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The effect of press draw and basis weight on woodfree paper properties during high-solids surface sizing

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ABSTRACT: In high-solids surface sizing of up to 30% solids, less starch penetrates the sheet, which means the sheet requires less drying. However, less penetration means the internal strength does not benefit from the starch as much as it does in conventional surface sizing. To compensate for this loss of internal strength, the Huygen internal strength of surface-sized paper can be increased by reducing the press draw from 3% down to 2% or lower. Starch penetration is further reduced, however, when the press-to-dryer draw is decreased because the lower press draw decreases the porosity of the basesheet. Moreover, reducing the press draw to less than 2% decreases the elastic modulus of the fiber network and reduces the bending stiffness of the sheet.

Application: Reducing the press-to-dryer draw to 2% or less can help compensate for a loss of internal strength in high-solids surface sizing.

The main role of sizing in writing and printing papers is to promote surface strength by binding fibers and filler particles to the surface. Starch is also expected to add internal strength to the sheet through liquid penetration [1]. When the starch remains more on the surface, however, it does not contribute as much to the internal strength [2, 3]. In sizing with a metered size press, solids contents vary from 5% to 18%, yielding starch applications of 0.7 g/m² to 4.0 g/m² [4]. On modern high-speed machines for fine paper and packaging board, a low solids content leads to a drying-limited process because of the high demands placed on drying capacity.

Recent studies [3, 5] on increasing the starch solids content from 8% to 30% have indicated that drying requirements can be reduced with a comparable amount of dry starch applied on the sheet. With decreased starch penetration, surface sizing with higher starch solids contents may cause a drop in the internal strength of the sheet. To compensate, it may be feasible to achieve the required internal strength before surface sizing by optimizing the wet-end process. This improvement can be accomplished through further optimization of the furnish components and the internal sizing process [3, 5].

According to Juppi and Kaihovirta [6], the press draw has a significant effect on many woodfree sheet properties such as internal strength and porosity. If the press draw is reduced from 3% to 1%, the internal strength of the sheet can be increased by up to 30% [6].

Juppi and Kaihovirta reduced the press draw by using dryer section runnability components to focus and intensify the negative pressure region on the opposite side of the dryer fabric at the opening wedge of the dryer cylinder. Additionally, lowering the basesheet basis weight below 80 g/m² is known to increase Scott bond values as a result of the decreased probability that planes will rupture in the sheet during Scott bond measurements [7].

We studied variable basis weights and press draws as tools for optimizing the final properties of surface-sized paper. The more specific aim was to study the combined effect of a reduced press draw and increased starch solids on the final paper properties. The question was, is it feasible to maintain the internal strength of a sheet by reducing the press-to-dryer draw to make up for the reduced penetration of starch? If we could compensate for the loss of internal strength, then surface sizing with high-solids starch solutions would be more successful.

EXPERIMENTAL

Materials

A woodfree furnish was used in making the base paper. The furnish was made from mill-produced reels containing 0.8% of wet-end starch. The furnish freeness was 505 mL CSF, the filler content was 23.3% ($CaCO_3$), the length-weighted fiber length was 1.28 mm, and the softwood:hardwood ratio was 30:70. A modified potato-based starch with low viscosity (Brookfield 100 rpm, 60°C) of 20 mPa•s at a 10% concentration was used as the surface sizing starch.

Methods

The base paper was produced on a pilot paper machine to basis weights of 69 g/m², 72 g/m², and 78 g/m² (bone dry) with three press-to-dryer draw levels (1%, 2%, and 3%). Press draw refers here to the relative speed increase from the press section to the first dryer group. The running speed in the paper machine trial was 1200 m/min.

Before surface sizing, the base paper rolls with a press dryness of 45% were dried to a moisture content of 97% at KCL, Helsinki, Finland. Nine rolls were made for surface sizing with high-solids starch solutions. In addition, one roll was produced at a basis weight of 77 g/m² and with a press draw of 3%. This roll was surface sized with a 10% starch solution as a reference sheet.

Surface sizing trials were run at a line speed of 1200 m/min and a linear load of 25 kN/m. The roll cover material was polyurethane with a hardness of 32 P&J and a roll diameter of 1415 mm. Film metering was performed with both 10-mm grooved rods (10% solids content) and 10-mm smooth rods (25% solids content). The grooved rod profile was selected based on a targeted wet film on the roll of approximately 24–25 g/m².

Grammage	SCAN-P 6:75
Density	SCAN-P 7:96
Ash content	SCAN P 5:63
Oil absorption,	SCAN-P 37:77
Cobb-Unger (10 sec)	SCAN-P 37:77
Air permeability, Bendtsen	SCAN-P 60:87
Bending stiffness, Taber	TAPPI 489 om-99
Internal strength, Huygen	TAPPI UM 403
Internal strength, Z-tensile	SCAN-P 80:98
Elastic modulus, Young	SCAN-P 67:93
Starch amount	TAPPI 419 om-91
Surface strength, IGT	SCAN-P 63:90

I. Test methods.

The aim was to produce a constant dry starch amount of approximately 1.5–1.8 g/m² per side with different starch solids. The rod type was selected based on measurements of the amount of wet film [8]. A single-nip soft calender was used at a machine speed of 1200 m/min, a steel roll temperature of 60°C, and a linear load of 45 kN/m. The top side of the paper was run against the steel roll. The hardness of the polymer roll was 90 ShD, and the diameter was 420 mm. The calender end moisture was 5.97% ± 0.42%.

Measurements

Paper properties were measured based on the test methods listed in **Table I**. Starch penetration curves and dimensionless numbers describing starch penetration were determined at VTT Processes, Jyväskylä, Finland, by a special method for analyzing starch penetration [9].

In this method, a microscopic RGB image of an iodine-stained cross section is first converted to gray scale. Next the gray scale image is reduced to a binary image through threshold processing to evaluate which pixels should be categorized to contain starch. In other words, which pixels are dyed darker than 0.8% of a parallel base paper sample, based on the wet-end starch content of the sheet.

The top and bottom edges of the cross section are determined next. The thickness of the cross section is standardized by scaling the height of all columns between the detected edges of the cross-sectional image to 200 pixels (**Fig. 1**, top). The distribution of starch-containing pixels is then determined in the *z*-direction from a single cross section.

A starch penetration curve (Fig. 1, bottom) is then defined by averaging distribution data from 16 parallel cross-sectional images. This penetration curve can be plotted either on a relative scale or as a g/m²-scaled simulated starch content (SSC) distribution by equating the integrated area under the curve to a known surface sizing starch amount. A penetration number, *Q*, is then defined as a dimensionless number where 0 means no penetration and 0.5 signifies starch evenly distributed in the *z*-direction.

RESULTS

Starch amounts measured from the paper samples are presented in **Table II**. An almost constant starch application was achieved with a total dry amount of 3.5 g/m² applied at 25% solids. With 10% solids content, however, the same dry amount

	Starch solids, %	Press draw, %	Grammage, g/m² 69	72	78
Ref.	10	3	—	—	2.38
Trials	25	1	3.51	3.49	3.51
	25	2	3.51	3.49	3.57
	25	3	3.44	3.50	3.52

II. Starch amounts applied, in g/m², at different basis weights, press draw levels, and solids contents.

was not reached. The difference in starch amounts applied has to be considered when evaluating the results at different solids contents.

Therefore, in the figures that follow, all curves are plotted as a function of the basis weight of the base paper—*i.e.*, the weight before surface sizing, even when the results relate to surface-sized samples. The points are plotted this way to make it easier to evaluate results from both surface-sized paper and base paper.

Starch penetration

Figure 2 illustrates the effect that press draw and basis weight have on starch penetration [9]. As the graph on the left shows, on the basis of SSC distributions, decreasing the press draw from 3% to 1% decreases the penetration of starch and boosts the amount of starch remaining on the sheet surface. This observation can be explained by the decreased openness of the basesheet as the press draw decreases. The graph also indicates that differences in starch penetration are more evident on the bottom side of the sheet. In our experiments, surface sizing at low solids (10%) resulted in an almost even distribution of starch through the *z*-direction, whereas the starch remained more on the surface of the sheet at 25% solids.

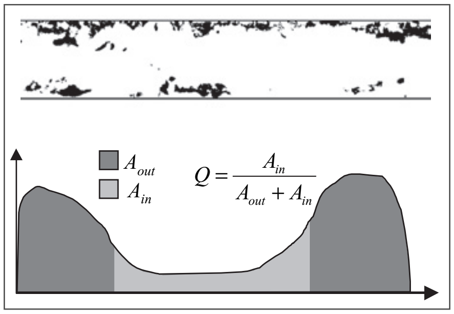
In graph on the right, a dimensionless penetration number, Q_{tot}, was used to characterize the starch distribution with different base papers surface sized with starch solution solids of 25%. The results are compared against the reference sample with 3% press draw and 10% starch solids. This figure further illustrates the relationship between press draw and consequent sheet openness and its effect on starch penetration. Here, decreasing the press draw seems to decrease the starch penetration consistently by closing the sheet. In addition, the starch penetration is shown to increase when the basis weight increases. This outcome can be explained by the increase in total void volume at higher grammages, which enhances the flow of liquid in the porous fiber network.

Air permeability

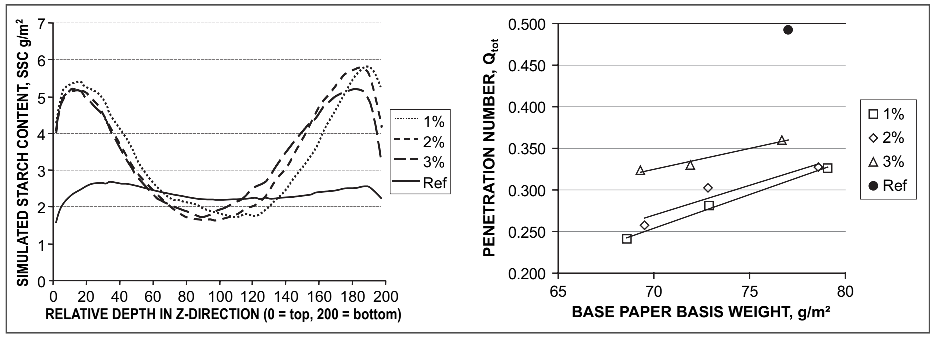
Figure 3 illustrates the effects of basis weight, press draw, and surface sizing on air permeability at different solids contents. Lowering the press draw reduces the air permeability of the basesheet considerably. This effect is also observed with a surface-sized sheet. Surface sizing with high-solids starch further reduces air permeability. The reduction in air permeability was achieved both by reducing the press draw and increasing the solids content, as previously reported [3, 5, 6].

Internal strength

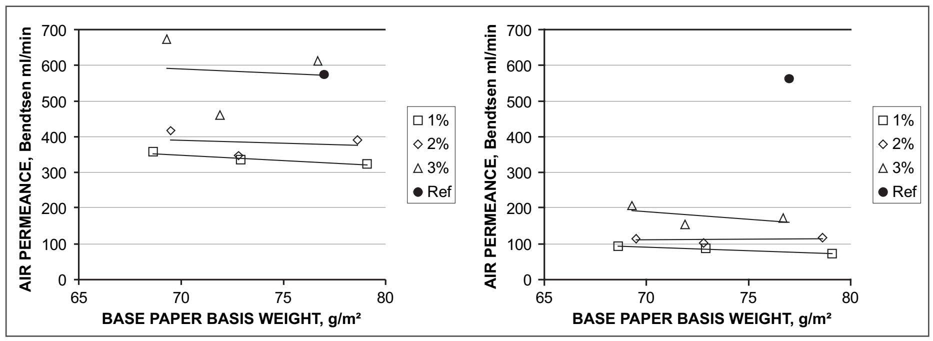
As reported earlier [6], reducing the press draw increases the internal strength of the basesheet, based on the Huygen measurement. The graph on the left in **Fig. 4** illustrates that lowering



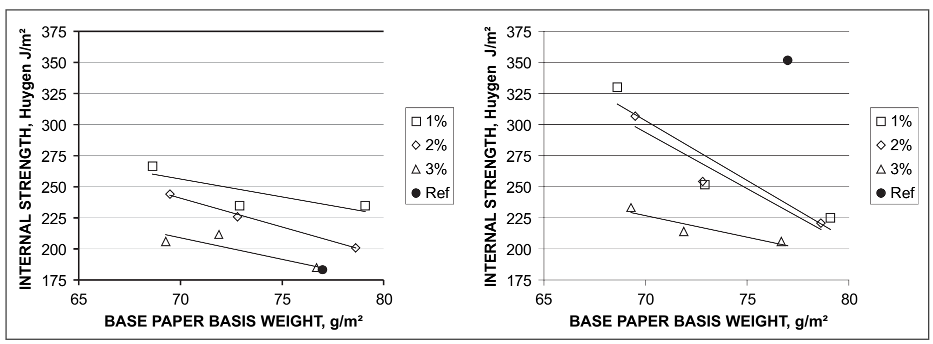
1. Derivation of the starch penetration curves and dimensionless penetration number from 16 cross sections stained with iodine and normalized for thickness.



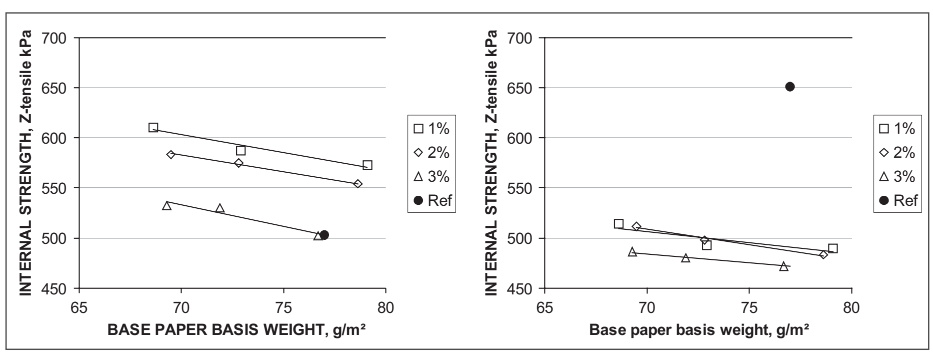
2. Starch penetration for the reference and trial samples as characterized by SSC distribution (left) and penetration number Q_{tot} (right).



3. Air permeability for base paper (left) and surface-sized paper (right).



4. Huygen internal strength for base paper (left) and surface-sized paper (right).



5. Z-tensile internal strength for base paper (left) and surface-sized paper (right).

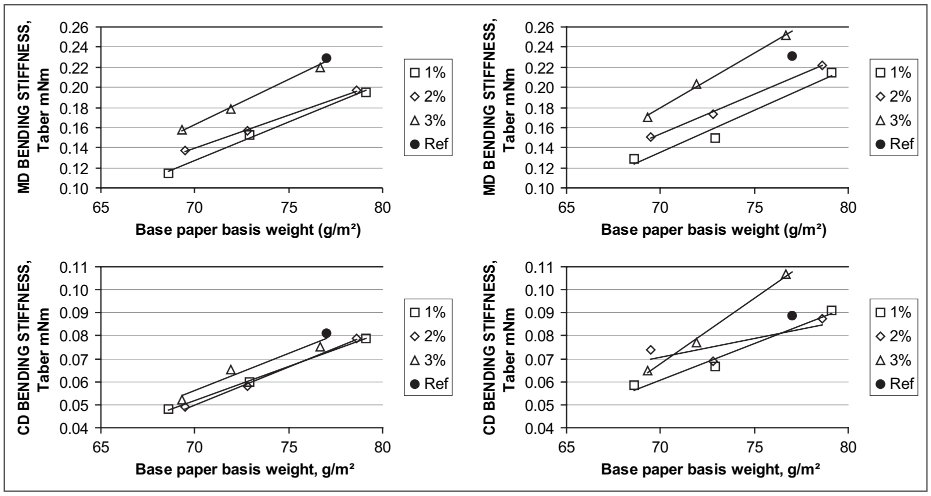
the press draw has the strongest positive effect on internal strength at low grammages. When the penetration of starch and the development of internal strength are compared at individual points on the graph, the increase in internal strength seems to be highest at the press draws of 1% to 2%.

This improvement at press draws of 1% and 2% is especially pronounced at the lowest grammages, even though the starch penetration for both is lower than at 3%, as presented in Fig. 2. Lowering the press draw under 2% does not seem to further enhance the internal strength of paper sized with high-solids starch—in contrast to the basesheet. Again, this outcome may be explained through the observations in Fig. 2, where starch penetration decreases further when the press draw is decreased below 2%. A decrease in starch penetration at a press draw below 2% will then counteract the increase in Huygen internal strength.

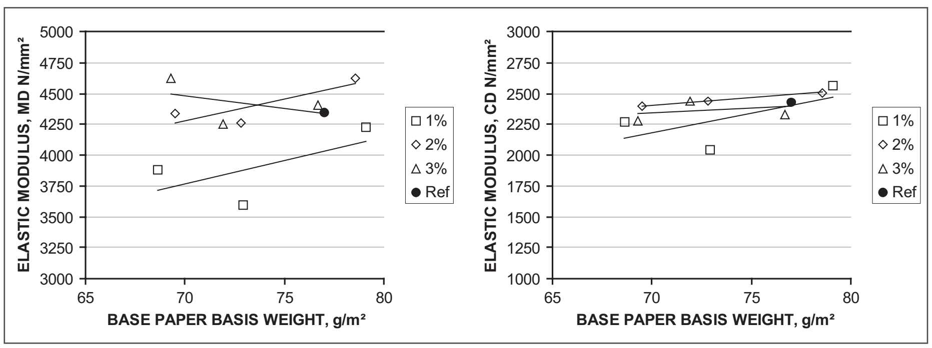
Although internal strength appeared to increase based on Z-tensile measurements, the values measured behaved somewhat differently than the Huygen values for internal strength when the press draw was decreased to 1–2%. The results are shown in **Fig. 5**. Here, high-solids surface sizing and calendering are actually lowering the Z-tensile strength as an absolute measurement compared to the basesheet.

As opposed to the Huygen results, decreasing the basis weight does not enhance the Z-tensile values much at a press draw of 1–2% compared to 3%. The increase in Z-tensile strength between different press draw levels remains fairly constant as basis weight decreases.

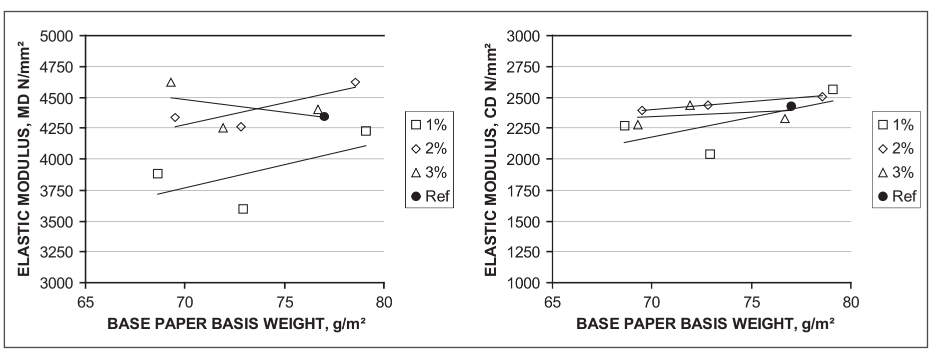
The Z-tensile increase in the basesheet as the press draw is reduced from 2% to 1% is offset, once again, by decreasing starch penetration. As the high-solids surface sizing reduces Z-tensile strength, the reference values for surface sizing with 10% starch solids are not reached.



6. Taber bending stiffness for base paper (left) and surface-sized paper in the machine direction (top) and cross-machine direction (bottom).



7. Elastic modulus of the base sheet in the machine (left) and cross-machine directions (right).



8. Surface roughness (Bendtsen) of the base sheet, top and bottom sides.

Huygen values increase and Z-tensile values decrease as high-solids starch is applied to the sheet. The different behavior in the values of the two measurements may be explained by the different principles on which they work. The Z-tensile method measures the *force* per unit area (*i.e.*, *z*-directional tensile stress) that is required to delaminate the specimen. The Huygen method measures the delaminating *energy*, which is similar to the more commonly used Scott Bond measurement.

At 25% solids content, the starch is concentrated on the surface of the sheet, leading to a steep *z*-directional starch gradient. Steep gradients in any mechanical construction can cause a local stress peak in the structure under load. This development may explain the actual decrease in Z-tensile strength even though starch binder is added to the fiber network. The Huygen measurement, which is based on the absorbed rupture energy of the sheet, may not be similarly effected by the structural gradients of the fiber network and its binder content.

Bending stiffness

Figure 6 presents the effects of basesheet properties and starch solids content on bending stiffness. The bending stiffness increases with higher basis weights. Increasing the press draw also had a positive effect on the bending stiffness.

Elastic modulus

The tendency toward reduced bending stiffness with lower press draws can be partly explained by the elastic modulus behavior of the basesheet (**Fig. 7**). The elastic modulus is more strongly affected by the press draw in the machine direction than in the cross direction.

With a high press draw of 3% directly after the press section with a sheet dryness of approximately 45–50%, the individual fibers in the fiber network may be straightened out in the machine direction. With a low press draw of 1%, the fiber network is taken to the drying section and dried into a more curly structure. This effect would lead to a lower elastic modulus for the fiber network because the fibers are less straight, where straightness contributes to the elasticity of the whole fiber network.

The observation that the elastic modulus depends on press draw, especially in the machine direction (Fig. 7, left), supports this assumption. The behavior of the bending stiffness at different press draw levels can therefore be partly explained.

Surface roughness

The effect of increased draw on the elastic modulus through the straightening out of fibers may be supported when the press draw effect on the surface roughness of the basesheet is observed. As **Fig. 8** shows, the press draw reduction increased the surface roughness (Bendtsen).

If this surface roughening reflects the fibers being dried into a more curly structure with a reduced press draw, then the roughness values should be higher with a press draw of 1%. Moreover, the press draw can be optimized in terms of the effect that roughness has on starch pick-up in surface sizing [10].

DISCUSSION

The effect of high-solids surface sizing reported here is in agreement with results from earlier studies [3, 5]. Furthermore, the effect of press draw on basesheet properties is in agreement with the findings of Juppi and Kaihovirta [6]. According to our results, the Huygen internal strength of high-solids, surface-sized paper can be increased by reducing the press draw to about 2%. This reduced draw will partly compensate for the loss of internal strength that results as the starch remains on the surface in high-solids sizing.

Decreasing the draw below 2% does not necessarily have a further effect on increasing the internal strength. The reason is that the low press draw decreases the porosity of the sheet, resulting in even less starch penetration. When we decreased the press draw, the starch penetration consistently decreased, which tended to counteract increases in the internal strength. When the press draw is too low, the elastic modulus of the fiber network decreases, which should have a negative effect on the bending stiffness of the sheet [7].

In our study, we noticed a difference between two different methods for measuring internal strength when the surface was sized with high-solids starch. While Huygen internal strength increased compared to the basesheet, the Z-tensile strength decreased. This difference can be explained by a steep *z*-directional gradient in the sheet caused by starch failing to penetrate the sheet. This gradient may create local areas of peak stress in the sheet structure under a *z*-directional load, which would result in lower resistance to rupture.

As explained, the penetration of starch is negatively affected when the press draw of the basesheet is reduced, which counteracts the increase in internal strength when a lower press draw is used. The effectiveness of decreasing the press draw to increase internal strength is most significant at low basis weights. At low grammages, the starch penetration is negligible, and any decrease in penetration has a minimal negative impact on internal strength.

CONCLUDING REMARKS

The internal strength properties of base paper for high-solids surface sizing can be optimized to a certain extent by adjusting the base paper's press-to-dryer web draw. The optimization strategies described here can be used when the aim is to improve air permeability, bending stiffness, and web runnability in high-solids sizing while preserving internal strength. Based on our results, the Huygen internal strength of surface-sized paper can be increased by reducing the press draw to 2% or lower.

Reducing the press draw will partly compensate for the loss of internal strength caused by decreased starch penetration at solids contents up to 25%. According to our starch penetration analysis, however, sheet penetration is reduced when the press draw is reduced. The lower press draw apparently induces a decrease in the porosity of the basesheet. This effect partially counteracts the ability of the starch to increase the internal strength.

Also, different behaviors were observed in the development of internal strength in regard to the Huygen and Z-tensile measurements. This difference may be explained by the tendency of high-solids starch to remain on the surface of the sheet and by the differences between the two measurement methods.

Lowering the press draw from 3% to 2% with high-solids surface sizing provides most of the positive effects, without deteriorating the bending stiffness too much by decreasing the MD elastic modulus of the fiber network. Decreasing the press draw below 2% does not enhance the internal strength of the final sheet, because of the decreased starch penetration at the lowest press draw levels. In addition, with a 2% press draw, there will still also be a sufficient window for adjusting the press draw based on press–dryer transfer runnability requirements.

With respect to the press draw effect on sheet roughness and the consequent effect on sizing pickup, optimizing the press draw can be a point of interest in terms of the surface sizing process.

The results presented here can be utilized to optimize the press draw for high-solids surface sizing. The aim could be to minimize the press draw below 2% when internal strength or air permeability are critical. On the other hand, the press draw can be maximized when the bending stiffness of the sheet is critical. **TJ**

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INSIGHTS FROM THE AUTHORS

According to our research, as well as other related literature, increasing the solids content results in an internal strength decrease of the sheet due to decreased penetration of the more viscous starch. We felt that increasing the internal strength of the base sheet as a result of optimizing the press to dryer draw might provide one solution to this problem.

We feel this research supports previous research, in that decreasing the press to dryer draw is known to have a strong effect to such paper properties as the internal strength. This previous work was giving the idea of using these parameters in compensating some negative effects concerning surface sizing in high solids contents. The most difficult practical aspect was to put together the needed pilot paper machine and coater trials studying these parameters.

In our research, we noticed that two internal strength measuring methods (i.e. Z-tensile and Huygen internal strength) behaved the opposite way. With starch on the surface, Huygen increased and Z-tensile decreased (compared to the base sheet). This was explained through looking at the gradients in the starch distribution: Steep gradients in any mechanical construction can cause a local stress peak in the structure under load. This development may explain the actual decrease in Z-tensile strength despite the addition of starch binder into the fiber network.

It was also noticed that the changes in porosity when press draw was varied did effect measured starch z-distribution. The starch penetration was measured with a newly developed method. Anyone that wants to optimize internal strength and bending stiffness of the WF sheet, especially when the surface sizing starch is concentrated on the paper surface, can benefit from this work.

The next step of this work would be to continue the introduction of surface sizing at high solids content of the starch solution at the mills. Also, the investigations on the effect of surface sizing starch on the elastic modulus and bendong stiffness of the paper will continue.

When this research was carried out, Lipponen and Grön were with Metso Paper, Inc., Järvenpää, Finland. Grön is now with StoraEnso, Finland. Email Lipponen at juha.lipponen@metso.com.

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