What FEA Analysis Can Tell Us About Spreaders

Jerry Brown
Essex systems
April 17, 2008 **Edited 12/10/09**

Introduction:

Concave and curved rollers are known to be effective spreaders and are commonly used in web processes. However, they are often misunderstood and misapplied. This presentation will use FEA graphics to show how they work and to illustrate limitations in their application.

The root cause of wrinkles is compressive stress. This is illustrated by the small red arrows near the downstream roller in Figure 1. Compressive stress in the span produces troughs that deepen until they reach a critical point where one (or more) may propagate onto the roller surface. Once formed, the wrinkle then grows and collapses on itself to become a permanent crease.

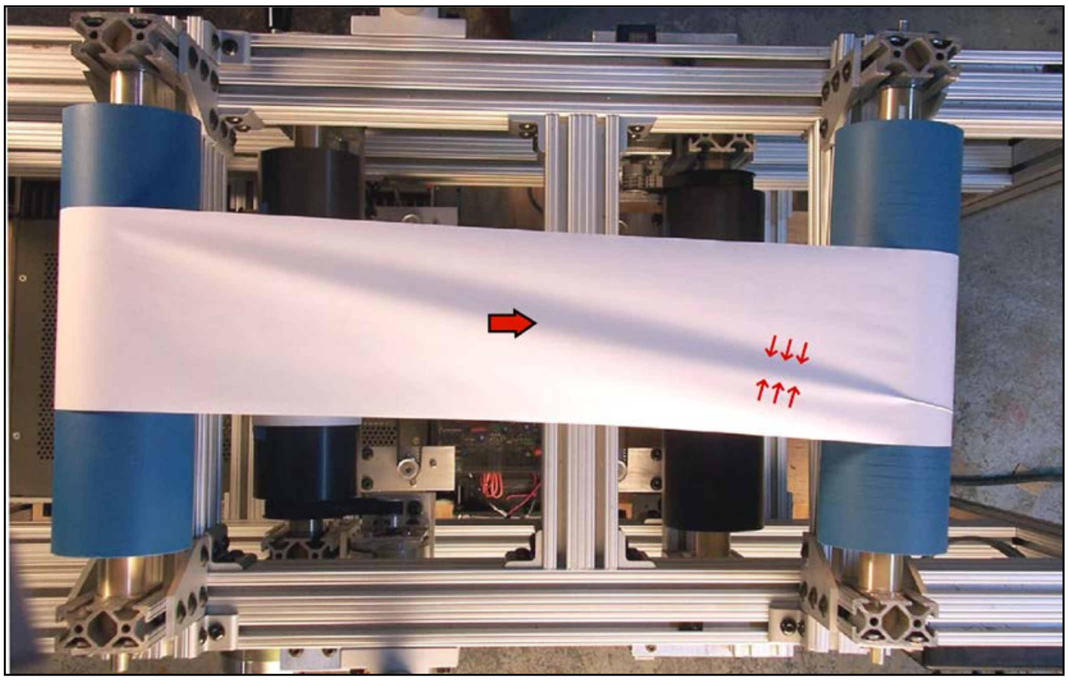

Figure 1
Compressive stress

One way to eliminate wrinkles is to eliminate the compressive stress. Two of the most common devices for doing this are concave and curved rollers.

One of the first things that FEA analysis can do for us is show us what a compressive stress pattern looks like. The setup in Figure 1 will be used as an example. Parameters for this experiment were: Length of span – 18 inches, Width of web – 4.5 inches, Thickness – 0.003 inch, Tension – 6 Lbf, Modulus – 500,000 psi, misalignment – 2.7 deg, Poisson's ratio – 0.25, Nominal MD stress - 444 psi.

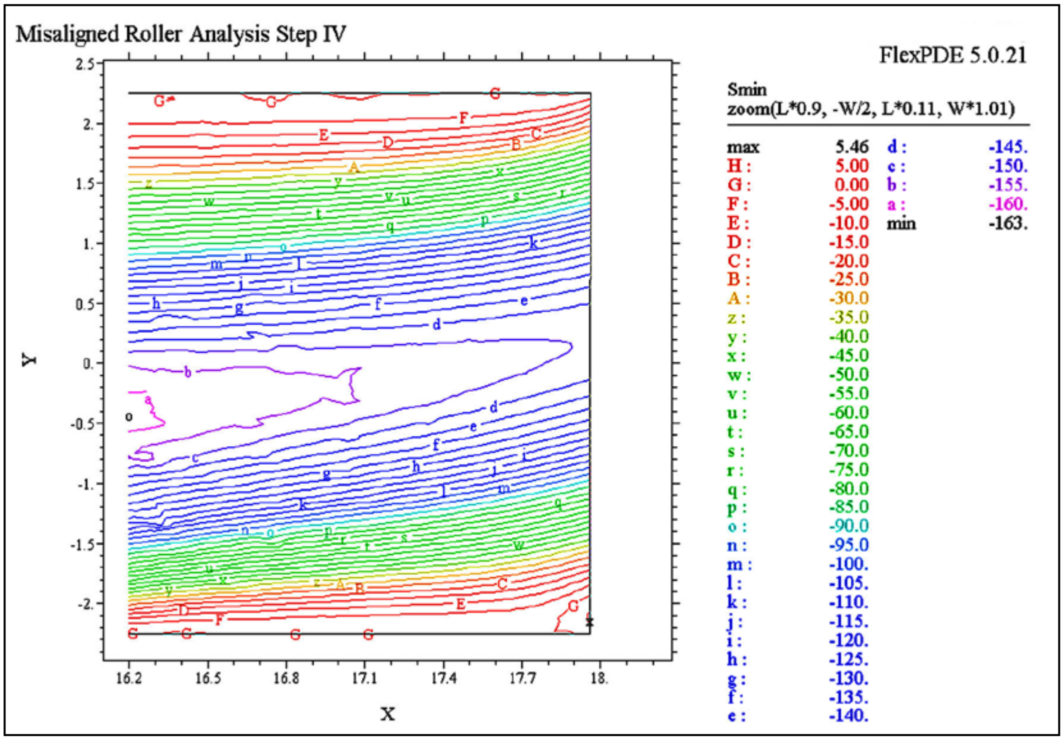

Figure 2

CD stress contour plot at entry to misaligned roller

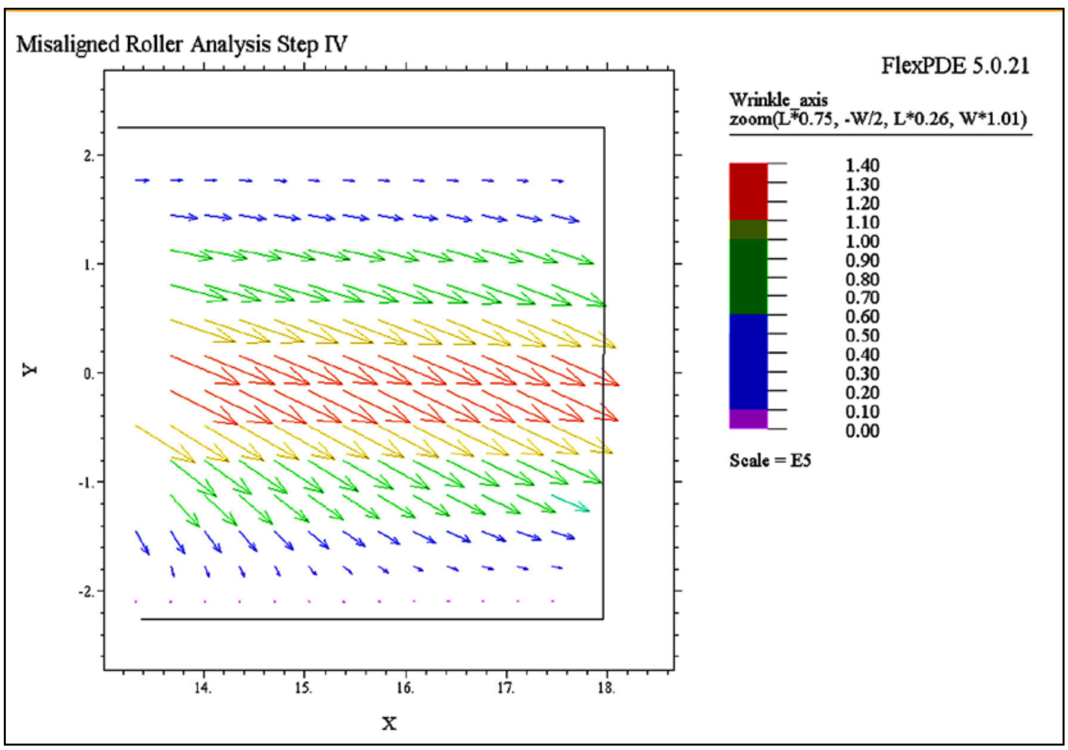

Figure 3

Wrinkle vector plot

Direction = Maximum MD stress. Magnitude = CD×MD stress magnitudes.

It should be noted that throughout this paper a negative value is understood to mean compressive stress.

Figure 2 shows the minimum CD stress. This stress is not oriented precisely in the CD direction. Shear stress rotates the stress field so that the maximum stress is rotated approximately -24 degrees from horizontal, which is aligns it with the trough in Figure 1. The minimum CD stress is therefore at an angle of -24 degrees relative to the vertical. Figure 3 attempts to provide a qualitative sense of the direction of the troughs and their location. Each of the vectors is aligned with the maximum MD stress at its location. The magnitude of the vector is set to zero if the minimum CD stress is not compressive. Otherwise, the vector magnitude is equal to the product of the two stresses.

Fundamental concepts:

Bowed rollers depend primarily on operation of the normal entry rule.

> *A web entering onto a roller will align its direction of travel perpendicular (normal) to the roller axis. If the web is not initially perpendicular, it will travel laterally on the roller at a rate proportional to the tangent of the angle between the web and the roller until it reaches the perpendicular condition.*

An extreme example is illustrated with a latex web at a misaligned roller in Figure 4.

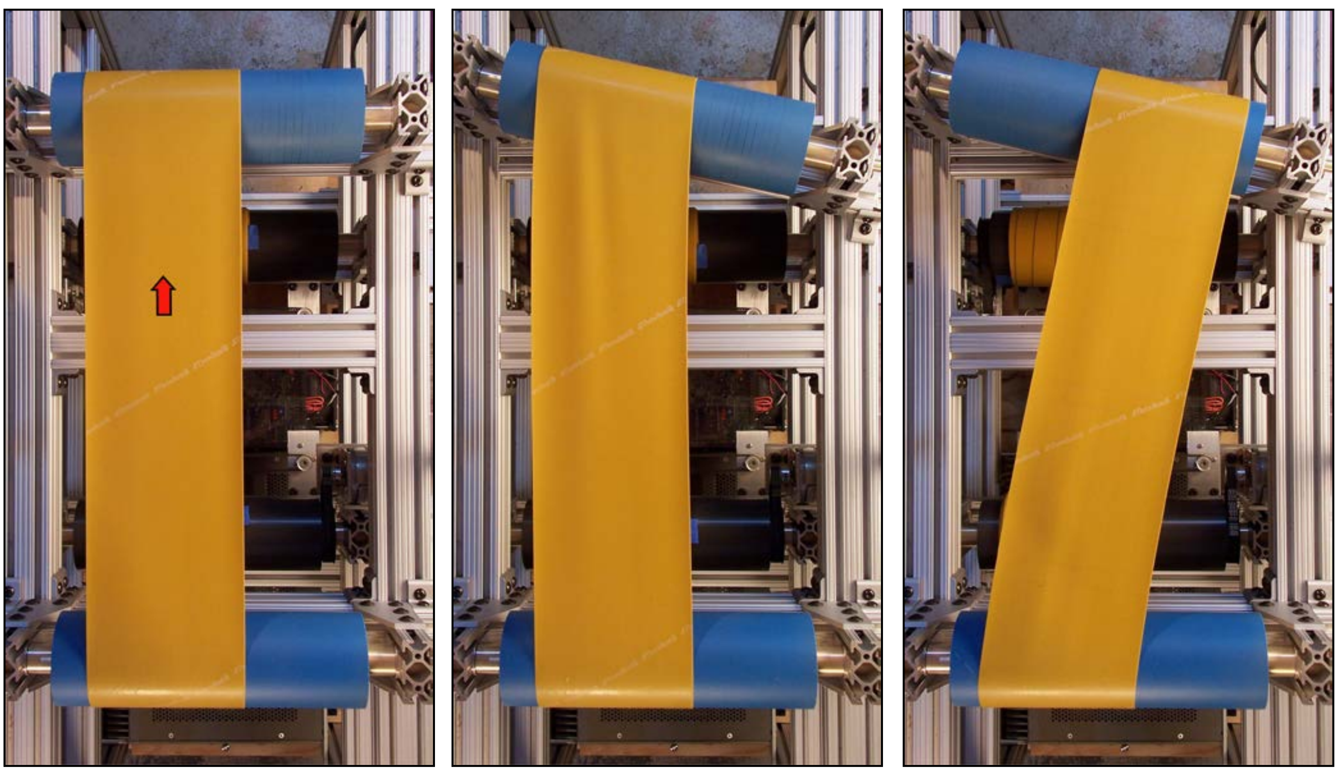

Figure 4

(a) Web traveling between aligned rollers
(b) Downstream roller misaligned by 12 degrees
(c) Final position of web after running long enough to reach its steady position

Concave rollers rely primarily on operation of the normal strain rule.

> *In a steady state, the ratio of the stretched lengths of an infinitesimal patch of the web at the entries of two successive rollers is proportional to the respective ratios of the web velocities at the two rollers (provided the strains and velocities are measured normal to the roller axes). In other words, if the web speeds up by 1% relative to the previous roller, it will have to elongate by 1% to insure that the mass flow is the same at the two locations.*

For a web of uniform thickness, the same rule applies across the web. For example, if the mass flow rate at each point across the upstream roller is constant (uniform diameter and uniform MD tension), then the mass flow rate at each point across the downstream roller must be constant, <u>regardless of its shaper</u>. This is why concave rollers spread. The explanation is as follows.

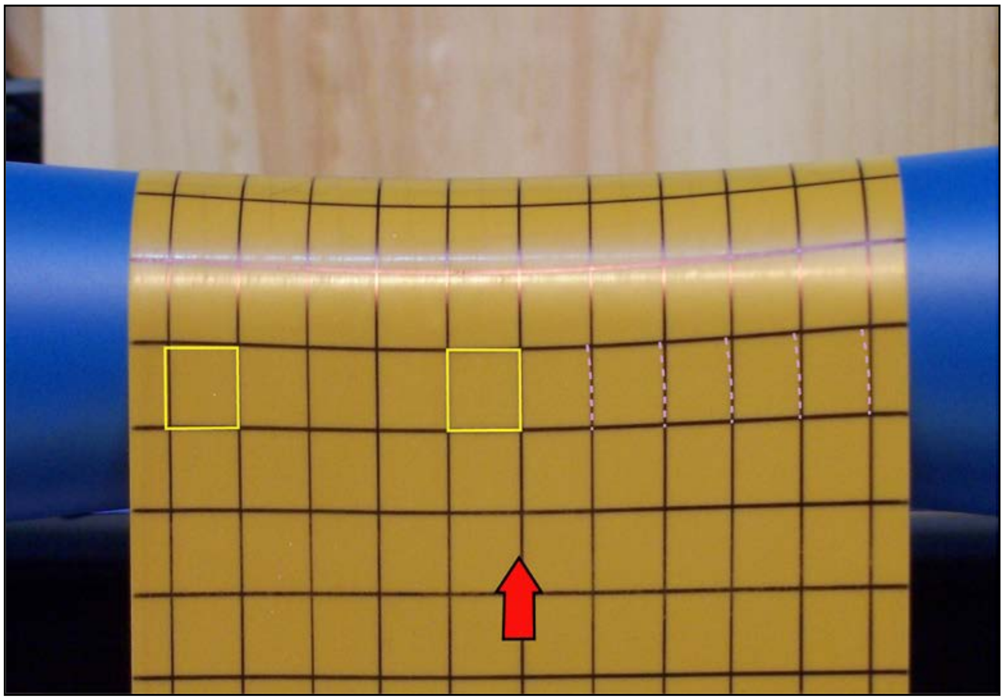

Figure 5
Illustration of normal strain

Figure 5 show a latex web on a highly exaggerated concave profile (don't try this at home). The increased roller circumference at the web edges produces higher speed at the edges relative to the middle. This in turn produces higher tension at the edges than at the center. This can be seen in Figure 5 by examining the yellow boxes. They were drawn on the photo, using photo-editing tools and have exactly the same dimensions. The black grid was drawn directly onto the web when it was in a relaxed state. The yellow box near the center fits the black grid perfectly. Near the left edge, the black grid has stretched in the MD direction so that it is a little longer than at the middle. There is also a small amount of CD contraction of the black grid due to Poisson's ratio. The overall effect, therefore, of the concave roller profile is to cause each of the black horizontal lines to take the shape of a "smile" at the roller. If it were not for the normal entry rule, the vertical lines of the grid would remain perpendicular to the curved horizontal line, causing them to "toe" in towards the center (like the dashed violet lines drawn on the photo). This doesn't happen because normal entry rule causes them to spread outward to meet the roller perpendicular to its axis. The net result is lateral spreading.

Spreading with a bowed roller:

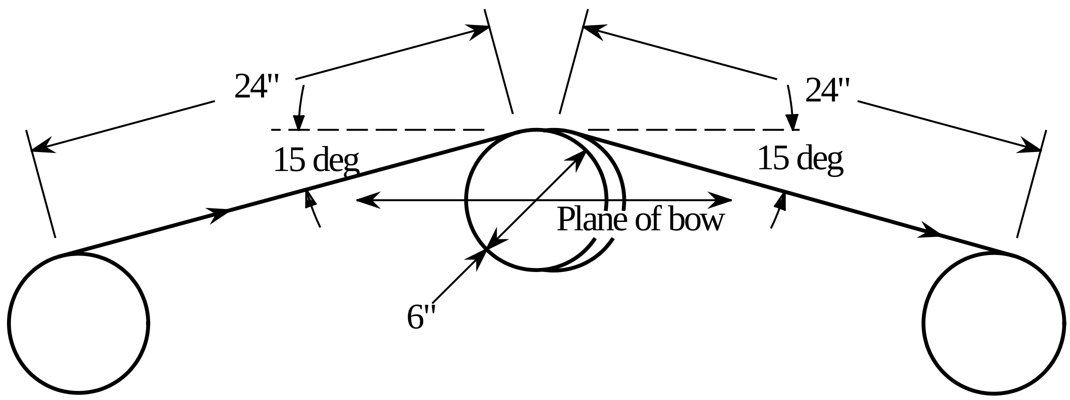

Figure 6
Bowed roller application

Figure 6 shows a typical bowed roller application. The perpendicular to the plane of the bow bisects the wrap angle to minimize pass line difference between the center and edges of the web. Other parameters are:

Width = 60 inches
Thickness = 0.0005 inch
Modulus = 600,000 psi (PET)
Poisson's ratio = 0.35
Roller length = 72 inches
Coefficient of friction between web and roller = 0.5

Bow is expressed in terms of the depth of the curve at the center relative to the ends of the roller. Three values will be studied – 0.02 and 0.04 and 0.08 inch. Results for CD and MD stress at the downstream ends of the entry and exit spans are shown in Figure 7, Figure 8, Figure 9 and Figure 10.

Also shown is a set of curves in Figure 11 that indicate whether the web will slip on the roller surface. For each case there are two curves. One is called the friction rate. It is a measure of the frictional resistance to moving on the roller surface for every point along the line of contact at the roller entry. The other is called the stress rate. It is a measure of the force trying to move the web at the same points. At points where the stress rate exceeds the friction rate, the web will slip.

Figure 7 shows that, for 0.08 inches of bow, the peak CD (spreading) stress at the entry to the bowed roller is almost equal to the nominal MD stress. Furthermore, the MD stress profile is affected very little by the spreading. Figure 8 shows that much of the spreading stress has disappeared at the next roller. But, there is a small residual effect. Figures 9 and 10 show the full stress patterns for both spans. It is evident that the exit span should be kept short if spreading action is required at the next roller (for example going into a nip).

Bowed rollers are often misapplied. A bow of 0.08 inches for a 72 inch roller doesn't sound like much. Larger bows would create a situation where the web would either have to slip laterally or reach CD stress levels exceeding the line tension.

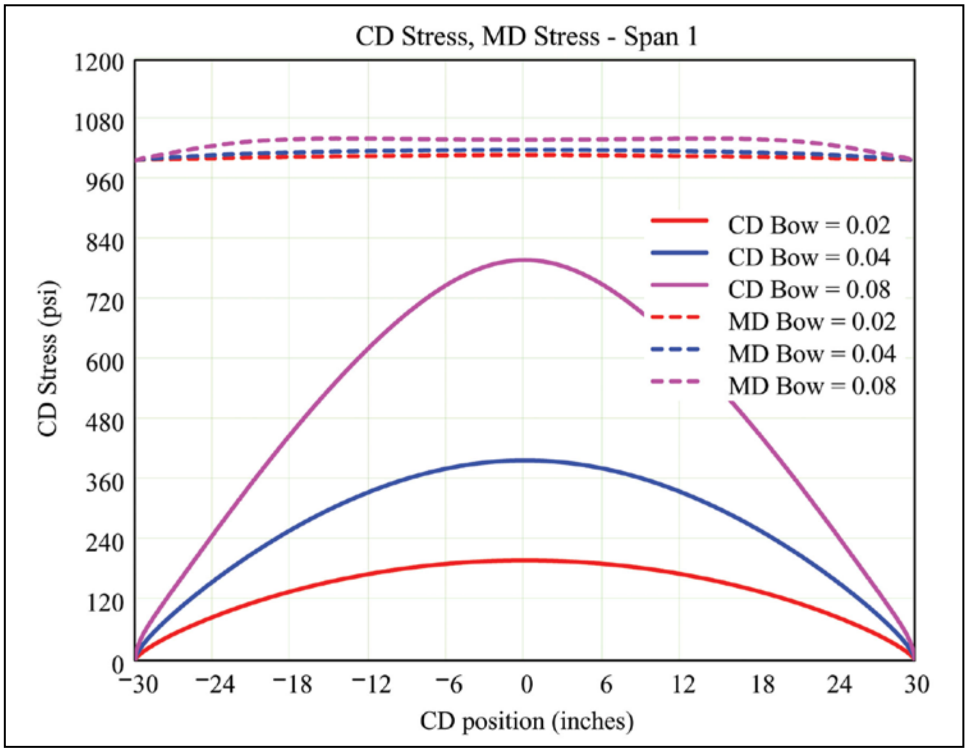

Figure 7
CD and MD stress at downstream end of entry span of bowed roller

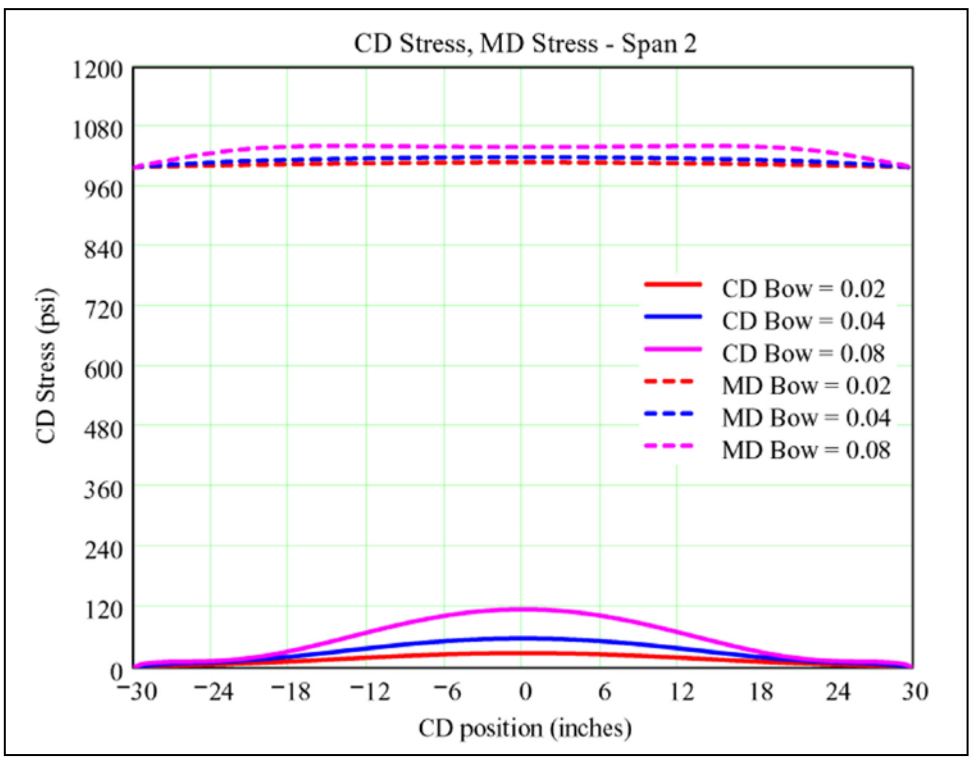

Figure 8
CD and MD stress at downstream end of exit span of bowed roller

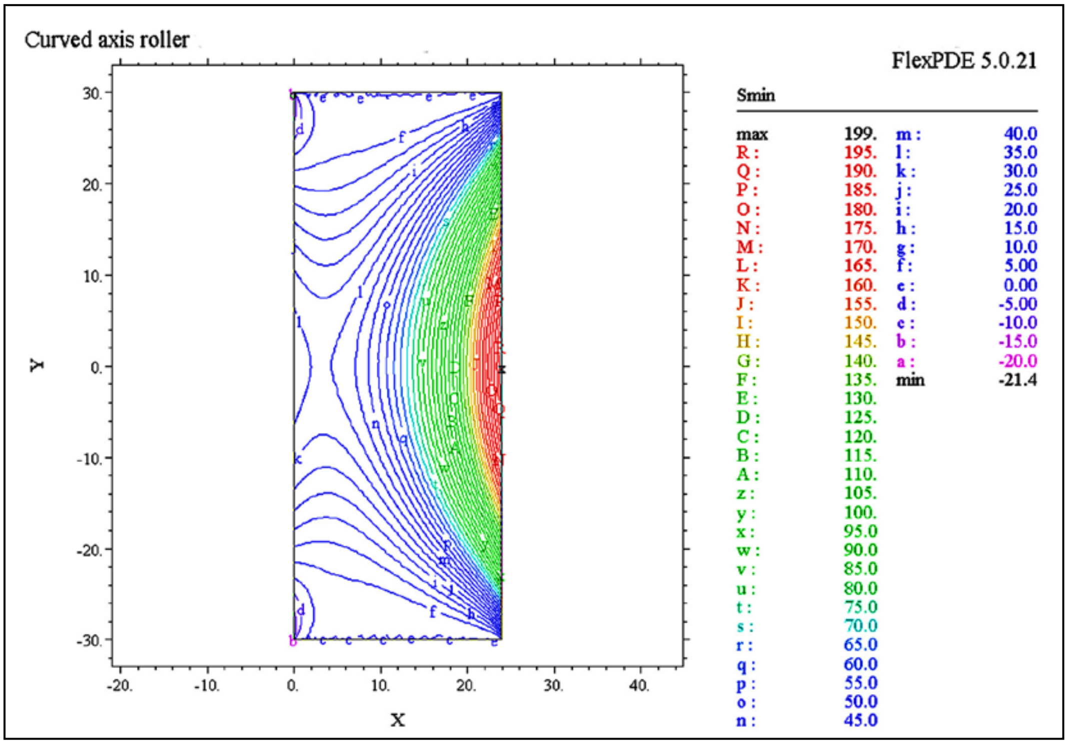

Figure 9

CD stresses in curved roller entry span – 0.02 inch bow

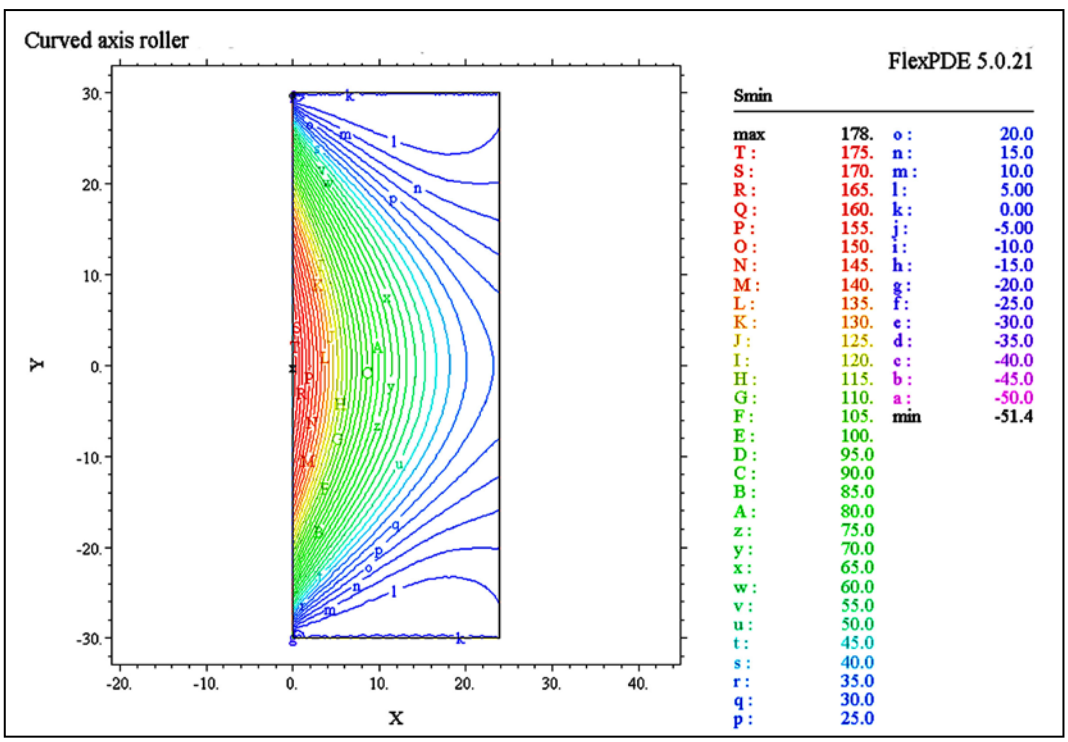

Figure 10

CD stresses in curved roller exit span - 0.02 inch bow

There is one last issue to address and that is whether there is sufficient traction on the roller to support the spreading action. Only the curves for maximum bow of 0.08 inch are shown since this is the worst case. The yellow curve is the friction rate. It is a measure of the frictional resistance to moving on the roller surface at every point along the line of contact at the roller entry. The blue curve is the stress rate. It is a measure of the forces trying to move the web. At points where the stress rate exceeds the friction rate, the web will slip. This happens only in a very narrow zone at each edge.

The friction rate is based on a friction coefficient of 0.5. Other values can be evaluated by scaling. For example, a coefficient of 0.25 would reduce the values on the yellow curve by 50%.

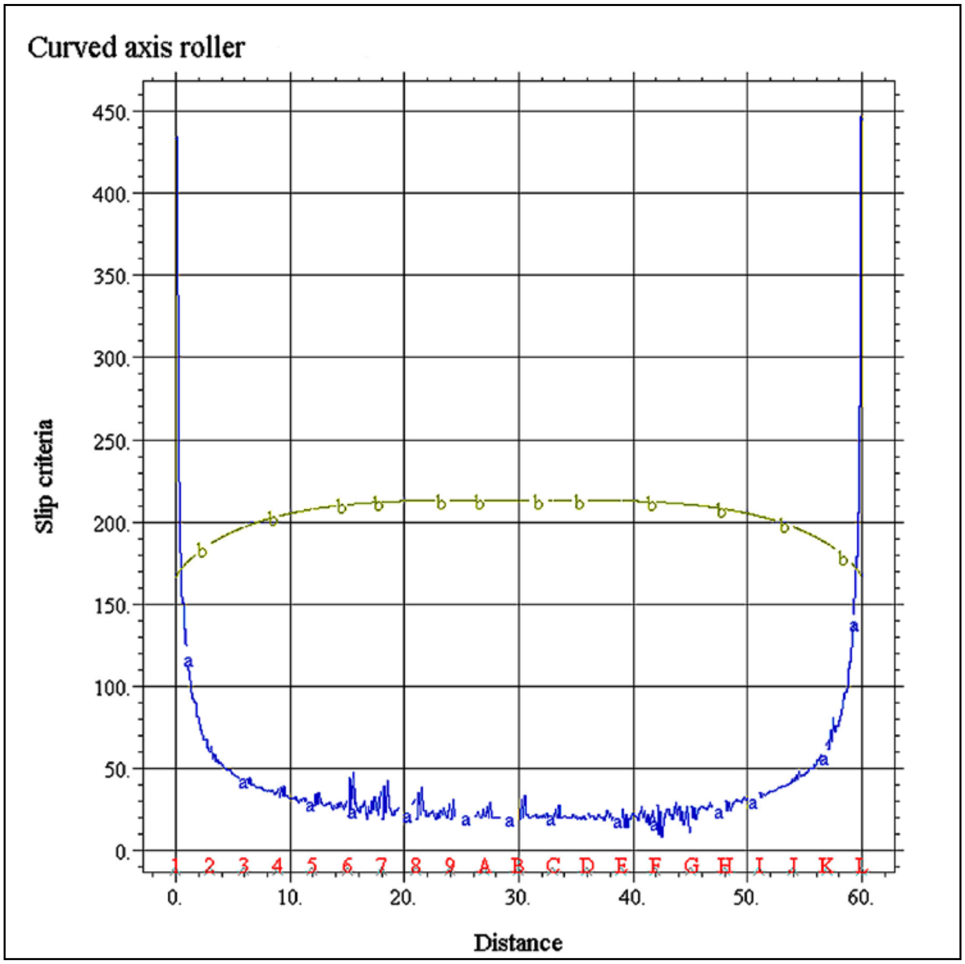

Figure 11
Web traction on bowed roller – 0.08 inch bow.

Spreading with a concave roller:

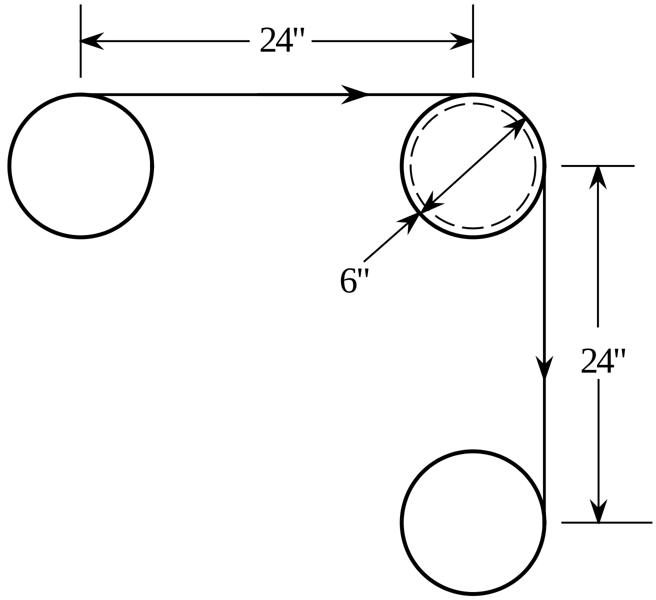

Figure 12
Concave roller application

Figure 12 shows a typical concave roller application. Web parameters are the same as in the case of the bowed roller.

The concave profile is circular and is specified by the depth of the profile on the radius at the center. Three profiles are studied - 0.005, 0.01 and 0.015 inch. Results similar to those for the bowed roller are presented in the following graphs.

Figure 13 shows that much of the CD spreading is at the expense of the MD profile. As the spreading gets more aggressive the center of the MD profile dips lower. The average MD tension doesn't change. But the tension available to produce traction is reduced in the center part of the roller where the spreading is strongest.

Note that the MD stress profile at the entry and exits of the concave roller are very different. At the entry the highest MD stress is at the center. At the exit, the lowest MD stress is at the center. This is not a mistake. It is due to the way that strain is transported into the exit span.

Examination of this and other studies leads to the following observations about concave spreaders.

- Very stiff materials such as PET require profiles that may be so shallow that they are of the same magnitude as the roller manufacturing tolerances.
    - For single-purpose lines, running constant width, it may be possible to optimize the profile design to overcome this difficulty.
- This type of spreader works best on stretchy materials like polyethylene.
- The benefits of spreading are seen mostly on the spreader roller itself. If the concern is spreading downstream, such as at the entrance to a nip, the exit span should be kept short.

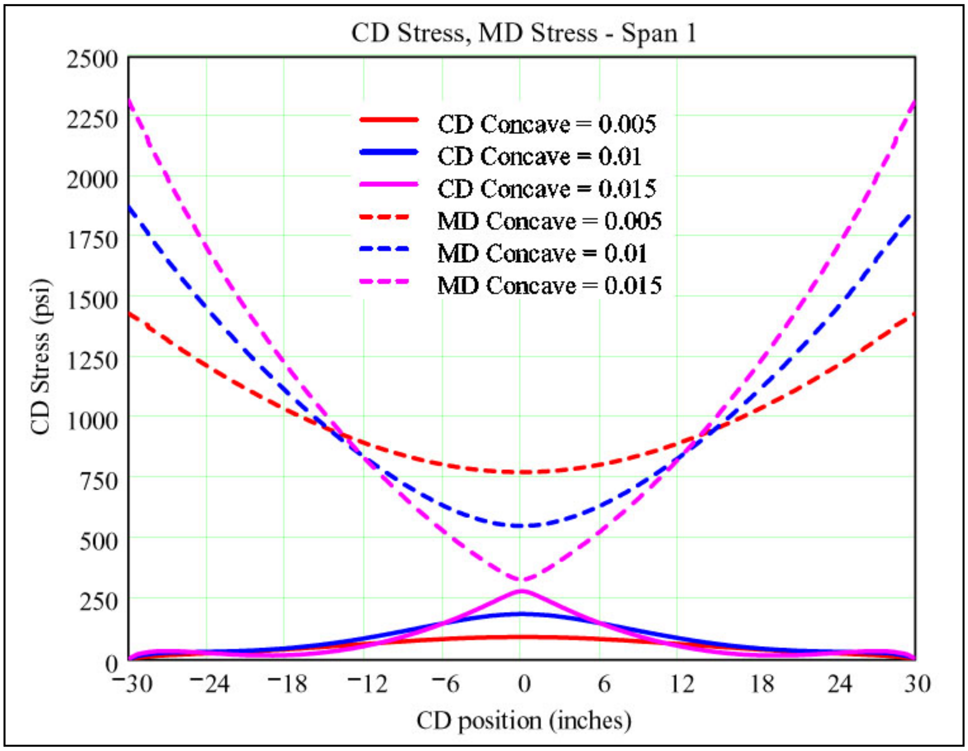

Figure 13
CD and MD stress at downstream end of entry span of concave roller

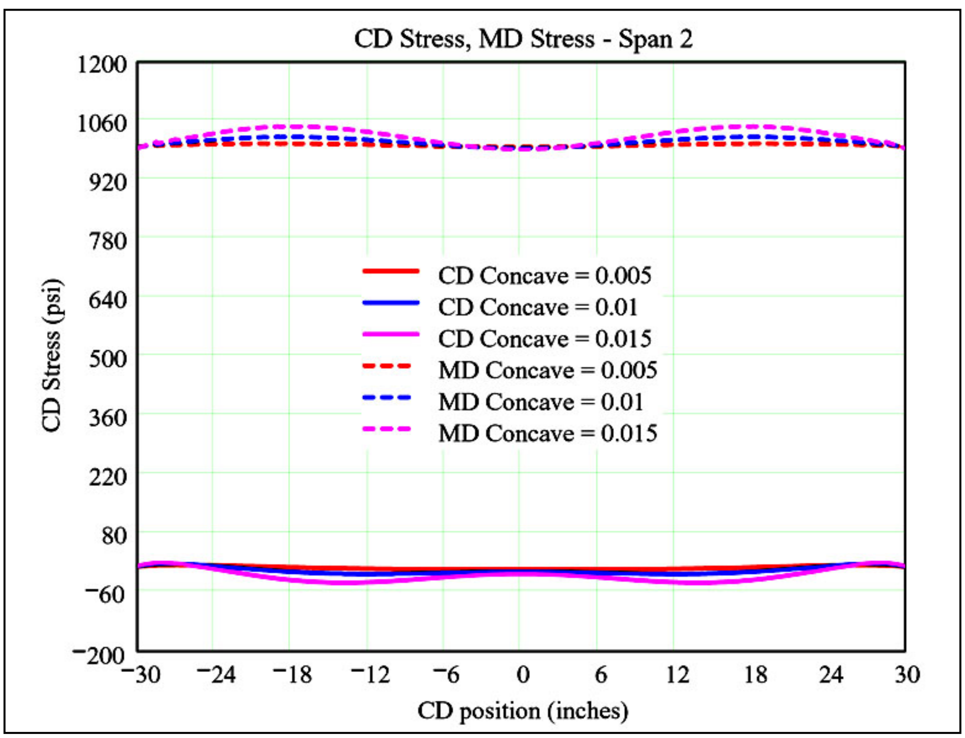

Figure 14
CD and MD stresses at downstream end of exit span of concave roller

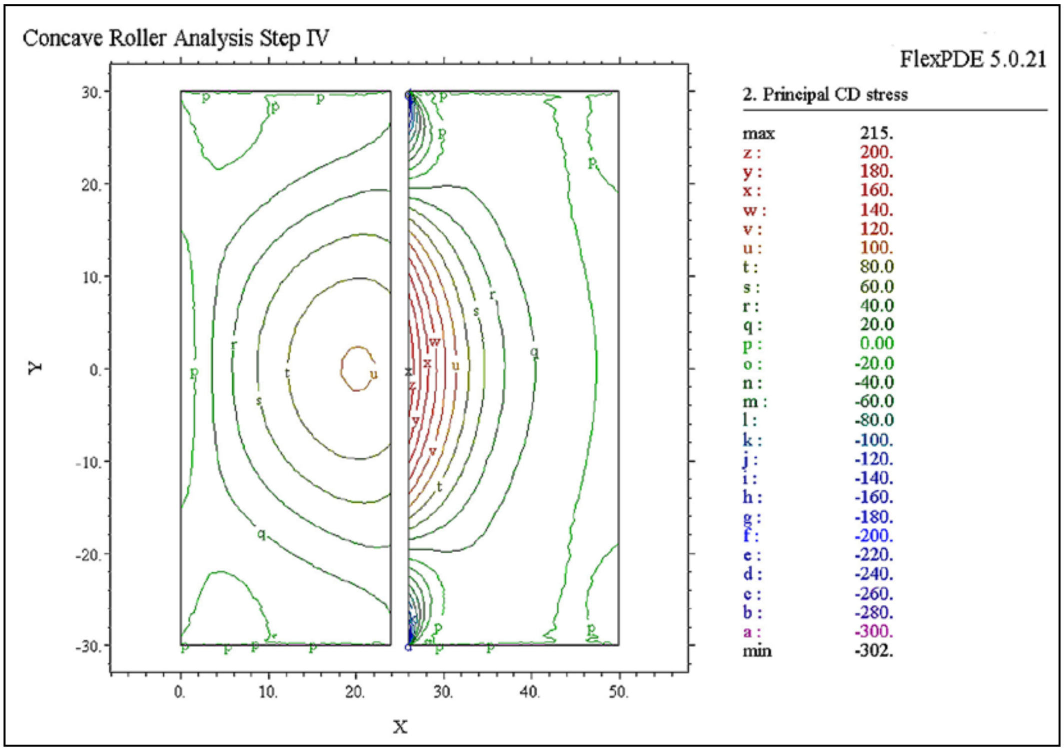

Figure 15
CD stresses in concave roller entry and exit spans – 0.005 in depth

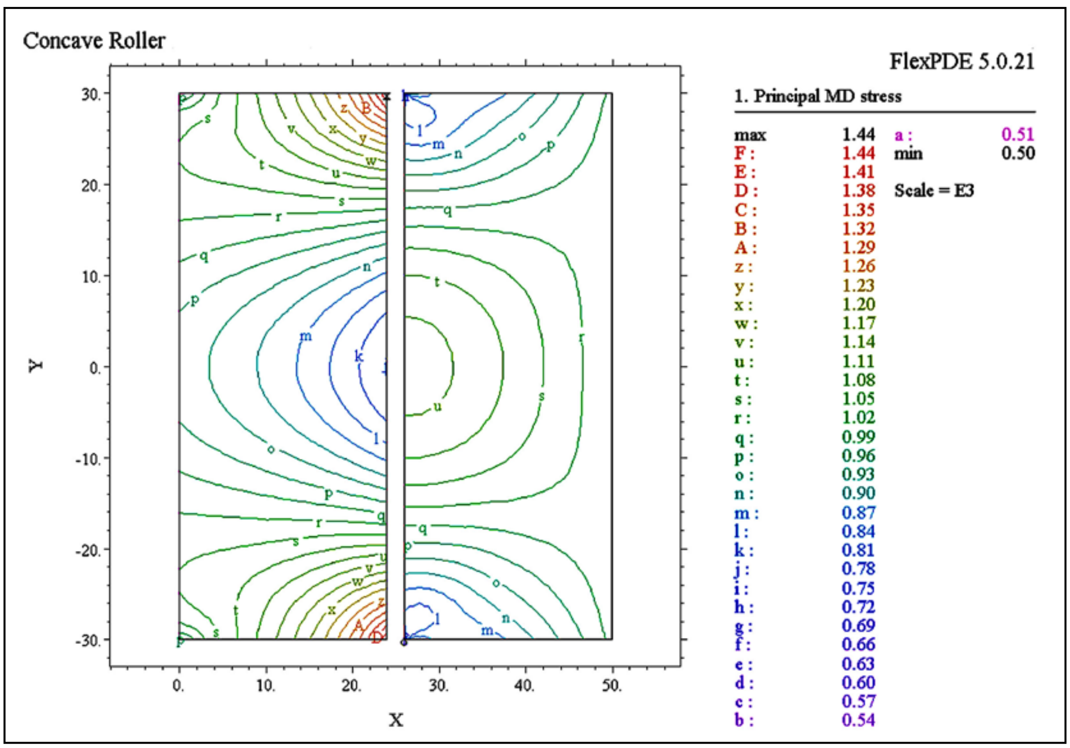

Figure 16
MD stresses in concave roller entry and exit spans – 0.005 in depth

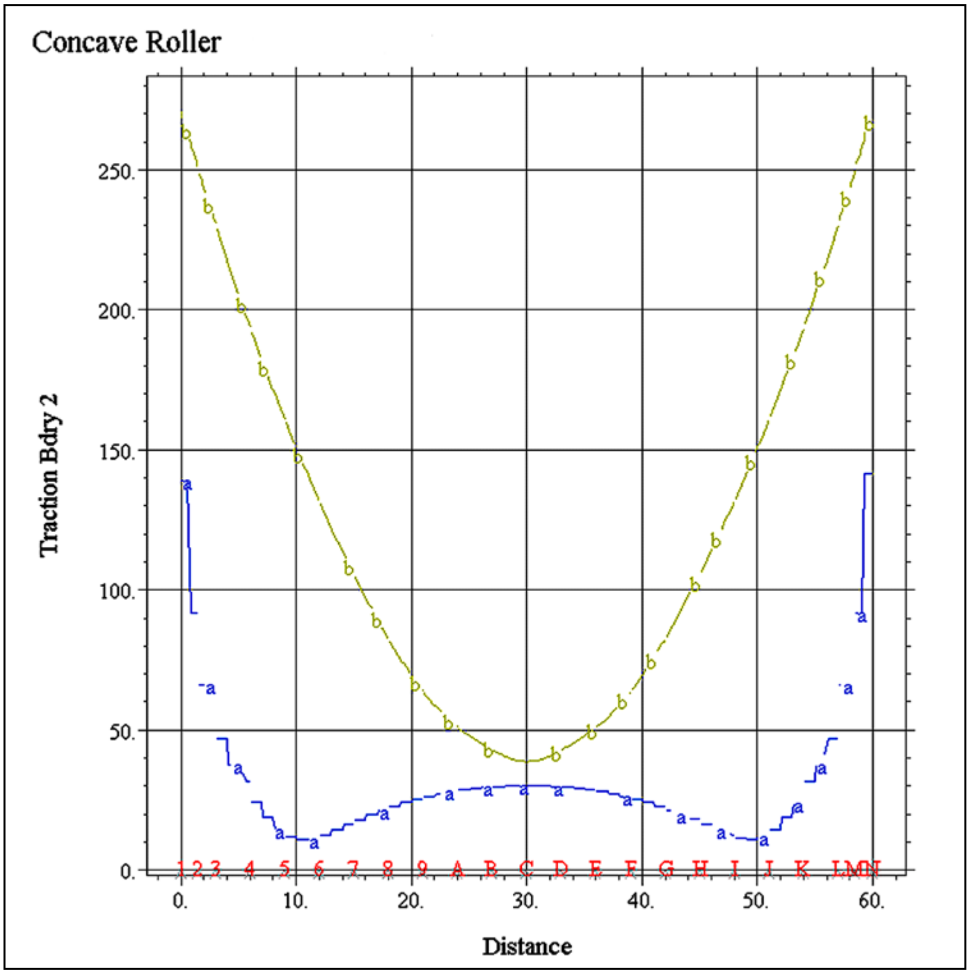

Figure 17
Web traction on the concave roller – depth 0.015 inch.

The concave roller discussion would not be complete without examining tape bumpers – the application of a band of thin tape around the circumference of the roller to produce a stepped profile. A study was done using the same application parameters as the other cases except that the profile was a 0.005 inch step on the radius that extended for one inch under each edge. Figure 18 shows that this produces a nice flat CD stress profile. It should be very effective at eliminating wrinkles. There are two zones at the transition from the tape to the roller where shear stresses create pronounced negative spikes. But, these are not generally wide enough to create problems, provided the spreading is kept modest.

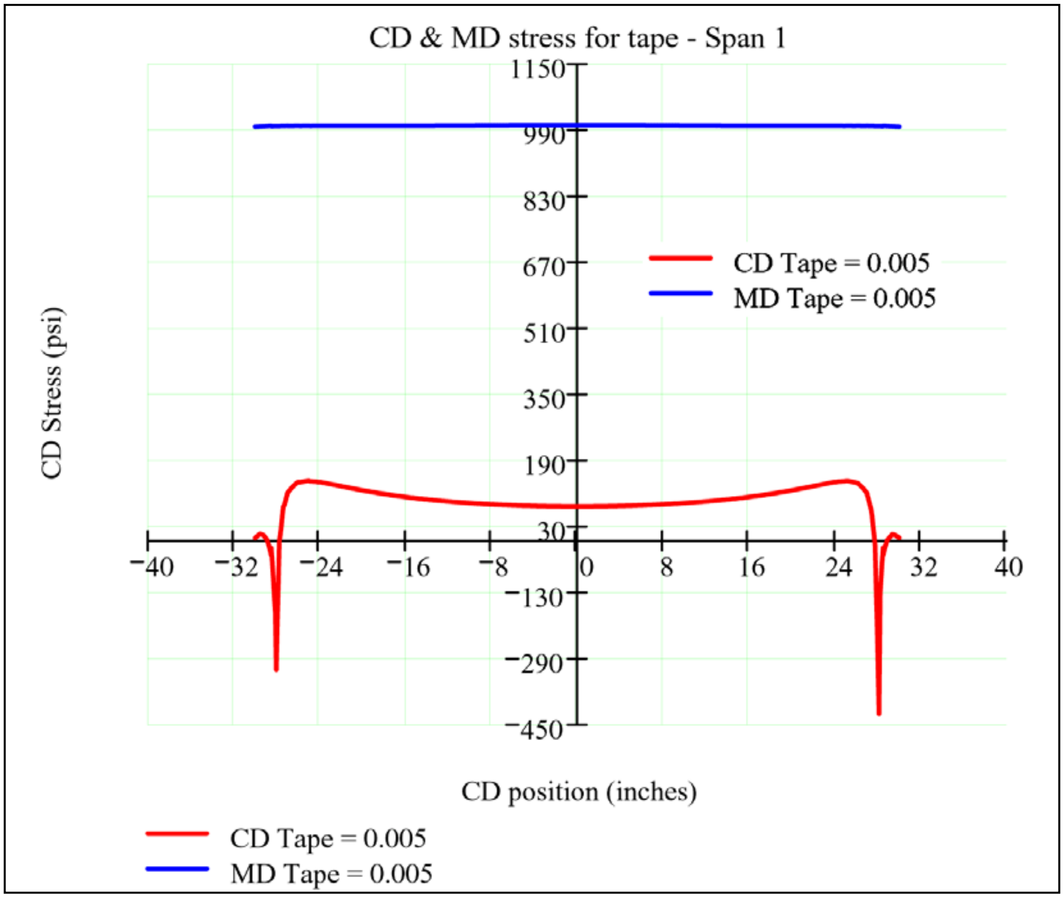

Figure 18
Spreading using 5 mil tape bumpers

Conclusions:

Bowed rollers are very effective spreaders that are theoretically superior to concave rollers. It is unfortunate that they have so many mechanical drawbacks – high turning torque, large tolerances on their diameter and high maintenance due bearing wear and flexural fatigue of the covering. Also, since most current designs offer features for adjusting bow and orientation they provide endless opportunities for misguided tinkering with the process.

Concave rollers can be very effective, low-maintenance spreaders if they are designed carefully for an application. Misapplied, they can be disastrous.

It is easy to overdo spreading of both types.

Bibliography:

Brown, J.L., "A New Method for Analyzing the Deformation and Lateral Translation of a Moving Web," Proceedings of the Eighth International Conference on Web Handling, June 2005, pp 39-59