Challenges in Winding Flexible Packaging Film

By R. Duane Smith
Product Manager- Specialty Winding
Davis Standard LLC
Fulton, New York, USA

Abstract

Every flexible film producer is faced with the challenge of producing quality rolls of film products. Since no film is perfectly uniform across its width, rolls of film must be wound so that these slight imperfections do not stand out in appearance and are not amplified during the winding process.

This paper addresses the importance of roll hardness and the proper profiling of roll hardness for consistently producing good quality rolls of flexible packaging films. It then discusses the winding principles used on all winders to control in-wound tension or roll hardness. Rules of thumb are given to help determine the proper amount of web tension for various types of films. Then the principles of nip and gap winding using controlled torque to produce the desired roll hardness are explained. After the discussion of how roll hardness is achieved, methods of roll hardness measurement are presented. Causes and remedies for many defects due to roll hardness are addressed. Information on the new reference book *The Ultimate Roll and Web Defect Troubleshooting Guide* is presented to further assist in consistently producing quality flexible packaging films.

Introduction

If all film webs were perfect, then the ability to produce perfect rolls of film products would not be much of a challenge. Unfortunately, due to the natural variation in resins, non-uniformities of the film formation processes, coatings and printed surfaces, there is no such animal as a perfect film. The winding operation's challenge is to wind film webs with slight imperfections being sure that these do not stand out in appearance and are not amplified during the winding process. Then, it is the responsibility of the winder operator to make sure that the winding process does not produce additional variations in the product quality. The ultimate challenge is to wind flexible packaging film that will run on a customer's process without problems and produce high quality products for their customers.

Importance of Roll Hardness[1]

Roll density, or in-wound tension, is the most important factor in determining the difference between good quality and poor quality rolls of film products. Rolls that are wound too soft will go 'out-of-round' while winding or while being handled or stored. The roundness of rolls is very important in a customer's operation to enable processing these rolls at maximum production speeds with minimal tension variations.

Rolls that are wound too tight will also cause problems. Tightly wound rolls of films can have blocking defect problems where the sheet layers fuse or adhere together. When winding extensible film on thin wall cores, winding hard rolls can cause the cores to collapse. This can cause problems in removing the shaft, or with inserting the shaft or chucks on the subsequent unwinding operation.

Rolls that are wound too tightly will exaggerate web defects. Typically, films will have slight high and low areas in the cross machine profile where the web is thicker or thinner. When winding hard rolls, the high caliper areas build on each other. As hundreds, even thousands of layers are wound; the high areas form ridges, or high spots, in the roll. As the film is stretched over these ridges, it is deformed. Then, when the roll is unwound, these areas produce a defect known as "bagginess" in the film. Hard rolls that have high gauge bands next to low gauge bands will produce a roll defect known as corrugations, or rope marks, in the rolls.

Slight variations in thickness will not be noticeable in a wound roll if sufficient air is wound into the roll in the low areas and the web is not stretched over the high areas. Still, the rolls must be wound hard enough that so they will be round and will stay that way during handling and storage.

Randomization of Cross Machine Variations

Some flexible packaging films, either by their extrusion formation process or by their coating and laminating process, have cross machine variations of thickness too severe to be wound without exaggerating these defects. To randomize cross machine variations in the wound rolls either the web or the slitters and winder are moved back and forth relative to the web as they are being slit and wound. This cross machine movement is called oscillation. For successful oscillation the speed must be fast enough to randomize thickness variations and slow enough that it does not strain or wrinkle the film. The rule of thumb for the maximum oscillation speed is 25mm (~1") per minute per 150 mpm (500 fpm) winding speed. Ideally the oscillation speed varies proportional to the winding speed.

Profiling Roll Hardness

As a roll of flexible packaging film material winds, in-wound tension or residual stresses build inside the roll. If this stress becomes greater during winding, the inner wraps towards the core will be put under high compressive loads. This is what causes a defect known as 'buckling' of the webs in localized areas in the roll. When winding non-elastic and high slip films, the inner layers will loosen; which can cause the roll to dish while winding or telescope when unwinding. To prevent this, the rolls want to be wound tight at the core and then wound with less tightness as the roll builds in diameter. This is commonly referred to as Roll Hardness Taper. The larger the finished wound roll's diameter, the more critical the roll hardness tapering profile becomes. The secret to building a good roll hardness structure is to start out with a good solid foundation and then to wind with progressively less in-wound tension.

The good solid foundation requires starting the winding operation on a high quality, properly stored core. Most rolls of film materials are wound on paper cores. The paper cores must be of sufficient strength that they can withstand the in-wound compressive tension caused by the film being wound tightly on the core. Typically paper cores are kiln dried to between 6-8% moisture. If these cores are stored in a high moisture environment, they will absorb this moisture and swell to a larger diameter. Then, after the winding operation, these cores can dry to a lower moisture level and will shrink in size. When this happens, the solid wound roll's foundation will be lost! This causes these rolls to have defects such as buckling, staring and/or telescoping when they are handled or unwound.

The next step in obtaining this required good winding foundation is to start winding with as much roll hardness as possible. Then, as the rolls of film material are wound, the roll hardness needs to be uniformly decreased. The suggested decrease in roll hardness at the finished diameter is generally between 25% and 50% of the starting hardness measured at the core.

The amount of starting roll hardness and the amount of taper of in-wound tension is generally a function of the Build-up Ratio of the wound roll. The Build-up Ratio is the ratio of the core's Outside Diameter (O.D.) and the wound roll's finished diameter. The larger the roll's final wound diameter (the taller the structure) the more important starting on a good solid foundation and winding a progressively softer roll becomes!

Table #1 gives a ***Rule of Thumb*** for the suggested amount of hardness taper based on the Build-up Ratio.

Rule of Thumb **for suggested amount of Wound Roll Hardness Taper**

- **25% on 3-5 to 1 Build-up ratio***
- **33% on 6-8 to 1 Build-up ratio***
- **50% on 9-12 to 1 Build-up ratio***

***Build-up ratio is Wound Roll Dia./ Core O.D.**

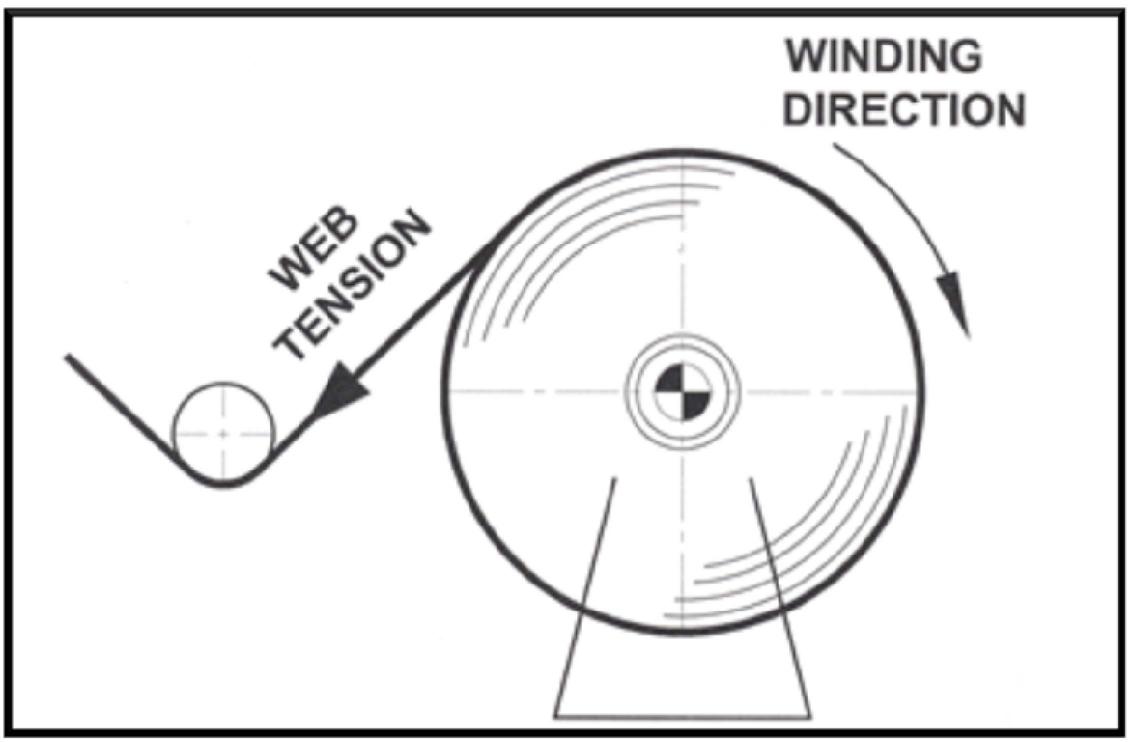
Table #1

How to Achieve Roll Hardness

The winding tools to develop roll hardness are Web **T**ension, **N**ip Pressure from a pressure or lay-on roll or winding drum and Winding **T**orque from a center drive when

Center/Surface winding film webs[2]. The following describes how each of these tools are used to develop hardness in rolls of film materials. Also ***Rules of Thumb*** for starting values to produce the required roll hardness of different flexible packaging materials.

<u>Web Tension Principle of Winding</u> - When winding elastic films, web tension is the dominant principle of winding used to control roll hardness. The more the film is stretched before winding, the harder the wound rolls will be. The challenge is to be sure that the amount of web tension does not induce significant permanent stresses in the film. When winding film on a pure center winder as shown in Figure #1, the Web **Te**nsion is produced by the Winding **T**orque from a center drive. Therefore, with center film winders Web **Te**nsion and Winding **T**orque are the same roll hardness principle. The web tension is set for the desired roll hardness at the start and then tapered as the film winds. The web's winding tension produced from the center drive is typically closed looped controlled with feedback by tension measuring transducers.



<u>Figure #1 - Tension Principle on a Center Winder</u>

The amount of starting and finishing web tension for a specific material often needs to be determined empirically. A good ***Rule of Thumb*** for the range of web tension is between 10% and 25% of the film's elastic limit. Many published papers suggest amounts of web tension to be used for specific web materials. Table #2 from the paper ***Guidelines for Web Conveyance and Winding Tensions for Polymer Films, Papers and Paperboard Webs***[3] lists suggested tensions for many web materials used in processing flexible packaging materials.

Films	Tension Range (Metric)	Tension Range (English)
Polyester	35 to 105 N/cm/mm	0.5 to 1.5 lbs/inch/mil
Polypropylene	14 to 35 N/cm/mm	0.2 to 0.5 lbs/inch/mil
BOPP	21 to 70 N/cm/mm	0.3 to 1.0 lbs/inch/mil
Polyethylene	7 to 21 N/cm/mm	0.1 to 0.3 lbs/inch/mil
Polystyrene	35 to 70 N/cm/mm	0.5 to 1.0 lbs/inch/mil
Vinyl (uncalendared)	3.5 to 14 N/cm/mm	0.05 to 0.2 lbs/inch/mil
Aluminum Foils	35 to 105 N/cm/mm	0.5 to 1.5 lbs/inch/mil
Cellophane	35 to 70 N/cm/mm	0.5 to 1.0 lbs/inch/mil
Nylon	7 to 21 N/cm/mm	0.1 to 0.3 lbs/inch/mil
Papers	25 to 40 N/cm/mm	0.35 to 0.5 lbs/inch/mil
Conversion: kg/cm/mm = Newton/cm/mm x 0.1		

Table 2

For winding on pure center winders, it is suggested that the starting tension be towards the higher value of the suggested tension range. Then smoothly taper the winding tension towards the lower suggested range given in this table.

When winding laminated web of several different materials, to obtain the suggested maximum web tensions for laminated structures, simply add the maximum web tensions for each of the materials that have been laminated together (usually disregarding any coatings or adhesives) and apply the sum of these tensions as the maximum web tension for the laminate.

The important tension consideration for laminating flexible film composites is that the individual webs need to be tensioned before they are laminated so that the strain (elongation of the web due to web tension) will be approximately equal for each web.
If one web is strained significantly more than the other web(s), curl problems or delamination wrinkling known as "tunneling" can occur in the laminated webs. The amount of tension should be a ratio of the modulus and the web thickness to prevent curl and/or tunneling after the lamination process.

Nip Principle of Winding– When winding inelastic films, **N**ip and **To**rque are the dominant principles of winding used to control roll hardness. The nip controls the roll hardness by removing the boundary layer of air following the web into the winding roll. The rolling nip also induces in-wound tension into the roll. The harder the nip, the harder the winding roll will be. The challenge for winding flexible packaging film is to have sufficient nip to remove the air and wind hard straight rolls without winding in too much in-wound tension in order to prevent causing roll blocking or deforming the web over the high caliper area.

The nip loading is less material dependent than web tension and will vary greatly on the material and the amount of roll hardness required. To prevent nip induced wrinkling of the winding film, the amount of nip is the minimum required to prevent air from winding into the roll. This nip is often held constant on center winders as *Mother Nature* provides the nip pressure taper with a constant nip loading force. As the rolls build larger in diameter, the footprint (area) of the nip between the winding roll and the pressure roll becomes greater. If the width of this footprint goes from a 6mm (1/4") at core to 12mm (1/2") at a full roll, then the winding nip pressure automatically tapers by 50%. Also, the amount of air following the roll's surface increases as the winder roll's diameter increases. This boundary layer of air increases the hydraulic pressure trying to open the nip. This increasing pressure adds nip loading tapering.as diameter builds. On wide, fast winders used to wind large diameter rolls, the nip loading may have to be increased as the roll winds to prevent air from winding into the roll.

Figure #2 shows a center film winder with an air loaded pressure roll which uses both the **T**ension and **N**ip tools to control the winding roll's hardness.

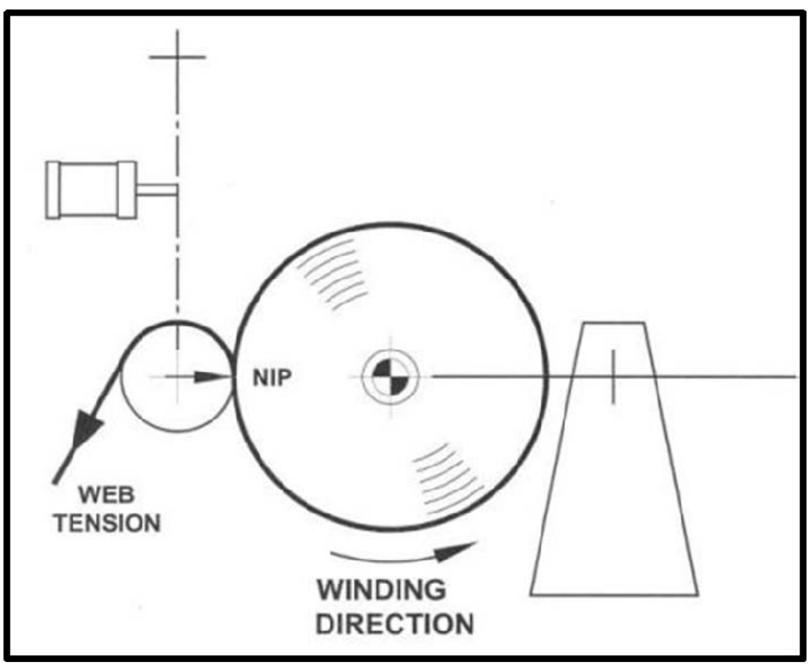
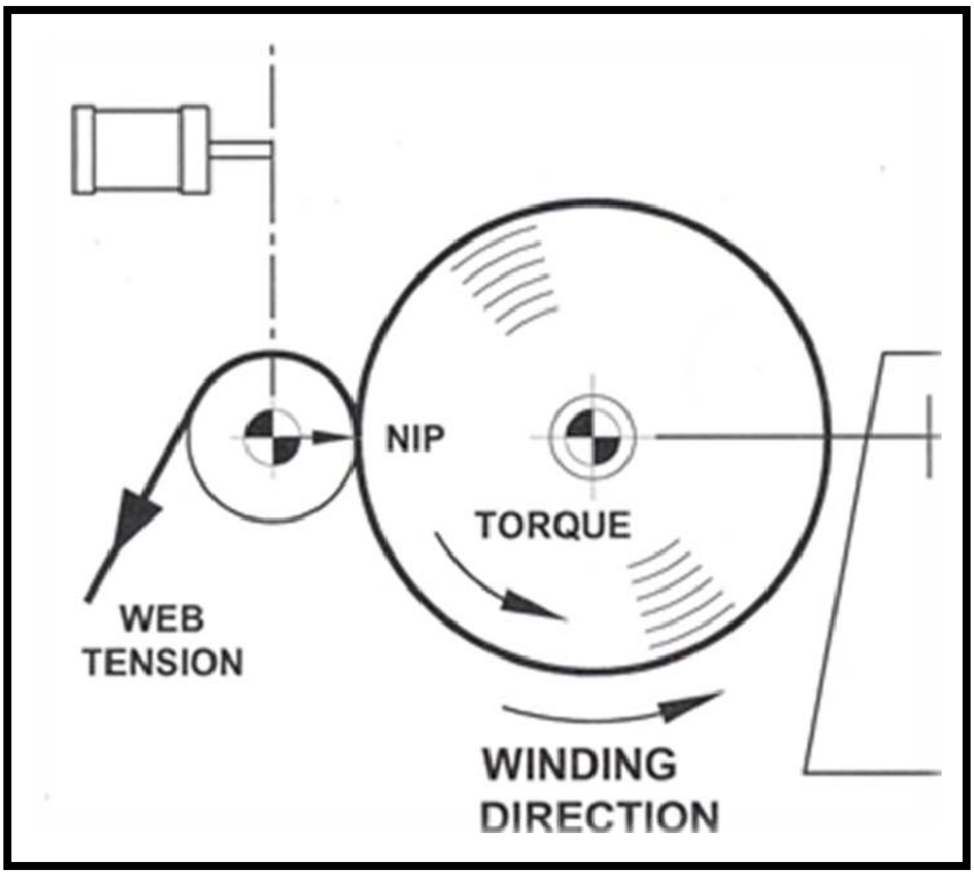


Figure #2 -: Tension & Nip Principles on a Center Turret Winder

Gap Winding– Sometimes air is our friend. Some films, especially "sticky" high coefficient films with uniformity problems need to be gap wound. Gap winding allows a small amount of air to be wound into the roll to prevent web blocking problems inside the rolls and to help prevent deforming webs that have high caliper band areas. To successfully gap wind these films, the winding operation needs to have the ability to maintain a small constant gap between the pressure roll and the winding material. This small controlled gap helps meter the air being wound into the roll and also directs the web squarely into the winding roll to help prevent wrinkling defects.

<u>Torque Winding Principle</u> - The **T**orque tool to obtain roll hardness is the force induced through the center of the winding roll. This force is transmitted through the web layers and cinches or tightens the inner wraps of film. As stated earlier, this **T**orque is used to produce the web tension on center winders. With these types of winders; web **T**ension and **T**orque are the same winding principle.

When winding film products on a center/surface type winder, the pressure roll is driven to control the web's tension as shown in Figure #3. The web Tension coming into the winder is independent from the winding tension produced from this Torque. The incoming web tension in normally held constant for a constant amount of strain in the web coming into the winder.



<u>Figure #3 – Center/Surface Winder with Driven Pressure Roll</u>

When winding film products on a center/surface type winder, the control of the winding tension is open loop controlled. Typically the winding tension starts at 25-50% greater than the incoming web tension. Then this winding tension is tapered as the roll builds in diameter to a value at or even less than the incoming web tension. The pressure roll's surface drive will regenerate or pull negative (braking) torque when the winding tension is greater than the incoming web tension. As the winding roll's diameter increases, the surface drive will gradually provide less braking until it reaches zero torque then winding tension equals web tension. If the winding tension is programmed to go below the incoming web tension, then the surface drive will pull positive torque to make up the difference between the lower winding tension and the higher web tension.

Center/surface winding should be used when slitting and winding films or other materials with large Poisson's Ratios which will change in width with changes in web tension. Center/surface winders keep the slit roll's width constant as constant web tension is brought to the winder. The roll's hardness is profiled from the center torque without producing neck-in width problems.

Film's Coefficient of Friction Properties Effect on Winding

The film's layer to layer coefficient of friction properties have a major effect on the ability to apply the **T.N.T.** principles to produce the desired roll hardness without roll defects.
In general, films which have a layer to layer coefficient of friction (COF) value of 0.2 to 0.7 will wind well. However, consistently winding defect free rolls of high slip or low slip (low COF or high COF) films usually presents major winding challenges

Low Coefficient of Friction Films High slip films have low layer to layer COF (generally COF< 0.2). These films will often have inner web slippage or cinching problems when they are winding and/or in subsequent unwinding operations or will have roll handling problems in between these operations. This inner web slippage can result in defects such as 'web scratching', 'dishing', 'telescoping', and/or 'starring' roll defects. Low COF films need to be wound as tight as possible at the core with high torque. Then the winding tension produced by this torque is tapered to a minimum amount at 3 to 4 times the core OD and the desired roll hardness is obtained using the Nip winding principle. Air is never our friend when winding high slip films! These films always need to be wound with sufficient nip loading to prevent air from entering the roll during the winding process.

High Coefficient of Friction Films Low slip films have high layer to layer COF (generally COF >0.7). These films will often have blocking and/or wrinkling problems. When winding high COF films, 'out-of-round' rolls can be experienced at low winding speeds and roll bouncing can be a problem when winding at higher speeds. As explained by well know consultant and columnist Tim Walker of TJWA Inc.,

> "…this is due to fact that the outer layers of a winding roll requires a small amount of sliding action as the layers first enters the winding roll. This sliding action produces inwound tension as the air following the web is ejected from the nip or out the sides. If the full width slides, this is not a problem. But, if one lane or spot sticks and the rest slide, then a local shear stress will develop near the sticking point. This local shear may form a small buckle or soft wrinkle in the top layer. In some products, a small bump or ripple can be wound over and ignored, but in other products (especially optically clear films), the next layer will not smoothly wind over a bump or ripple, but will instead conform over the bump, producing a slightly larger bump or ripple. As additional layers are added, like a rolling snow ball, the defect will often get bigger with each turn." (Walker, 2009)

These bump or ripple defects in high COF films are commonly called slip knots or slip wrinkles. These films are best gap wound with a minimum gap between the following roll and the winding roll. Spreading needs to be provided as close to the winding point as possible. A FlexSpreader covering on a well wrapped idler roll just before the winder has helped to minimize slip wrinkle defects on high COF winding applications.

Measuring Roll Hardness

Winding of film is often referred to as an "Art". This is because the setting and programming of the **T**ension, **N**ip and **T**orque will vary depending on:

- The type and design of the winder
- The type of web material being wound
- The width of the rolls being wound
- The speed of the winding operation

Not only will the same settings provide different roll hardness with the variations above, but also different film products and different end use applications will vary the roll hardness and profile desired. However, after the hardness profile has been established, this hardness must be reproducible on a consistent basis. To insure that wound rolls of film is produced with consistent roll hardness, hardness measuring devices must be available to the winder operators. With these devices, an operator can check roll hardness and make adjustments accordingly to insure that the roll hardness is within the acceptable range for that product.

To measure the roll hardness across the outer surface of the roll, it is suggested that a Rhometer, Schmidt Hammer or a 'PAROtester' be used. These are 'impact' based devices for measuring 'relative roll hardness' on a relative scale. The Schmidt Hammer was developed for concrete hardness testing and has been borrowed for use on roll hardness testing. The PAROtester is a similar device that was developed specifically for evaluation of the hardness of paper, foils and films rolls. The PAROtester is considerably more sensitive, has less impact energy and is less operator dependant due to its more defined direction of impact then the Schmidt Hammer. A new device called a TAPIO RQP (Roll Quality Profiler) is similar to the PAROtester and has the added feature of automatically sampling at fixed distances across the roll as it is rolled along the surface. This device was specifically developed for flat paper grades but also works well on many grades of film.

A Smith meter is an instrument that can be used to measure the hardness profile from the core to the outer wraps of the roll. The Smith meter measures the penetration of a small needle as it is inserted in-between the wraps of the web along the roll's sides.

With computerized data acquisition systems, such as the Davis-Standard AccuWind system, it is now possible to calculate the Roll Density Factor (RDF) and plot the relative roll density from core to full roll as the roll winds. These systems compare the actual winding roll's diameter with the theoretical diameter and plot the ratio as a function of the winding roll's diameter. The RDF curve is displayed to the operator on the Operator Interface Terminal (OIT) at the winder console.

PAROtester **TAPIO RQP**

<u>Hardness Devices for Measuring Roll Hardness across Roll</u>

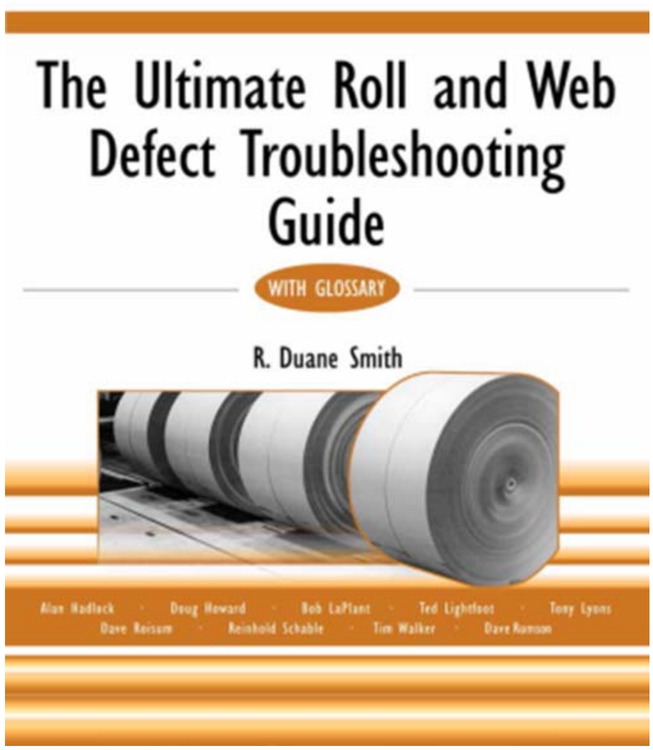
Smith Needle **AccuWind™ Roll Density Curve**

<u>Hardness Devices for Measuring Roll Hardness From Core to Full Roll</u>

The Ultimate Roll and Web Defect Troubleshooting Guide[4]

This article has presented a number of roll defects caused by improper roll hardness. The challenge of identification and elimination of these and other roll and web defects has been made easier by a new reference book ***The Ultimate Roll and Web Defect Troubleshooting Guide*[4] .** This book is the updated and expanded version of TAPPI Press's best seller ***Roll and Web Defect Terminology***[5] . The expanded version with valuable information for identifying and troubleshooting 224 roll and web defects was written and edited by 22 Industry Experts with over 500 years of combined experience in web handling and winding. The Ultimate Roll and Web Defect Troubleshooting Guide incorporates complete chapters dedicated to Extrusion Coating and Laminating, Web Handling, Slitting and Wrinkling Defects. It has been recognized by web producing and converting industry experts as the most comprehensive reference guide available for addressing roll and web defects.

The Ultimate Roll and Web Defect Troubleshooting Guide is available through TAPPI Press at www.TAPPI.org/bookstore.



In Conclusion

Winding good rolls of flexible packaging film is a challenge that every operator faces. Consistently winding good rolls depends on the consistency of bringing good film to the winding operation. A winder operator's job is not to camouflage poor quality flexible packaging film products into shippable rolls. His or her responsibility is to handle films with slight imperfections and to produce quality rolls that will run without problems on the downstream customer's process, and produce high quality products for their customers. Understanding the winding principles and how they

are used to control roll hardness profiles is the first step in winding rolls without defects. I hope that the information presented will help in meeting the challenges of consistently producing quality rolls of flexible packaging film products.

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BIOGRAPHY OF R. DUANE SMITH

R. Duane Smith is Product Manager of Specialty Winding at Davis-Standard LLC.

Duane is widely known throughout the Paper, Film and Nonwoven Industries for his technical knowledge on web handling and winding with over 43 years of experience working in this area.

He has two patents in the winding area.

Duane has made over 85 technical presentations and published over 30 articles in major international trade journals and magazines. He has been an instructor at 16 TAPPI short courses and has published three books through TAPPI Press. He is the editor of TAPPI Press' first e-book, *The Ultimate Roll and Web Defect Troubleshooting Guide*.

Duane is the author of the winding chapter of the TAPPI Film Extrusion Manual and the author of the Unwinding and Splicing chapter and co-author of the winding chapter of the TAPPI Extrusion Manual. Duane has been honored by the TAPPI Board of Directors naming him a TAPPI Fellow and by the Society of Plastic Engineers by awarding him the SPE Certificate of Recognition for his "Significant Contributions made to the Society and the Plastic Industry. He can be reached at dsmith@davis-standard.com