Lamination Defined

Lamination is...

The process of combining two or more substrates, creating a product of combined properties not found in any layer individually.

Laminate Properties

- Moisture Barrier
- Light Barrier
- Vapor Barrier
- Oxygen Barrier
- Abrasion Resistance
- Heat Sealability

- Gloss/Matte Finish
- Aesthetics
- Strength
  - Tear Resistance
  - Break Strength
  - Modulus
- Release
Laminated Products

- Flexible Packaging
- Cartons
- Heat Sealable Insulation
- IDs (passports, licenses)
- RFID Tags
- LCD Displays
- High-Tech Fabrics
- Reflective Sheeting

Gaskets

Lamination Methods

- Wet Lamination
- Dry Lamination
- Thermoplastic Lamination
- Reactive Lamination
- Extrusion Lamination

Lamination Micro-View

Coat:
Applying the bonding layer to A, forcing intimate contact, excluding air at A interface.

Laminate:
Applying substrate B to the bonding layer, forcing intimate contact, excluding air at B-interface.

Substrate A
Bonding Layer
Substrate B

Coating and laminating processes are dependent on a material’s response to pressure, temperature, and time.

Dry Lamination

- Solvent (or water)-based adhesives
- Solvent is removed prior to lamination
- Lamination is typically integrated with coating / drying.
- Common for products with adhesive end-use (e.g. labelstock)

Convection Drying
**Wet Lamination**

- Water or solvent based adhesives
- One of the laminates is absorbent
- Bonding fluid is applied cold then dried in laminate form
- Common for bonding paper, non-wovens, and fabrics.

**Thermoplastic Lamination**

- Thermoplastic film softens when heated and hardens when cooled.
- The thermoplastic film is pre-heated to soften, then combined with the second web.
- High nip loads required to flow high viscosity material.
- Commonly have heated nip rollers. (Laminate should be cooled prior to winding.)

**Thermal Pre-Heat Chill**

Cooling may be needed after any hot process. Don't wind hot!

**Reactive Lamination**

**Externally Initiated Cure**
- Solvent free coating between substrates.
- Coating cured via UV, E-Beam, moisture (or other reaction initiator) in laminate form.
- For light-based cure, one web is transparent.

**Material Cure**
- Two-part adhesives or epoxies form chemical bond over time.
- Coating and laminating must be completed within limited "pot-life", the time between mixing and hardening.

**Extrusion Lamination**

Extrusion lamination combines extrusion coating and laminating in one step.
Extrusion Lamination

- Bonding material is thermoplastic heated above its melt temperature.
- Slot dies apply the heated material and control the final coating temperature. Slot dies may be used in either drop or knife mode.
- Advanced slot dies have rotating rods to smooth the coating.

Internal Print Lamination

- Protect printing from abrasion and UV degradation...
- ...by reverse printing on the inner surface of a clear film, then laminating the printed side to a second substrate.

Curl

Many web products have a flatness specification. Web curl describes lack of flatness.

Elastic Curl

The most common cause of curl is mismatched strains at lamination.
**Elastic Curl**

1. Materials are laminated under tension. 

   ![Image](T>0)

2. When tension is removed, materials return to unstrained dimensions. 

   ![Image](T=0)

3. Non-uniform recovery creates curl. 

   ![Image](T=0)

**Tension = Stretch and Neck**

For solid materials, tension and compression stresses do not significantly change density. Therefore, dimensional increases in one direction cause decreases in other directions.

**Measure Laminate Curl**

Quantify curl magnitude and direction with MD and TD strips.

1. Cut strips in machine and transverse directions. 
2. Measure orientation and radius of curvature. 
3. If MD curl is high, try lowering inside radius web’s tension. 
4. If TD curl is high, look for cause in coating or web dimensional change.

**Web Elasticity**

Material properties **modulus** ($E$) and **Poisson’s ratio** ($\nu$) determine how a stretches under tension. Webs respond to tensile stress, defined as both force over area. In tensioning, the important area is the cross-section: thickness x width.

- **Stress**, $\sigma = \frac{F}{tw}$
- **Strain**, $\varepsilon = \frac{\sigma}{E}$
- **Web strains** are commonly $< 1\%$. 

Tensile Stress
**KEY CONCEPT**

**Stress**

Stress and pressure are both defined in units of force per area. To better understand any web process, convert forces into stresses by dividing the load by the cross-sectional area it is exerted over.

Use: Machine tension is commonly set in units of force, such as lbf, kgf, or N. For an “apples-to-apples” comparison of different products or processes, calculate tensile stress by dividing tension load by product thickness and width. Example: 50 lbf creates higher stress if exerted over a smaller area. Across a 50” wide and 0.010” thick web, the tensile stress is a low 100 psi. For 50” by 0.001”, the stress is 1000 psi. Loaded on 1” by 0.001”, the stress is 50,000 psi!

**Strain**

Strain is dimensional change in a solid material in reaction to stress. For positive stresses, materials will elongate in the direction of the stress. For negative stress or pressure, materials will compress. Strain is calculated as the change in dimension divided by the original dimension.

Use: When a web is forces to conform around variations in roller parallelism or diameter, the web’s response will begin by determining the web strain. Example: If a roller diameter varies from 5.00” to 5.05”, the web develop a 1% strain differential to conform to roller.

**Web Spring Constant**

An elastic web has a spring constant, $k$, proportional to thickness X width X modulus.

Use: Calculating the web stretch created by tension
Example: Matching strains of different webs at laminating to prevent curl.

Use: Calculating tensile stress created by web strain
Example: Determine the tension variations created from the web conforming to roller diameter variations.
Modulus Defined

Modulus is defined as the slope of the initial linear portion of the elastic stress-strain curve. It describes a web’s "stretchability."

\[ E = \frac{\Delta \sigma}{\Delta \varepsilon} \]

Stress \( \sigma \) (psi) vs Strain, \( \varepsilon \) (%)

- High modulus: Foils, Papers, Polyester, BOPP, HDPE
- Low modulus: PE, Vinyl, PU

Web Pressures

**Unnipped** systems are dependent on web tension and roller radius.

\[ P = \frac{T}{r} \]

Example:
1 PLI, 2” radius = 0.5 psi

**Nipped** systems can focus high load over a small area, creating high pressure, independent of tension and radius.

\[ P = \frac{N}{bw} \]

Example:
10 PLI, 0.5” footprint = 20 psi

The Ideal Laminator in 25 Steps?

Tensioning

1. Driven steel roller and idling or torque driven rubber roller.
2. Minimize curl by tensioning each web match pre-laminating strains.
3. Exit tension set equal to the sum of the input tensions.
4. Minimize accumulation wrinkles by pulling out bagginess with tension.
5. Drive the compliant roller with a torque-assist, if needed to avoid shearing thick, soft adhesives or substrates.
Laminating Drive Options

**Neither Roller Driven**

**Driven Steel Roller**

**Direct-Driven Steel Roller**

**Idling Rubber Roller**

**Torque-Driven Rubber Roller**

Idling Nip Torque

What drives the idling nip roller?

If $t_{web} < \delta_{rubber}$

Steel roller and web drive the idling nip.

If $t_{web} > \delta_{rubber}$

The web drives the idling nip.

$t_{web} = \text{web thickness}$

$\delta_{rubber} = \text{rubber indentation}$

Laminating Drive Options

For low tension laminating, often leads to problems from drag and inertia.

Good for most products, but may have too much shear thicker laminates

One in tension mode, one in torque, most advanced laminating.

Rule #1 of Laminating

Match Strains of Incoming Webs.

To prevent elastic curl, set input tension ratio proportional to web spring constants.

$$\epsilon_A = \epsilon_B$$

$$T_A = t_A E_A$$

$$T_B = t_B E_B$$

$$\sigma_A = \frac{T_A}{E_A}$$

$$T_{LAM} = \frac{\sigma_A}{\epsilon_A} = \frac{T_A}{t_A E_A}$$
Rule #1 of Laminating

Example Strain Calcs:

\[ \varepsilon_A = \frac{\sigma_A}{E_A} = \frac{T_A}{t_A E_A} \]

- \( T_A = 0.5 \) PLI
- \( t_A = 0.001" \)
- \( E_A = 40,000 \) psi (OPP)

\[ \text{Stress} = \frac{0.5}{0.001} = 500 \text{ psi} \]
\[ \text{Strain} = \frac{500}{40000} = 1.25\% \]
\[ \text{Strain / PLI} = \frac{1.25\%}{0.5 \text{ PLI}} = 2.5\% \text{ per PLI} \]

- \( T_B = 0.5 \) PLI
- \( t_B = 0.0005" \)
- \( E_B = 500,000 \) psi (PET)

\[ \text{Stress} = \frac{0.5}{0.0005} = 1000 \text{ psi} \]
\[ \text{Strain} = \frac{1000}{500000} = 0.2\% \]
\[ \text{Strain / PLI} = \frac{0.2\%}{0.5 \text{ PLI}} = 0.4\% \text{ per PLI} \]

Rule #2 of Laminating

Set Laminate Tension to Sum of Input Tensions.

To reduce in-nip shear and allow minimum nip load without slippage.

\[ T_{LAM} = T_A + T_B \]

Compliant Roller Recommendations

- Lamination processes should be designed to achieve a desired pressure, not by total load or load per width.
- Rubber rollers should have 10-30 mils deflection under anticipated process pressures.
- Both rollers should have sufficient diameter and wall thickness to keep deflection under process conditions to be less than 20 percent of rubber roller indentation.
- Default should be cylindrical roller. A crowned roller can offset pressure variations from deflection, usually only needed in extremes of high width to diameter ratio or high nip loads.
Why Measure Pressure Variations?

For consistent product quality, you need:

- Uniform pressure across a nip.
- Uniform pressure across nips of sister process lines.

Average Pressure vs. Indentation

- \( P \) vs \( \delta \) is directly proportional to cover thickness.
- \( P \) vs \( \delta \) is independent of radius.

Simple Nip & Air Model

\[
N = 4\eta V \frac{R_{eq}}{h_o} + \frac{4}{3\pi} \frac{T}{R_{wr}} \sqrt{2R_{eq}h_o}
\]

Small relative to first term

\[
N = 4\eta V \frac{R_{eq}}{h_o}
\]

\[
h_o = 4\eta V \frac{R_{eq}}{N}
\]

\[
R_{eq} = \frac{R_{wr}R_{nip}}{R_{wr} + R_{nip}}
\]

Nipping Recommendations

1. Avoid gapped or indentation controlled nipping.
2. Load should be delivered by pivoting rubber roller via pneumatic or hydraulic pressure limited to 50% above maximum process load requirements.
3. Both rigid and articulating nipping systems can be successful. Rigid systems must close and hold their parallelism to the non-moving roller. Misalignment should be less than 5-10% of rubber indentation. Articulating nipping rollers (where each side can move independently) should have even flow control to close squarely.
Nipping Recommendations (cont’d)

- Use nip footprint measurements to verify crossweb nip uniformity.
- Use flow control to prevent nips from slamming shut or flying open, but don’t overly restrain or cut off flow.
- Sufficiently guard nip rollers for safe operations. Nip roller should quickly open to a gap of over 4-inches.
- Nip point should be well-lit and easily viewable.
- Avoid wedging nips.

Nipped Rollers Load Options

Many processes require high pressure nipped rollers:

- Pneumatic Loaded
- Engagement Loaded
- Gravity Loaded

Nip System Comparison

<table>
<thead>
<tr>
<th>Pneumatic</th>
<th>Engagement</th>
<th>Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adv.</td>
<td>P ind. Rubber, thickness</td>
<td>Simple</td>
</tr>
<tr>
<td>Disads.</td>
<td>Direct relation of $N = f(P, \text{psi})$</td>
<td>Can control thickness (gap mode)</td>
</tr>
<tr>
<td></td>
<td>Added complexity</td>
<td>P is NOT independent</td>
</tr>
<tr>
<td></td>
<td>Rubber, thickness, speed</td>
<td>Rubber, thickness, speed</td>
</tr>
</tbody>
</table>

Ensure Nipping Alignment

1. Ensure all rollers and shafts are cylindrical, concentric, and straight.
2. Level and tram fixed roller.
3. Level and tram nipping roller’s pivot shaft.
4. Transfer shaft parallelism to nipping roller, through parallel and equal length arms.
5. Close nip and ensure good alignment through footprint measurement.
Wedging Nips

When the nip is closed, if the nip arm angle is not parallel to the nipping tangent line, then the nip load is magnified by a wedging factor.

\[ F_{\text{nip}} = \frac{F_{\text{roller}}}{\cos \theta} \]

Nip Deflection Compensation

- Increase Diameter
- For nips, L/D<5
- Compliant Covering
- Fixed Crowned Roller

Wrinkling Recommendations

1. Avoid pre-nip wrinkling with a spreader and/or skewing rollers/bars immediately upstream of the nip point.
2. Entry rollers for each web should create short spans (<18") and small pre-nip point wrap angles.
3. If your product often has extreme left-right bagginess (defined as bagginess not resolved by tension or spreading), wrinkles can be avoided by using a 90-degree wrapped entry roller that pivots parallel to entry span and twists in pre-entry span.
4. Avoid larger wrap angles on all rubber nip rollers.
5. Avoid 90-degree wrap angle on nipping rollers to prevent deflection-induced tracking wrinkles.
6. Use large wrap angles on steel nip rollers only if needed for pre-heating.

Worst Case: Baggy Web + Nips

\[ V_{\text{WEB}} = 100 \]
\[ V_{\text{WEB}} = 101 \]
Adjustable Roller: Best Practice

Set up entry roller with 90° wrap.

Angle entry roller parallel to entry span, lengthening baggy side.

Baggy Edge

Delaminating & Curl Rec’s

24 After laminating, avoid small diameter rollers in handling thick laminate with weak bond.

25 To prevent defects associated with build up of delamination or bubbles ahead of rollers, use laterally ridged rollers, as needed.

26 Avoid post-nip wrap on nipping rollers. Pull the web straight out.

Bonus: New this week…

Compliant Roller Benefits

Lamination nips usually include at least one compliant roller.

Compliance is needed to compensate for:

- Roller deflection,
- Roller hardness or diameter variations,
- Web thickness variations

Elastomer Nip Deformation

Elastomeric roller covers deform, elongating near the nip point and bulging before and after.

Hysteresis, a differing response in the compression-recovery cycle, creates internal heat…

…which can lead to significant elastomeric degradation or melting.
Elastomer Nip Deformation

What is the surface speed of a rubber nip roller driven by a steel roller?

\[ V_{\text{rub., unnipped}} < V_{\text{rub., nipped}} = V_{\text{steel}} \]

Equivalent Radius

The equivalent radius, \( r_{eq} \), of a nip formed by two rollers is the same as one roller twice as small pushed against a flat plate.

\[ r_{eq} = \frac{1}{1 + \frac{1}{r_A} + \frac{1}{r_B}} \]

Example:

\[ R_a = 6", \ R_b = 6" \]

\[ R_{eq} = 3" \]

Footprint vs. Engagement

Smaller diameter = Smaller footprint
Footprint vs. Engagement

\[ b = \sqrt{8r_{eq}\delta} \]

\[ r_{eq} = \frac{1}{1 + \frac{1}{r_A/r_B}} \]

\[ \delta = \text{Engagement} \]
\[ b = \text{Footprint} \]
\[ r_A = \text{Rubber Roller Radius} \]
\[ r_B = \text{Steel Roller Radius} \]

For small penetrations, \( \delta/t<0.07 \)

Calculate Nip Load

Given Machine Settings: Nip Air Pressure (psi)

Convert to Process Condition: Nip Load (lbs/in)

Calc. cylinder force from pressure and area

\[ F_{CYL} = nPA = nP(2\pi r_A^2) \]

Calc. leveraged nip force

\[ F_{NIP} = F_{CYL} \left( L_{CYL}/L_{NIP} \right) \]

For vertical nips, include roller weight effect

\[ F_{NIP} = F_{CYL} \left( L_{CYL}/L_{NIP} \right) \pm W_{NIP} \]

Calculate Nip Load:

\[ N = F_{NIP}/W \]

Nip Force per Width (N)

\[ F_N = F_1 + F_2 \]

\[ N = F_N / w \]

Nip Pressure Equations

\[ N = \frac{F_N}{w} = \frac{2}{3} \left(1 - \nu \right)^2 \frac{E_o \sqrt{2r}}{1 - 2\nu} \frac{\delta^3}{t} \]


(According to Dr. JK Good, this can be used for rubber strains up to 7 percent.)

\[ E_o (psi) = 20.97 e^{0.0564 \left( Shore A \right)} \]

\[ E_o (kPa) = 145 e^{0.0564 \left( Shore A \right)} \]

### Rubber Modulus vs. Durometer

**Modulus vs. Shore A**

\[
E_o (\text{psi}) = 20.97 e^{0.0564 (\text{Shore A})}
\]

\[
E_o (\text{kPa}) = 145 e^{0.0564 (\text{Shore A})}
\]

### Nip Pressure Equations

**Nip Pressure Equations**

\[
N = \frac{F_N}{w} = \frac{2 \left(1 - \nu^2\right) E_o \sqrt{2r}}{3 \left(1 - 2\nu\right) t} \delta^2
\]

Reversing this equation to get indentation from nip load:

\[
\delta = \sqrt{\frac{3 tN \left(1 - \nu^2\right) \left(1 - 2\nu\right)}{2 \sqrt{2r} E_o \left(1 - \nu^2\right)}}
\]

Assuming a Poisson’s ratio of 0.46 simplifies to:

\[
\delta = \sqrt{\frac{0.23 N t}{E_o^{0.5} \nu}}
\]

### Modeling Rubber Covered Nip Rollers in Web Lines

Modeling Rubber Covered Nip Rollers in Web Lines, J.K. Good, Oklahoma State University, Stillwater, OK, Proceedings of the Sixth Annual Conference on Web Handling, 2001
Nip Load (PLI) vs. Indentation

Nip Roller References
- Air Entrapment and Residual Stresses in Roll Wound With a Rider (Nip) Roller, JKGood and SM Covell, Oklahoma State University, Stillwater, OK, pp 78-92, Proceedings from the Third International Conf on Web Handling, 1995
- Entrained Air Films in Center Wound Rolls - With and Without the Nip, RMTaylor and JKGood, Oklahoma State University, Stillwater, OK, pp 189-202, Proceedings from the Fourth International Conf on Web Handling, 1997
- Contact Mechanics, K.L. Johnson, Cambridge University Press, 1985

Two Rules of Elastomer Nips
- #1 Maximize elastomer hardness, but enough compliance to ensure full width contact and minimize pressure variations.
- #2 Minimize Load, but enough to squeegee air and ensure line contact.

Both reduce hysteresis and increase life.

Elastomeric Roller Covers
Important Characteristics of Elastomer Coverings:
- Elastic
- Durable
- Non-Porous
- High Coefficient of Friction
- Chemically Resistant
- Moldable
- Conductive?
Elastomer Roller Care

1. Eccentricity:
   - Always rest rollers on their journals to avoid flat spots or surface damage.
   - Open nips when web line is stopped.
   - Periodically rotate roller in long-term storage.

2. Cleaning:
   - Clean with isopropyl alcohol or MEK on a lint free cloth.
   - Do not clean hot rollers.
   - Clean once per shift.
   - Clean before storing.
   - Clean the entire exposed surface, including the ends.

3. Degradation / Damage:
   - Avoid UV exposure (including sunlight, cure lamps, and fluorescent lights).
   - Avoid ozone exposure (from motors and corona treaters).
   - Never use a razor near the elastomer surface.

4. Replacement:
   - Change out rollers when damaged or worn.
   - Periodically measure for uniform footprint and hardness.

Nip Pressure vs. Width

Typical end-loaded nipping rollers will deflect away from each other, reducing pressure and contact at the nip’s center.

Nip Variations vs. Load

Nip deflection is directly proportional to load.

Excessive nip loads lead to increase variation and associated problems.

Nip Deflection Compensation

For nips, L/D<5

- Compliant Covering
- Fixed Crowned Roller
Skewed / X Nipped Rollers

To end-loaded rollers will bow away from each other.

Skewing the rollers, so their deflecting shape wraps slightly around the opposing cylinder reduces pressure variations.

This technique has a subtle, but sometimes significant effect, especially with steel-on-steel nips.

Note: Ensure you don’t have this misalignment in your nips if you don’t want it.

Addendum

• Measuring Nips

Measure Nip Gap

• For a fixed gaps, use a feeler gauge to measure the space between rollers.

• For a fixed interference, use a known spacer (S) and set the gap (G). Removing the spacer will create the fixed interference (G-S)

Some nips are set using a fixed opening or interference dimension.
Measure Nip Load

Method 1 (lower nip loads)
1. Wrap a rope around the nipping roller.
2. Attach the rope to a handheld force gauge.
3. Measure the force at various input pressures.
4. Divide the sum of the forces by web width to convert to pounds per inch load.

Method 2 (higher nip loads)
1. Insert two compression force gauges on either side of a nip.
2. Close the nip and load at various levels.
3. Divide the sum of the forces by web width to convert to pounds per inch load.

Nip Footprint Measurement 1

Measure nip contact area using a series of sticky notes.
1. Close the nipping roller and apply full load (with nip not rotating).
2. Place a series of Post It™ notes on one roller, pushing them as far into the nip point as possible and stick them in place.
3. Open the nip and measure the gap between opposing notes.
4. Look for MD contact length variation as a sign of non-uniform nip pressure.

Nip Footprint Measurement 2

Measure nip contact area using knurled foil.
1. Open the nipping rollers
2. Place a strip of knurled foil across the nipping area.
3. Close the nip with the desire force.
4. Open the nip and inspect the area where the knurl was flattened.
5. Look for MD contact length variation as a sign of non-uniform nip pressure.

Contact:
Stowe Woodward - Neenah, WI
Junille Hintz 920-729-7000

Nip Footprint Measurement 3

EZ-Nip - $300 / 200 ft.
A single sheet pressure sensing film.

- Thickness: 15 mils (0.076 mm)
- Humidity Range: 10-90% RH
- Pressure Minimum: 300 PSI (20.8 kg/cm²)

www.sensorprod.com/nip.php
Nip Footprint Measurement 4

P-Nip - $2000

Sensor Products Inc.
300 Madison Avenue
Madison, NJ 07940 USA

Phone: 1.973.884.1755
Fax: 1.973.884.1699
Toll Free (U.S. Only): 1.800.755.2201
Email: sales@sensorprod.com

www.sensorprod.com/nip.php

Nip Footprint Measurement 5

Sigma-Nip - Depending on the length of the chain and how many sensors, cost is from $8k to $16K.

For 60" around $10K

www.sensorprod.com/nip.php

Nip Pressure Measurement 1

Insert a steel-brass ‘hot dog’ into the loaded nip and measure the force to slide the steel strip. Calculate the nip load from the measured frictional force, COF, and geometry.

\[
\mu = \frac{F}{2 \mu_w S}
\]

Folded Brass Sleeve
0.001" (25 \( \mu \)m) thick

Steel Shim Stock
0.002" (50 \( \mu \)m) thick

\( \mu \) = Brass-Steel Friction Coefficient (use 0.25)
\( N \) = Nip load per width (lbs/in or N/m)
\( F \) = Frictional force to slide steel vs. brass (lbs or N)
\( w_s \) = Width of steel strip

Nip Pressure Measurement 2

Tekscan’s sensors detects pressure changes as a electrical resistance drop though a conductive ink.

The array sensor is 0.005” thick and read every 0.1” over a 1” by 16” area.

Tekscan®
307 West First Street
South Boston, MA 02127-1309
800-248-3669
www.tekscan.com
System Cost ~$25000
Nip Pressure Measurement 3

AutoNis XP - The complete system with scanner, and software is $4000

www.sensorprod.com/nip.php

Nip Pressure Measurement 4

Stowe Woodward’s Smart Roll™ Technology is a battery-powered, fiber optic measurement sensor set embedded in the roller covering to measure load and temperature, with wireless communication to your PC.

The Smart Roll system adds $30,000 to the price of a 200”-wide rubber or polyurethane covered roller. Narrower application should be significantly less.

www.stowewoodard.com

Laminate Defects

Common defects associated with laminate products and processes include:

- Curl
- Bubbles
- Delamination
- Tunneling

Curl

Causes:
- Differential dimensional change of one layer vs. another.
- Mismatched elastic strains at laminating.
- Dimensional change from aging or external factors (long term cure in coatings, heat stability and films, hygroscopic expansion of papers).

Cures:
- Understand and control dimensional stability of all materials.
- Balance strains using tension ratio based on spring constants (thickness x width x modulus)
- Control humidity and other external factors.
Laminating Film Options

How Material Selection Affects Curl Defects:

Example: Film for book cover lamination

**Polyester (PET)**
PET features excellent scruff and scratch resistance, durability and good folding characteristics. PET has high tensile, tear and impact strength and retains these outstanding properties and remains tough and flexible once applied.

It is a popular choice for book covers and dust jackets, presentation folders and video cartons.

**Polypropylene (OPP)**
OPP has a good combination of cost and overall characteristics. It is the clearest and brightest of these films. Because of its softness, OPP folds extremely well.

Applications include write-on/wipe-off calendars, posters, presentation folders and labels.

**Nylon**
Nylon is a durable product with excellent scuff- and scratch-resistance. Nylon laminating film is popular particularly for book covers and dust jackets, due to its ability to absorb moisture from the air at about the same rate as the paper substrate.

RESULT: Significantly less curl!
Nylon is the film of choice for most book manufacturers.

---

**Bubbles**

**Causes:**
- Failure to squeegee air from nip deflection, nip diameter variations, nip hardness variations, not enough nip compliance, web bagginess, or caliper variations
- Gasses emitted from internal layer’s residual solvent or cure byproduct

**Cures:**
- Improve nipping system to eliminate squeegee error source.
- Change to porous substrate
- Improve drying or curing.

---

**Tunneling**

**Causes:**
- Gross failure to squeegee air continuously in a lane from nip deflection, nip diameter variations, nip hardness variations, or caliper variations
- Accumulation of bubbles ahead of a nip, roller, or winding roll.
- Laminates contacting ahead of nip point due to bagginess or sagging.

**Cures:**
- Improve nipping to eliminate squeegee error.
- Install a laterally ridged roller to pulse-feed bubbled web, avoiding accumulation.
- Increase entry angles and increase tension to pull baggy web taut, preventing early contact.

---

**Delamination**

**Causes:**
- Poor laminate bond.
- Shear on bond interface from roller curvature.
- Shear stresses increase with small diameter.
- Worsens with thicker layer on roller contact side.
- May be triggered by bubble accumulation upstream of roller.

**Cures:**
- Improve laminate bond before wrapping rollers.
- Increase roller radius to reduce laminate shear.
- Eliminate bubbles
- Install a laterally ridged roller to pulse-feed bubbled web, avoiding accumulation.