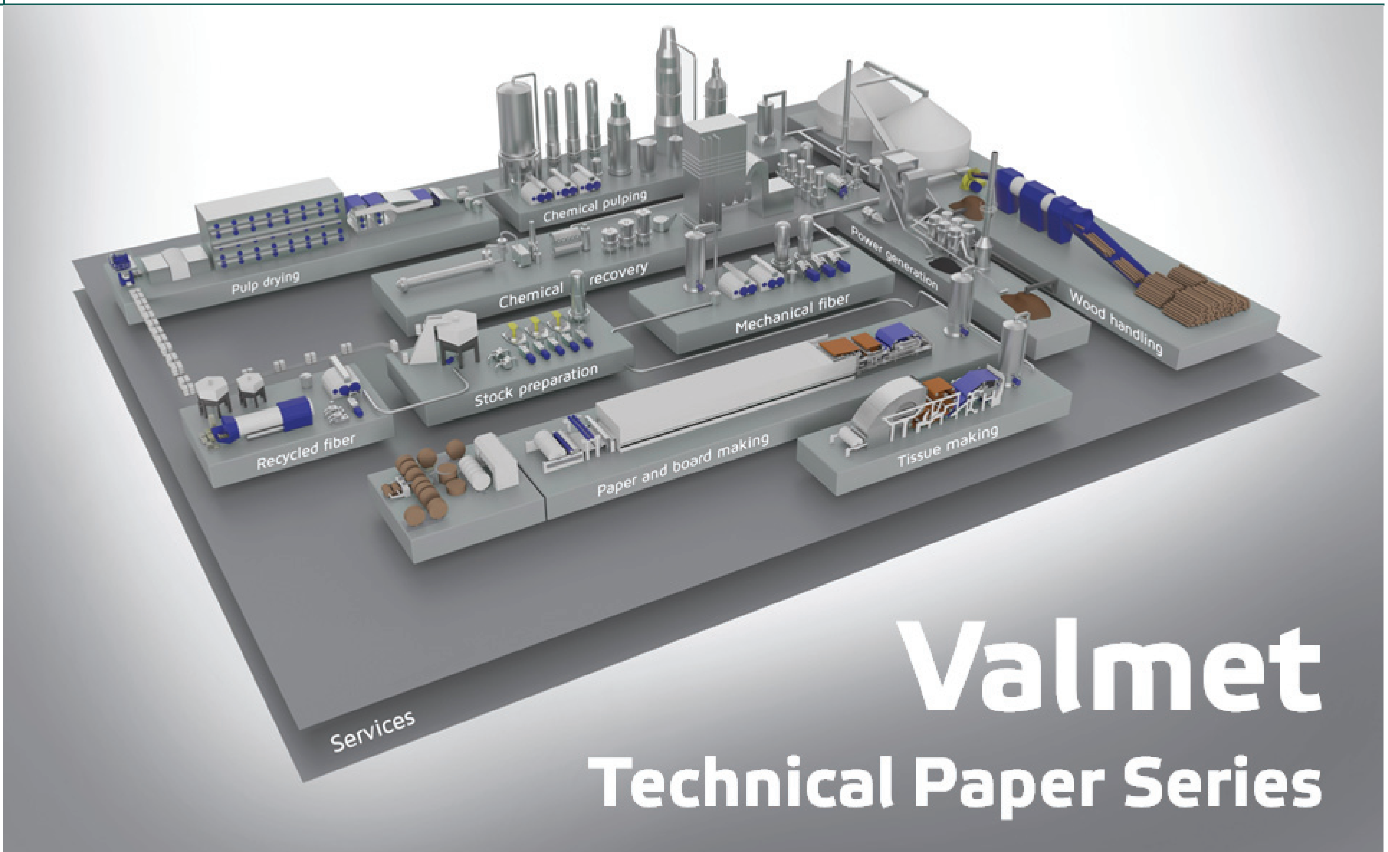

Metal Belt Calendering of Uncoated and Coated Paper

Executive Summary

The effect of metal belt calendering on the quality of uncoated and coated paper was studied in two pilot scale trials. The targets of these studies were to find out: 1) is it possible to save fiber in uncoated paper with metal belt final calendering and 2) could the finishing process of coated paper be made more efficient by using metal belt pre-calendering prior to coating.

The results show that metal belt pre-calendering reduces the need for final calendering for double-coated fine paper. Two calendering concepts were compared: 1) new metal belt pre-calendering + 4 soft nip finishing and 2) conventional soft nip pre-calendering + 10 roll multinip finishing. The new concept with metal belt pre-calendering can reach the quality level of conventional 10 roll multinip calendered papers. It produced slightly better bulk with similar end product smoothness, and the bending resistance was clearly higher. Another benefit of the new concept is a simpler and more efficient finishing layout.

Introduction

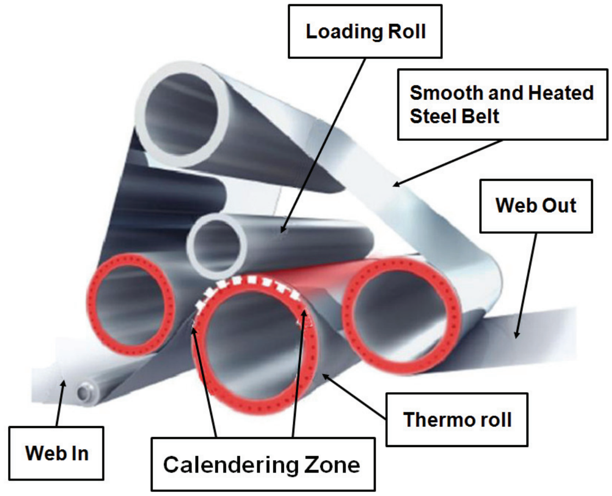

Figure 1. Schematic picture of a ValZone metal belt calender

Metal belt calendering is based on plasticization of the paper or board web during a very long calendering zone. The calendering zone is formed between a heated steel belt and a heated thermo roll (**Figure 1**). Additional pressure can be applied by pressing the web between the belt and thermo roll with a loading roll. The calendering zone is one meter long, which is approximately 100 times longer than the zone length of a conventional hard or soft nip calender (**Figure 2**). Due to the very long calendering zone, only light pressure is needed in the smoothing process. A shoe calender is another known solution in which a long calendering dwell time is used. However, the metal belt calendering zone is still much longer than the length of the shoe. Usually, the shoe length varies between 30-200 mm and the length of the longest shoe ever made for calendering is 280 mm.

Since 2006, metal belt calendering has made a break-through in coated boardmaking. In modern boardmaking lines, a metal belt calender is used instead of a hot hard nip calender because clearly higher quality can be reached with a long calendering zone. Also bulk-consuming MG cylinder and wet stack processes have been replaced by a metal belt calender on an industrial scale. With high bulk and stiffness values of metal belt calendered board, it is possible to decrease grammage of board. On the other hand, the metal belt calendering process can also be used to make high quality products with higher grammage. Thus boardmakers now have the ability to optimize between raw material savings and premium surface quality. Furthermore, metal belt calendering has remarkably increased the efficiency of conventional boardmaking lines, because MG dryers and wet stacks are usually capacity bottlenecks for board machines.

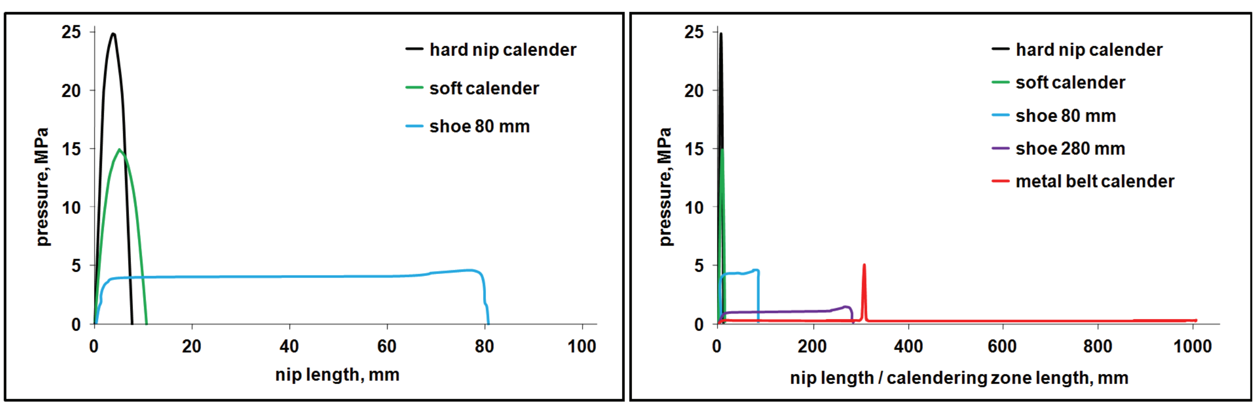

Figure 2. Metal belt calendering zone length compared to conventional calender types' nip lengths. Calendering pressures are calculated with the web in the nip.

Recently, application of the metal belt calendering process has begun in papermaking lines. The first uncoated fine paper machine with a metal belt calender started up in 2010. In pilot testing, the metal belt calendered paper has shown some very interesting properties. For example, the metal belt calendered paper feels very smooth. In fact, the conventional surface roughness measurements like PPS or Bendtsen have been found unable to predict what the surface would feel like. Thus KCL (which has merged with VTT) has been developing an analysis method whereby paper samples are ranked according to hand-felt smoothness by a trained panel group. Metal belt calendered paper gives relatively low "feel roughness" values. This means that the surface roughness of metal belt calendered paper feels as smooth as that of a paper that has been soft calendered into clearly lower Bendtsen or PPS roughness. Higher roughness values mean higher bulk values - and higher bulk means a possibility to reduce fiber.

Metal belt calendering has also been extensively piloted for use with coated grades. It has been reported earlier that there is a clear benefit in using metal belt pre-calendering for single-coated fine paper. The trend in finishing of single-coated paper has been toward the use of heated soft calenders instead of conventional supercalenders, but with double-coated fine paper grades the soft nip final calendering has so far not been found to produce adequate quality. Therefore, it was decided to study the idea of intensive metal belt pre-calendering combined with lighter final calendering for double-coated fine paper. The conventional concept and the new idea to produce high-quality double-coated fine paper are illustrated in **Figure 3**. Traditionally, one or two multinip final calenders are placed off-line after the coating process, but in the new concept a four-nip soft calender is situated on-line after the coating units. Earlier studies have not shown great potential in the pre-calendering of paper. However, all of those studies have only concentrated on traditional short-nip pre-calendering concepts, not metal belt calendering.

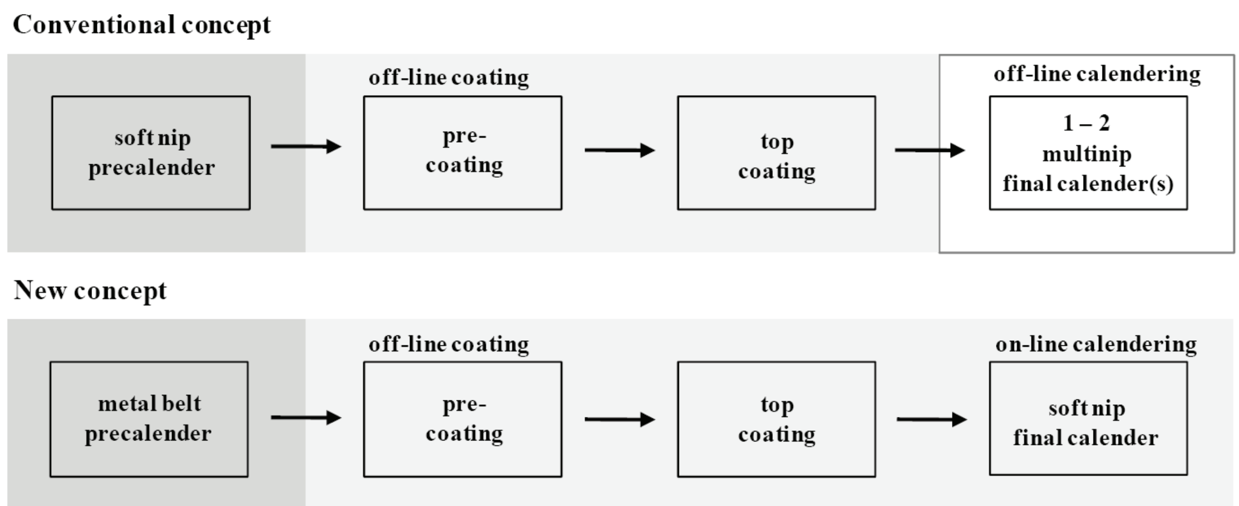

Figure 3. Conventional concept and a potential new way to produce double-coated fine paper

Experimental

Extensive pilot trials were arranged at Valmet's pilot facility in Järvenpää, Finland, to produce: 1) bulky uncoated fine paper and 2) high-quality double-coated fine paper.

Uncoated fine paper trial

A comparison of final calendering for 60 to 70 g/m² base paper was made with metal belt calendering and single-nip soft calendering. The properties of the base paper used in the uncoated fine paper trial are presented in **Table 1**. In contrast with traditional fine papers, the base paper contained 40% BCTMP. Filler was $CaCO_3$.

	Grammage g/m^2	Thickness µm	Bulk cm^3/g	Bendtsen roughness top side ml/min	Bendtsen roughness bottom side ml/min
Offset 70 (filler 24%)	69.9	112	1.62	448	370
Offset 70 (filler29%)	68.4	108	1.57	421	344
Offset 65 (filler 24%)	63.7	104	1.63	453	361

Table 1. Laboratory measurements of base paper

The soft nip pilot calender is presented in **Appendix 1 (A)**. A top nip was used in the first stack and all the other calender nips were open during the run. A summary of the 1-nip soft calendering variables is shown in **Table 2**.

Calendering concept	1 x soft/hard roll nip
Calendering speed, m/min	1450
Linear loads in calibration (70 g/m^2, filler 24%), kN/m	15, 25, 35, 45, 65, 105, 145
Linear load in further test, kN/m	145, 200
Thermo roll surface temperature, ºC	120ºC
Polymer roll hardness, ShD	91
Polymer roll surface temperature, ºC	ca. 25ºC (not heated)

Table 2. Soft nip running conditions

The metal belt pilot is presented in **Appendix 1 (B)** and the metal belt calendering variables are shown in **Table 3**.

Calendering concept	Metal belt claender
Calendering speed (production scale), m/min	1450
Calendering speed (pilot scale, m/min	654
Calendering dwell time, ms	43
Linear loads in calibration (70 g/m^2, filler 24%), kN/m	0*, 5, 10, 20, 30, 50, 70
Metal belt pressure against paper, MPa	0.2
Linear loads in further test with all grades, kN/m	13, 20, 30
Thermo roll surface temperature, ºC	120
Steel belt surface temperature, ºC	80

*only metal belt pressure used (0.2 MPa)

Table 3. Metal belt pilot machine running conditions

The calendering zone length in the metal belt calender is the contact length between the steel belt and the thermo roll. The calendering zone of a production-scale calender is typically 1035 mm. However, the calendering zone in the pilot scale metal belt calender is only 467 mm. As the dwell time of the metal belt pilot calendering is targeted to be the same as in the production scale calender (target 1450 m/min), the speed of the pilot scale calender was set at 654 m/min.

Coated fine paper trial

A base paper of 55 g/m² was surface sized, pre-calendered, pre-coated, top coated and final calendered in the trial. The surface sizing and coatings were carried out with constant methods but two different pre- and final calender combinations were utilized. The trial program is presented in **Appendix 2**.

Property	Base paper	Surface sized paper	
Furnish; long fibers (pine) / BCTMP / mill broke	33% / 49% / 18%		
Ash content	10.9%		
Basis Weight	53.6 g/m^2	56.1 g/m^2	
Moisture	6.6%	6.5% for soft nip pre-calender	8.6% for metal belt pre-calender
Thickness	93 µ m	97 µ m	
Roughness, Bendtsen, top side	630 ml/min	785 ml/min	
Roughness, Bendtsen, bottom side	550 ml/min	670 ml/min	

Table 4. Properties of paper before and after surface sizing

The base paper was surface sized with a metered size press pilot, illustrated in **Appendix 1 (C)**. Both sides of the paper were sized with oxidized potato starch with a dry size amount of 1.0 g/m². The properties of the base paper and the surface sized paper are listed in **Table 4**. The surface size formulation is presented in **Table 7** together with coating color formulation.

The surface sized paper was pre-calendered using two different concepts: a single-nip soft calender (polymer/steel roll) and the metal belt calender. The pre-calendering linear loads in both calendering methods were chosen based on a linear load calibration series. In the soft nip calendering, a typical quite low linear load level was selected for the coated paper. For the metal belt pre-calendering, a linear load resulting in a remarkably smoother paper surface was chosen. The idea was to use the high smoothing capacity of the metal belt calendering process in order to reduce the down-stream

Pre-calendering concept	1 soft/steel roll nip
Calendering speed, m/min	1400
Linear load, kN/m	30
Thermo roll surface temperature, ºC	120
Polymer roll hardness, ShD	94
Pre-calendering concept	**Metal belt calendar**
Calendering speed (production scale), m/min	1400
Calendering speed (pilot scale), m/min	623
Calendering dwell time, ms	45
Linear loads in calibration, kN/m	10 – 70
Linear load for coating, kN/m	50
Thermo roll surface temperature, ºC	130
Steel belt surface temperature, ºC	100

Table 5. Pre-calendering running conditions

smoothing needs. With both pilot calenders, the rougher side of the base paper was pre-calendered against the hot thermo roll to compensate for roughness two-sidedness.

The same pilot equipment was used in the case of the uncoated fine paper trial - i.e. the single-nip soft pilot calender illustrated in **Appendix 1 (A)** (1st nip was used) and the metal belt pilot calender in **Appendix 1 (B)**. The pre-calendering running conditions are summarized in **Table 5** on the previous page. The key properties of the pre-calendered papers can be seen in **Table 6**.

Property	Soft nip pre-calendered paper	Metal belt pre-calendered paper
Moisture	6.4%	5.8%
Caliper	87 µm	74 µm
Roughness, Bendtsen, top side	275 ml/min	80 ml/min
Roughness, Bendtsen, bottom side	300 ml/min	70 ml/min

Table 6. Key properties of pre-calendered paper

The pre-calendered paper was pre- and top coated with the pilot coater by using a blade coater with jet application; see **Appendix 1 (C)**. The coater speed was 1400 m/min. The coating color formulation (together with the sizing formulation) is presented in **Table 7**.

	Surface sizing	Blade coating	
		Pre-coating	Top-coating
Coat Weight, g/m^2	1	11	11
Starch	100	4	4
$CaCO_3$ (coarse)		100	
$CaCO_3$ (fine)			75
Clay			25
SB-latex		9	8
CMC			0.2
Dispersant		0.3	0.5
OBA		0.4	0.4
Solids, %	10.3	65.5	64.4
Brookfield 100, Viscosity, cps	39	608	1035

Table 7. Surface size and coating color information

The coated paper pre-calendered with the single-nip soft calender was final calendered with a 9-nip calender pilot (**Appendix 1 (D)**) and the coated paper pre-calendered with the metal belt calender was finished with a four-nip soft calender pilot (soft nip pilot calender in **Appendix 1 (A)**). The four-nip soft calender was simulated as a pilot unit by running the paper through the 1st and 3rd nips twice. The calendering running conditions are presented in **Table 8**. The multinip calender was run with typical

Final calendering concept	9-nip multinip calender	4-nip soft calender
Pre-calendering concept	1-nip soft calender	Metal belt calender
Calendering speed, m/min	1400	1400
Linear load, kN/m	100, 200, 300	250, 300, 400
Thermo roll surface temperature, ºC	120	160
Polymer roll hardness, ShD	94	94

Table 8. Final calendering conditions

temperatures. Somewhat elevated temperatures were used in the four-nip soft calendering to produce equal quality.

Laboratory measurements

The reported laboratory tested data was calculated as an average of the paper testing results for both sides.

First, all samples were conditioned according to SCAN-P 2:75.

The Bendtsen roughness was measured according to ISO 2494.

The Parker Print Surf (PPS_{10}) small-scale roughness was measured with a soft offset backing according to the TAPPI standard T 555 pm-94.

Bulk was calculated as the paper caliper divided by the basis weight of the sheet samples conditioned according to SCAN-P 2:75.

The brightness was measured according to ISO 2470.

The opacity was measured according to ISO 2471.

The paper gloss was measured at 75 degrees, according to TAPPI T 480.

The bending resistance was measured at 15 degrees of bending, according to ISO 2493.

The VTT Touch and Feel panel evaluated the roughness of the samples using a numerical category scale, where the panelist placed the extremes at the beginning and end of the scale and the rest of the samples between the extremes. The distance between the samples correlates with the degree of difference. For example, when the roughness perception was evaluated, the panelists placed the smoothest sample as 0 and the roughest at the other end. Then they placed all the other samples between the smoothest and roughest samples. The panelists were also allowed to give remarks on the samples in writing.

The result of the touch and feel evaluation is the mean of the panelists' evaluations. The significance of the difference between papers was estimated by calculating the Least Significant Difference (LSD value). The LSD value was calculated with the following equation:

$$LSD = t_{\alpha/2df_E}(2MS_E/b)^{1/2}$$

Where:

$\alpha/2df_E$	is the upper- $\alpha/2$ critical value of the t-distribution with df_E degrees of freedom,
MSE	is the mean square of error from the ANOVA table and
b	is number of panelists.

If the mean evaluations between the samples differ by more than the LSD value, the difference between the samples is statistically significant.

Results & discussion

Uncoated fine paper

The calendering linear load calibration for uncoated fine paper is presented in **Figure 4**. These linear load series demonstrate the high calendering capacity of the metal belt calender - i.e. the ability to produce low Bendtsen roughness values at low linear loads. The effective calendering result is a combination of a very long calendering dwell time created by the steel belt contact and a pressure peak created by the loading roll.

Figure 5 presents the bulk and Bendtsen roughness and **Figure 6** the Bendtsen roughness and bending resistance of the uncoated fine paper. The metal belt calender clearly produced higher bulk and bending resistance values than soft nip calendered trial points at the same Bendtsen roughness level. The paper has a bulky structure and high bending resistance because only low pressure is used in metal belt calendering.

The high bulk values of the metal belt calendered paper can be utilized in two ways: 1) by reducing the paper grammage or 2) by increasing the filler content. **Figure 5** shows that an increase in the filler content (24 to 29%) reduced the bulk values but lowering the basis weight (70 to 65 g/m^2) does not affect the bulk values. Both an increase of filler content and a reduction of grammage affect the paper bending resistance. Still, the bending resistance of metal belt calendered paper is at the same level as the soft nip trial points with higher grammage and less filler (**Figure 6**).

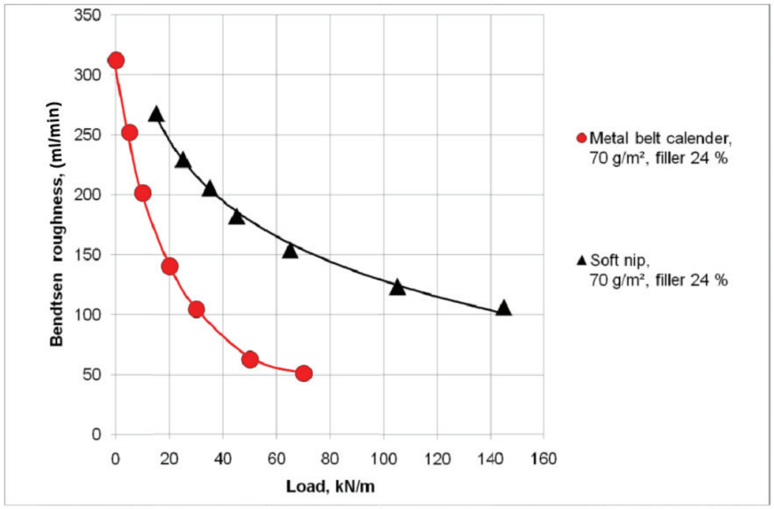

Figure 4. Calendering linear load series. 0 kN/m in metal belt calendering means that only the metal belt pressure is used (=0.2 MPa).

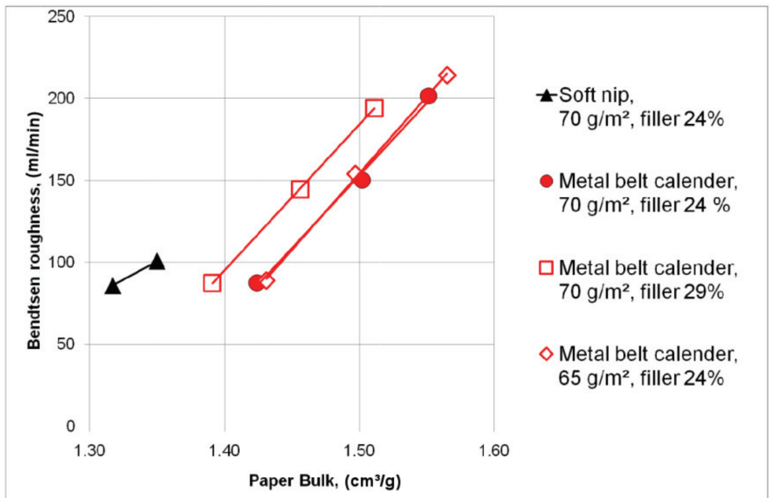

Figure 5. Bulk and Bendtsen roughness

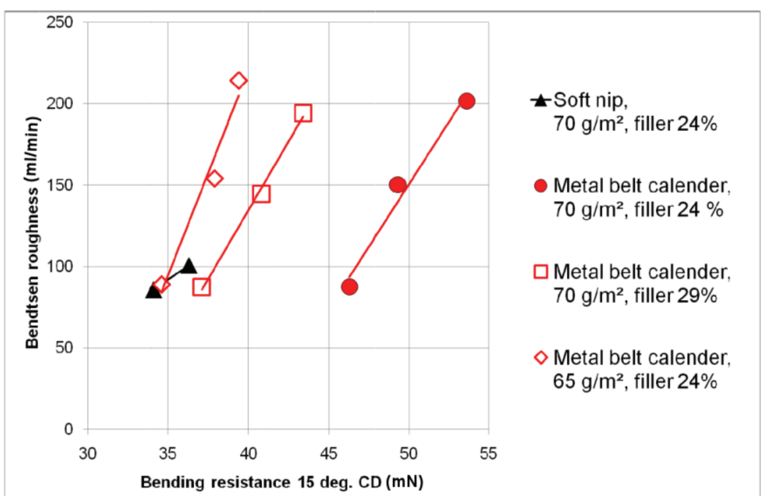

Figure 6. Bending resistance and Bendtsen roughness

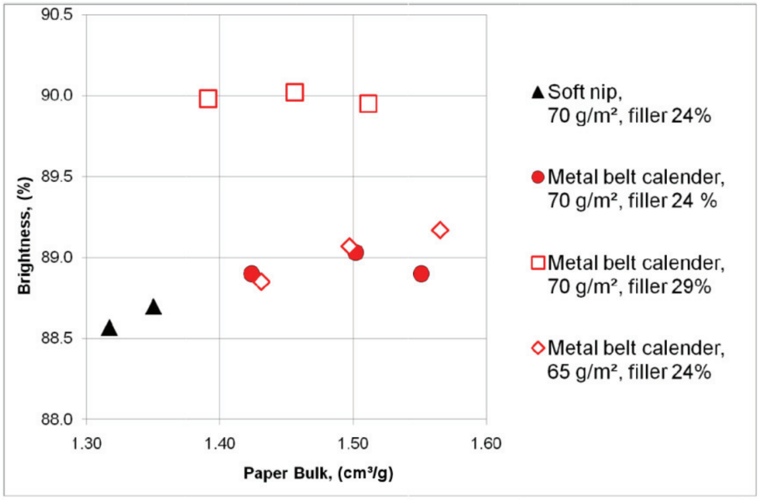

Figure 7. Bulk and brightness

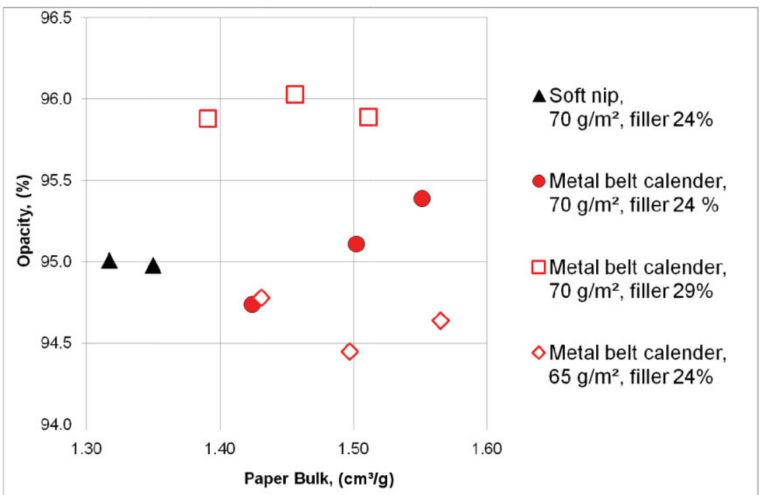

Figure 8. Bulk and opacity

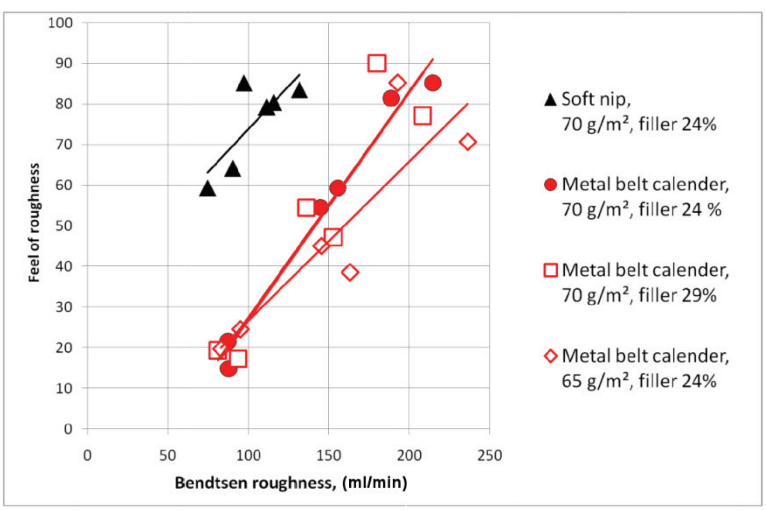

Figure 9. Bendtsen roughness and feel of roughness

There were no significant differences in the optical properties between the metal belt calendered and soft nip calendered paper of lower filler content (24%). In the case of the 70 g/m² grammage paper, the brightness and opacity values were slightly higher for the metal belt calendered trial points compared to the soft nip trial points (**Figures** 7 and **8**). This is logical as the reduced compression in metal belt calendering saves some light scattering in the sheet. The opacity of the lower grammage paper (65 g/m²) was slightly lower but the brightness values were higher than that of the soft nip calendered trial points. Increasing filler content improves the optical properties. The brightness increased by 1.8% units and the opacity by 2.0% units.

As earlier studies have shown, the metal belt calendered papers feel smoother than the Bendtsen roughness measurement indicates. **Figure 9** shows that the metal belt calendered paper at the Bendtsen roughness 130 to 160 ml/min felt smoother than soft nip calendered paper at the Bendtsen roughness 70 to 90ml/min. Consequently bulk values of metal belt calendered paper are even higher at the same feel roughness level (clearly more than 10%) than at the same Bendtsen roughness level (**Figure 5**). The filler content or grammage of the paper did not significantly affect the feel roughness properties.

Coated fine paper

Figure 10 illustrates the bulk and PPS roughness of the coated final calendered papers. Soft nip pre-calendering and the

9-nip final calendering gives an ability to reach lower PPS roughness values than a combination of metal belt pre-calendering and four-nip final calendering. However, the metal belt pre-calender and four-nip final calender produced better paper bulk at the same PPS roughness level. The high nip amount in the final calendering reduces paper bulk more than the effective metal belt pre-calendering - even if the consequent final calendering by four soft nips is done at relatively high temperature and loads.

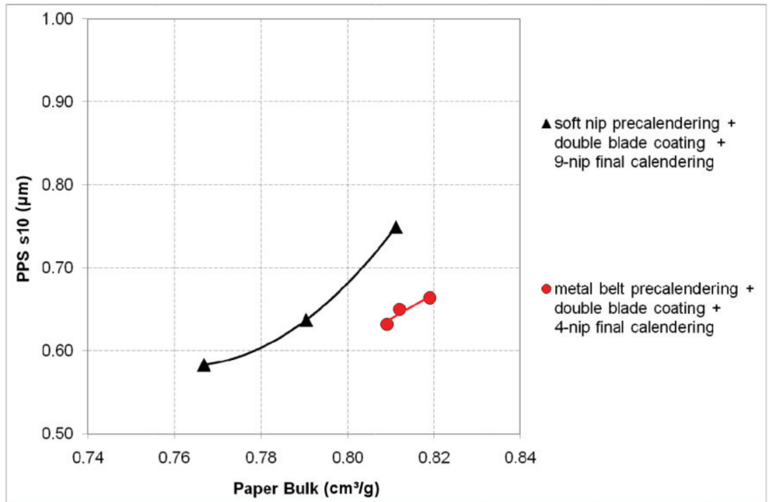

Figure 10. Bulk and PPS roughness of coated fine paper

Coated fine paper gloss is presented in **Figure 11**. The 9-nip final calendering has more potential to produce paper gloss but a relatively high level can also be achieved with four-nip soft final calendering at higher paper bulk.

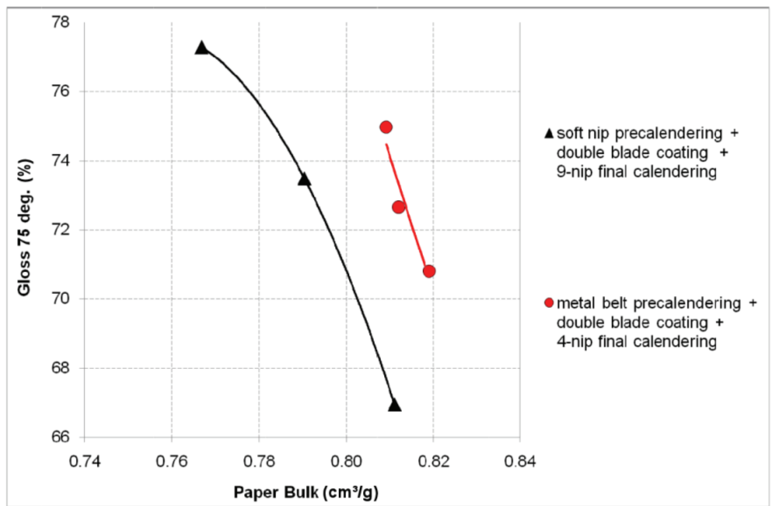

Figure 11. Bulk and gloss of coated fine paper

The bending resistance (15 deg.) of coated fine paper in the machine direction can be seen in **Figure 12** and in the cross-direction in **Figure 13**. The combination of metal belt pre-calender and four-nip soft final calender saves paper bending resistance more than soft nip pre-calendering and 9-nip final calendering.

The optical properties, brightness and opacity, are illustrated in **Figure 14**. It appears that the number of nips affects the opacity more and the temperature has more effect on the brightness. Thus soft nip pre-calendering and 9-nip final calendering gives better brightness but the metal belt calender combined with four soft nips produces better opacity.

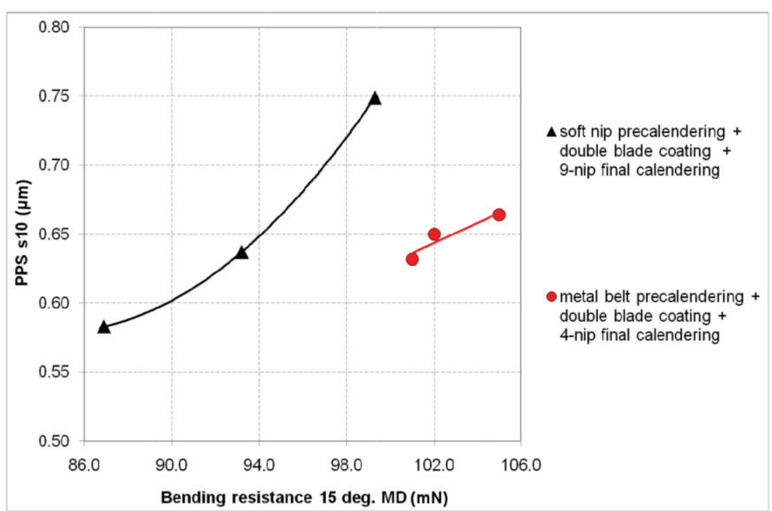

Figure 12. Bending resistance MD and PPS roughness of coated fine paper

Conclusions

Uncoated fine paper

The bulk saving capacity of the metal belt calendering process was demonstrated by comparing traditional soft nip final calendering of uncoated fine paper with metal belt calendering.

1. The metal belt calender gives higher bulk and bending resistance values compared to the soft nip calender. The paper bulk is 7% higher at the same Bendtsen roughness level,
2. The high bulk and bending resistance of metal belt calendered paper can be utilized by reducing the grammage of the paper. When the grammage was reduced by 7% (70 to 65 g/m²), the bending resistance of the paper was still at the same level as the soft nip calendered trial points (at the same Bendtsen roughness level).
3. The optical properties at the metal belt calendered trial points were at the same level as the soft nip calendered trial points. The opacity was slightly lower (-0.2 to 0.7 %), when grammage was reduced (70 to 65 g/m²). The brightness values were higher than the soft nip calendered trial points (0.2 to 0.6 %).
4. Another way to take advantage of metal belt calendering is to increase the filler content when the fiber amount in paper is reduced. The total grammage remains the same. In general, the price of filler is significantly cheaper than the price of fiber.
5. The filler content could be increased by 5% units (24 to 29%) in the metal belt calendered paper and the paper bending resistance remained higher than that produced with the soft nip calender.
6. Increasing the filler content improves the optical properties; the brightness increased by 1.8% and the opacity by 2.0%.
7. The metal belt calendered paper feels smoother than the Bendtsen roughness measurement indicates. At the same feel of roughness level, bulk is more than 10% higher. Reduced grammage or filler content increase didn't significantly impact feel roughness properties.

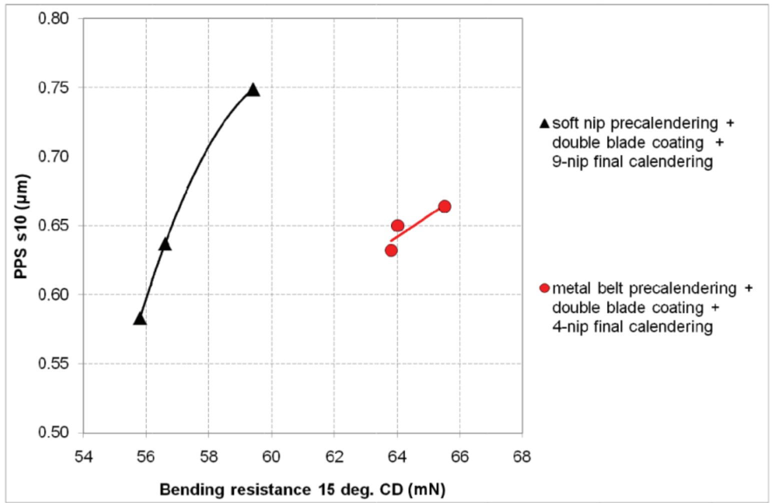

Figure 13. Bending resistance CD and PPS roughness of coated fine paper

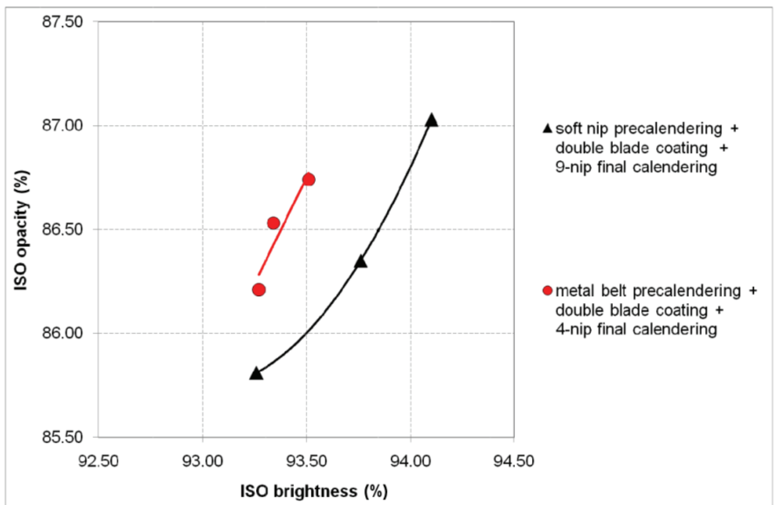

Figure 14. Optical properties of coated fine paper

Coated fine paper

The high smoothing capacity of the metal belt calendering process was demonstrated by comparing a traditional concept of soft-nip pre-calendering and multinip final calendering with a new concept of using a metal belt in the pre-calender position followed by four soft nips in the final calender position.

1. The intensive metal belt pre-calendering reduces the need for final calendering after coating for double-coated fine paper. The new concept based on pre-calendering with a metal belt has clear potential to simplify final calendering in the production of double-coated fine paper.
2. The new concept based on metal belt pre-calendering gave slightly better bulk with similar end product smoothness, but the difference in bending resistance was significant (8 to 14%).
3. There were no major differences in the optical properties between the new and the conventional concept. The conventional concept retains some potential for gloss increase and the brightness is better maintained than with high-temperature soft nip final calendering. The new concept has a slight advantage in opacity.

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This white paper combines technical information obtained from Valmet personnel and published Valmet articles and papers.

Valmet provides competitive technologies and services to the pulp, energy and paper industries. Valmet's pulp, paper and power professionals specialize in processes, machinery, equipment, services, paper machine clothing and filter fabrics. Our offering and experience cover the entire process life cycle including new production lines, rebuilds and services.

We are committed to moving our customers' performance forward.