Preferred citation: J.K. Good. The science of winding paper rolls. In **Products of Papermaking**, *Trans. of the Xth Fund. Res. Symp. Oxford, 1993*, (C.F. Baker, ed.), pp 855–881, FRC, Manchester, 2018. DOI: 10.15376/frc.1993.2.855.

The Science of Winding Paper Rolls

James K.Good, PhD, PE
Professor and Noble Research Fellow
Web Handling Research Center[1]
School of Mechanical and Aerospace Engineering
Oklahoma State University
Stillwater, Oklahoma
USA

ABSTRACT

In many cases paper products are of a wound roll format. The wound roll product must have integrity such that it does not slip internally or telescope in printing or other converting operations or in the hands of a consumer if the wound roll is the final format of the product. Winding models which predict internal stresses within wound rolls begun development over twenty years ago. The purpose of this paper is to (1) show how the models can be used to insure roll integrity and (2) show how paper properties can affect the integrity of the wound roll and (3) show recent developments in wound roll models.

1 The Web Handling Research Center is a National Science Foundation Industry/University Cooperative. The sponsors include the National Science Foundation, the Noble Foundation, the State of Oklahoma and an industrial consortium of which 3M Company, Beloit Corporation, E.I.Dupont de Nemours & Co.(Inc.), Eastman Kodak Company, Fife Corporation, Hoescht-Diafoil Corporation, ICI Americas, James River Corporation, Kimberly-Clark Corporation, Mead Central Research, Mobil Chemical Company, Polaroid Corporation, Reliance Electric Company, Rexham Corporation, Sonoco Products Company, Specialty Coatings Group Inc., Union Camp Corporation, Valmet-Appleton Inc., and Worldwide Process Technologies are members.

A HISTORY OF INTERNAL STRESS MODELS FOR WOUND ROLLS

There are several wound roll stress models in existence which differ mainly in the manner in which the web material properties are allowed to vary. All of these models apply only to the center winding technique. Some reference will be made to a machine direction. The machine direction in a web line is the direction in which the web travels through the web line.

Early models, Gutterman (1) and Catlow et al. (2), assumed that a wound roll could be modeled as a linear isotropic material, where the radial modulus was equivalent to the circumferential modulus of elasticity ($E_r = E_\theta$). The next generation of models, Altmann (3) and Yagoda (4), assumed the wound roll could be modelled as a linear anisotropic material, where E_r is unequal to E_θ although both parameters are assumed to be constants. In reality the radial modulus of a wound roll is a parameter which encompasses both structural and material nonlinearities. Paper, plastic film, and other webs have asperities upon their surfaces and when the web is wound or stacked asperities from one surface contact asperities upon the next surface. Thus upon compression the contact area becomes a function of radial or normal pressure and the measured radial modulus, E_r, is a function, typically nonlinear, of radial pressure. Thus the most realistic models of Pfeiffer (5), Hakiel (6), and Willett and Poesch (7) allow for nonlinear anisotropic properties.

Hakiel combined equilibrium, compatibility, and material relationships to yield a second order differential equation in radial pressure:

$$r^2\frac{d^2\sigma_r}{dr^2} + 3r\frac{d\sigma_r}{dr} - \left[\frac{E_\theta}{E_r} - 1\right]\sigma_r = 0 \qquad \{1\}$$

where r denotes a radial location in the wound roll, E_θ and E_r denote the respective circumferential and radial Young's moduli and σ_r denotes the radial pressure. Equation {1} requires two boundary conditions for solution. The second order differential equation must be solved several times for the wound roll as the geometry, boundary conditions, and material parameters are continually changing throughout the winding process. Restating equation {1} in a slightly different form:

$$r^2\frac{d^2[\delta\sigma_r]}{dr^2} + 3r\frac{d[\delta\sigma_r]}{dr} - \left[\frac{E_\theta}{E_r} - 1\right][\delta\sigma_r] = 0 \qquad \{2\}$$

Hakiel implemented a finite difference technique to solve equation {2}. The radial modulus E_r is a function of the radial pressure σ_r and is measured using a material testing system, the procedure for which has been documented by Pfeiffer (8). Each time the equation is solved, the radial stress distribution obtained must be added to the sum of all the previous radial stress distributions which resulted from previous solutions of the equation or:

$$\sigma_{ri} = \sigma_{ri} + \sum_{j=i+1}^{n} \delta\sigma_{rij} \qquad \{3\}$$

where $d\sigma_{rij}$ denotes the radial stress in the ith layer due to the winding on of the jth layer. This procedure is continued until the total n layers have been wound onto the roll. With a known radial stress distribution the tangential stresses can be calculated from the equilibrium expression:

$$r\frac{\partial \sigma_r}{\partial r} + \sigma_r - \sigma_\theta = 0 \qquad \{4\}$$

The boundary conditions used to solve equation {2} are obtained by considering both the inner and outermost layers of the wound roll. At the inner layer, the radial deformation of the first wound on layer should be equal to the radial deformation of the core. Mathematically this is stated as:

$$u(1) = - \frac{\delta\sigma_r(1)}{E_c} \qquad \{5\}$$

where E_c represents the radial stiffness of the core and $\dot{u}$ represents the normalized radial deformation (by dividing by the outside radius of the core) of the first layer. After use of compatibility and material expressions the radial deformation can be eliminated yielding the following relationship:

$$\frac{d\delta\sigma_r}{dr}\Big|_{r=1} = \left[\frac{E_\theta}{E_c} - 1 + \nu_{r\theta}\right]\delta\sigma_r\Big|_{r=1} \qquad \{6\}$$

in which $\nu_{r\theta}$ is Poisson's ratio which governs deformation in the r direction due to a stress in a θ direction. The second boundary condition involves the outer layer. The circumferential stress, σ_θ, is equivalent to the incoming web tensile stress, T_w, in the outer layer. Treating the outer wrap of the wound roll as a thin wall pressure vessel the radial stress can be related to the circumferential stress via the relationship:

$$\delta\sigma_r \,|_{r=s} = \{T_w \,|_{r=s}\} \frac{h}{s} \qquad \{7\}$$

where h is the web thickness and s is the radial location of the current outer wrap of the winding roll.

APPLICATION OF THE MODEL FOR VARIOUS WEBS

To develop an understanding of how material properties affect the radial pressure within a wound roll the model described in the previous section was applied to three paper webs: (1) 0.089 mm Bond, (2) 0.071 mm News, and (3) 0.051 mm Light Weight Coated, a magazine grade. The model was run assuming a centerwinding configuration keeping winding tension, core stiffness, Poisson's ratio of the web stack($\nu_{r\theta}$), and the inner and final outside radius of the wound roll constant. Thus the only input parameters which were allowed to vary were E_r and E_θ. Note that the ratio of these parameters affects the solution of the second order differential equation in radial pressure {2} which is solved n times for a roll wound of n layers. Table 1 contains all parameters required to run the winding model for the web materials discussed.

Web	Bond	News	LWC	PET 442	PET S
thickness μm	89	71	50.8	23.4	23.4
inside radius - cm	4.445	4.445	4.445	4.445	4.445
outside radius - cm	13.335	13.335	13.335	13.335	13.335
E_c Core Stiffness - GPa	11	11	11	11	11
E_t - GPa	4.13	3.37	8.268	4.13	4.13
$E_r=A+B\sigma_r+C\sigma_r^2+D\sigma_r^3$ - KPa					
A	14.74	0	0	0	0
B	65.2	50.6	72.84	390.3	186.94
C	-.0628	-.0964	0	.0325	.007
D	0	.0001	0	-3.37* 10^{-5}	-2.53* 10^{-5}
$\nu_{r\theta}$	0.01	0.01	0.01	0.01	0.01
μ_s if applicable	.28				
μ_k if applicable	.14				
T_w winding tension - N/m	350	350	350	50	50

Table 1. - Web Material and Wound Roll Parameters

The material properties cited are the results of material tests performed at the Web Handling Research Center. The resulting radial pressure profiles are shown in Figure 1.

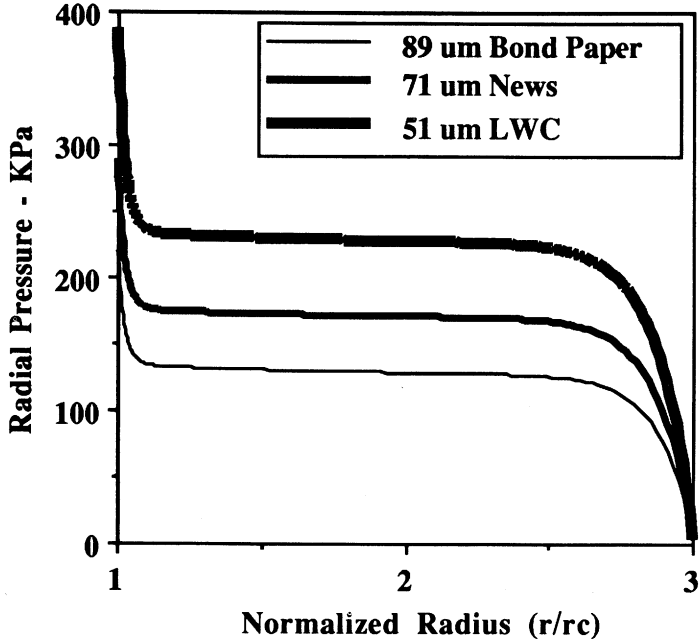

Figure 1. - Centerwinding Various Grades of Paper at a Tension of 350 N/m

Characteristic of many paper webs is the plateau in radial pressure seen over a large domain in radius. This is due to constant winding tension and a large ratio of E_θ over E_r.

This ratio is a function of the local pressure σ_r and thereby is a function of the radial location in the wound roll. This ratio has been plotted in Figure 2 as a function of pressure for the three paper webs discussed. Note that the News and Bond grades have nearly the same variation in E_θ/E_r as a function of pressure but that the Light Weight Coated paper has a significantly larger values of E_θ/E_r over the same pressure domain.

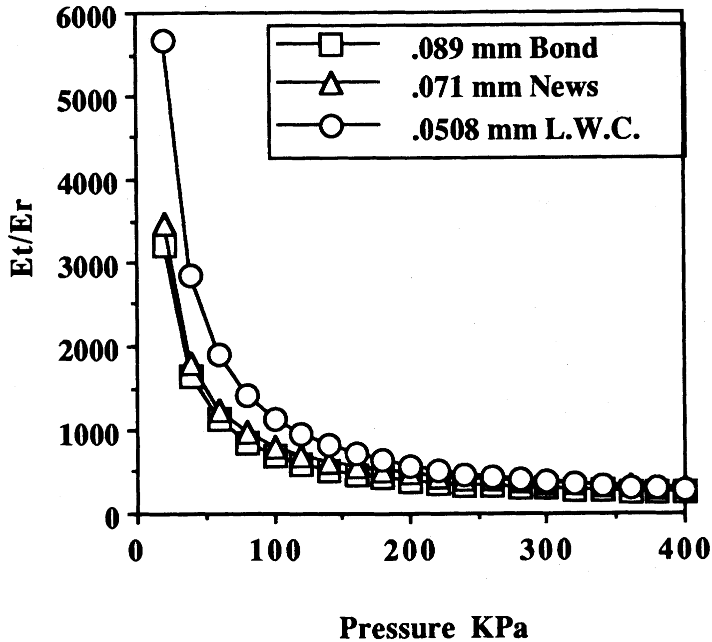

Figure 2. - Dependence of Et/Er upon Paper Grade

There are however significant differences in the radial pressures computed for each of the three grades as was shown in Figure 1. The paper making process can have a profound effect upon the radial pressure profile. Fiber length and orientation, types of fibers in the furnish, fiber density and coatings influence the tangential modulus E_θ.

The radial modulus E_r is highly dependent upon web surface characteristics as well. Thus any process which affects the surface such as supercalendaring and coatings will affect E_r. To illustrate this point an extreme case is presented. The surface roughness of polyester film is controlled via the addition of micro-particulates during the extrusion process. In Figure 3 the radial stresses are shown for two polyester webs which were centerwound at a winding tension of 50 N/m.

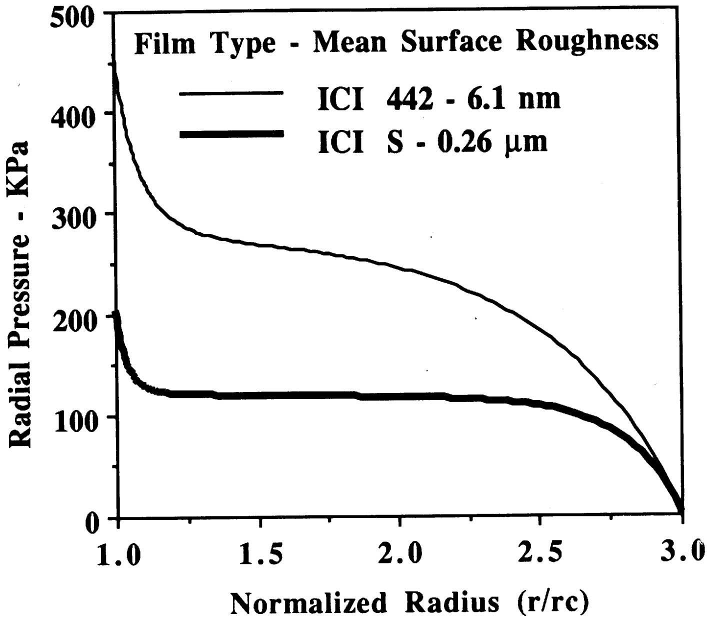

Figure 3. - Effect of Surface Roughness upon the Centerwinding of .0234 mm Polyester at a Winding Tension of 50 N/m

The two webs are identical except one has a mean surface roughness of 6.1 nm while the other has a mean surface roughness of 0.26 µm. The difference in the internal radial stresses is significant. Similar to the data presented for the paper grades given in Figure 2, E_θ/E_r is plotted as a function of pressure in Figure 4.

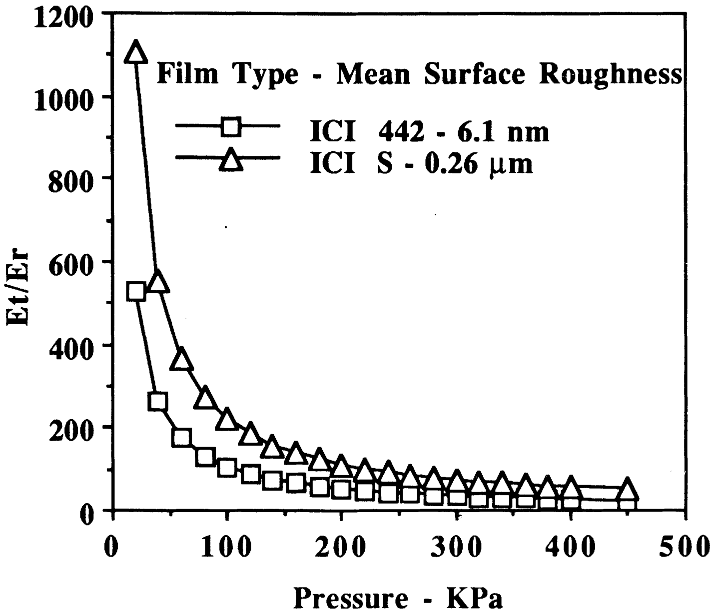

Figure 4. - Dependence of Et/Er upon Film Roughness for .0234 mm Polyester Film

Note that the values of E_θ/E_r at a given pressure are significantly larger for the polyester webs when compared to the paper data presented in Figure 2. All web and winding data for the polyester webs are shown in Table 1.

USEFULNESS OF WOUND ROLL STRESS MODELS

Now with an understanding of how the paper properties can affect the internal pressures predicted by wound roll models, a discussion of why knowledge of the internal stresses within wound rolls is important is in order. There are a number of wound roll defects which are detrimental to web quality as seen by web converters (those who convert wound rolls to discrete sheet products of some sort).

One defect which is common is a condition in which the core has deformed radially inward due to the radial pressure, shown typically in Figure 1, to an extent that the circumferential stress σ_θ becomes compressive. In such a condition the web material near the core locally buckles in a starred pattern and typically becomes waste. Yagoda (9) showed via the use of his wound roll model, which employed a constant E_r, that the model could be used to ascertain what core stiffness E_c would be required to prevent this type of failure. The cost of a core is directly related to core stiffness and since most producers of paper do not recover their cores from the converters as little as possible is spent upon the cores. Use of the wound roll models can help one decide what core stiffness is required to prevent starring and therefore make an informed decision upon what lowest cost core can be purchased while maintaining roll quality. As an example the .089 mm Bond paper for which results were presented in Figure 1 will be used again. In Figure 5 the radial pressures resulting from various core stiffnesses are shown.

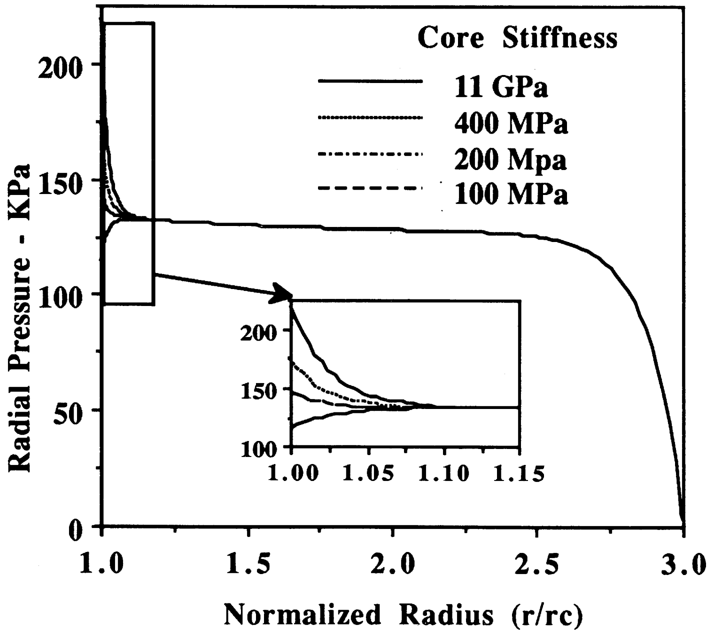

Figure 5. - Effect of Core Stiffness upon Radial Pressure for .089 mm Bond Paper Centerwound at a Tension of 350 N/m

The core stiffness of 11 GPa represents an aluminum core often used in the laboratory with an inner and outer radii of 3.81 and 4.445 cm, respectively. The core stiffnesses of 400, 200, and 100 MPa are representative of core tubes manufactured from kraft fibers. In Figure 6 a plot of the circumferential stresses are shown and it is evident that a core stiffness of about 200 MPa is required to prevent compressive circumferential stress that when combined with the radial pressure will promote starring.

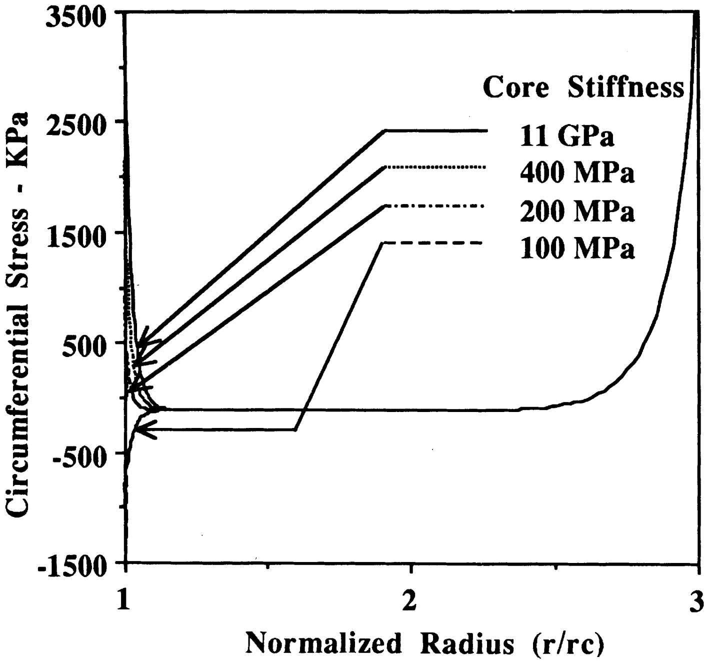

Figure 6. - Effect of Core Stiffness upon Circumferential Stress for .089 mm Bond Paper Centerwound at a Tension of 350 N/m

Internal slippage within an unwinding roll can result in web breaks and in the scratching of paper coatings. Web line tension control systems are at best capable of removing tension disturbances with frequency content less than 3 Hz. Internal slippage occurs in a stick-slip jerking motion which will cause spikes in the web line tension which can break the web. Thus sufficient radial pressure must be wound into rolls to prevent the internal slippage from occurring during rewind or converting operations. Again the wound roll models are useful because with knowledge of the radial pressures which resulted from the last winding operation on the roll the ability of the roll to resist internal slippage can be calculated. The radial pressure beneath a specific layer multiplied by the cylindrical area of that layer, the static coefficient of friction, and the radius of that layer results in the ability of the wound roll to resist slippage at that layer:

$$T_{Cap} = \sigma_r(2\pi r w)\mu_{st} r \qquad \{8\}$$

where w is the width of the wound roll. As an example again consider the bond paper (w = 15.24 cm)which was wound at a constant tension of 3933 KPa. In Figure 7 the torque capacity of the wound roll to resist slippage is plotted as a function of radius. Also shown is the largest torque which was applied during winding which in constant tension winding occurs as the final lap is wound onto the roll. Closer examination of the numbers shows that if the unwind tension exceeds about 615 N/m that slippage will begin to occur beneath the outer layer. If the unwind tension exceeds 4100 N/m slippage will occur in the vicinity of a normalized radius of 1.063, near the core, but slippage would also be occurring in the outer three layers as well. Thus with knowledge of rewinder and converting line web tension levels one can predict when and if slippage will occur.

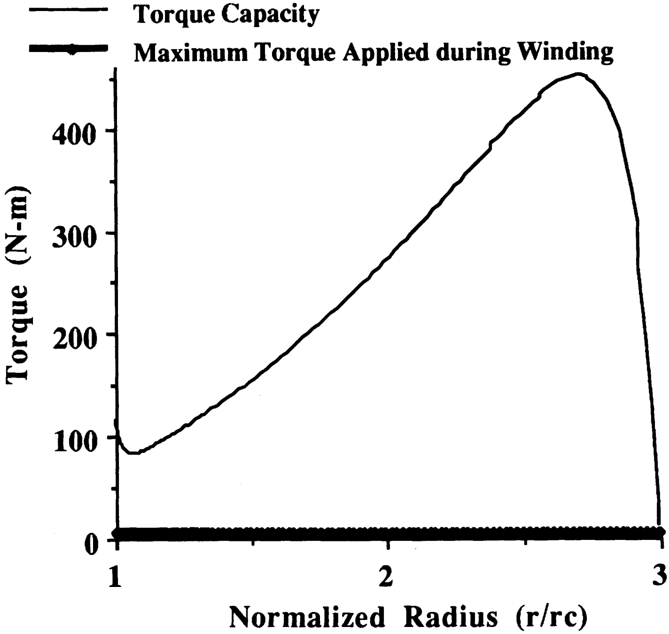

Figure 7. - Capacity of .089 mm Bond Paper Centerwound at 3933 KPa to Resist Slippage

Starring does not necessarily have to occur in the vicinity of the core. Eriksson (10) noted that whenever circumferential compressive stress exists that starring could be expected. The starring instability was described as being due to the layers of the wound roll being simultaneously subjected to radial compressive stress (i.e. pressure) and circumferential compressive stress. Although this is useful as a guide to prevent starring it is by no means quantitative proof starring will occur as many rolls are centerwound at constant tension without starring defects and centerwinding always results in a broad radial domain in which compressive circumferential stresses exist, refer to Figure 6.

RECENT ADVANCES IN WINDING MODELS

One advance involved the extension of the winding models which had previously only been applied to centerwinding to other types of winders. A large number of paper winders have rollers which may or may not be driven in contact with the winding roll. The rollers are often called nip rollers and hereafter will be called the nip herein. For quite some time the nip has been known to induce a tension, called the nip induced tension, which when added to the web line tension would become the tension in the outer layer of the winding roll, Pfeiffer (11). Good and Wu (12) and Good and Fikes (13) produced the first quantitative explanation of how the nip induces this tension and experimentally verified their theory. Good, Wu, and Fikes (14,15) and Good and Fikes (16) proved that in a large number of cases in which the nip roller was an undriven idler that the tension wound in to the outer layer of the winding roll could be modeled simply as:

$$\mathbf{WIT} = \mathbf{T_w} + \frac{\mu_k \mathbf{N}}{\mathbf{h}} \qquad \{9\}$$

where μ_k is the kinetic coefficient of friction between adjacent layers of web in the winding roll and N is the nip loading in units of load per unit width of contact. The premise of expression {9} was that the WIT could not exceed the sum of the web line tension and an additional force which could not exceed the ability of the nip to trap a differential tension in the outer layer of the winding roll from one side of the nip to the other. This relation for WIT was used to replace the web line tension T_w in expression {7}:

$$\delta\sigma_r \big|_{r=s} = \{\mathbf{T_w} + \frac{\mu_k \mathbf{N}}{\mathbf{h}}\} \frac{\mathbf{h}}{\mathbf{s}} \qquad \{10\}$$

Expression {10} was used as a boundary condition for the previously developed wound roll model to develop a model for centerwinding with an undriven nip roller in contact with the winding roll, refer to Figure 8.

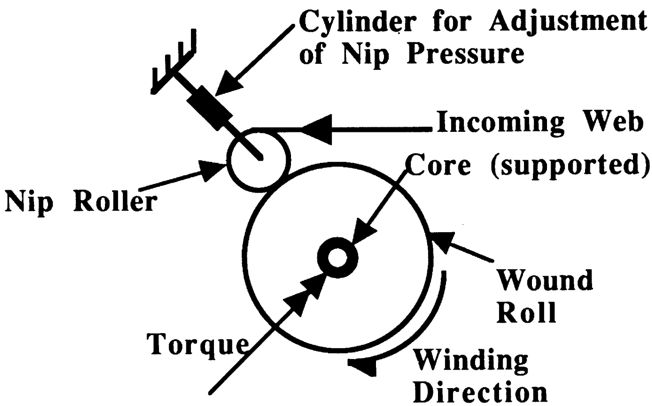

Figure 8. - A Center Winder with an Impinging Nip Roller

As an example results for the 0.089 mm bond paper wound at two nip loads are shown in Figures 9 and 10. The experimental pressures were measured using the pull tab method which was first documented in the literature by Monk, Lautner, and McMullen (17). The agreement between theory and experiments was deemed excellent.

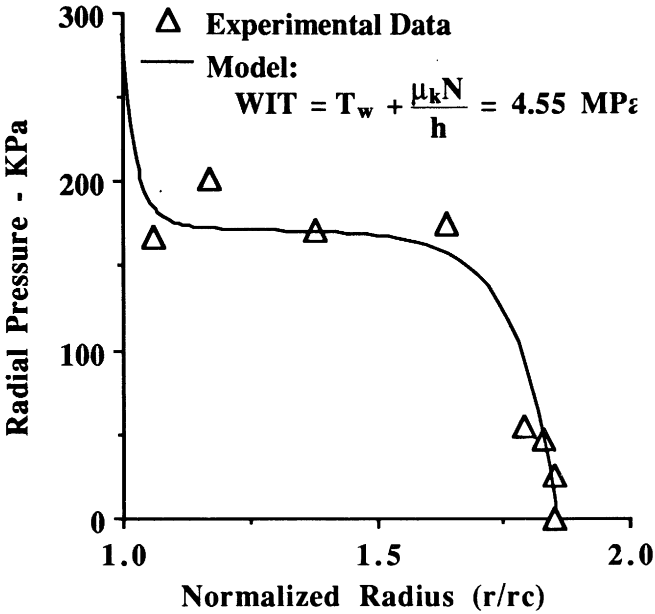

Figure 9. - Centerwinding at a 3.45 MPa Web Stress with a Nip Load of 7.0 N/cm

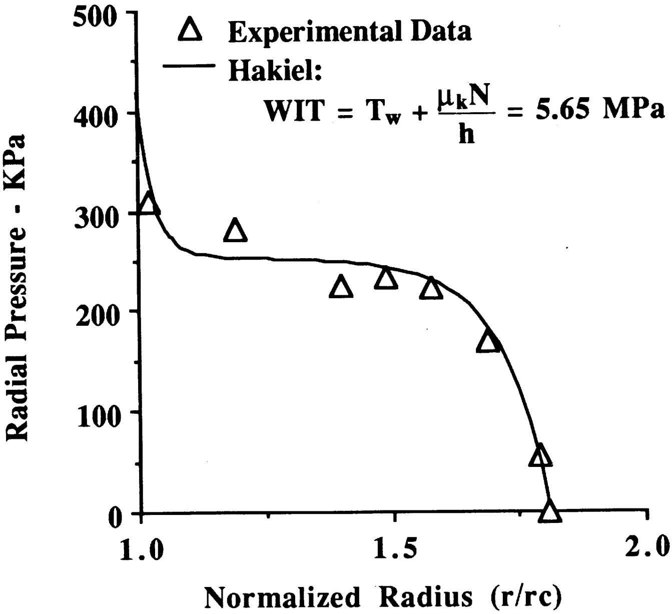

Figure 10. - Centerwinding at a 3.45 MPa Web Stress with a Nip Load of 14 N/cm

Another advance in theory has been the extension of two dimensional wound roll models to study defects which result from thickness nonuniformity across the width (in the cross machine direction) of the web. Web thickness can vary due to nonuniform drying conditions or to nonuniform dispensation of paper onto the wire at the head box. Papers published by Kedl (18) , Hakiel (19), and Cole and Hakiel (20) all relate the nonuniform thickness to a nonuniform tension or strain in the web. In Kedl's derivation the nonuniform web thickness causes the nominal radius of a layer winding onto the outside of the roll to be nonuniform in the CMD direction as well. Since the wound roll is rotating at some angular velocity (ω) the lineal velocity of the web as it contacts the winding roll also varies across the web width ($V= r\omega$). In the span upstream of the winder all of the web across the web width is assumed to be traveling at the same velocity (V_o) and subject to uniform tension and strain(ε_o). When the web contacts the winding roll it has attained a new velocity ($r_i\omega$) and a new strain (ε_i) which varies across the width of the web as:

$$\varepsilon_i = 1 - \frac{V_o(1-\varepsilon_o)}{r_i\omega} \qquad \{11\}$$

The tension is then estimated at discrete locations across the width of the web using:

$$T_{wi} = E_t\varepsilon_i \qquad \{12\}$$

The winding model is then run at these discrete locations so that pressure profiles can be developed as a function of radius and across the width of the web. For this model to be accurate r_i used in equation {11} should be computed by the wound roll code since it represents the true outer radius of the wound roll which is affected by E_r, E_θ, T_{wi}, etc. Kedl verified his model using force sensitive resistors to measure the radial pressure and Hakiel and Cole verified their model using a core instrumented for pressure measurement and a measurement system which accurately measured the surface of the wound roll.

Another advance in theory resulted from an extended study of centerwinding. Good and Pfeiffer (21) and Good, Pfeiffer, and Giachetto (22) showed that the centerwinding model could be grossly in error for highly compressible webs such as many paper grades. The error could be corrected if the boundary condition {7} for the outer layer was modified. It was determined that the wound in tension in the outer layer was less than the web line tension as was previously assumed. The decrease in WIT was attributed to the radial deformation of the outside of the wound roll which was caused by the addition of the most recent layer. The wound in tension was calculated using the expression:

$$\mathbf{WIT} = \mathbf{T_w} + \mathbf{E_\theta \frac{u}{s}} \qquad \{13\}$$

where u is the radial deformation of the outer layer, defined positive in an outward radial direction. The addition of a new layer of web will cause an inward movement of the layer beneath and thus u is always negative and the WIT is always less than the web line tension T_W. The radial deformation for all layers is computed via the wound roll model but has to be extrapolated for the next layer since the radial deformations are calculated after the internal stresses are obtained. Figure 11 shows the results of modified versions of Hakiel's and Pfeiffer's model and the original model, which used expression {7} for the outer boundary condition, with experimental data superimposed.

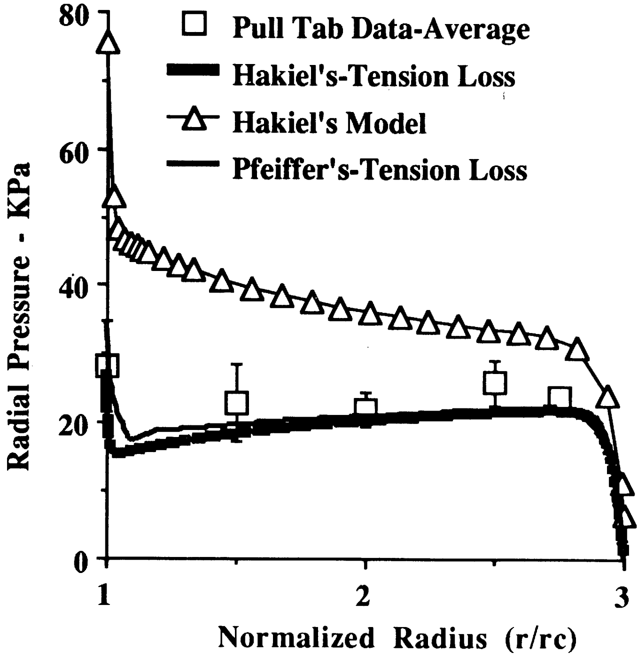

Figure 11. - Centerwinding 0.071mm News Print at a Constant Tension of 1.72 MPa

In this case the experimentation involved the news print whose properties were listed in Table 1. There are two items of interest to be noted in Figure 11 which include (1) the discrepancy which can exist if radial deformation beneath the outer layer is ignored and (2) based upon the experimental data how well the modified model performs.

The experimental data are the results of pull tab tests which were executed during three experimental winds. The data points plotted represent the average pressure measured during the three tests while the error bars indicate the standard deviation of the data for a small population.

CONCLUSIONS

Wound roll models have developed and are becoming powerful tools for engineers and scientists to study the behavior of stresses within the roll. This paper has attempted to make the points of how paper properties affect the internal stresses within the wound roll, how these stresses can be used to make quantitative off-line assessments of defects, and how these models are being extended to replicate conditions which exist within industrial winders. Improved roll quality can be obtained by use of these models. However not all types of winding have yet been modeled nor have all wound roll defects been quantified in terms of wound roll stresses. The models are currently quite useful but with the amount of research which is currently being concentrated upon model development and defect analyses it is quite possible in the near future that thorough estimates of wound roll quality will be made entirely from computations. Thus what has previously been deemed a black empirical art where many rolls are wound under various winding conditions in attempts to reduce defects is becoming a ***science*** in which optimal winding conditions are studied based upon computed results, profiles for winder tension and nip loading will be selected, and hopefully the time required to setup a specific winder to wind a specific paper grade will be greatly reduced.

REFERENCES

1. Gutterman, R.P., "Theoretical and Practical Studies of Magnetic Tape Winding Tensions and of Environmental Roll Stability." US Contract No. DA-18-119-SC-42, 1959.

2. Catlow, M.G., and Walls, G.W., "A Study of Stress Distribution in Pirns." Journal of Textile Institute, Part 3, 1962, pp.T410-429.

3. Altmann, H.C., "Formulas for Computing the Stresses in Center Wound Rolls." TAPPI Journal, Vol. 51, No.4, 1968, pp. 176-179.

4. Yagoda, H.P., "Integral Formulas for Wound Rolls." Mechanics Research Communications, Vol.7, No.2, 1980, pp. 103-112.

5. Pfeiffer, J.D., "Internal Pressures in a Wound Roll of Paper." TAPPI Journal, Vol. 49, No. 8, 1966, pp 342-347.

6. Hakiel, Z., "Nonlinear Model for Wound Roll Stress." TAPPI Journal, Vol. 70, No. 5, 1987, pp.113-117.

7. Willett, M.S. and Poesch,W.L., "Determining the Stress Distributions in Wound Rolls of Magnetic Tape using a Nonlinear Finite Difference Approach." ASME Journal of Applied Mechanics, Vol.55, 1988, pp.365-371.

8. Pfeiffer, J.D., "Measurement of the K2 Factor for Paper." TAPPI Journal, Vol. 64, No.4, 1981, pp. 105-106.

9. Yagoda, H.P., "Resolution of a Core Problem in Wound Rolls." ASME Journal of Applied Mechanics, Vol.47, 1980, pp. 847-854.

10. Eriksson, L.G., and Rand, T., "Physical Properties of Newsprint during Winding." TAPPI Journal, Vol. 56, no. 6,

1973, pp. 153-156.

11. Pfeiffer, J.D., "Mechanics of a Rolling Nip on Paper Webs." TAPPI Journal, Vol. 51, No.8, 1968, pp. 77A-85A.

12. Good, J.K., and Wu, Z., "The Mechanism of Nip Induced Tension in Wound Rolls." accepted for publication the ASME Journal of Applied Mechanics, 1992.

13. Good, J.K., and Fikes, M.W.R., "Predicting Internal Stresses in Centerwound Rolls with an Undriven Nip Roller." TAPPI Journal, Vol. 74, no. 6, 1991, pp. 101-109.

14. Good, J.K., Wu, Z., and Fikes, M.W.R., "Stresses within Wound Rolls Wound in the Presence of a Nip Roller", Proceedings of the First International Conference on Web Handling, Web Handling Research Center, Stillwater, Oklahoma, May 19-21, 1991.

15. Good, J.K., Wu, Z., and Fikes, M.W.R., "The Internal Stresses in Wound Rolls with the Presence of a Nip Roller", accepted for publication the ASME Journal of Applied Mechanics, 1992.

16. Good, J.K., and Fikes, M.W.R., "Using FSRS to Measure Radial Pressure in Wound Rolls", Proceedings of the First International Conference on Web Handling, Web Handling Research Center, Stillwater, Oklahoma, May 19-21, 1991.

17. Monk, D.W., Lautner, W.K., and McMullen, J.F., "Internal Stresses within Rolls of Cellophane." TAPPI Journal, Vol. 58, No.8, August 1975.

18. Kedl, D.M., "Use of Two-Dimensional Winding Models to Predict Wound Roll Stresses that Occur due to Circumferential Steps in Core Diameter or to Cross Web Caliper Variation." Proceedings of the First International Conference on Web Handling, Web Handling Research

Center, Stillwater, Oklahoma, May 19-21, 1991.

19. Hakiel, Z., "On the Effect of Width Direction Thickness Variations in Wound Rolls." Proceedings of the First International Conference on Web Handling, Web Handling Research Center, Stillwater, Oklahoma, May 19-21, 1991.

20. Cole, K.A., and Hakiel, Z., "A Nonlinear Wound Roll Stress Model Accounting for Widthwise Web Thickness Nonuniformities." Proceedings of the 1992 Winter Annual Meeting of the American Society of Mechanical Engineers, Symposium on Web Handling, Nov 8-13, Anaheim, California, AMD- Vol. 149, 1992, pp. 13-24.

21. Good, J.K., and Pfeiffer, J.D., "Tension Losses During Centerwinding." Proceedings of the TAPPI 1992 Finishing and Converting Conference, Nashville, TN, Oct 18-21, 1992, TAPPI Press, 1992, pp 297-305.

22. Good, J.K., Pfeiffer, J.D., and Giachetto, R.M., "Losses in Wound-On-Tension in the Centerwinding of Wound Rolls." Proceedings of the 1992 Winter Annual Meeting of the American Society of Mechanical Engineers, Symposium on Web Handling, Nov 8-13, 1992, Anaheim, California, AMD- Vol. 149, 1992, pp. 1-12.

Transcription of Discussion

THE SCIENCE OF WINDING OF PAPER ROLLS

J K Good

B Phillips, Shotton Paper Co plc, UK

Thank you for your interesting paper. I have a couple of enquiries. I notice that your model only extends to rather small radii - I am in the newsprint business and we wind to 1250mm. Secondly, I notice we are talking about centre winding here. As far as I know in the newsprint industry we have not centre wound for 20 years.

Do your models extend to conventional two drum winders?

J K Good

In response to your first comment, let me say, at Oklahoma State University I have winders but they are not large winders. So that is the reason we saw rolls not being wound to large radii. In terms of these models being applicable to large diameter rolls, yes they are. In answer to your second question: I presented how these models can first of all model centre winding with an undriven nip. I cannot present these results to you at the moment since I work within a proprietary consortium but I can tell you that these models already have been adapted to handle surface winding which is what you do with either a duplex winder or two drum winder. So, I can only tell you, yes, the models are applicable with appropriate modifications.

B Phillips

Most of our problems do not come from near the core area because we have that sorted out by now, but on the larger diameter there are problems with the winder wrinkles (pucker wrinkles, crepe wrinkles, two minute puckers) at the outside within a couple of centimetres on the top of the reel. How can you explain that on your circumferential stress model?

J K Good

Let us discuss crepe wrinkles. You saw that in all cases, the radial pressure within the wound roll is decaying rapidly as we approach the outside of the winding roll. One of the common problems of winders, especially surface winders, is that as we near the end of the wind, we also lose tension because we are cutting off one roll and begin winding on another core. The web line tension may drop low right at the end of the wind. The radial pressures are going to be quite low and resistance to slippage between layers has become minimal. Now in terms of the phenomenon that can cause slippage to occur – it is the rolling resistance between the nips and the winding roll that is making layers slip and finally compress into the short period wrinkles you are experiencing. It does not surprise me that you see crepes only near the outside of the roll since the resistance to slippage is minimal at the outer radii.

Let me follow on to that, and say that you may think you have solved most of your core problems – we have sat and listened to discussions on viscoelasticity of paper in the last few days but cores are just as viscoelastic as paper is. People who are not in tune with this in making sure that their cores are subjected to the same environment and moisture levels at which they are going to be wound, with paper in many cases, find their cores falling out or core slippage occurring. I do not think the issues of cores are as simple as may be thought.

Dr R Popil, MacMillan Bloedel Research, Canada

You have alluded to the fact that the radial and the circumferential modulii are controllable through the papermaking process. Are these two quantities related to the transverse modulus and in-plane modulus of paper? Secondly, you referred to the phenomenon of starring. Is that related to the CD corrugations that you see quite often on the winding of rolls which is referred to as "fluting"?

J K Good

The answer to the second question is yes. The answer to the first question was alluded to in my presentation but the circumferential modulus in the wound roll is the MD modulus of the paper. How much control you really have over the radial modulus is somewhat unclear to me. I know that it is effected by calendering. Calendering will make the paper smoother, increase density, and decrease thickness but if it is a parameter which you have control over or not, that is not obvious to me at this point.

Dr C Fellers, STFI, Sweden

I am interested in the friction aspect here. I am currently involved in ISO Standardisation and development of new equipment. Are you aware of any measurements of the effect of these high pressures - about two orders of magnitude higher than normal - on friction?

J K Good

When I approached friction in my study here it was in its use in the wound-on-tension equation. My point to you would be is that I would be testing friction using an apparatus that looked somewhat like a winder for my application, because the ASTM specification has this 2" x 2" flat plate and it puts a uniform pressure over the surface of the paper, much different from a passing nip. I see that the standardisation of the coefficient of friction measurement is going to be a very difficult thing to do because in that the coefficient of friction of paper depends on a number of things. You can run the ASTM test with constant load and keep running it on the same paper sample and you will see the coefficient of friction first decrease because of the smoothing effect of calendering the paper and then later as the paper begins to gall the coefficient of friction will increase.