

Paper structure and printability as controlled by the fibrous elements

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ABSTRACT: The surface structure and printability of *radiata* pine TMP sheets are sensitive to the character and content of their long fiber and fines fractions. Thin-walled fibers of juvenile wood generally produce sheets that have better optical properties and better half-tone and solid-tone printing properties than do the thick-walled fibers of mature wood. Secondary fines bring pulp freeness down faster than do primary fines but do not provide a compensating increase in the print performance. Sheet pore size distribution influences print-through but not half-tone dot quality. These observations were determined by examining the structure and printing behavior of newsprint-equivalent, oriented laboratory sheets made from pulps of 100 mL, 70 mL, and 50 mL CSF.

Application: Sheet properties are sensitive to the precise level of fiber character and sheet fines content. By manipulating the fiber and fines fractions, papermakers can improve sheet properties.

Paper printability is largely defined by the paper surface and structure, which are determined by the quantity and quality of the component fiber and fines fractions [1–5]. The larger cross-sections and longer length of mature wood fibers mean the sheet containing them will consolidate differently than a sheet composed of the smaller fibers of juvenile wood [6]. An increase in refining will generally improve the consolidation and bonding of the fiber [7–8]. The upper limits to fiber and pulp quality are constrained by the size and structure of the fiber, by the response of the fiber to its processing, and by the limits that conventional processing practices impose.

By manipulating the qualities and quantities of these fractions, the papermaker has the opportunity to break through these process constraints and the limitations imposed by the raw material. To do so would be to tailor the pulp to meet the customer's needs for the performance of the paper. The first step toward this goal is to determine how the printing performance is affected by the composition of the pulp. Therefore, we examined the sensitivity of newsprint-type paper to its fiber and fines content in terms of the paper's performance in printing, both in half-tone and solid-tone printing.

THE EXPERIMENT

Project strategy

The papers analyzed were principally of 45 g/m² and were derived from pulps at a freeness of 100 mL CSF. We set boundaries on the fiber size by using either juvenile

or mature wood of a single softwood (*radiata* pine). **Table I** presents basic information on the wood samples.

We carried out three interrelated experiments, which we refer to as Parts A, B, and C. In each part, the long fibers of each wood type, mature or juvenile wood, were mixed with fines of their own wood type. The variables examined were: the wood fiber type (juvenile or mature wood), the energy for refining long fibers (0–2000 kW•h/o.d. ton), the ratio of primary to secondary fines (2:0–2:2), and the fines concentration (as a change in freeness).

We did not compare the whole fines fractions of these two fiber types. An earlier comparison of juvenile wood (as core wood) and mature wood showed that their fines are similar in the way they behave in papermaking [6]. Furthermore, although mature wood has slightly greater wood extractives content than juvenile wood has, we did not examine the potential impact of this difference on sheet surface energy and printability.

Fiber and fines fractions

One metric ton of each wood type was thermomechanically refined in PAPRO's Jylha SD 52/36, 1.25-MW refiner to a freeness of about 200 mL CSF. **Table II** presents basic data on pulp quality for both the juvenile and mature wood. The sample was screened to isolate the long fiber sample for further refining. The refining conditions used are known to retain juvenile wood fiber length better than mature wood fiber length [9].

We obtained five samples of long fiber of each wood type by applying refining

energy at levels of approximately 0, 500, 1000, 1500, and 2000 kW•h/o.d. ton. A Britt jar with a 200-mesh screen was used to isolate the primary fines (predominantly particulate) from the short fibers and to isolate the secondary fines (predominantly fibrillar) produced during the refining of the 1000 kW•h/o.d. ton of long fiber fraction.

Three experiments

In the Part A experiments, we focused on the long fiber quality, testing the performance of the long fiber at different degrees of refining energy. We also determined the relative need for the fines fraction to achieve a target freeness. The percentages of fines required to manufacture pulps with a freeness of 100 mL CSF from the individual long fiber fractions (refined to different degrees) were calculated from the freeness response curves of mixes of the long fiber with fines at concentrations of 0%, 10%, 20%, 30%, 40%, and 50%. **Figure 1** shows the form of the freeness response curves.

Short fiber was included with the long fiber in its original proportion. The fines were added as a composite of 2 parts primary fines to 1 part secondary fines.

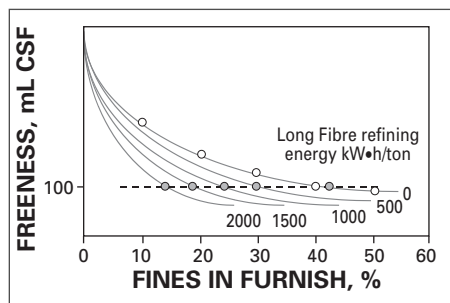
In Part B, focusing on fines quality, we tested the relative influence of the primary and the secondary fines in each individual series of furnishes of the 1000 kW•h/o.d. ton long fiber fractions. Each fines combination was mixed with long fiber of the same wood type. The percentage of fines required to produce pulps at 100 mL CSF was determined in the same manner as in Part A. The mixture ratios were 2:0, 2:1, 2:1.5, and 2:2.

	JUVENILE	MATURE
Tree age, years	11	27
Wood density, kg/m ³	365	425
Oven-dry content, %	40.1	42.8
Fiber length, mm	2.23	2.95
Fiber width, mm	43.2	47.6
Cell wall thickness, mm	12.7	15.1
Coarseness, mg/m	0.178	0.270

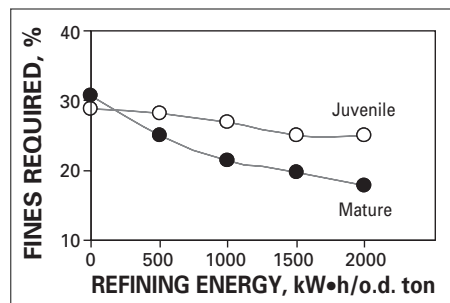
I. Basic quality information on the wood samples.

	JUVENILE	MATURE
Baseline pulp		
Freeness, mL CSF	218	260
R30, Bauer McNett, %	43.0	52.7
Refining, kW·h/o.d. ton	2505	2230
Long fiber fraction		
Reject rate, %	37.5	62.1
R30, Bauer McNett, %	69.0	81.0

II. Quality data for baseline pulps derived from both juvenile and mature wood.



1. The amounts of fines required to produce a furnish of 100 mL CSF from each long fiber fraction were determined from these individual freeness response curves.



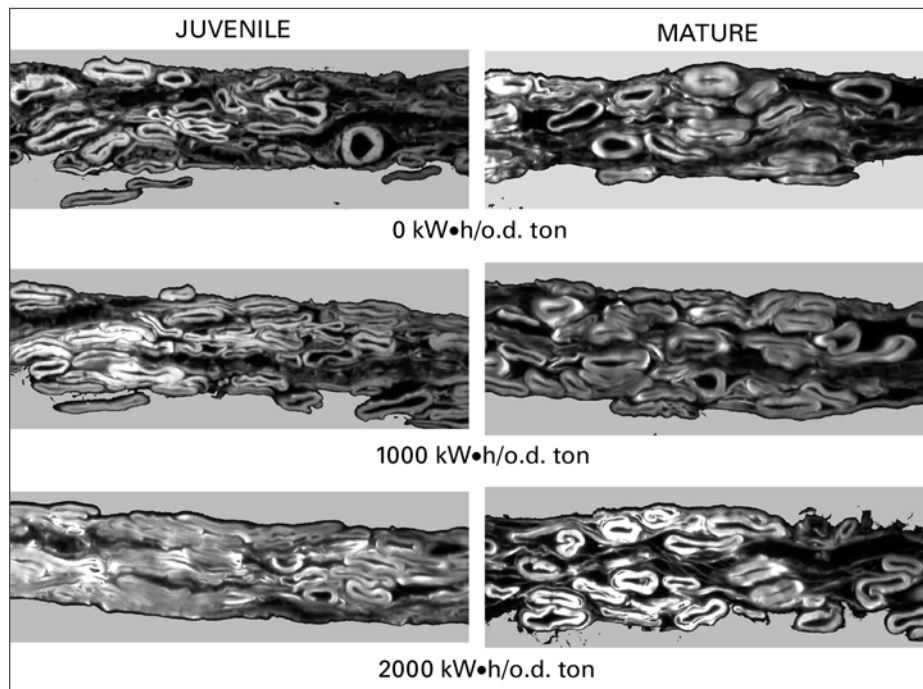
2. Fines required for different mixtures, each at a freeness of 100 mL CSF.

In the third part, Part C, we examined the impact of increased fines quantities on the fiber network. We did so by adding extra fines to pulps of 100 mL CSF to produce pulps of 70 mL and 50 mL CSF. The fines were added as a mix of 2 parts primary fines to 1 part secondary fines to 1000 kW·h/o.d. ton refined long fiber.

The freeness response curves of Part A were used to determine the proportions of fines to be added. In practice, the pulps at the lower freeness level had freeness values of 52 mL CSF (juvenile wood) and 64 mL CSF (mature wood).

Sheet preparation and analysis

Laboratory sheets were dynamically formed from each furnish mix with an extensively modified CTP former. This former had been rebuilt to give superior control of the jet and wire speeds and stock flows and to improve cross-sheet profiles and paper uniformity. The sheets produced were calendered.



3. Impact of long fiber refining energy on the structure of 45-g/m² sheets of both juvenile and mature wood fibers.

All paper properties were determined with PAPRO methods. Solid-tone printing was performed with an IGT AIC-5 press. Strips were printed at inking levels of 2.4 μ m and 4.8 μ m, and results were interpolated at print density levels of 0.85 and 1.00. Print-through was divided into its three components: direct show-through, pigment penetration, and vehicle absorption.

Half-tone offset print performance was measured with an IGT F1 press that had been modified to enable standard, wet lithographic printing. This press also supports image analysis. Pore size distribution was measured with a gas drive, PMI 6.0, capillary-flow porometer.

LONG FIBER QUALITY

Fines requirement

As Fig. 2 shows, there was a pronounced difference between the long fiber fractions of juvenile and mature wood in their demand for make-up fines to produce pulps of 100 mL CSF. Whereas the fines demand of the juvenile long fiber decreased by only 4% with the applica-

tion of 2000 kW·h/o.d. ton, the fines demand of the mature long fiber decreased by 13%.

Sheet consolidation

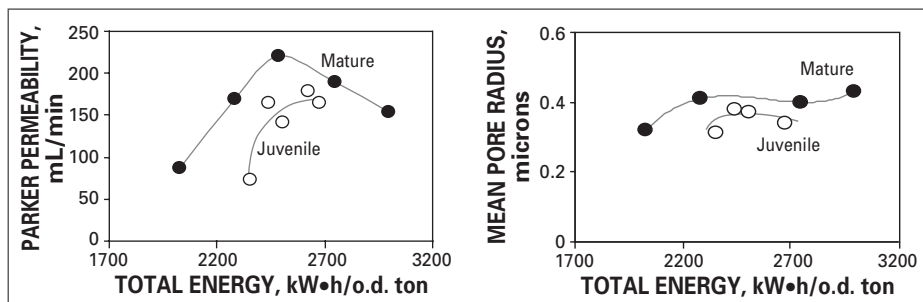
As a group, the sheets from juvenile wood fiber were able to be calendered to higher densities (610–630 kg/m³) than those from mature wood fiber (540–580 kg/m³). Microscope cross-sections, as shown in Fig. 3, confirm both the density differences between fiber types and the increase in fiber and sheet consolidation with increasing refining energy.

Permeability

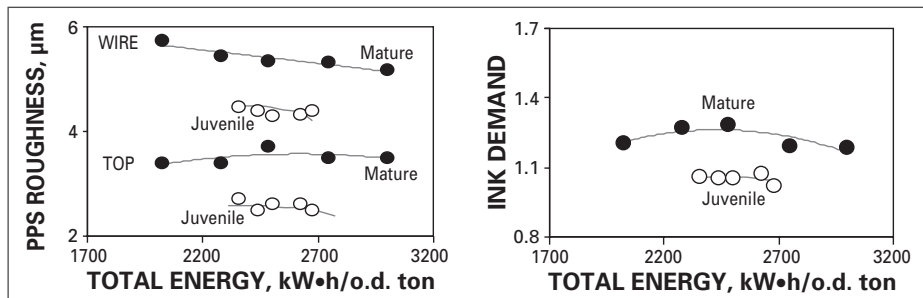
At equal levels of total refining energy, the juvenile wood fiber generally formed less permeable sheets than those of the mature wood fiber, as Fig. 4 shows. The number of pores in a sheet generally followed permeability, and there was no discernible difference between fiber types for this parameter.

Figure 4 also shows that the mean pore radius was larger for the mature wood fiber than for the juvenile wood fiber. The mean pore radius also increased with the reduced fines content

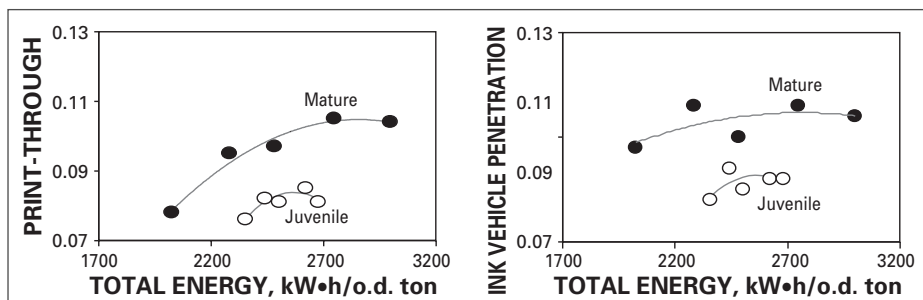
FIBERS AND FINES



4. Permeability and mean pore radius (100 mL CSF).



5. Total refining energy vs. surface roughness and ink demand (100 mL CSF).



6. Print-through and the ink vehicle penetration component of print-through at 0.85 print density on the top side of the sheet (100 mL CSF).

of the sheets for the more extensively refined long fiber. Conversely, the juvenile wood fiber appears to have sufficient flexibility at high refining levels to close up the sheet structure and compensate for the (lesser) reduction in fines.

Surface roughness

On both sides of the sheet, the larger mature wood fibers lead to rougher surfaces than the surfaces of sheets formed from juvenile wood fibers. Figure 5 shows this relationship and also shows that for both types of fiber, the fines-rich, top surface is smoother than the wire-side surface, which is relatively lean in fines.

Furthermore, there is a distinct drop in wire-side surface roughness with the refining of the mature wood fiber. However, there is little difference in the wire-side values of the sheets derived from juvenile wood fibers.

Ink demand

The smoother top surface of the sheets of both fiber types required substantially less ink than did their respective, rougher wire-side surfaces (not shown). Between fiber types, the smoother sheets of the juvenile fiber required less ink to achieve a print density of 0.85 than did those of the mature fibers, as also shown in Fig. 5. This result is consistent with the related study of Jones *et al.*, who compared the printability of sheets made from chemical pulps composed of either thin-walled fibers from spring wood or thick-walled fibers from summer wood [10].

Print-through, strike-through, and show-through

For each side of the sheet, both print-through and strike-through were greater for the less opaque and more porous sheets of mature wood fiber than they were for the sheets of juvenile wood

fiber. Figure 6 bears out this comparison for print-through. Print-through and strike-through were also greater for the fines-lean, wire-side surface than for the top-side surface. The more open wire-side has a higher ink demand and may also allow the ink to penetrate further into the surface.

On the other hand, there is no difference, for either fiber type, between the two sides in their show-through. The less opaque mature wood fibers do, however, exhibit more show-through than do the juvenile fibers, for either surface.

On the more open, wire-side surface, the sheet from pulp of mature wood fibers allowed pigment penetration that was marginally higher than for the sheet from pulp of juvenile wood (not shown). In the more closed, top-side surface, there was no difference between the sheets of the two fiber types. In all instances, as Fig. 6 also illustrates, comparisons between the fiber types on both sides of the sheet showed that the mature fiber led to greater vehicle absorption than did the juvenile fiber.

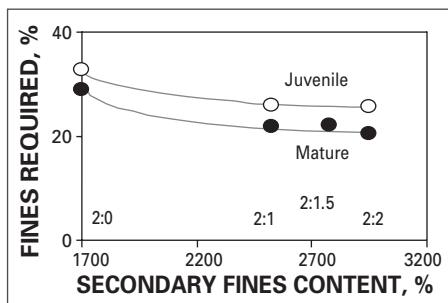
Half-tone print performance

The small data sets of half-tone print performance were difficult to analyze statistically. We did not observe consistent, strong trends or definitive differences arising from differences in fiber type or levels of refining energy.

FINES QUALITY

Relative to the primary fines, the secondary fines were efficient in lowering freeness but were not effective in maintaining the performance properties of the sheet. This outcome was more pronounced for the case of the mature wood fiber than for the juvenile wood fiber. For both fiber types, the initial addition of secondary fines (*i.e.*, from a mix ratio of 2:0 to 2:1) had a substantially greater impact on the character of the mix than did the addition of further quantities, as Fig. 7 shows.

The effect of this large difference in the fines required dominated this part of the experiment. Overall, the sheets containing higher proportions of the secondary fines generally had poorer optical, surface, and print properties than did the control sheets with no secondary fines. This outcome is not due to the quality of the fines but is the direct result of lower fines content.



7. Secondary fines required to make up pulps at 100 mL CSF.

FINES QUANTITY

Sheet consolidation

As we progressively added more fines to the fibers to give pulps of lower freeness, the sheet samples increased in density. The micrographs of Fig. 8 show that this increase was greater for the mature wood fiber than for the juvenile wood fiber.

Similarly, with the enriched fines content in the pulp, the sheet permeability decreased, and the number of pores in the sheet increased, as Fig. 9 shows. At high fines contents, it is possible for the sheets made from the pulp of mature wood to achieve the same high opacity but not the light-scattering coefficient of the sheets derived from the pulp of juvenile wood (not shown).

Ink demand and half tone dot

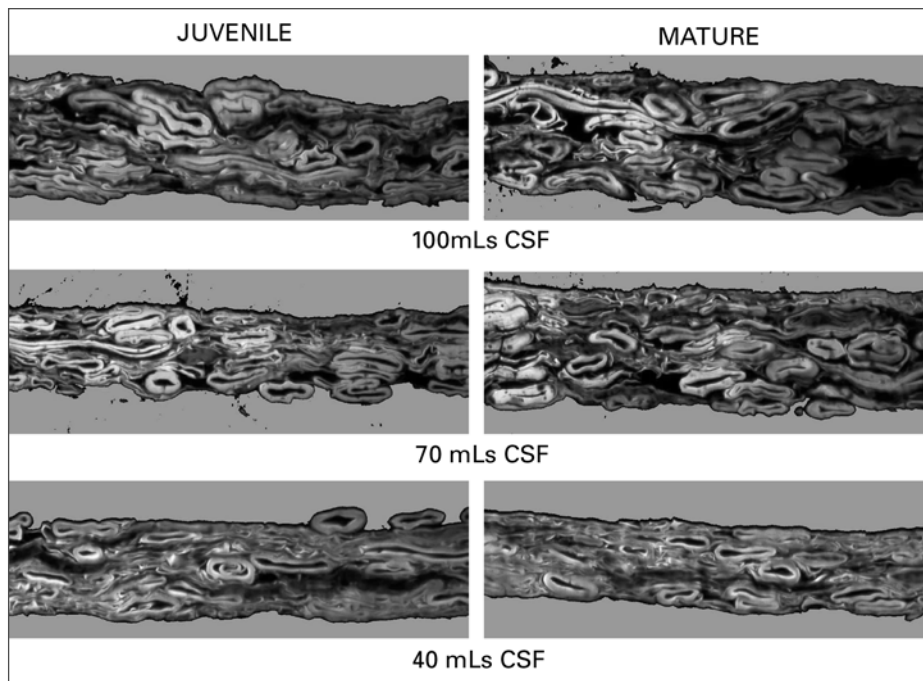
Ink demand decreases with decreasing freeness (and increasing fines content). At all fines contents examined, the juvenile fiber has a lower ink demand than the mature fiber has. Consistent with this finding, the variability of the half-tone dot was greater for the sheets of the mature fiber than for the juvenile fiber, as shown in Fig. 10. Surprisingly, within each set of sheets formed from either the juvenile wood or mature wood fiber type, the substantial change in the number of pores in the sheet did not result in any strong improvement in the quality of the half-tone print dot.

Print-through, show-through, and strike-through

The analyses in Part A established that the print behavior of the mature wood fiber was not as good as that for the juvenile wood fiber for the pulps of 100 mL CSF. This trend was also observed at lower freeness. The impact of the increased fines content caused both pigment (not shown) and vehicle penetration to decrease markedly (Fig. 11).

CONCLUSIONS

In these experiments, we tested the interrelated impacts that fiber size, fiber quality, and the quality, quantity, and type



8. As increasing proportions of fines were added to the fraction of long fiber (refined to 1000 kW·h/o.d. ton), the sheets produced from them decreased in freeness.

of fines have on the structure and print performance of newsprint-equivalent sheets. These observations may be used to interpret and better understand the contribution of the fiber and fines components of commercial TMP pulps.

- When refined at different levels of energy, long fiber from juvenile wood is less sensitive than long fiber from mature wood to the contribution of the fines fraction for the development of its overall pulp properties and the properties of sheets derived from it. The observation of this behavior reinforces earlier observations that the more slender and thinner-walled juvenile wood fiber is better able to consolidate in the sheet than the larger and thicker-walled mature wood fiber [11]. Thus, the pulp of juvenile wood is less dependent on the fines fraction for the development of its properties than is the pulp of mature wood.
- Juvenile wood fiber collapses under constant calendering loads to yield sheets of higher densities than the sheets derived from the pulp of mature wood.
- Sheets made from the fibers of juvenile wood are less porous and have smoother surfaces than those made from the fibers of mature wood. Maximum values obtained for sheet porosity, ink demand, and print optical properties indicate that the sheet

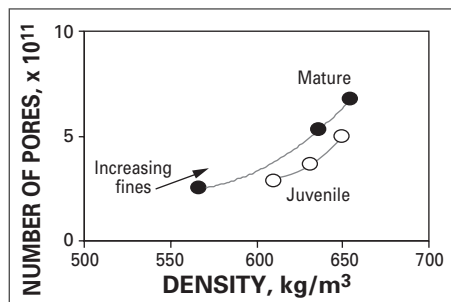
is very sensitive to the precise level of fiber character and sheet fines content.

In our efforts to maintain the freeness of 100 mL CSF, we were able to reduce the amount of fines added at high levels of refining because of the increased fiber flexibility. This reduction in fines caused the sheet to be more open and to have higher print-through and show-through. As the long fiber was further improved at the higher levels of refining, the sheet closed up with the better conformability and consolidation of the fiber, which would improve the sheet's per

- Secondary fines are more efficient than primary fines in their contribution to the freeness behavior of the pulp. Thus, it takes less bulk in secondary fines to yield a specific freeness when mixed with a particular fiber type. Secondary fines are not, however, correspondingly more efficient in their contribution to the printing parameters of the sheet.

The implication is that refining conditions that favor the preferential generation of secondary fines will cause freeness to fall faster than the print parameters will increase. Conversely, mechanical pulps of equal freeness produced from different wood samples and by different processes are unlikely to produce

FIBERS AND FINES

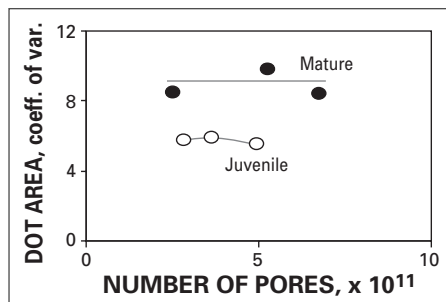


9. The number of pores in the sheet increases with increasing fines and decreasing freeness.

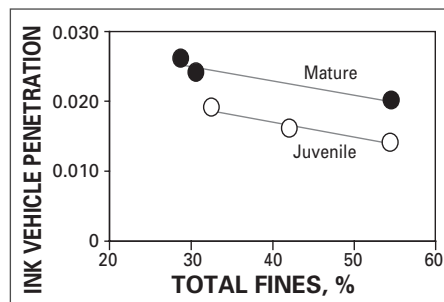
sheets of equal print quality, because of their differences in primary and secondary fines contents.

- Ink demand appears more sensitive to fiber size and quality than to the pulp fines content. Ink demand is lower for sheets characterized by the smaller fiber of juvenile wood than by the longer fiber of mature wood.
- Increased quantities of fines in a fiber network will cause marked increases in sheet density and corresponding decreases in sheet porosity and roughness. These changes allow reduced ink demand and improved print performance. In this study, we were able to infer relationships between pore structure characteristics and half-tone print quality, but we could not give definitive trends.

TJ



10. The coefficient of variation for the half-tone dot area with decreasing freeness.



11. The vehicle penetration component of print-through on the wire-side surface with decreasing freeness.

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INSIGHTS FROM THE AUTHORS

With our research, we wanted to achieve a new level of understanding of the impact of TMP fiber and fines quality and quantity on paper structure and printability, within the boundaries established by the juvenile and mature fiber of a representative commercial softwood. This research extends earlier work by our laboratories, and the work of others, to a new level of insight.

The large scale of the experiment and its exacting practical requirement to prepare 100 CSF furnishes of differing fiber qualities and fines quantities was the most demanding part of the study. The different behavior of the primary and secondary fines fractions in influencing both paper printability and furnish freeness is of interest and is leading to new thinking on how pulp refining strategies may be changed to improve paper strength and printability, and furnish drainage.

We hope that, through our work, mills will recognize that the development of the individual pulp fractions does impact substantially on process economics and paper quality (value), and transfer the concepts of this study to their own process operations. Invariably, this will require an audit of pulp fiber quality across the mill.

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