

## **WOUND ROLL STRUCTURES AND PRACTICAL APPLICATIONS**

**By**

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### **ABSTRACT**

Winding is an integral process in the manufacturing and converting of nearly all web materials such as paper, film, tissue, nonwovens, aluminum and steel. Wound rolls are the most convenient, economical, and most prevalent form of storage and transport for web materials.

Wound rolls store web materials compactly without folding or cutting. Wound rolls are a form of compressed packaging. A roll that has been wound firm enough for routine handling in a converting process has often compressed the material by more than 25%.

From a business standpoint, web materials are sold based on two broad categories:

- Geometry – Diameter, Width, Core Diameter, Roll Length, Lay flat properties, etc.
- Physical Properties – Modulus, Tensile strength, Caliper, Softness, Color, etc.

It is common to see defects such as:

- Loss of caliper in high loft webs
- Telescoping, cinching, gross internal slippage
- Large flat spots due to storage & handling
- Floppy edges and baggy lanes
- Slit width growth after winding
- Roll blocking
- Print registration shift

This presentation will explain how the material properties will determine which of two wound roll structures will result. Each of these will react differently when larger rolls are pursued. Proven methods to document your wound roll structure will be presented. Eight methods to improve your delivered quality will be offered.

## NOMENCLATURE

BW	Basis weight
CD	Direction, lateral across the plane of the web
MD	Direction, longitudinal in the plane of the web
ZD	Direction, perpendicular plane of the web
$\rho$	Density, roll
ID	Diameter, inside
OD	Diameter, outside
ILP	Interlayer pressure
L	Length
E	Modulus
$E_r$	Modulus, Radial
$E_{zd}$	Modulus, Stack
$E_t$	Modulus, Tangential
$\epsilon$	Strain
$\sigma$	Stress
W	Width

## WOUND ROLL STRUCTURES

Every layer of material stored inside of a wound roll will experience three stresses: MD, CD and ZD (Figure 1). The shape of these stresses is known as the wound roll structure.

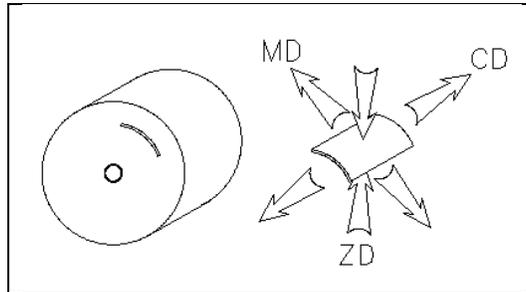
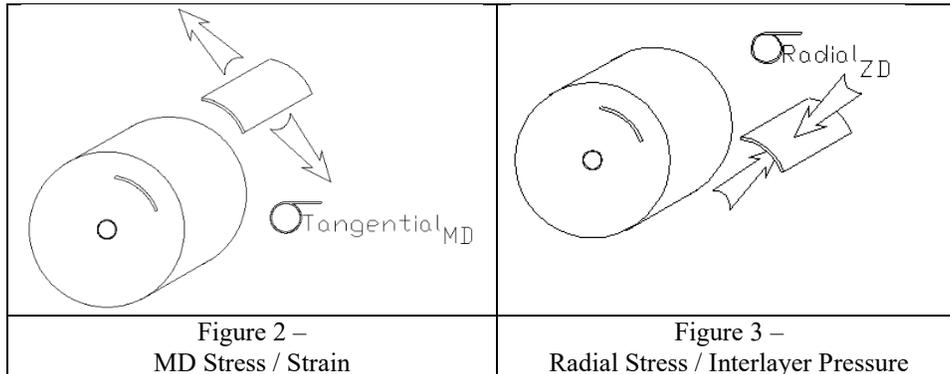


Figure 1 – Wound Roll Stresses – MD, CD & ZD

This paper will focus on MD and ZD stress and ignore the CD stress. Figure 2 defines MD stress. For a given in plane (MD) modulus one can calculate strain. Strain is relatively easy to measure for a web in a wound roll. For the sake of this paper we will focus on MD strain.

Figure 3 shows that the radial stress or “Interlayer Pressure” is perpendicular to the plane of the web. Interlayer pressure is the force that acts on the web such that it will reduce the caliper of a high loft web like tissue.



The wound roll structure describes the shape of MD and ZD stresses. There are only two types of wound roll structures: “Soft Roll” and “Hard Roll”. The naming convention “Soft” versus “Hard” is not completely satisfactory. This is not to be confused with a qualitative assessment of how hard a roll is wound. It really deals with the relationship between the MD modulus versus the ZD modulus of the web.

If the MD modulus is significantly greater than the ZD the roll structure is described as a “Soft Roll”. There is significant compliance in the ZD direction. The web can be compressed in the ZD direction easily. Examples of web materials that fall into this category are: Creped Tissue, Spunbond and Film/Spunbond laminates.

If the MD modulus is approximately the same as the ZD modulus the roll structure is described as a “Hard Roll”. In the ZD direction the web is fully compressed. This is often referred to as a fully compressed roll structure. Examples of web materials that fall into this category are: Film, Cast rubber, MD Elastics and Highly Textured Tissues.

Figure 4 gives us an overview of the two types of wound roll structures.

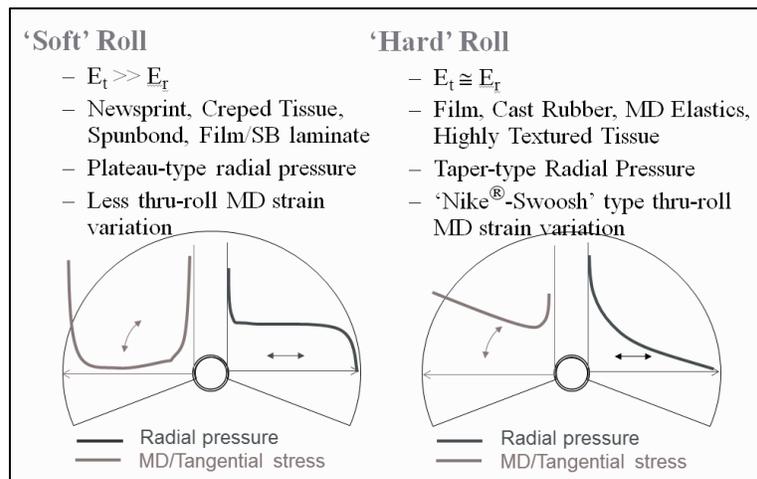


Figure 4 – Wound Roll Structures – Two Types

A soft roll will display an S shaped interlayer pressure profile. The interlayer pressure peaks at the core and will have a wide plateau thru the middle of the roll.

A hard roll will display a parabolic decay profile for interlayer pressure. It also peaks at the core but will drop off quickly and will not have a plateau in the middle of the roll.

It is a common misbelief that the MD strain thru roll will be the same from the outside of the roll to the core. The outer layers of the roll compress the inner layers. This interaction will result in one of two unique MD strain thru roll profiles as shown in Figure 4.

A soft roll will have a U shaped profile for stored MD strain. Recall that the outer layers are under tension and are compressing the highly compressible layers of web on the inside of the roll. Note that the web stored in the middle plateau is at a nearly zero stress condition in the plane of the web. In some examples the web may be under a slight compression. The only reason the web does not buckle is due to the stabilizing effect of the core and the interlayer pressure.

Conversely a hard roll will have a Nike™ Swoosh profile for stored MD strain. This is because the web is fully compressed. The web will resist being compressed any more. All of the web stored in the roll is under tension.

Figure 5 summarizes the wound roll structure for a “Soft roll”.

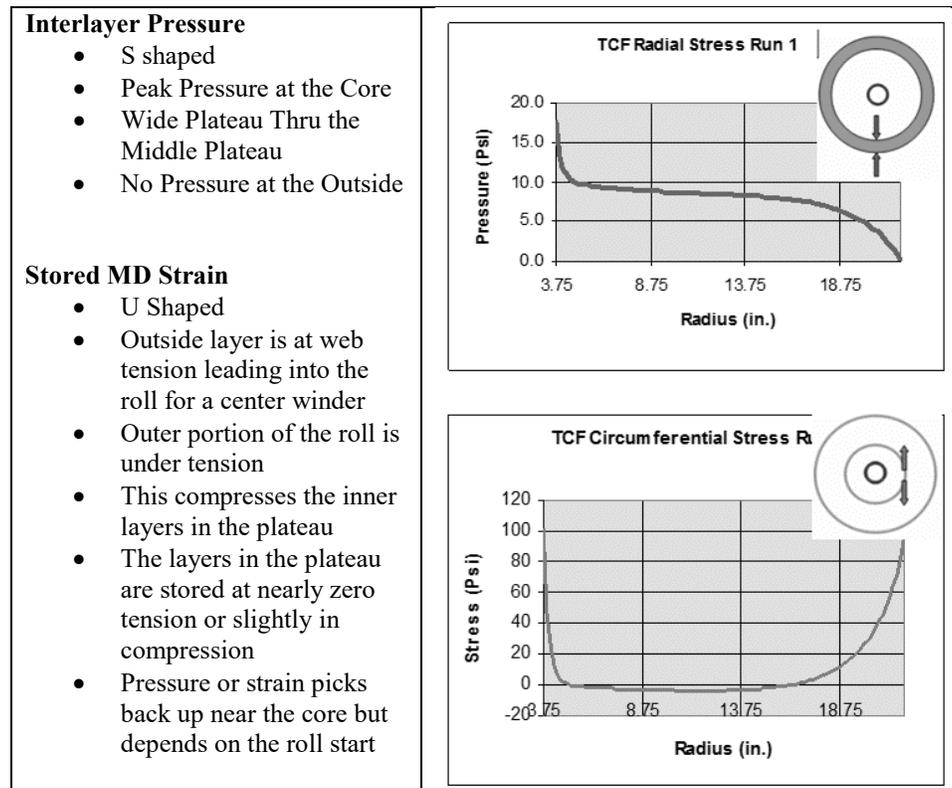


Figure 5 – “Soft Roll” Wound Roll Structure

Figure 6 summarizes the wound roll structure for a “Hard roll”.

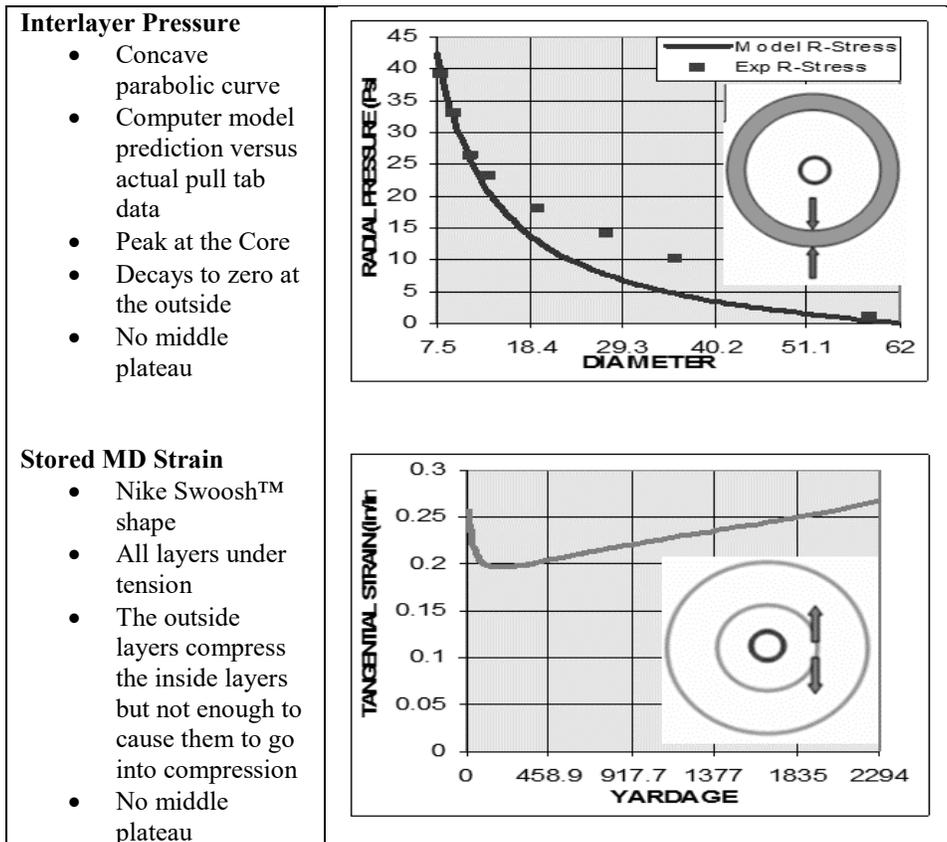


Figure 6 – “Hard Roll” Wound Roll Structure

Figure 7 shows what happens when more material is added to a given wound roll structure. The addition of more material on a soft roll does not make a big effect on the interlayer pressure or stored MD strain. Conversely the addition of more web material on a hard roll will have a dramatic effect on the interlayer pressure and stored MD strain for a hard roll. It is important to know what type of wound roll structure you have in order to make improvements to your delivered quality.

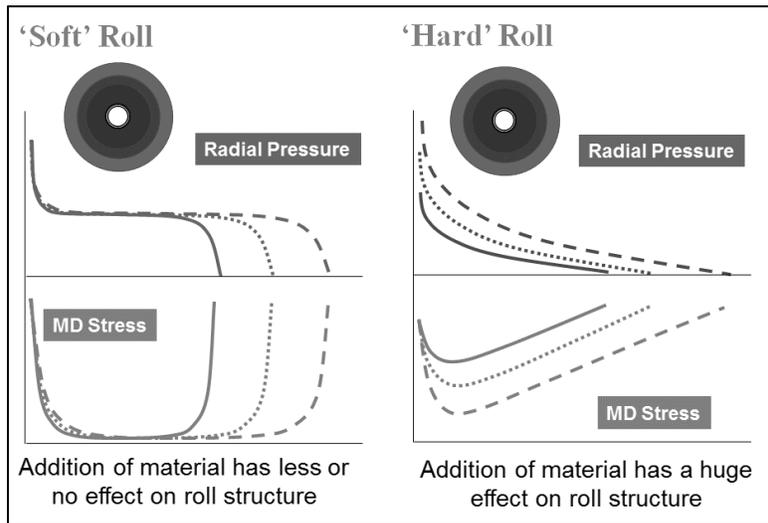


Figure 7 – Impact of More Material

## METHODS TO DOCUMENT WOUND ROLL STRUCTURE

### Document Interlayer Pressure

There are two proven ways to measure interlayer pressure.

- Wind in pull tabs
- Reverse pull tab test

When possible you can wind tabs into the building roll. This can be very dangerous so one must be careful when placing the tabs into the building roll. Once the tabs are wound into the roll use a hand held load cell to measure the force to remove the tab. This test is generally reserved for a slow speed pilot line application.

A much safer method is to use a reverse pull tab technique. The edge of the roll must have a clean slit edge. Insert a ruler or a rod into the side of the roll to a repeatable dimension. Use a hand held load cell to measure the force to remove the tab. A minimum of twelve radial positions are recommended. More maybe required. It often takes an hour to document the first roll as you figure out your technique. Once you are in practice you can document a roll in 15 minutes. It is recommended to use the same person to document interlayer pressure as this technique can be dependent on who takes the measurements.

In both cases one can convert the pull tab force to pressure by conducting a calibration experiment. Cut a cube of material away from the wound roll you just tested. Cut coupons to a known dimension (eg: 4" x 4"). Place a pull tab into this stack of material at the same distance it was previously inserted into the roll. Place a known amount of force onto the stack using static weights or a tensile frame with a compression load cell. Calculate the pressure exerted onto the stack (EG 160# / 16 in<sup>2</sup> = 10 psi). Use the same hand held load cell to remove the pull tab. Repeat this exercise for three loads that represent three interlayer pressures. Calculate a calibration coefficient to convert pull tab force to interlayer pressure. The relationship will be linear.

Note – the use of force sensitive resistors is not recommended. There are many applications for them such as measuring nip profile across a wide nip. However they are

difficult to calibrate, not highly repeatable and are very sensitive to ambient & inter roll temperature. A steel ruler and a good hand held load cell is all you need.

See Figure 8 for the simple tools that can be used to conduct a reverse pull tab test.



Figure 8 – Tools for a Reverse Pull Tab Test

See Figure 9 for an example of the data collected and the resulting graph. For this example the calibration coefficient is 12. Pressure [psi] = Pull Tab # x 12 psi/#

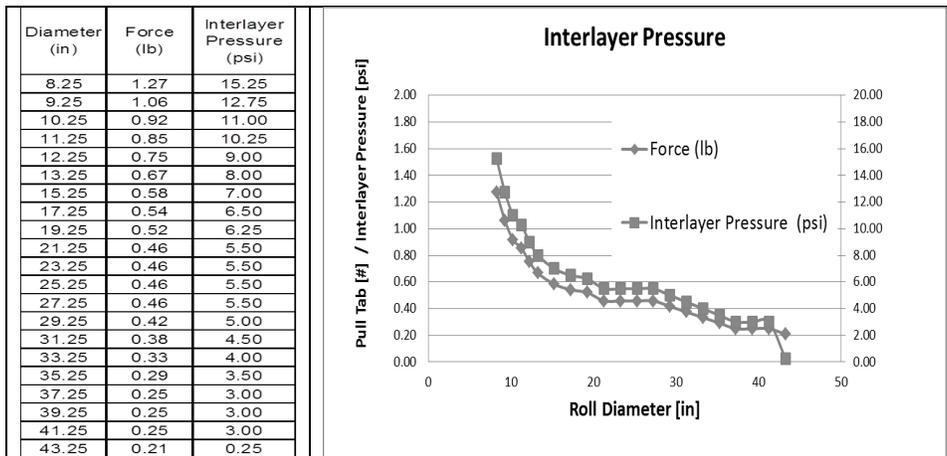


Figure 9 – Reverse Pull Tab Measurements

See Figure 10 for measurements that were taken from a sample 60” diameter roll of tissue. Note how the caliper is the inverse shape of the interlayer pressure. This is an example of a Soft roll structure. The S shape profile for interlayer pressure results in an inverse S shape relationship for caliper.

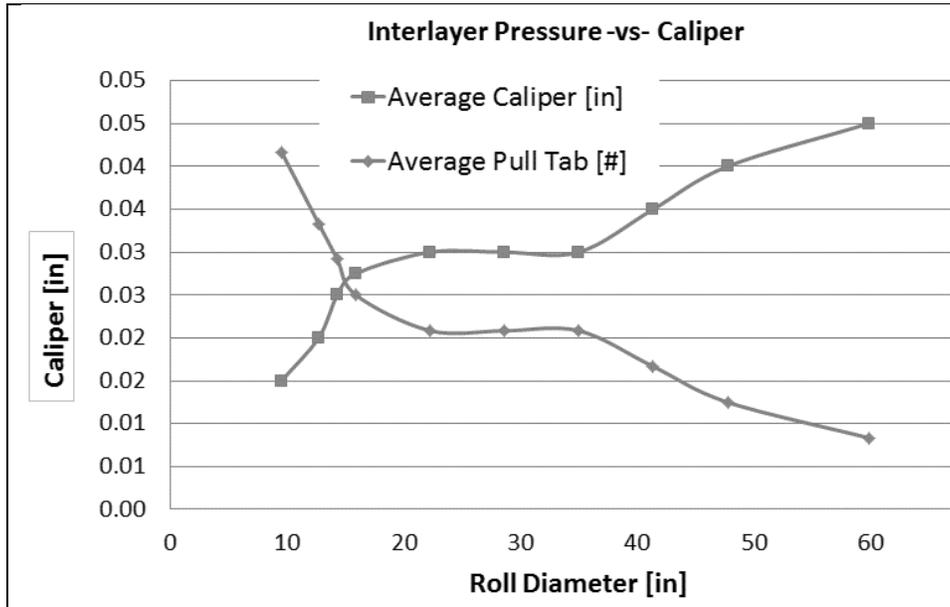


Figure 10 – Inverse relationship between Interlayer Pressure and Measured Caliper

#### **Document Stored MD Strain**

There are two proven ways to document your stored MD strain thru-roll:

- Measure repeating patterns on your web
- Print Registration marks before the Winder

If you have a repeating pattern (eg - print repeat, embossing pattern) on your web you can often measure from one feature to the same repeating feature. Measure the roll circumference. Calculate roll diameter. Measure the repeat length on the roll. Strive to take the longest measurement possible. For example if your nominal repeat length is 12” – it is better to measure the distance of three repeating cycles (→ 36” nominal). You may be looking for a difference of 1-2% stored strain difference. The longer repeat length will increase your resolution and accuracy.

If your web does not have a repeating pattern you should print one on the web before it enters the winding process. Figure 11 shows an installation of a printer from Ryeco. They offer several robust printers that are ideal for an application such as this. You can print a visible mark or an invisible one using special inks or water based solutions. Again it is important to use a nominal length that is as long as possible that will facilitate the length measurement on the roll. You should be able to measure to 1mm accuracy. Use a 250mm repeat pattern for 3” cores; 500mm for 6” cores and 1000mm for 20” cores. This will allow measurements all the way to the core.



Figure 11 – MD Registration marks

Figure 12 documents the Stored MD strain on roll and off for another roll of tissue. Note that the “off roll” measurements were taken by removing the sample from the roll. Lay it out on a smooth table to allow a second measurement. Off roll strain will be less than the on roll strain. The amount of difference is due to plastic deformation.

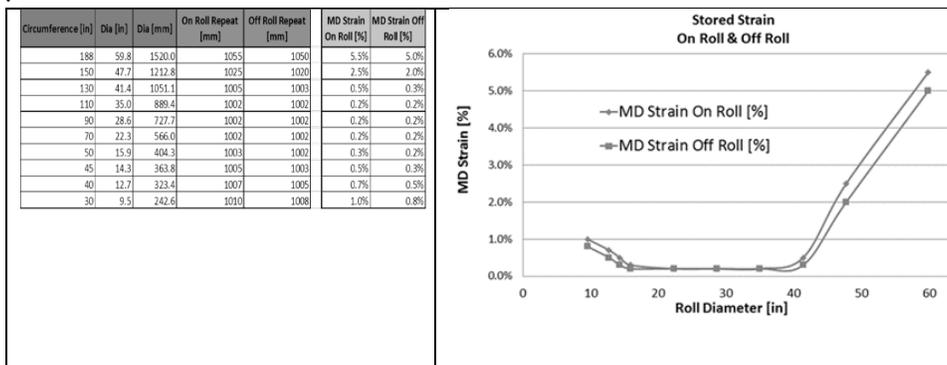


Figure 12 – Stored MD Strain – On Roll & Off Roll

Figure 13 shows the relationship between stored MD strain for an elastomeric laminate material and the elongation. Note that the Nike™ Swoosh stored MD strain results in an opposite shape for elongation.

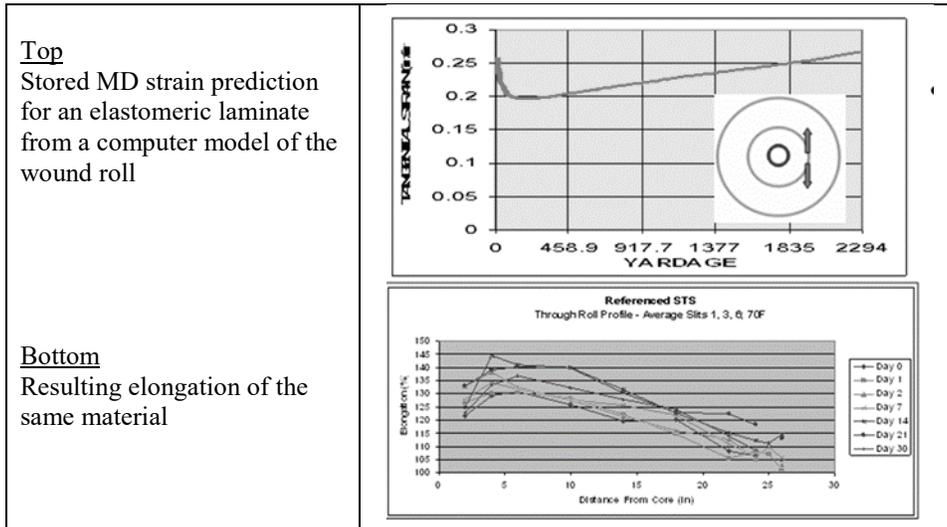


Figure 13 – Impact of MD Strain on Thru roll properties

**METHODS TO IMPROVE DELIVERED QUALITY**

**Document & Control Average Wound Roll Density**

Average Wound Roll Density is a single metric that allows one to understand your wound roll structure. This is particularly true for compressible materials such as nonwovens, tissue and high loft webs. You only need three parameters: Roll Diameter, Roll Length and Basis Weight. This information is typically on your roll ticket and is stored in your PLC. You should calculate this for every roll you make. Refer to Figure 14 for US and SI calculations. Begin to track roll density to determine when your process is out of control (typically beyond +/- 10%). It is important to note that for a given roll density your wound roll structure will be consistent. If you are making individual slits across the deckle you should calculate actual slit roll density using the standard method: Density = Net Mass / Slit Roll Volume. Your actual slit roll densities will vary linear to cross deckle basis weight profile.

$$\rho \left( \frac{kg}{m^3} \right) = (1000) * \frac{BW * L}{\left( \frac{OD^2}{4} - \frac{ID^2}{4} \right) * \pi}$$

*BW: Basis Weight ( $\frac{g}{m^2}$ )*

*L: Length on Roll (m)*

*OD: Outer Roll Diameter (mm)*

*ID: Inner Roll Diameter/Core Diameter (mm)*

*W: Machine width or roll length (mm)*

*$\rho$ : Roll Density ( $\frac{kg}{m^3}$ )*

Figure 14 – Average Roll Density Calculations

### **Document & improve your wound roll structure**

Document your average wound roll density. Document your thru roll interlayer pressure and stored MD strain. Look for any step changes in your wound roll structure. Determine what is causing this anomaly and correct it. If your roll density is held constant your wound roll structure will be repeatable for your customer.

### **Use the Proper Winding Technique**

Document your in-plane modulus and yield strain. Use tension loop control for web that have a yield strain less than 3%. Use draw control for webs that are stretchy in the machine direction.

### **Install, Calibrate and Use Load Cells**

A \$6,000 dollar load cell installation can help you solve a million dollar problem. Work with your vendor to install & calibrate load cells in your process. Even if you are running in draw control you should monitor your actual web tension to protect yourself from a failed idler bearing or an accidental selection of an improper draw. Link the load cell data onto trend charts that can be used to monitor your process.

### **Reduce Caliper Loss in High Loft Webs**

Document and control your roll density. Reduce winding tension and nip to reduce your roll density. Implement coreshaft relieving for surface winders to tare out the weight of the heavy coreshaft during the winding process. All nonwoven webs are temperature sensitive. Reduce the web temperature to below room temperature before the winding process. Likewise reduce your storage temperature and any required time in a hot environment. Consider refrigerated shipping for high valued webs. You may be required to reduce your roll diameter and/or increase your core diameter. A 12" core will have considerably less caliper loss as compared to a 3" core for the same roll density. In unique cases when the web is nipped or laminated before the winding process try to reverse the profile. Open up or relax the nip for the web that is placed at the core. Close up the nip as the building roll approaches the outside diameter.

### **Address Telescoping, Cinching or Internal Slippage**

Begin by documenting the slip plane diameter. Strike a straight line on the side of the roll before unwinding. Look for any movement in this roll during the converting process. Document your interlayer pressure – torque capacity will be directly related. Look for a root cause on your winding process. Eliminate any sudden changes in tension or nip loading near the slip plane. Increase your average roll density when possible. An alternate approach is to increase your winding tension and/or nip just beyond the slip plane. Consider using larger diameter cores or winding to a smaller outside diameter. Where possible increase the web to web coefficient of friction. Ask your customer if they are willing to use less torque to accelerate the roll up to speed at a slower rate. Directly measure your wound roll's torque capacity. Hold the outside of the roll fixed and rotate the core using a torque wrench. The roll will eventual slip which will establish your torque capacity. A web that has a significant cross machine basis weight profile will be more prone to slip where the basis weight is low.

### **Reduce Floppy Edges and Baggy Lanes**

Identify and reduce cross deckle basis weight variations. Reduce roll density. Reduce web temperature before entering the winder and in storage. If possible, wind the web loose; allow it to age 72 hours and rewind it to final dimensions at target roll density.

When required consider winding a sacrificial layer to reduce internal wound roll stresses that drive floppy edges and baggy lanes.

### **Address Slit Width Growth after Winding**

Document your final slit width thru roll and after aging. Reduce roll density by reducing tension and/or nip. Replace draw control with tension loop control. Reduce the web temperature before the winding process and in storage. Consider refrigerated shipping when called for. Use a large taper tension only for the last 10% of the roll length to salvage the material near the outside diameter.

### **PROCESS OPTIMIZATION TIPS**

- “Until you use dollars you will not make sense”. Focus on the cost of the opportunity. It is essential to drive any waste or quality problem into dollars. Armed with this information you will be able to make a business case for making an improvement.
- “Don’t fix it if it is not broken” is a common maxim. Rarely is it true in a manufacturing environment. Most everything is broken at some level once you start digging into it. Don’t be surprised what you see. There is a Dilbert™ comic strip in nearly every process. Have fun chasing down what is driving your waste levels.
- Don’t be quick to jump to a conclusion. This is a common problem when you are working on what appears to be a common problem. Direct observations are required. You will not be able to make any improvement unless you know that you know that you are working on the right problem.
- Collaborate with many others to solve problems. It is common to overestimate what you can do by yourself and underestimate how powerful it is to have several people looking at the problem with a different perspective.
- Make a point to ask your operators what they think. This may take some prodding as they may not believe that you really want to hear what they have to say. Ask different people on the crew what they think. You will most likely find someone brave enough (or mad enough) to give you some critical feedback that may solve the mystery you are trying to uncover.
- Trust but verify. Take all the feedback you can gather. Form a theory that will describe what you are trying to solve. Verify your theory with direct measurements or trials on the process. Look for other losses that don’t seem to be related. Are they related? It is common to find several random facts that when combined explain the issue you are working on.
- Use the shape tool to filter the evidence you are collecting. The shape of the problem must have the same shape (or reverse shape) as the root cause.
- Use powerful tools such as trend charts, cameras and DVR’s to allow you to retrieve info from the last time an event occurred.
- Educate yourself. Purchase and study Dave Roisum’s books on “Mechanics of Wound Rolls” and “Critical Thinking in Converting”.
- Attend the “Applications Seminar on Web Handling” presented by the Web Handling Research Center at Oklahoma State University (405-744-8902).
- If your company experiences more than \$50k annual waste associated with wrinkles, winding, web handling, tension control or converting consider a membership with the Web Handling Research Center at Oklahoma State University.

## ACKNOWLEDGEMENTS

I have spent the majority of three decades studying web handling and winding. I have many people to thank for their advice and assistance.

**Bruce Feiertag** first introduced me to the broad topic of web handling and the Web Handling Research Center. He was a great friend to me over the years and set me onto the path that I am on today. God speed Bruce.

**Keith Good** developed so much technology that I was able to apply in my corporate life. His ability to define and solve complicated subjects has been an inspiration to me. He guided me to study and understand the relationships between material properties, winding and wound roll mechanics. It has been a great joy to know and work with Keith over two decades.

**Ron Markum** can build anything. He has prototyped many things that I have used to conduct research in winding and material properties. Thank you, Ron, for your hard work and can do it attitude.

**David Roisum**'s books on winding, web handling and troubleshooting have been a great resource to me over the years. It is an honor to serve on AIMCAL's technical advisory board with David.

**Tim Walker** for his practical insight to simplify complex topics and his thousands of technical training documents. Thank you, Tim, for making this presentation in my absence.

**Bob Coxe** and I worked together for more than two decades. Bob is a controls expert and has helped me hundreds of times to solve winding and web handling issues in the field. His trend charts are a thing of joy to study and apply.

**Karl Reid** founded the Web Handling Research Center in 1986. His steady leadership and investment into others have greatly benefitted the WHRC's industrial sponsors and other industries that make and convert web products. He launched the first IWEB in 1991. You are here today because of Karl's vision to give back. Thank you, Karl, for your inspirational leadership. I count it a joy to call you a friend.