A SYSTEMS APPROACH TO REDUCING WINDING DEFECTS AT ALCOA-WARRICK OPERATIONS

by

B. J. Becker
Alcoa
USA

ABSTRACT

When processing coated aluminum, coil winding defects can be a major detractor to recovery, flowtime, and customer satisfaction goals for coil coating and slitting operations. Over the past several years, extensive studies have been performed at Alcoa on individual parameters in an attempt understand their effect on coil collapse and other winding problems. These studies improved understanding, but did not fully explain the collapse defect. Recent work has concentrated on the analysis of all important variables together as a "system." The focus of this paper is to explain interactions between variables which influence coil collapse, and how this defect can be minimized by optimizing the system of winding a coil.

INTRODUCTION

Aluminum coating and slitting operations wind finished product into coil form for shipment to customer locations. When winding thin gauge aluminum sheet, a winding defect known as coil collapse must be understood and controlled. Coil collapse is a condition which manifests itself as a deformation of the coil inside diameter (ID) and results in an unacceptable product. The two major types of coil collapse are referred to as "sag" and "V-buckle."

V-buckle collapse is the failure of the wraps at the coil ID which manifests itself in a sharp "V" in the core and/or metal as shown in Figure 1. The "V" can occur anywhere around the circumference of the coil ID. V-buckle collapse is caused by a high level of compressive tangential stress along with other factors. Sag collapse manifests itself by the coil ID deforming under the weight of a coil into an oval shape as shown in Figure 2. Sag occurs due to the forces of gravity overcoming the resistant forces of friction and the radial stress within a coil.

This paper specifically addresses coil collapse defects. However, other winding defects such as telescoping, clockspringing, and coil dishing can be explained using the same basic principles.

PROCESS PARAMETERS

This section explains the factors which influence the collapse rate in the winding process. These are typically parameters which can be varied by the line operators to minimize the collapse frequency.

Winding tension

Winding tension is the single most important process condition to control to produce a quality wound coil. Any coated aluminum coil wound on a fiber core can be made to V-buckle collapse by increasing the tension enough, or can be made to sag collapse if the tension is decreased enough. The key is, of course, finding the optimum set point for a given coil. The proper tension target is dependent on many equipment and product variables. Therefore, optimal winding tension cannot be set without understanding of basic fundamentals of the product and equipment being utilized.

Fiber core stiffness

Many winding models have quantified the effect of fiber core properties on stress values. Because the fiber core compresses significantly as the aluminum sheet is being wrapped, the first several wraps have a very negative (or compressive) tangential stress. As the coil builds, the previous wraps begin to act more like an "aluminum core," and the succeeding wraps then have tangential stress near zero throughout most of the coil.

Work by Gerhardt and Qiu of Sonoco Products Company addressed the issue of fiber core radial stiffness (1,2). This information led to more accurate information for the boundary condition of the fiber core in the winding models. These models estimate the internal stresses in a wound coil. Pressure between wound aluminum and the fiber core was measured in coils wound at the Alcoa facility in Newburgh, IN, in 1996. Measured pressures closely agreed with radial pressures predicted using the WINDER[1] model and core stiffness values reported by Sonoco.

For Alcoa's applications, fiber cores have been designed to protect the coil ID's from transportation damage. The cores are typically not designed to support the weight of a coil or to prevent coil collapse. At a given tension setpoint, a core with high stiffness (E_c) reduces the compressive tangential stress at the ID, which makes a coil less likely to V-buckle. Therefore, raising the stiffness of the core allows a higher tension setpoint, which in turn stabilizes the coil ID (reducing the likelihood of sag collapse) by increasing the radial stress.

Figures 3 and 4 show the difference in the tangential and radial stress values near the coil ID for 16" ID, .500" thick fiber cores with different radial stiffness values at the same winding tension. The coils wound on the high stiffness cores have 19% less compressive stress near the ID. Therefore coils wound on the higher stiffness cores, assuming all other variables remain constant, are less likely to V-buckle collapse.

---

[1] WINDER V4.2, A proprietary winding analysis software package developed by the Web Handling Research Center, Oklahoma State University

We have wound coils at high tensions to increase radial pressure and minimize loose coil ID's. However, this has often led to V-buckle type collapse due to the increase in compressive tangential stress. Several trials on multi-cut coated product on Alcoa's slitters have verified that higher stiffness cores allow coils to be wound at higher tensions without increasing the frequency of V-buckle collapse. Therefore more stable coil ID's can be obtained with the improved cores.

Ironing rolls

Installation of ironing rolls (also called lay on or rider rolls) has been effective in reducing the frequency of collapse and clockspringing. Ironing rolls are the most effective method known to reduce the amount of air entrained into a coil. This increases the effective wrap to wrap traction which in turn minimizes clockspringing and sag coil collapse. The contact pressure of the ironing rolls must be high enough to "squeeze out" the entrained air, but not too high to cause excessive wear or quality problems on the coil.

PRODUCT PARAMETERS

This section describes the important effect product characteristics can have when winding coated aluminum. These parameters are often either intrinsic to the processing paths, or are specifically requested as a customer requirement. Therefore, these parameters are typically more difficult to change than the previously discussed process parameters.

Wrap to wrap traction

Wrap to wrap traction is very important to the tendency of a coil to collapse. Low traction combined with low radial force makes a coil susceptible to sag type coil collapse. Low traction can also make other wound coil stability problems such as telescoping, coil dishing, and interlayer slippage defects more likely.

The major factors influencing wrap to wrap traction of a wound coil are surface characteristics of the sheet, lubricant thickness present between the wraps, and radial pressure between the wraps. Surface characteristics of the sheet are determined by incoming metal surface roughness, coating type, coating thickness, and coating application method.

Actual measurement of wrap to wrap coefficient of friction (COF) has proved to be a highly variable process. Because of the cost, time, and often questionable results of actual COF measurements, this method of estimating wrap to wrap traction was abandoned. Using the concept that COF is proportional to real area of contact between the wraps, another method was used to estimate COF. Because the lubricant levels are relatively constant, measurement of sheet surface roughness has been used to estimate relative COF between products. A stylus-type contact measurement device was used to collect sheet roughness data. This method has proved to be a quick, inexpensive, and adequate estimate of COF for the purposes of this study.

Extensive data collection has shown that for each coating system, there is generally a relationship between incoming surface roughness and coated surface roughness. At a given coating weight, the relationship of incoming metal roughness to coated roughness is strong. See Figure 5 for an example of the relationship of incoming roughness to coated roughness with thick coatings. Figure 6 shows the same relationship with thinner coatings.

Data collected to date indicates that the higher the coating thickness, the smoother the coated surface. It is not believed that the relationship between coating weight and roughness is linear, but that the lower the coating weight, the larger the impact of the coating weight change on the surface roughness. Figure 7 shows a graphical view of the relationship between coating weight and coated surface roughness for different incoming roughness conditions.

Radial compressibility

The radial compressibility of a coil is an important factor in determining the within coil stress distribution. This value is needed for use in the WINDER program and can only be obtained through experimentation (careful compression of a stack of the product.) Figure 8 shows a sample of stack testing data of coated aluminum sheet.

Across width product thickness variability

Variability in product thickness across the sheet width is an important factor in winding a quality coil. Product thickness variability is the addition of two factors:

a) Across width metal thickness profile

b) Across width coating thickness profile

The metal thickness in the center of the sheet is typically greater than the edge thickness due to aluminum rolling operations. When winding coated product, the across width coating thickness profile must also be considered. Different across width composite profiles (metal and coating summation) can result in drastically different behavior of the wound coil. When the product is significantly thicker in the center of the sheet, higher compressive tangential and radial stresses give the coil a tendency to V-buckle collapse. When the edges are significantly thicker than the center, air escape from the coil is impeded and the resulting lower traction between wraps make the coil likely to sag collapse. Empirical observations of very large numbers of coils suggests that the optimum across width profile for overall wound coil quality is a product with good symmetry that is slightly thicker in the center than the edges.

DISCUSSION OF WITHIN COIL STRESS DISTRIBUTION

When trying to determine the optimum winding conditions, a study of the within coil stresses is necessary. If a coil is wound at a very low tension, the radial stress is relatively low. This will not only make the coil susceptible to sag collapse, but it will also lessen the overall strength of the wound coil. Therefore, the tension setpoint needs to be as high as possible without causing V-buckle collapse. All products have an optimum "window" for winding tension, but when the product changes from run to run (or sometimes coil to coil), it is very difficult to determine the proper tension target. Often the tension target is changed on a coil based on the performance of the previous coil. If the product characteristics are significantly changing, it is very difficult to target the tension properly.

THE “TENSION WINDOW”

In an attempt to visualize how different parameters affect coil collapse, a “tension window” was devised. The tension window is defined as the range of winding tension which a coil with certain characteristics can be properly wound.

The illustration shown in Figure 9 shows how the range of acceptable tension is narrowed when running products with a low COF. The same visualization can also be used for other parameters. For example, lowering the core stiffness value closes the window from the top. Running sheet with across width thickness greater on the edges closes the window from the bottom. The tension window can be closed completely for certain low COF products due to low traction, high across width thickness variability, and/or low core stiffness.

SUMMARY AND CONCLUSIONS

In summary, the following list of variables must be considered to improve wound coil quality of coated aluminum sheet:

WINDING TENSION

TRACTION BETWEEN WRAPS
  Coated surface roughness
    incoming roughness
    coating type
    coating thickness
    coating application method
  Entrained air
    ironing roll
    process speed
  Lubricant thickness and viscosity

ACROSS WIDTH THICKNESS VARIABILITY
  Coating thickness profile
  Metal thickness profile

FIBER CORE STIFFNESS

At Alcoa, we found that the following action items reduced the frequency of coil collapse:

1. The wrap to wrap traction of coated products has been increased by use of ironing rolls and careful control of incoming surface roughness and coating thickness.
2. Collapse sensitive products are run at higher winding tensions using higher stiffness cores.
3. The across width thickness variability of coated products was reduced.
4. Proper measurement and control of winding tension is maintained.

The results of this work are shown in Figure 10. By analyzing the coil collapse problem as a system, rather than a collection of independent variables, the rate of coil collapse has been reduced at Alcoa, Warrick Operations by over 60%!

ACKNOWLEDGMENTS

Many have contributed to the information included in this paper. Special thanks are order to the following: Albert Wang - Alcoa Technical Center, Neil Vernon and Jim Vanada - Alcoa, Warrick, Jim Rushing - Alcoa, Knoxville, and Pete McCoy, Bruce Shackelford, Terry Gerhardt, Chuck Johnson, Thomas Wallace, and Ricky Freeman of Sonoco Products Company.

REFERENCES

1. T. D. Gerhardt and Y. P. Qiu, "Paper Tube Deformations During Winding Process," Presented in Mechanics of Cellulosic Materials, AMD-Vol. 145/Md-Vol 36, 1992.

2. T. D. Gerhardt, "External Pressure Loading of Spiral Paper Tubes: Theory and Experiment," ASME Journal of Engineering Materials and Technology, Vol. 112, pg. 144-150, 1990.

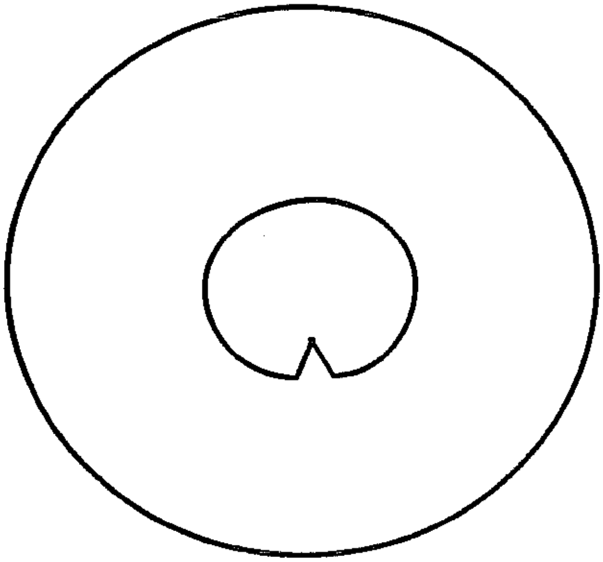

Fig.1 Depiction of "V-buckle" type coil collapse

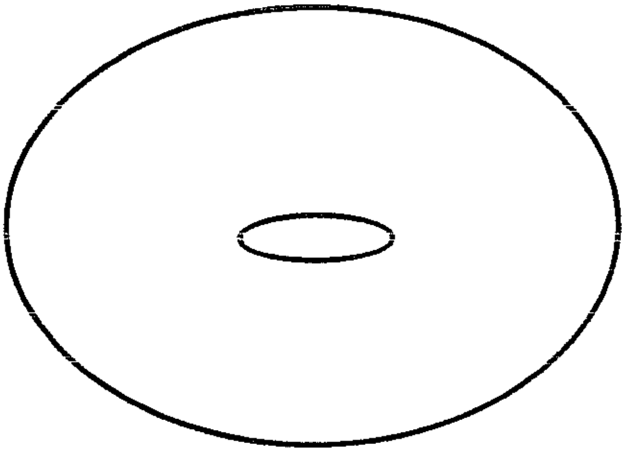

Fig. 2 Depiction of "Sag" type coil collapse

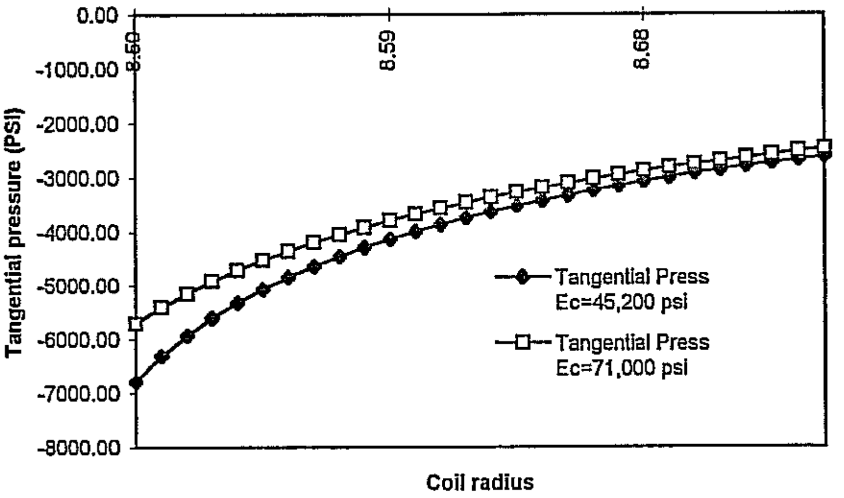

Fig. 3 Tangential pressure at the coil inside diameter for core with different stiffness values

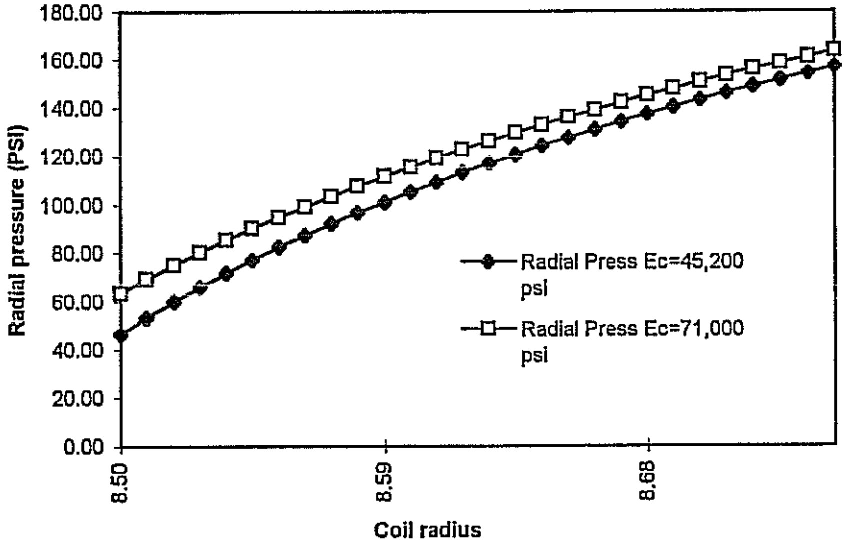

Fig. 4 Radial pressure at the coil inside diameter for cores with different stiffness values

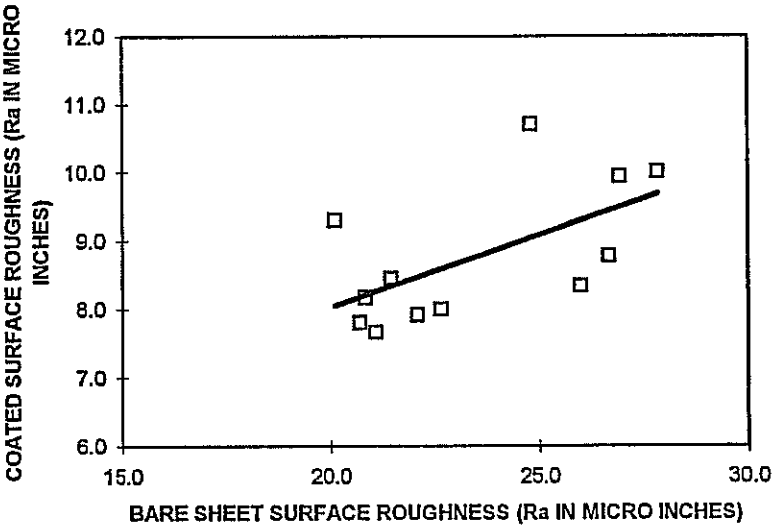

Fig. 5 Coated surface roughness for different values of bare incoming sheet - high coating weight

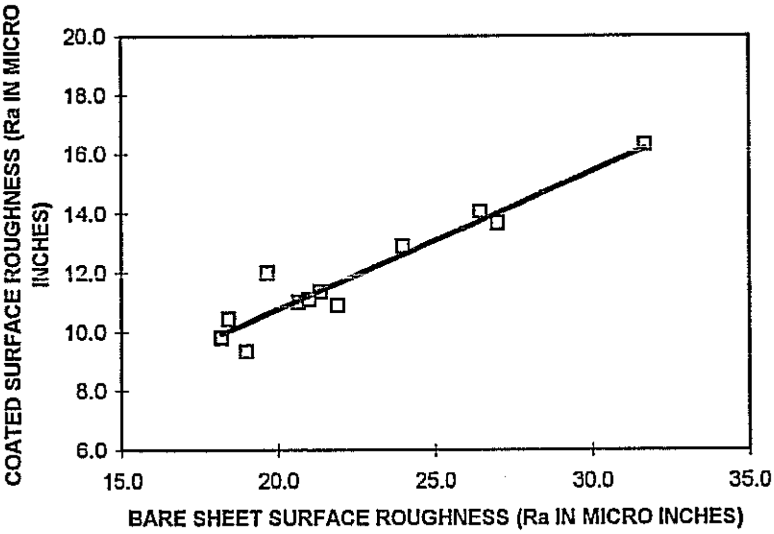

Fig. 6 Coated surface roughness for different values of bare incoming sheet - low coating weight

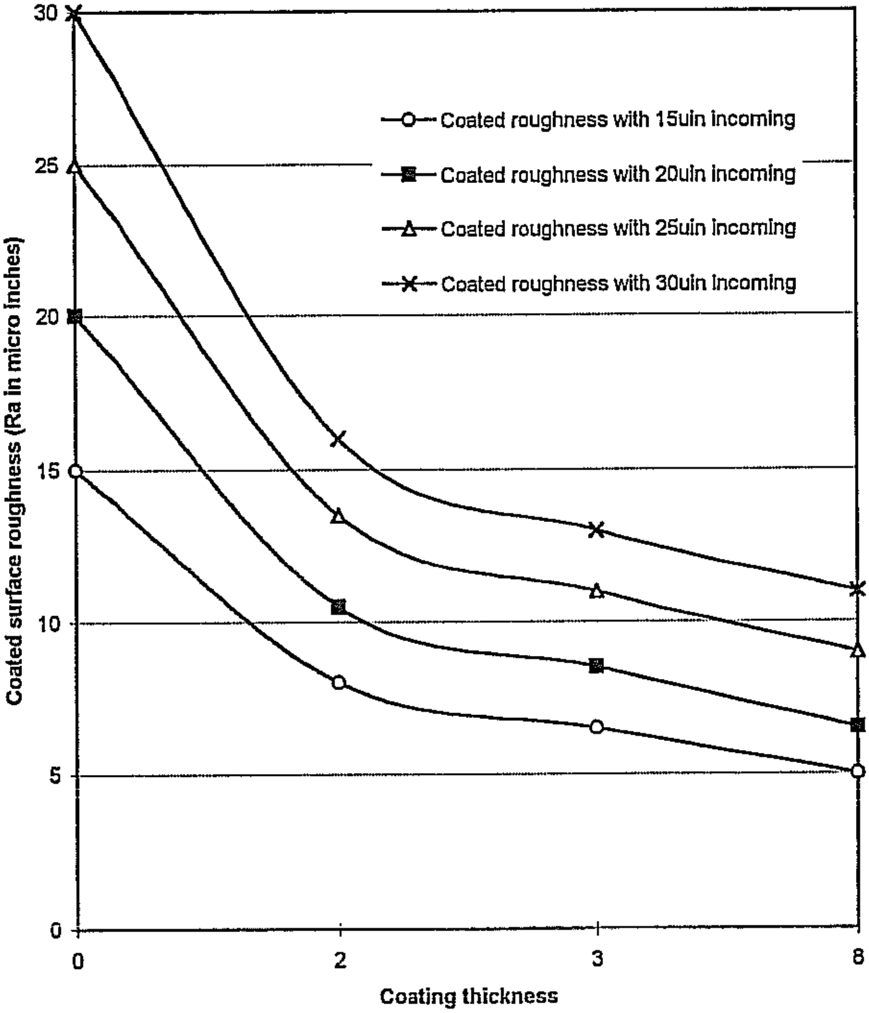

Fig. 7 Incoming surface roughness and coating thickness effect on coated surface roughness

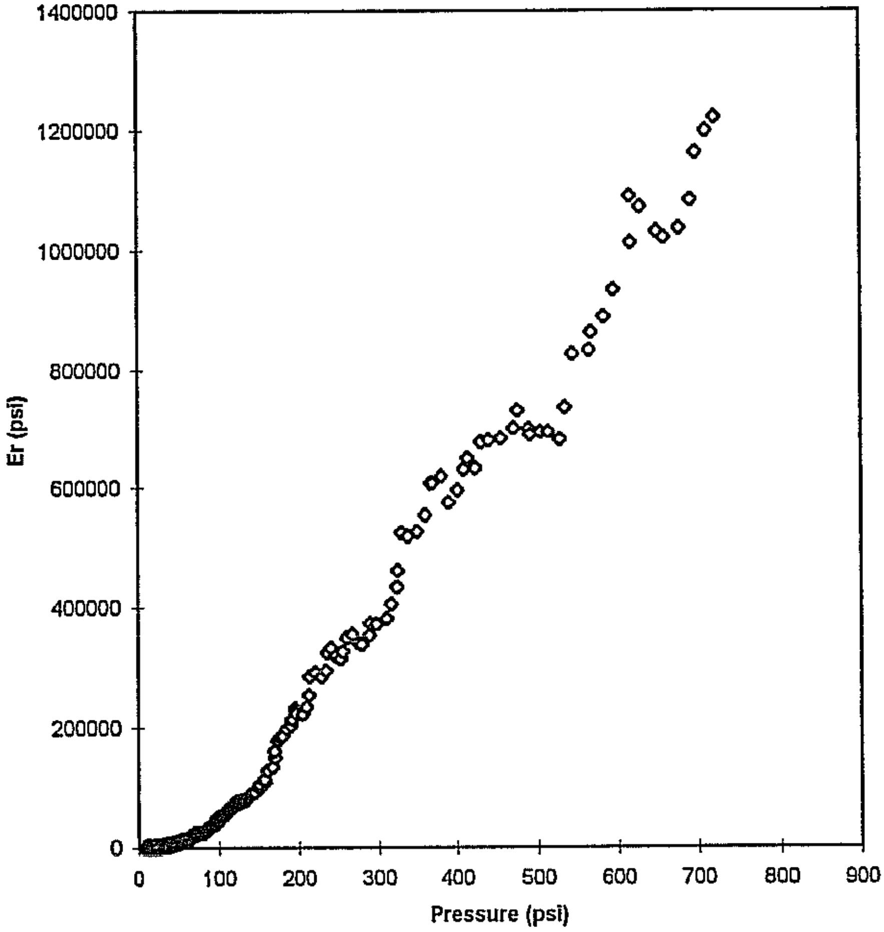

Fig. 8 Sample of stack testing results for coated aluminum sheet

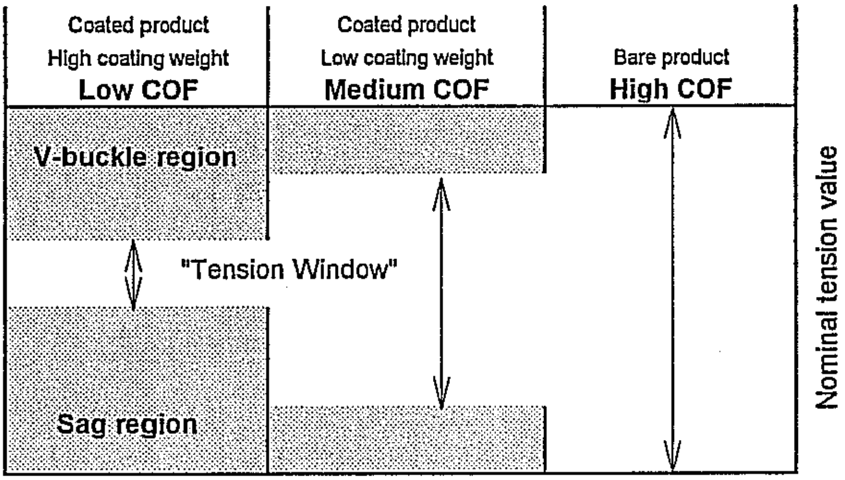

Fig. 9 Depiction of how lower coefficient of friction narrows the acceptable winding tension range

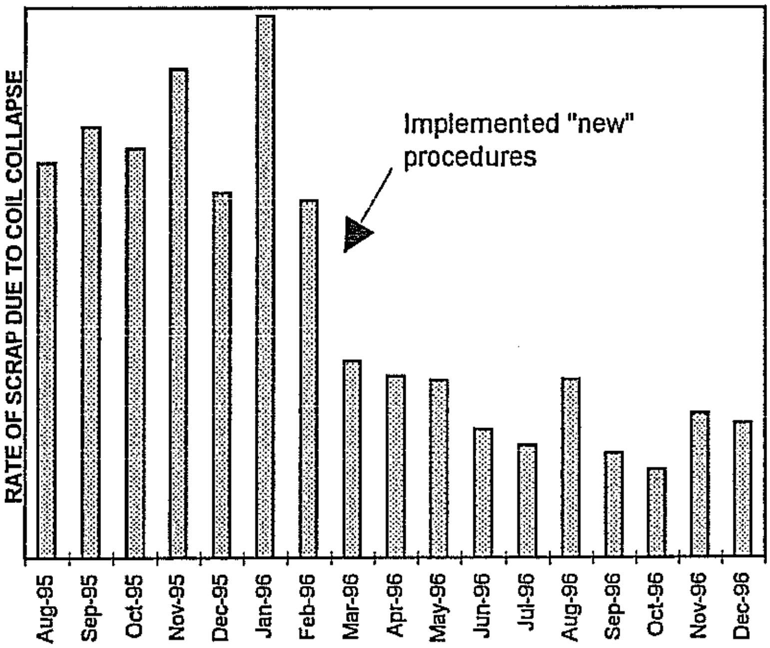

Fig. 10 Reduction in the rate of coil collapse

Question - Did your rider roller help reduce your telescope problems or just sag and V-buckle problems even though it was that far away from the nip position.

Answer - Yes, it reduced all problems and definitely reduced telescoping.

Question - I have a question on the values of coefficient of friction you use for high, medium, and low.

Answer - We have tried to measure the coefficient of and friction often with questionable results, the high, medium, low are qualitative only.

Question - What is the nature of the ratio between the tensile modulus to the radial modulus in your product, it must be very high? This would mean that it would be almost impossible to have any residual tension in your coil; you form it into raw form and it suddenly disappears if it moves in 2 microns on the core radius, you loose all your tension in layers.

Answer - The winding models show 150 psi radial pressure inside the coil is the maximum. Even though the ratio of the moduli may be large this industry runs very high winding tension compared to the paper and film industries..

Question - Where is the energy in winding stored, is it compressing the core?

Answer - Some of it is I'm sure.

Question - Did you try or consider winding it in a higher tension to and later reduce to form a more relaxed stable core and then wrapping it in a coil?

Answer - Yes, as much as 50% taper

Question - When you do this, do you find the interlaps have a much higher coil set that may cause a problem with the customer? When its unwound does the residual curl cause a problem with the customer.

Answer - The type of presses used aren't sensitive to coil set.