THE TAXONOMY OF WRINKLES

By

Timothy J. Walker
T. J. Walker and Associates, Inc.
USA

ABSTRACT

Taxonomy is the practice and science of classification. Without taxonomy, everything is lumped into one pot and confusion prevails. All wrinkled or buckled webs should not be filed under one category. Just as birds are observed and divided by what they look like and where they appear wrinkled webs have characteristic visual clues and common causes. Much of taxonomy in other fields is justified by the ability to separate the good from the bad, such as managing invasive species. For wrinkles, all forms are considered invasive and undesirable, but taxonomy will help to understand the causes of specific wrinkles and help point the direction of either eliminating the cause or finding an appropriate remedy based on the cause.

This paper outlines one approach to categorize wrinkling causes based on over twenty year's observations and the contributions of other experts of wrinkle prevention and elimination. This taxonomy divides buckled webs by three locations: in spans, on rollers, and within rolls. Buckled webs on rollers, the narrow definition of wrinkling, are divided into four mechanisms. Shear wrinkles, as defined by the work of Gehlbach, Good, and Kedl. Tracking wrinkles (or principle stress wrinkles) where the left and right sides of a web track toward the web's centerline (or other lane) with enough crossweb compressive stress to induce buckling. Constrained expansion wrinkles, such as develops in on-roller conduction or radiant heating or hygroscopic expansion in the outer wraps of a paper roll. Accumulation wrinkles, the only wrinkle species forming dominantly crossweb creases, where the compressive stresses build up in the machine direction. This paper includes over 50 examples of where these wrinkle mechanisms occurs despite our best efforts.

WHY CREATE DIFFERENT SPECIES OF WRINKLED WEBS?

We could happily call all out-of-plane shapes in webs *wrinkles* if there was no motive to go beyond this simple terminology, but wrinkles are in the least a nuisance, but in reality a great source of waste and lost profits that easily measure in the millions whether counted in pound, kilograms, US dollars, Euros, or Yen. Our goal is to minimize or eliminate wrinkles as we would invasive pests. To find the appropriate bug-killer, we need to identify whether our problem is ants, spiders, mosquitoes, or flies. Therefore, assuming different species of wrinkles will require different solutions, it should prove quite useful to develop an appropriate taxonomy.

DICTIONARY DEFINITIONS AND WRINKLE TAXONOMY

We bring our everyday language with us wherever we go, including work; so it is not surprising that many terms regarding wrinkled and buckled webs come straight from Standard English.

Wrinkle, definition: A small furrow, ridge, or crease on a normally smooth surface, caused by crumpling, folding, or shrinking.[1] Middle English, back-formation from wrinkled, wrinkled, probably from Old English gewrinclod, past participle of gewrinclian, to wind, crease.[1]

Buckling, definition: An instance of bending, warping, or crumpling; a bend or bulge.[1] Bending of a sheet, plate, or column supporting a compressive load.[2] Latin bucca, mouth or cheek.[1] Bucca begets buckle as the attaching mechanism for helmet straps that includes bending the strap through the metal buckle.

A TWENTY-YEAR HISTORY OF WRINKLE TAXONOMY

In the landmark paper "Prediction of Shear Wrinkles in Web Span," Gehlbach, Good, and Kedl[3] set out to define and understand the most pervasive wrinkle cause – misaligned rollers. The definitions from this paper were repeated at the first IWEB in 1991 where Gopal and Kedl state:

> *"…we will define at wrinkles as a permanent out-of-plane deformation in the web going over a roller, and a trough as an out-of-plane deformation in the web between rollers. Both wrinkles and troughs are formed when the web undergoes a net decrease in width dimension. This will occur when a compressive principal stress is introduced into the cross-web direction by a combination of tension and shear. Wrinkles created under this loading are called shear wrinkles"*[4]

This was an excellent contribution to the taxonomy of wrinkles, one I have used as a foundation of my approach, especially dividing troughs from wrinkles.

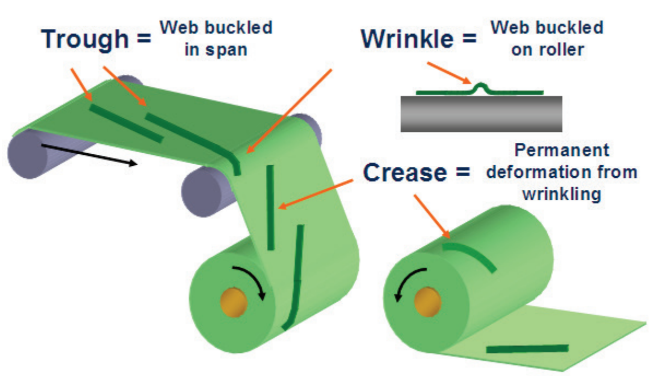

Figure 1 – Troughs, Wrinkles, Creases Defined

In 1993, the Second International Conference on Web Handling (IWEB) contained three papers that extended the taxonomy of wrinkling:

First, Dr. John Shelton enters with “Buckling of Webs from Lateral Compressive Forces,” providing some additional terminology.

> *“Uniform waves across a tensioned free span or across the surface of a wound roll of a thin web have been a mystery for many decades. Free span waves have been described as “troughs” or “fluting” while waves across a wound roll have been called “corrugations,” “ridges,” and “bands.” The term “corrugations” is appropriate for either case, in light of their similarity to sheets of old-fashioned corrugated metal…”*[5]

This opens up the field of wrinkle taxonomy beyond spans and roller to include buckled web in winding or wound rolls.

Second from Finland, “Web Tension and Wrinkles in the Printing Press” by Linna, Moilanen, and Parola where the wrinkling phenomenom (sic) was described as:

> *“The wrinkling phenomenom in the printing press can be seen as cockling of paper in the machine direction of the web.”*[6]

Completing the trifecta of 1993 wrinkle papers were Benson, Chiu, LaFleche, and Stack with “Simulation of Wrinkling Patterns in Webs Due to Non-Uniform Transport Conditions” seeking to define out-of-plane patterns in web spans immediately upstream of nipped rollers.

> *“…two commonly observed wrinkling patterns colloquially called “rivers” and “lakes”…three wrinkling patterns are of the “rivers”, “lakes”, and shear-induced type.”*[7]

The three wrinkle patterns of rivers, lakes, and shear-induced were created from downstream tension variations where tension was either high in the center, low in the center, or high-low across the width, respectively. In their paper, these tension variations were implied to be created by nipped rollers at the end of a span. Without reviewing the complex interaction of webs and nipped rollers, there are cases when a nip can create all three of these downstream tension profiles.

In only three years, the list of terms to describe buckled webs includes: *wrinkles, troughs, waves, fluting, corrugations, ridges, bands, cockling, rivers, lakes, and shear wrinkles.*

IWEB Year	Wrinkles Papers	Spreading Papers	Buckling in Rolls
1991	1	-	-
1993	3	3	-
1995	1	-	-
1997	3	2	2
1999	1	-	-
2001	2	-	-
2003	2	-	-
2005	4	1	1
2007	0	2	-
2009	4 (scheduled)	-	-
Total	21 / 300 (7%)	8 / 300 (<3%)	3/300 (1%)

Table 1 – IWEB Wrinkling, Spreading, and Buckling Papers

In 1997, McDonald and Menard discuss the crepe wrinkles, a defect unique to paper roll winding.

> *"Crepe wrinkles are created during reeling and winding of paper rolls against a rolling drum. These defects are associated with interlayer movement of paper within the body of the roll."* [8]

Looking at all the papers of all the IWEB conferences through 2007, barely ten percent of the papers address web wrinkles, roll buckles, or the associated topic of spreading. In all, 33 IWEB papers have addressed wrinkling (see Table 1), many that help describe the details of shear wrinkles (with regimes and cases based tension and traction conditions), a couple that advance the understanding of twisting-induced wrinkles. Perhaps due to the limited number of papers and diverse authors, the terminology and breadth of wrinkle-related IWEB papers seems small in contrast to the magnitude of the problem within industry.

Moving beyond the IWEB proceedings, some of the more recent published work on web handling with references to wrinkling terminology include:

In 2002, William Hawkins[9] describe two wrinkle defects, both related to wound rolls, using MD wrinkles interchangeably with tin canning and TD wrinkles for all wrinkles oriented transversely.

In 2002, I presented my first effort at wrinkle taxonomy in my TAPPI PLACE presentation "Web Wrinkles: Diagnosis and Remedies." [10] Having learned much of my wrinkle terminology from the early shear wrinkle work of Good and Kedl, a wrinkle was a web handling defect, not a wound roll defect, and was differentiated from troughing as a buckled web on a roller (where troughs are buckles in spans).

Though shear wrinkles were the stars of wrinkling research and roller alignment was the top suspect, I had encountered enough other wrinkling (buckled web on rollers) that were neither shear wrinkles nor caused by roller misalignment that there seemed a place for an expanded set of terminology. As with most taxonomy, the motive was to rid the converting industry of these undesired defects and roller alignment alone was not going to be enough. Like taxonomy of household pests, the goal of taxonomy was to divide wrinkles by cause in expectation that at least some remedies would be cause specific.

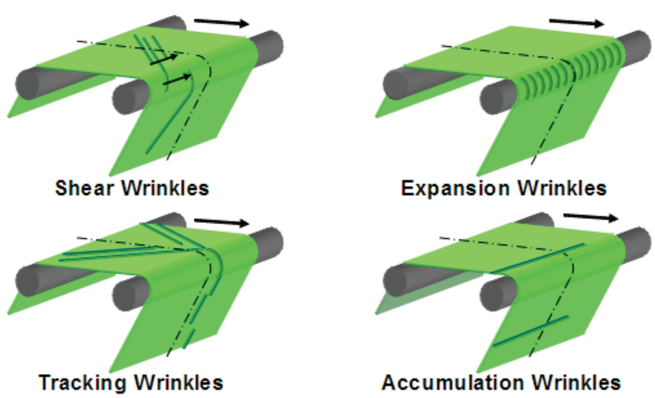

Figure 2 – Four Wrinkle Mechanisms

Wrinkles were divided first into the general direction of the creases (machined vs. transverse direction) then the machine direction wrinkles were divided again into three groups for a total of four wrinkle categories: shear wrinkles, tracking wrinkles, expansion wrinkles, and feed variation wrinkles (later called accumulation wrinkles). At this point, buckling in spans was considered only an online inspection nuisance and buckling in wound rolls deferred to a consideration of winding, not web handling.

Dr. David Roisum, author of many books on web handling, presents broader discussion of wrinkles in a full chapter in the TAPPI Roll and Web Defect Terminology 2nd Edition. Dr. Roisum takes on roll and web wrinkling in Chapter Four.

> *"A web is wrinkled when it is not as flat as a sheet of glass...A troubleshooter can read shadows in the web. If the root cause gets a little stronger...can push the shadow to become a crease or foldover."* [11]

The chapter goes on to describe the fourteen types of wrinkles, including:

- In-roll Wrinkles: *Buckles, crepe wrinkles, and tin canning* (which is grouped with uniformly spaced MD wrinkles)
- Roll Surface Wrinkles: *Cockle and moisture welts*
- Web Wrinkles: *MD wrinkles* both *uniformly* and *non-uniformly spaced*, *diagonal shear wrinkles* both *symmetric* and *asymmetric*, *TD wrinkles*, *hard wrinkles*, and *cutter wrinkles* (which is unique to sheeting, not web handling)
- Non-Flat Webs: *Baggy lanes, baggy patches*, and *curl*

Dr. Roisum makes good progress here in both expanding the range of wrinkle terms to include wound roll buckles and to create defining terms unique to their cause to aide in diagnosis and remedies of wrinkled or buckled webs. In the same book's Chapter One: Roll Defects - General, Dr. Roisum described buckled defects among other 'General' roll defects, including *crushed core, loose core, bad start, crushed roll, out-of-round roll, and knots in rolls*. In Chapter Two: Roll Defects – Web Profile, Dr. Roisum and Alan Hadlock describe additional roll buckling defects, including *gauge bands, corrugations, ridges* (for both paper and film), *tin canning*, and *starred rolls*. [12,13]

WHEN IS A WRINKLE A WRINKLE?

In web as in cloth, the term wrinkles is typically reserved for 'ironed in' deformation. In clothing, intentional wrinkles are called creases and undesired folded deformation marks are called wrinkles. In web handling, the tradition has been that all folded deformations are undesired and are referred to as creases or wrinkles, sometimes with the modifier 'hard' creases or wrinkles.

If you are viewing a sheet sample of a web, the out-of-plane shape of the web can be separated into buckling and non-flatness. In most references, mere non-flatness has not been grouped with buckled or wrinkled defects. Non-flat defects such as curled, rippled, skewed, and baggy webs are out-of-plane and could be considered buckled under compressive stresses. In their initial onset, these defects can be temporarily remedied with strain of nominal web tension. Separating the defects of curl, skew, and bagginess is not intended to play down their severity; only to divide them into a defect classification of their own distinct from wrinkles, just as the waves or tailoring of a shirt as it hangs loosely are different from wrinkles.

If a supplier sends you a roll of wrinkled product, there isn't much you can do to remedy the problem, but you can begin the process to identify the source by describing the buckling defect. Considering a sheet sample, the most common sorting of wrinkles is by direction of the crease line into three categories: machine direction (MD), transverse direction (TD), and angled (usually an angle of more than 5 degrees off cardinal headings of MD and TD). These categories are useful in describing wrinkles created from an upstream source, but do not provide enough information to identify the source or eliminate a wrinkle.

Sorting wrinkles by crease angle at the end of the process or while observing a wound or unwinding roll may provide some insight about their likely cause, but it's like figuring out how the horse got out of the barn by observing the escaped horse. You might notice if the horse has a saddle or if the reigns are broken, but it will fairly difficult to diagnose how the horse escaped from its rider, corral, or barn. As with escaping horses, so too wrinkles, the best diagnosis will be at the scene of the crime or better, yet, while the crime is underway. Wrinkle diagnosis is best completed through observing wrinkles as they first form.

WHERE DO WEBS BUCKLE?

Wrinkles and buckled web defects can form in five scenarios: in a span, on a roller, at the surface of winding roll, within the winding roll, and within a roll during transport, storage, or unwinding. In seeking out the source event of wrinkles, there are two approaches, either progressing from the beginning of the process to the end or working from the first viewed wrinkle and moving upstream. Since roll-to-roll processing often includes passes through multiple processes, a final product with wrinkles could find its cause anywhere upstream. Working with suppliers of roll goods, the first step will be to determine if the wrinkles are forming in the end use process, in shipping, transport, and storage, or in the supplier's process. *(Note: This taxonomist adheres to the roller vs. roll convention, reserving the short term roll for a wound package of web and roller for the driven or idling elements used to transport the web.)*

<u>Unwinding, Roll Transport, Storage</u>

The web buckle is created within the roll in transport, shipping or unwinding if the product appears unbuckled at winding, but buckled at unwinding, the buckling must be forming within the roll during winding, transport, storage, or unwinding.

If you have access to the previous process that supplied your unwinding rolls, you can learn much more. First, try to determine if the web was wrinkled entering the winder of the last process or if the wrinkles are forming within the wound roll after entering the winding roll, during transport, during storage, or at unwinding. There are a limited number of causes that will wrinkle a web within a winding or wound roll, but most will only buckle the web, but will not fold or crease the web.

Many wound roll defects develop over time due to the dynamic of thermal or moisture changes, material relaxation or viscoelasticity, entrained air escape, or changes in the core. Rolls can also be damaged by the shocks and inertias of handling.

Tin-canning and cross-web corrugations are both buckled web defects that can form after winding, but neither is known to form hard angled creases. Crepe wrinkles and cinching-related foldovers are both defects that could be consider accumulation wrinkles (TD wrinkles) with a winding or unwinding roll. Expansion from moisture or temperature welts may create buckled and possible creased web in the outer layers of a roll.

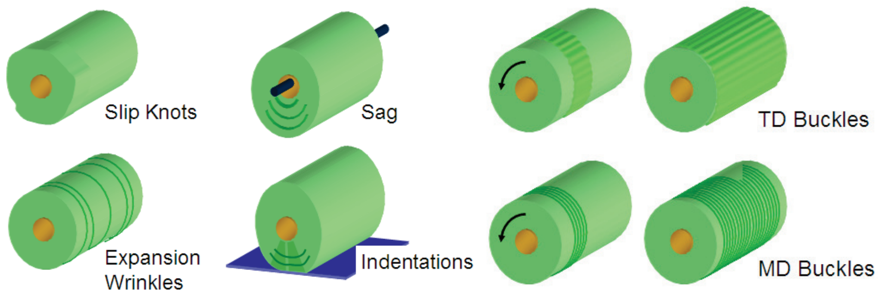

Figure 3 – Buckled Defects in Rolls

Within the Winding Roll

The web buckle is created within the winding roll if the roll is carefully removed from the winder, gently unwound with little tensioning or inertia torques, and the wrinkles are found in the web as it unwind without any significant transport or storage time.

Layers near the core will buckle and crease if the core they are wound upon collapses from pressure beyond its buckling criterion. Even if the core remains unbuckled, softly wound layers near the core may buckle and crease from high pressure of winding rolls with large buildup ratios. Rapid deceleration may drive the outer layers past the inner layers creating machine direction foldovers at any major slip interface.

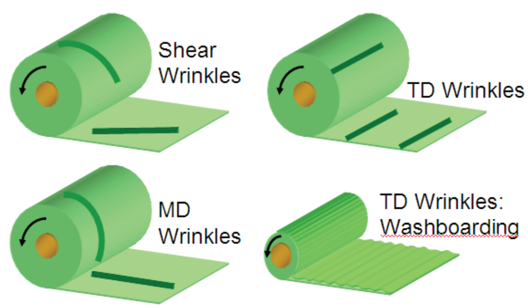

Figure 4 –More Buckled Defects in Rolls

At the Winding Roll's Surface

The web buckle is created at the outside of the winding roll if the web is buckled and wrinkle-free on the last roller before winding, then the buckling or wrinkle is forming at the contact with the winding roll and you are in the right position to observe and eliminate the defect.

A wound roll is a lousy roller. Most winding rolls have consistently poor levels of eccentricity, diameter variations, and misalignment that make even bad rollers look good. Leaving a winding roll in control of a long entry span is a recipe for wrinkles. Though many turret winders have optimized geometry in their winding position (either nipped or gapped winding), they commonly lose their ideal geometry during the index cycle as the nearly finished roll rotates to the unloading position.

On a Roller

The web buckle is created on a roller if the web appears smooth under all the conditions above and the buckles are hard creases in the web (though some softer webs may form wrinkles on rollers without forming hard creases). It is difficult if not impossible to crease a web in a span (except in extreme curling or gathering).

Most causes of wrinkles are not within the wound roll, but happen either at the point of winding or anywhere upstream of winding. The ideal place to observe and categorize wrinkles is at the point of origin, namely the rollers and spans in the immediate area where the web first travels over a roller in a buckled form (or onto the winding roll). If the wrinkles and creases are observed at their onset, there are three areas to help classify wrinkle species: trough (shape and angle), wrinkle (position and motion), and crease (geometry, both angle and length, and frequency).

In a Span

The web buckle is created in a span if the buckled web must be forming in the span between rollers if it always appears smooth on every roller and all of the above conditions.

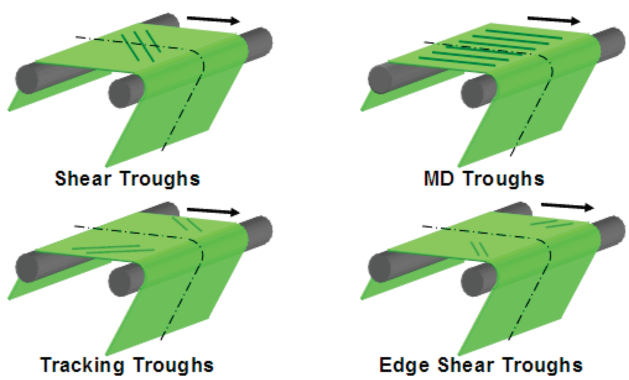

Figure 5 – Buckled Web in Spans

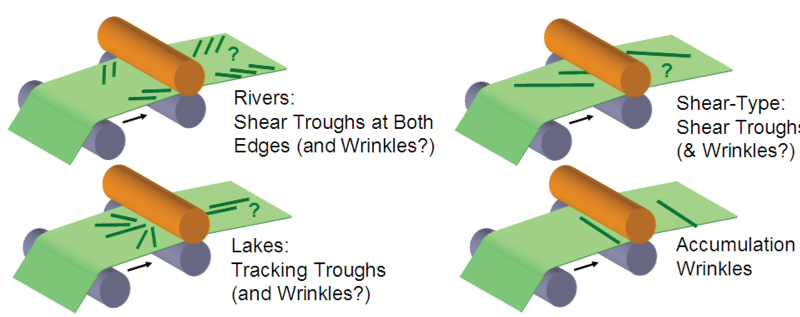

Figure 6 – Buckled Web in Spans near Nips

A PROPOSED TAXONOMY OF WRINKLED AND BUCKLED WEBS

Buckled Web Between Rollers (Troughing)

Troughing: The web is out of plane in the span between rollers.

Root Causes and Mechanisms: Troughs are omnipresent. The mechanisms for shear and tracking wrinkles will create troughs before and after they reach the severity to maintain a buckled web on the roller.

Web is bending left or right (see mechanisms of shear wrinkles below).

Two sides of the web are tracking towards each other (see mechanisms of tracking wrinkles below).

Buckled Web on Rollers (Wrinkling)

Shear Wrinkles: The web is buckled in the crossweb (transverse) direction on a roller or as it enters a winding roll (wrinkling) due to lateral bending in the upstream span. Shear wrinkles are always accompanied by angled troughs in the upstream span and form wrinkles that appear to walk across the roller, often forming angled creases in the web.

Shear Wrinkle Mechanisms and Root Causes: All shear wrinkles have three pre-requisites:

1. A mechanism that bends the web laterally.
   Sufficient friction to bend the web laterally.
   Sufficient friction to hold the web in a buckled form while on the roller.

The common causes of web bending that lead to wrinkles are:

- Roller misalignment
  - Transition from station-to-station
  - Uneven thermal expansion
  - Most common misalignment problems
  - Pivoting and indexing rollers (dancers, nips, turret winders)
  - Linear sliding rollers (e.g. linear dancers, accumulators)
  - Adjustable rollers
  - Cantilevered rollers (esp. with large wrap angles)
  - Steering rollers (span too short)
  - Pedaling unwinding and winding rollsTapered roller diameter with good traction or poor traction
- Asymmetric roller or roll diameter variations
  - Wear of rubber rollers, especially high load nip rollers
  - Winding roll with low-high crossweb thickness profile of web, coating, or bubble in laminate
  - Winding roll building asymmetrically due to crossweb bagginess variation
  - Winding over a buckle from offset start of thick web
  - Improper initial machining
- Short term lateral shifts in the web, either step or sinusoidal shifting
  - Shifted layers in unwinding rolls
  - High frequency oscillation of poorly tuned web guide
  - Web shift from sudden transition in tracking, alignment, splice, or nipping.
- Uneven nip loading

- Misalignment of nipping rollers
- TD web thickness
- Uneven loading mechanism due to unequal air supply or air / pneumatic cylinder friction or hysteresis
- Side-to-side differences in nip stop blocks or gap controllers

♦ Uneven wear or Durometer variations of rubber rollers

♦ Uneven tension from differential peeling off upstream roller or unwinding roll.

♦ Uneven forces pushing laterally on the web.

Tracking (MD) Wrinkles: The web is buckling in the crossweb (transverse) direction forming creases in the machine direction on a roller or as it enters a winding roll (wrinkling) due to a tracking mechanism where two sides of the web track towards each other. Tracking wrinkles are characterized by symmetric angled creases in the upstream span and wrinkles that form in a single position on a roller (though that position may be transient or wandering depending on the tracking mechanism and web-roller traction). Crease from tracking wrinkles tend to be machine direction.

Tracking Wrinkle (MD) Mechanisms: All tracking wrinkles have three pre-requisites:

1. A mechanism that bends the two sides of the web towards each other.
   Sufficient friction to bend the web laterally.
   Sufficient friction to hold the web in a buckled form while on the roller.

The common causes of tracking that lead to wrinkles are:

♦ A convex roller profile with good traction, especially intentionally crowned roller used to compensate for nipping roller deflection.

♦ A concave roller profile with poor traction.

♦ A bow or deflection in the direction of the incoming web due to: gravity, tension, nip loads, or incorrect orientation of a bowed roller.

♦ Web expanding in the span upstream of a roller due to: temperature increase, moisture absorption, viscoelastic recovery after tension decrease.

♦ Baggy center web in long spans.

♦ Excessive twisting in a span.

On-Roller Expansion Wrinkles: The web is buckled in the crossweb (transverse) direction on a roller due to width-wise web expansion while in contact with the roller (or by width-wise contract of the roller surface).

On-Roller Expansion Wrinkle Mechanisms: All tracking wrinkles have two pre-requisites:

1. A mechanism expands the web width while in contact with a roller.
2. Sufficient friction to hold the web in a buckled form while on the roller.

The common causes of on-roller expansion that lead to wrinkles are:

♦ Tension change on a driven or clutched roller from high to low tension

♦ Moisturizing paper (and other materials with high coefficient of hygroscopic expansion)

♦ Heating films and foils (and other materials with high coefficient of thermal expansion)

Accumulation Wrinkles: All or a portion of the width of the web is under machine direction compression and buckling as it passes over a roller, through a nip point, or enters a winding roll.

Accumulation Wrinkle Mechanisms: The top causes of accumulation wrinkles are:

- Baggy webs and nipped rollers
- Overfed nips in calendar stacks, nipped rollers with large pre-nip wraps, and surface winders
- Delamination of laminates ahead of rollers (especially small diameter rollers)
- Laminate air bubble tunneling / accumulation
- Air bubbles in nipped winding
- Nip-induced compression at unwinding

Buckled Web in Roll (Buckles)

TD Buckles in Rolls: Transverse direction buckling is created by machine direction compressive stresses (a.k.a circumferential or hoop stresses) have exceeded the buckling criteria of the layers within a wound roll. TD buckles may be throughout a roll, but more commonly occur in a particular region (e.g. near the core, on one side, between gauge bands).

TD buckling defects have many names, including core buckles, starring, spoking, corrugations, crossbuckles, softbands, gapping, and peaking.

TD buckles occurring near the core radiate in small or large triangular patterns and are usually called starring or spoking defects. Starring is a paper industry term, where the buckled layers in rolls of thicker papers may form 2 to 5 large triangular shaped patterns that may radiate 2 to 20-inches from the core. Spoking is a film industry term, where the buckled layers in rolls of thinner films will form 10 to 50 narrow spike-like patterns that usually only radiate 0.25 to 1-inche from the core

.

TD Buckle Mechanisms: The top causes of TD buckles are:

- Cross-buckles and softbands: TD buckles that form in the wound roll where lanes of below average thickness web or coating wind in the same lateral position for many layers. The layers in the thin lanes are unsupported and fall towards the core, relieving their hoop tension, and with enough radial change, go into hoop compression and buckling.
- Starring and spoking: TD buckles occurring near the core radiate in small or large triangular patterns and are usually called starring or spoking defects. Starring/spoking form under the combination of a) a core with less stiffness than the layers near the core and b) high pressure compressing the core changing its radius by more than the strain in the web.
- Starring is a paper industry term, where the buckled layers in rolls of thicker papers may form 2 to 5 large triangular shaped patterns that may radiate 2 to 20-inches from the core.
- Spoking is a film industry term, where the buckled layers in rolls of thinner films will for 10 to 50 narrow spike-like patterns that usually only radiate 0.25 to 1-inche from the core.
- Soft start buckles: Viewed from the side or upon unwinding a roll, buckled layers are found near, but not immediately at the core. Where starring and spoking are due to core compression, soft start buckles are caused when the

initial layers of a winding roll have low tension, wrinkles, or misalignment buckles and are subsequently compressed by the pressure of the wound roll.

- Softbands and crossbuckles: Buckles in low thickness bands (soft bands), across the full width of the roll, or in the most dramatic case, the entire roll sags into an eggs shape.
- Peaking, gapping, and delamination (specific to pressure sensitive adhesive products): When adhesive layers shrink in the thickness direction by post-wind drying or lateral viscous flow, layers or the full roll may shift from hoop tension to hoop compression. In linered PSA products, this may create defects similar to starring, spoking, softbands, and crossbuckles, but it may also cause delamination within the roll. In self-wound PSA products, since the layers are bonded together with adhesion, extreme loss of tension will not lead to sagging or egg-shaped rolls, instead forming buckling throughout the roll. In narrow rolls, the in-roll delamination may traverse the entire width of the roll creating a defect called gapping or tunneling. If the high compressive hoop stresses are throughout the entire roll, the exterior of the roll may lose it roundness, forming buckled ridges (referred to as peaking or gearing).
- Core collapse, core crushing: When the pressure on the core exceeds its buckling strength, the core buckles and the layers of the roll follow.

MD Buckles in Rolls: Machine direction buckles form from transverse direction compressive stresses have exceeded the buckling criteria of the layers within a wound roll, often called MD lines or tin-canning. MD buckles may be throughout a roll, but more commonly occur in a particular region (e.g. near the core, on one side, between gauge bands).

MD Buckle Mechanisms: The top causes of MD buckles are:

- TD hygroscopic expansion of the outer layers of roll wound at low humidity, absorbing moisture in the outer layers from a humid environment.
- TD thermal expansion of the outer layers of roll wound at low temperature, then exposed to elevated temperatures.
- TD width growth from recovering necked width as layers change there high wound-on tension to their lower (or compressive) in-roll tension. The tension loss and width recovery is driven by compression of the inner layers of a roll by the pressure of the outer layers or from any mechanism that causes a roll's layers to lose thickness over time, including entrained air escaping, coating drying, adhesive layers flowing laterally, paper core drying, and surface asperities relaxing. (This defect is most common in thin film winding, especially thin films coated with hard coatings.) Note: MD tin-canning wrinkles have a predictable wavelength as a function of product thickness and roll diameter which should differentiate them from frozen-in troughs, which shouldn't change wavelength vs. roll diameter).

Slip Knot Buckles in Rolls: Slip knots are buckled regions of a winding roll where the shear between sticking and slipping contact buckles the web. Slip knots are usually found in the outer layers of winding optically clear films with pressure-dependent coefficient of friction between the top and bottom sides of the web. Slip knots may starts dark spots that look like the layers have a 'wetted' contact. In the extreme condition, as additional layers are wound on, small slip knots may grow like a snowball forming into large odd-shaped buckles

Slip Knot Buckles Mechanisms: The top causes of slip knot buckles are:

- ♦ Non-uniform pressure in the topmost layer of a winding roll combined with pressure-dependent coefficient of friction cause the entering web layer to stick in some areas and slide in neighboring area, creating a local shear stress and subtle buckling.
- ♦ Layers wound on top of subtle slip knots have a slightly larger shears stress and buckled area, leading to viscous cycle where once initiated slip knots only magnify.
- ♦ Slip knots may originate from surface contamination where a particle as small as 4-mil (100 microns) create a high friction point as it acts as a tent pole under the top winding layer.

SUMMARY

The taxonomy in any field is never the work of one person but the accumulation and assimilation of the more useful terminology. This paper is not intended as chiseled in stone commandments, but as a continuation of the development of the taxonomy of this highly valuable sub-specialty of web handling and winding. Are troughs, wrinkles, creases, and buckles the best or only terms for compression-induced defects? No, but if they prove helpful in solving defects of wrinkled and buckled webs across companies, commercial partners, academia, and industries, then the goal of this paper has been accomplished. We need taxonomy to advance the science and engineering of web handling.

"…what we cannot talk about we must pass over in silence," Ludwig Wittgenstein, Tractatus Logico-Philosophicus

REFERENCES

1. American Heritage Dictionary of the English Language, Fourth Edition. Boston: Houghton Mifflin Company, 2000.
2. Buckling, McGraw-Hill Dictionary of Scientific and Technical Terms. McGraw-Hill Companies, Inc., 2003. Answers.com 22 May 2009, http://www.answers.com/topic/buckling.
3. Gehlbach, L.S., Good, J.K., and Kedl, D.M., "Prediction of Shear Wrinkles in Web Span," TAPPI Journal, Vol. 72, No. 8, August 1989.
4. Gopal, H. and Kedl, D. M., "Using Finite Element Model to Define How Wrinkles in a Single Web Span without Moment Transfer," Proceeding of the First International Conference on Web Handling, Stillwater, OK, 1991, p. 291.
5. Shelton, J.J., "Buckling of Webs from Lateral Compressive Forces," Proceeding of the Second International Conference on Web Handling, Stillwater, OK, 1993, p. 304.
6. Linna, H., Moilanen, P., and Parola, M., "Web Tension and Wrinkles in the Printing Press," Proceeding of the Second International Conference on Web Handling, Stillwater, OK, 1993, p. 326.
7. Benson, R.C., Chiu, H.C., LaFleche, J., and Stack, K.D., "Simulation of Wrinkling Patterns in Webs Due to Non-Uniform Transport Conditions," Proceeding of the Second International Conference on Web Handling, Stillwater, OK, 1993, p. 334.

8. McDonald, J.D., and Menard, A., "Layer-to-Layer Slippage within Paper Rolls during Winding," Proceeding of the Second International Conference on Web Handling, Stillwater, OK, 1997, p. 12.
9. Hawkins, W. E., The Plastic Film and Foil Web Handling Guide, CRC Press, Boca Raton, Florida, 2002.
10. Walker, T. J., "Web Wrinkles: Diagnosis and Remedies," Proceedings, TAPPI PLACE Conference, Boston, MA, September 9-12, 2002, TAPPI PRESS, Atlanta.
11. Roisum, D. R., Roll and Web Defect Terminology, Chapter 4, Roll and Web Defects – Wrinkles, TAPPI PRESS, Atlanta 2007.
12. Roisum, D. R., Roll and Web Defect Terminology, Chapter 1, Roll Defects – General, TAPPI PRESS, Atlanta 2007.
13. Roisum, D. R. and Hadlock, A., Roll and Web Defect Terminology, Chapter 2, Roll Defects – Web Profile, TAPPI PRESS, Atlanta 2007.

The Taxonomy of Wrinkles **T. J. Walker,** T. J. Walker & Associates, Inc., USA

Name & Affiliation	**Question**
Steve Lange, Procter & Gamble	I only remember a couple of things from biology in high school. But since you brought taxonomy, the pneumonic my biology teacher said for remembering kingdom, phylum, class, order, family, genus, and species, was Keep People Clean and Odor Free, Get Soap. If you want to do taxonomy, there are some analogous classifications that need to be brought up. You might want to think about what are the files, what are the classes, so that you can break these down.
Name & Affiliation	**Answer**
Tim Walker, T. J. Walker & Associates	That is the standard taxonomy that is used in biology. I think there are others out there.
Name & Affiliation	**Comment**
Steve Lange, Procter & Gamble	The patent system has to classify a lot of different areas of technology and understanding. The library science people spend their lives doing this kind of thing. Before you argue about the terms, we should agree on the structure on how you are going to break it down.
Name & Affiliation	**Comment**
Dilwyn Jones, Emral Ltd.	Just an observation, you were talking about naming wrinkles after people. Tim, I think you have your own. You have wrinkles which are walkers across the roll.