ROLL DESIGN EFFECT ON NIP PRESSURE

by

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ABSTRACT

The quality of reeling process is a key factor in achieving production efficiency, especially when machine speed and paper width continue to increase. For calendered and coated grades of paper the main problems are the formation of air entrapment, web instability and wrinkles. Nip pressure may be used as a tool for controlling the air entrapment as well as for limiting large wound on tension that would lead to yielding or wrinkling defects within the wound roll.

In this paper nip pressure is studied as a function of geometrical and material parameters of the rolls in order to identify and quantify their individual and cumulative influence. For this purpose measurements with Tekscan's pressure-sensing technology and Fuji's colour-forming and developing films were performed together with finite element calculations.

The results offer a better understanding of the connection of geometrical and material parameters to the quality of reeling process and can be used as practical guidelines for designing reeling rolls.

NOMENCLATURE

a	width of the nip
D	nominal roll diameter
E_0	Young's modulus for rubber
F	nip load
k	material parameter for rubber, calculated as a function of hardness
p	contact pressure
r	radius of the contact circle

S	shape factor for rubber
t	rubber cover thickness
w	width of roll pair in contact
α_R	coefficient calculated as a function of radial deformation of rubber
β_R	coefficient calculated as a function of radial deformation of rubber
δ	penetration of rubber covering due to nip load
ν	Poisson's coefficient

INTRODUCTION

In literature the reeling process is considered a special case of the winding process [3] and a lot of research is concentrated on this subject. What makes reeling different, is the length, shape, material and deflection of the rolls, which contribute to the highly non-linear nature of the phenomenon. When non-permeable web materials are reeled, undesirable air entrapment occurs, which leads to poor quality of wound roll. In total absence of entrained air, caliper variation translates strongly into diameter variations, and often wrinkling. Thus the nip load must be high enough to limit the air entrapment, but simultaneously sufficiently low not to induce large wound on tension. The nip pressure profile along the reels should stay close to linear, yet be somewhat lower at the edges in order to improve the elimination of air in the longitudinal direction. The focus of this research is to measure the said nip pressure limits and to identify and control the parameters that influence them.

THEORY

The first step of the research is to identify the theoretical parameters that are contributing to changes in nip pressure profile. A comparison between several analytical methods used to describe the contact between rubber covered rolls is presented in [1]. In order to calculate the nip load, Good [1] recommends formula {1} for lower strains and formula {2} for higher strains.

$$F = \frac{1}{3} \cdot \frac{(1-\nu)^2}{1-2\cdot\nu} \cdot \frac{E_0 \cdot \left(1+k \cdot S^2\right)}{1-\nu^2} \cdot \frac{\sqrt{(2\cdot\delta)^3 \cdot \sqrt{\frac{D}{2}}}}{t} \qquad \{1\}$$

$$F = E_0 \cdot w \cdot \sqrt{t \cdot D} \cdot \left(\alpha_R + \frac{k \cdot D}{t} \cdot \beta_R\right) \qquad \{2\}$$

The relation between the nip load applied on two solids of revolution and the distributed contact pressure, in machine direction, in accordance with [2] is:

$$F = \int_{0}^{a} p(r) \cdot 2\pi \cdot r \, dr \qquad \{3\}$$

In the relation {1} and {2} only nominal diameters and width of the rolls, thickness, shape and material of the covers are taken into account. If for shorter rolls the deflection due to loading and gravity is small, it can not be anymore neglected when the length increases. Also, the material and geometrical parameters of the shell, shafts and flanges must be considered.

The calculation of the nip pressure profile is not a simple task using analytical methods, therefore a numerical method was chosen. The variables taken into account in this research are the shape and material of the cover, the shape of the flanges situated at the edge of the spools and the quantity of paper reeled on the spool.

The precision of a finite element model increases with the number of elements but this is limited by the calculation capacity of the computers. In big models where the dimensions are over 10 meters, not all the geometrical parameters can be studied, for example the influence of the narrow grooves or of the roughness of the rolls. In these cases local models must be done.

The end effect must be also taken into account. In accordance with [2] if one roll is longer than the other a sharp stress is concentrated at the end of the roll in calculations while in measurements it is much smaller or it doesn't appear at all. This is explained by the possibility of the material to slightly expand in axial direction and thereby reducing the pressure at the end in reality.

MODELLING

The rolls were modelled using the commercial code Abaqus version 6.5. The geometry was realised in three dimensions and the mesh was refined only in the contact area. The concentrated loads and the boundary conditions were applied on the shafts in the area of bearing cages.

Metallic materials were modelled using the published values of elastic modulus and Poisson's coefficient. Based on existing tests data, the elastomers were modelled using the Marlow form of strain energy potential and assuming incompressibility and isothermal response or using linear elastic models where the Young's modulus is calculated as a function of the material hardness [1]. The paper was modelled as a linear orthotropic material in accordance with [5].

MEASUREMENTS

The methods used for measuring the nip pressure were: Tekscan pressure sensing technology and Fuji's colour forming and developing films. In both cases the sensors and the films were covering all the contact area in cross direction.

Each of the methods has advantages and limitations. Fuji's films exhibit a smoother pressure variation and the thickness and stiffness of the material has a lower interference on the nip pressure but the sensitivity of the measurements is limited between 0,2 – 0,6MPa. The Tekscan's technology has a wider pressure range but calibration of the sensors in order to have no differences from a one to another is more difficult to realise.

THE INFLUENCE OF THE SHAPE AND COVER MATERIAL OF THE DRUM ON NIP PRESSURE PROFILE

Nip pressure was measured for 3 types of drums: uncovered, covered with hard elastomer, and covered with soft elastomer. The measurements were performed without paper on the spool and only the maximum values of the nip pressure were presented and compared.

For hard cylindrical drums, any variation in spool diameter is visible in nip profile. In this measurement at the middle of the spool, in the ungrooved area, a 0,05mm difference in spool diameter induces a high difference in nip pressure (Fig.1.). If the drum is covered with hard elastomer the errors in spool diameters are not visible anymore, but the stiffness difference between the edges and middle of the roll, as well as the loading effects are influencing the pressure profile (Fig.2.).

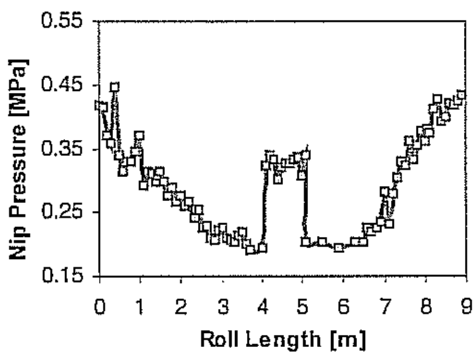


Figure 1. Uncovered Drum. Fuji's Film Measurements.

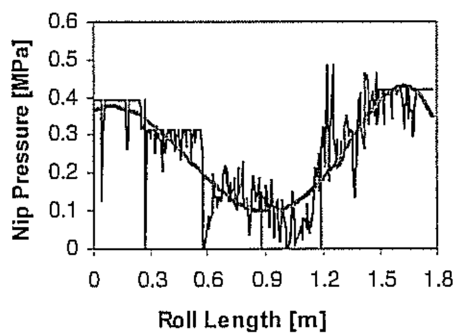


Figure 2. Drum Covered with Hard Elastomer. Tekscan's Sensor Measurements.

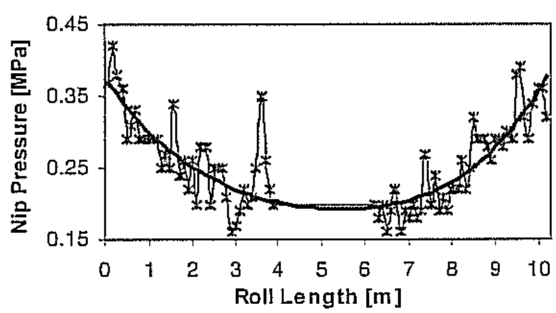


Figure 3. Drum Covered with Soft Elastomer. Fuji's Film Measurements.

A drum covered with soft elastomer exhibits the same pressure profile, with peaks at the edges and lower pressure in the middle of the rolls as in the previous cases (Fig.3), but the differences are lower.

Quantitative comparison between the measurements performed with different devices is very useful for calibrating the measurements, but they must take into account all the particularities of the methods. For Fuji's technology if the pressure is lower than 0,2MPa there is no colour impressions on the films. Therefore in the first case, uncovered drum, the pressure differences between the edges and the middle may be between 0,24 and 0,45MPa compared with the second case, drum covered with hard elastomer where the difference is 0,3MPa and the last case, drum covered with soft elastomer 0,15MPa.

For a better understanding of the phenomena, a finite element model was realised for these cases. The comparison between the measured and calculated pressure profile are presented in Figures 4-6.

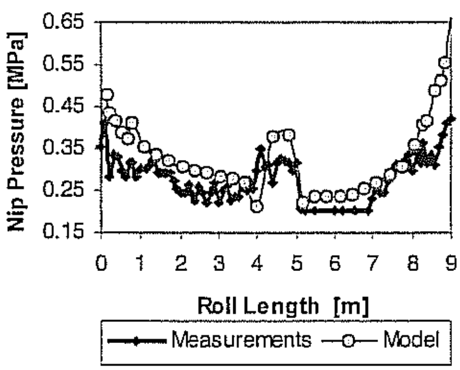


Figure 4. Model versus Measurements. Uncovered Drum.

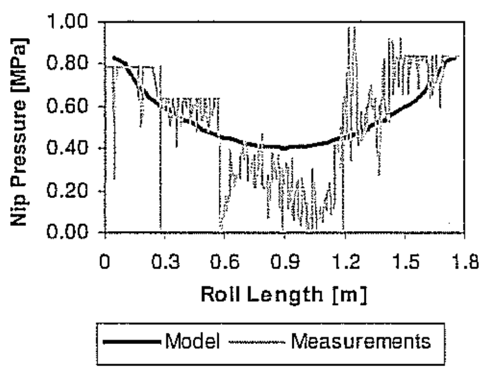


Figure 5. Model versus Measurements. Drum Covered with Hard Elastomer.

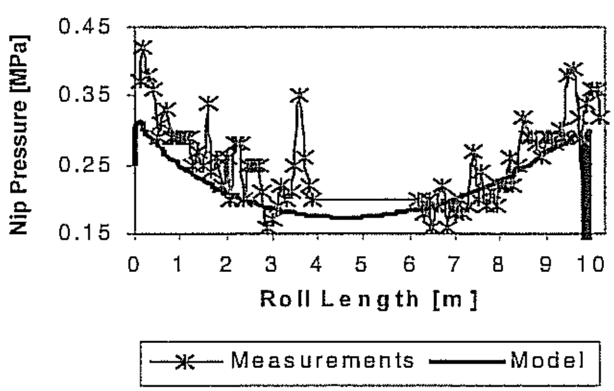
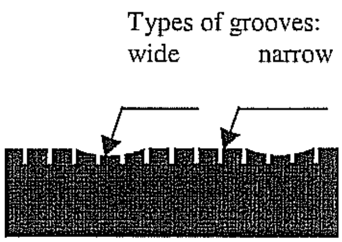
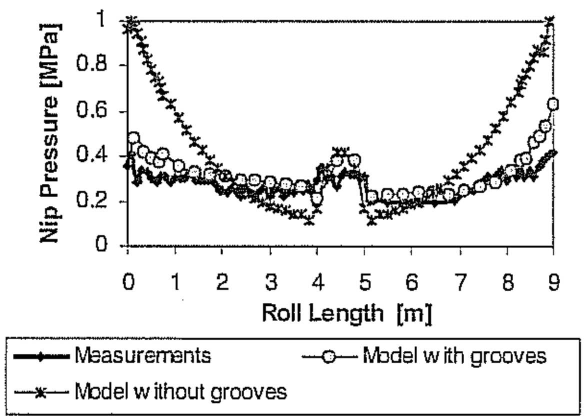


Figure 6. Model versus Measurements. Drum Covered with Soft Elastomer.

The highest difficulties in calibrating the model were met for the uncovered drum, that in comparison with the others have wide grooves on its surface. Even if the grooves could not be modelled with high accuracy due to numerical limitation, their influence on nip pressure is visible in Figure 7.



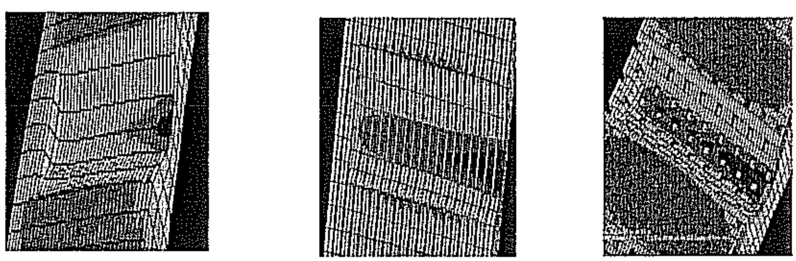


a) b)

Figure 7. Uncovered Drum.
a) Types of Grooves, b) Comparison between Measurements, Model with Wide Grooves and Model without Grooves.

The existence of the wide grooves decreases the nip pressure at the edges and increases its value in the middle of the rolls, but the presence of zones with very low pressure may favour the air suction inside of the paper roll and development of the air bags.

The effect of the narrow grooves and of holes on the pressure profile was analysed on small models and the results indicate increases of the maximum pressure level in the contact area (Fig.8-9) without any changes in the pressure profile.



a) b) c)

Figure 8. Different Types of Drum.
a) Smooth Drum, b) Drum with Narrow Grooves, c) Drum with Holes.

Analysis of the presented data leads to conclusion that a better pressure distribution in cross direction may be obtained with soft cover drum. In order to optimise the profile and decrease the pressure at the edges a crowned profile is a good choice for compensating the roll deflection.

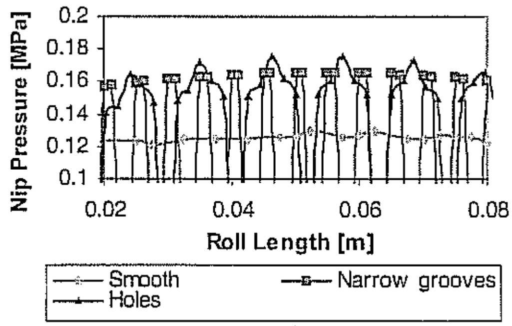


Figure 9. Comparison Between the Calculated Pressure Profile for Different Types of Grooves.

In Figure 10 is presented a comparison of the measured pressure profile for crowned and cylindrical shape of a drum covered with the same material. A similar profile was obtained by modelling the crowned drum (Fig. 11). By decreasing the nip pressure at the edges of the rolls the airflow in cross direction is not restricted and the formation of air bags is limited.

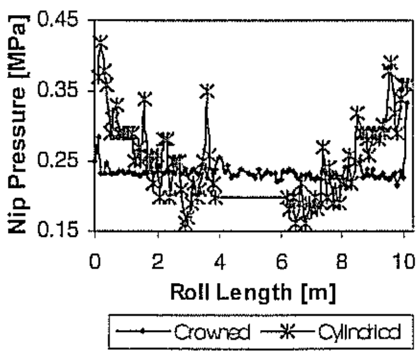


Figure 10. Measured Data. Cylindrical Drum Compared with Crowned Drum.

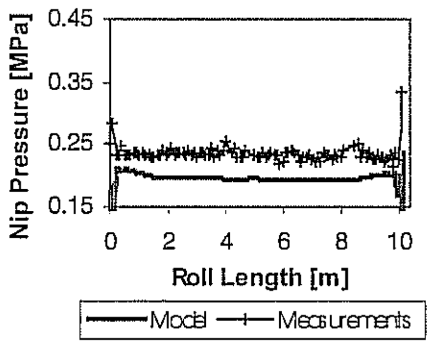
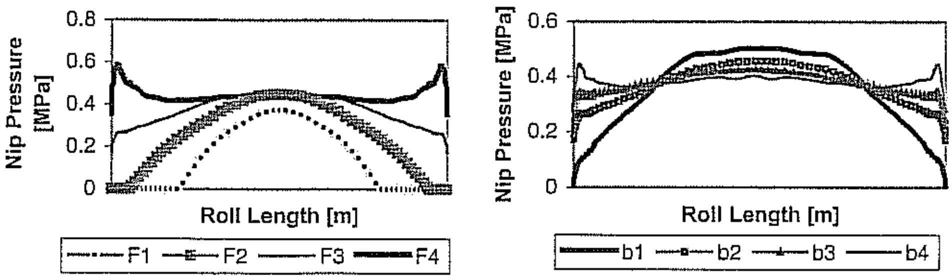


Figure 11. Model versus Measurements. Crowned Drum.

The challenge is the calculation of the optimum crowning value. In Figure 12 is presented the influence of the nip load and crowning on the pressure profile. Increasing the nip load from F1 to F4 we can change the nip pressure distribution from contact only in the middle of the rolls (F1) till peaks on the edges of the roll (F4). Assuming that in the beginning of the reeling the nip load is constant, a higher crowning (b1) induces also a contact only in the middle of the roll, while decreasing the crowning value (b4) we ended up with peaks at edges.



a) b)

Figure 12. Nip Pressure Profile.
a) Influence of Nip Load on Nip Pressure for the same Crowning, F1<F2<F3<F4.
b) Influence of Crowning Amplitude on Nip Pressure for the same Nip Load, b1>b2>b3>b4.

Due to the good agreement between the calculated and measured results, the finite element program can be used to describe and visualise the spatial profile of nip pressure for analysed cases (Fig.13).

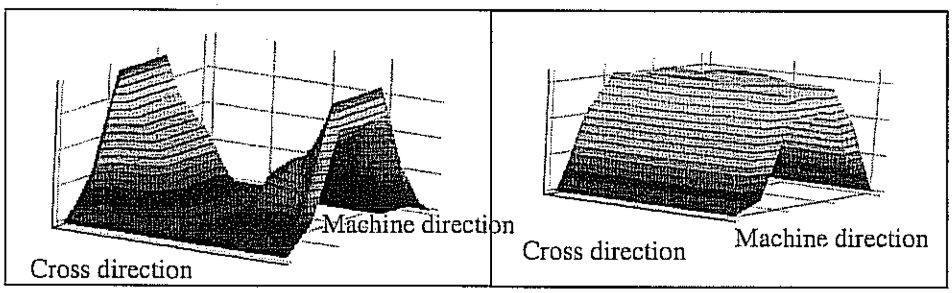


Figure 13. Nip Pressure Profile for Cylindrical Drum and Crowned Drum.

THE INFLUENCE OF THE SHAPE OF THE FLANGE ON NIP PRESSURE PROFILE

The influence of the flange on nip pressure profile was analysed by measuring the nip pressure between the same uncovered drum and two types of spools that had different kinds of flanges inside. The purpose of this research was to verify if the material and geometry of the shafts and flanges that are not considered in analytical approach of the contact problem have effect in long rolls. The results showed a better pressure distribution for the case when the spool has a smaller variation of the stiffness in cross direction (Fig.14).

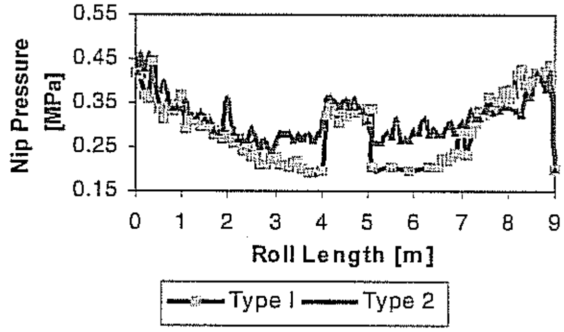
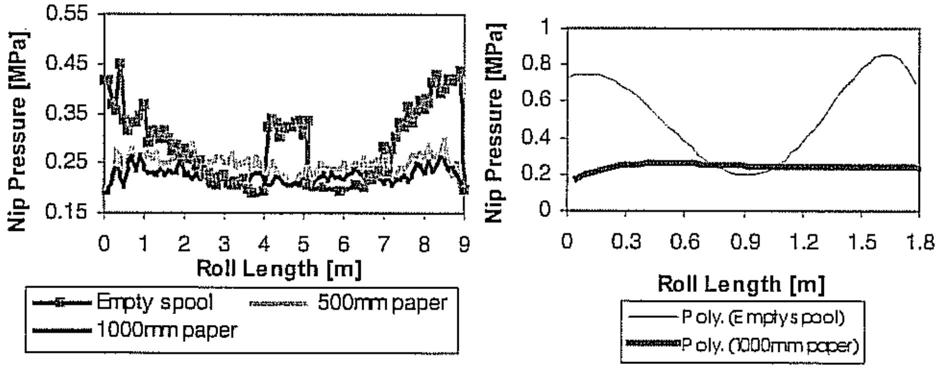


Figure 14. Flange Geometry Influence on Nip Pressure. Measured Data.

THE INFLUENCE OF THE PAPER ON NIP PRESSURE PROFILE

The nip pressure profile between the drum and spool changes with the amount of reeled paper. By adding paper the nip becomes wider and the maximum values of the pressure decrease.

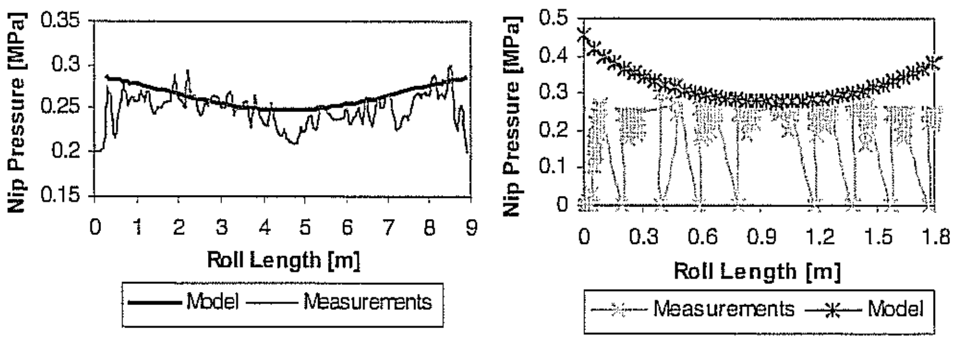
In Figures 15 it is presented a comparison between the nip pressure profile measured for uncovered drum in three cases: empty spool, 500mm and 1000mm thickness of paper on spool and for drum covered with hard elastomer in two cases: empty spool and 1000mm paper on spool.



a) b)

Figure 15. Paper Influence on Nip Pressure
a) Uncovered Drum, b) Drum Covered with Hard Elastomer.

A softer contact improves the pressure profile, but the initial tendency of higher pressure at the edges is still notable. The finite element model shows the same tendency of linearising the pressure with the exception of the end part (Fig. 16).



a) b)

Figure 16. Comparison Between Measured and Calculated Nip Pressure for Reels with 1000mm Thickness Paper on the Spool.
a) Uncovered Drum , b) Drum Covered with Hard Elastomer.

CONCLUSIONS

- Reeling with crowned drum covered with soft elastomers offers a more linear pressure distribution in cross direction and a better quality of the reeling, less air bags and wrinkles.
- The nip pressure profile in cross direction for reels with hard cylindrical drums may be improved by shallow grooves.
- Crowning is a tool for improving the airflow in cross direction and diminishing the tendency to form air bags.
- The flanges geometry and spool dimension errors are visible only in the beginning of reeling, but they are important for creating the hard core of the parent roll.
- The narrow grooves and small holes that enable air streams to pass through the nip in machine direction have no influence on the profile of nip pressure, although they constantly increase the maximum values.
- After calibrating the model the changes in geometrical and material parameters can be analysed and the impact of these changes on reeling quality can be estimated.

REFERENCES

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Name & Affiliation	
Name & Affiliation David Pfeiffer JDP Innovations	**Question** I would like to know if the reel is designed for all grades of paper. Is it necessary on all grades to wind without torque assistance on the start up or do you include torque on the reel spool to aid in winding a good reel?
Name & Affiliation Gabriela Simbierowicz Metso Paper Inc.	**Answer** What I was presenting in this paper is for calendared and coated paper, so it is only for one kind of paper. When changing the paper type the drum diameter and spool diameter might change and in this case we were using torque difference as you said.
Name & Affiliation Dave Roisum Finishing Technologies, Inc.	**Question** I have witnessed a similar problem with the rider roll on a two drum winder. Could this technology be applied there as well?
Name & Affiliation Gabriela Simbierowicz Metso Paper Inc.	**Answer** I can tell you that I was pretty satisfied with agreement between measurements and modeling. In principle you can model anything but this is a static model. I was using the nip pressure because in principle the nip pressure doesn't change with speed and friction and so on. Only the shear stresses are changing. For static conditions we can model almost anything.
Name & Affiliation Stefan Geissenberger Druckmaschinen AG	**Question** Did you test and analyze OST rolls or glass fiber rolls?
Name & Affiliation Gabriela Simbierowicz Metso Paper Inc.	**Answer** Only steel rollers covered with elastomers: polyurethane or rubber.
Name & Affiliation Stefan Geissenberger Druckmaschinen AG	**Question** We learned in our plant there is a big difference between steel and glass fiber because you have also elastic deformation in the glass fiber.
Name & Affiliation Gabriela Simbierowicz Metso Paper Inc.	**Answer** You have to model the materials different.