have a rate of 1000 lb/hr LDPE, Melt Temperature 600°F, a Strip Temperature of 100°F, and 3°F Water Temperature Rise?

\[ \text{GPM} = \left[\left( \frac{1000 \times 0.75 \times (600-100)}{3 \times 500} \right) \times 1.3 \right] = 325 \text{gpm} \]

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Quick Calculation for Cooling Tonnage

\[ \text{Ton} = \left[ m_p \times 0.75 \times \Delta T_p / 12,000 \right] \times 1.2 \]

- \( M_p \): Extruder Output, lb/hr
- \( \Delta T_p \): Temperature Change Polymer, °F

\[ \text{Ton} = \left[ 1000 \times 0.75 \times (600-100) / 12,000 \right] \times 1.2 = 37.5 \text{ Ton} \]
Chill Roll Contact Time

Calculate Contact and Recover Time and Length for a Extrusion Line Having a 24 inch Chill Roll with a 220° Wrap at a Line Speed if 500fpm.

Contact Time, sec = \( \frac{\text{CR Diameter} \times \text{Wrap}\%}{\text{Line Speed} \times 22.93} \)

\[ = \frac{24 \times 220}{500 \times 22.93} \]
\[ = 0.46 \text{ sec} \]

Recovery Time, sec = \( \frac{\text{CR Diameter} \times (1-\text{Wrap}\%)}{\text{Line Speed} \times 22.93} \)

\[ = \frac{24 \times (360-220)}{500 \times 22.93} \]
\[ = 0.29 \text{ sec} \]

Chill Roll Contact Length

Calculate Contact and Recover Time and Length for a Extrusion Line Having a 24 inch Chill Roll with a 220° Wrap at a Line Speed if 500fpm.

Contact Length, ft = \( \frac{\text{CR Diameter} \times \text{Wrap}\%}{1376} \)

\[ = \frac{24 \times 220}{1376} \]
\[ = 3.84 \text{ ft} \]

Recovery Length, ft = \( \text{CR Diameter} \times \frac{3.14}{12} - \text{Contact Length} \)

\[ = 24 \times 3.14/12 - 3.84 \]
\[ = 2.44 \text{ ft} \]
Troubleshooting – Problems Related to the Laminator

- A problem with its causes will be listed
- Solutions are based on what we have gone over in this presentation.
- Audience will give answers by filling out workbook as each problem is given.
- Group discussion and review of solutions.

Solutions Workbook

<table>
<thead>
<tr>
<th>Problem</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
<th>#5</th>
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<tr>
<td>Solutions</td>
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<td>Chill Roll to Die (Left/Right)</td>
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<td>Increase Nip Pressure</td>
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<td>Change Stripper Position</td>
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<td>Chill Roll Fouled (Clean)</td>
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<tr>
<td>Call Beth</td>
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</tbody>
</table>
Problem #1

- Poor Adhesion of Extrudate to base or laminated substrate.
- Due to: Inadequate oxidation only
  - There are two solutions related to the laminator for this problem

Problem #2

- Poor adhesion of the polymer to the substrate.
- Due to: Premature Cooling
  - There are three possible solutions to this problem
Problem #3

- Poor Adhesion of the Polymer to the Substrate
- Due to: Sticking to the Chill Roll
  - There are two possible solutions to this problem

Problem #4

- Excessive Odor
- Due to Over-Oxidation
  - There is one solution relating to the laminator for this problem
Problem #5

- Poor Heat Sealability
- Due to: Over-Oxidation
  - There is one solution related to the laminator for this problem

Problem #6

- Poor Adhesion Across the Web
- Adhesion is good in some areas and poor in others
- Due to: Reduced Thermal Conductivity
  - There are two possible solutions related to this problem and one is tricky!!
Conclusion

- Equipment and Purpose
- Chill Water System Design and Control
- Basics of Process
- Calculations
- Troubleshooting
- Thanks to Optex Process Solutions, LLC