Impulse drying of recycled multi-ply linerboard: Laboratory-scale studies

David I. Orloff

ABSTRACT: Impulse drying was simulated in the laboratory to evaluate its effect on linerboard containing recycled fiber. Single- and two-ply sheets were produced from virgin fiber, OCC (old corrugated containers), and blends of both pulps. Drying performance was insensitive to pulp lignin content but sensitive to pulp species, with southern white pine performing better than Douglas-fir. Key pulp-substitution variables were identified by comparing the performance of impulse drying with double-felted pressing. For single-ply blends, impulse drying provided superior strength up to 50% OCC content and superior drying performance up to 75% OCC content. Two-ply sheets were made with a thin top layer of virgin fiber and a thicker bottom layer of either 100% OCC or a kraft/OCC blend. Sheets with a blended bottom ply showed superior dryness and strength when top-ply freeness was 450 mL CSF or more. Sheets with a bottom ply of 100% OCC showed enhanced dryness and strength when top-ply freeness was 600 mL CSF or more.

KEYWORDS: Bogus boards, lignin content, liner boards, multi-ply boards, Pinus, Pseudotsuga menziesii, *reclaimed fibers, shock drying.*

Ongoing laboratory and pilot-scale research at the Institute of Paper Science and Technology (IPST) has demonstrated that heavyweight grades of paper, such as linerboard, can be successfully impulse dried *(1–15)*. That research has shown that sheet delamination can be avoided by a combination of processing strategies:

- Make the prepressed sheets highly permeable to water flow.
- Reduce excessive heat transfer to the sheet to avoid destructive internal flash evaporation at the exit of the impulse dryer.

Research at IPST suggests that a sheet with high Darcian permeability (i.e., a low hydrodynamic specific surface area) can be obtained by limiting refining to the minimum required for product aesthetics and by prepressing the sheet to as high a solids as possible. Additional research also suggests that excessive pressure-dependent heat transfer can be eliminated by using press-roll surfaces composed of materials having low thermal conductivity, low heat capacity, and low density.

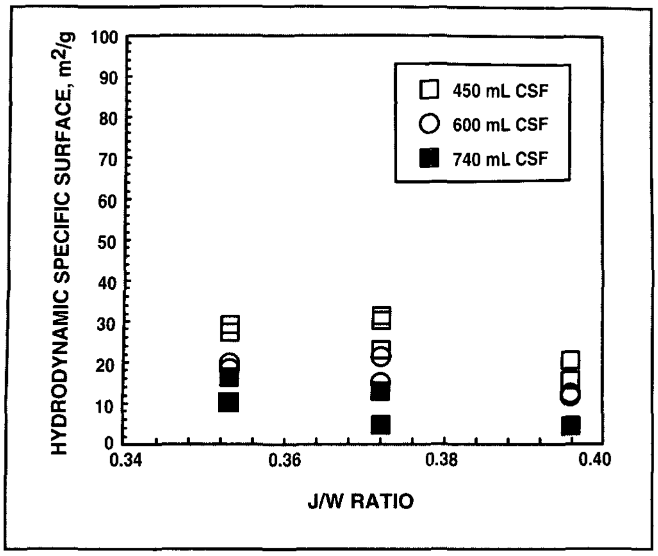
Previous impulse-drying research at IPST has been limited to the use of single-ply linerboard sheets made from virgin southern pine that had been minimally refined to eliminate shives. In contrast, commercial linerboard is usually two or three ply and composed of blends of virgin kraft and recycled fiber.

While the precise recycle content varies from mill to mill, there is escalating environmental pressure to increase recycle content. U.S. mills typically use recycled fiber from old corrugated containers (OCC) collected at warehouses and other high-volume locations. In current practice, the amount of recycled fiber included in linerboard is limited by the decrease in sheet strength that occurs as recycle content is increased. To achieve acceptable strength, mills either limit recycle content or further refine the recycled fiber, which has a negative impact on water removal and machine speeds.

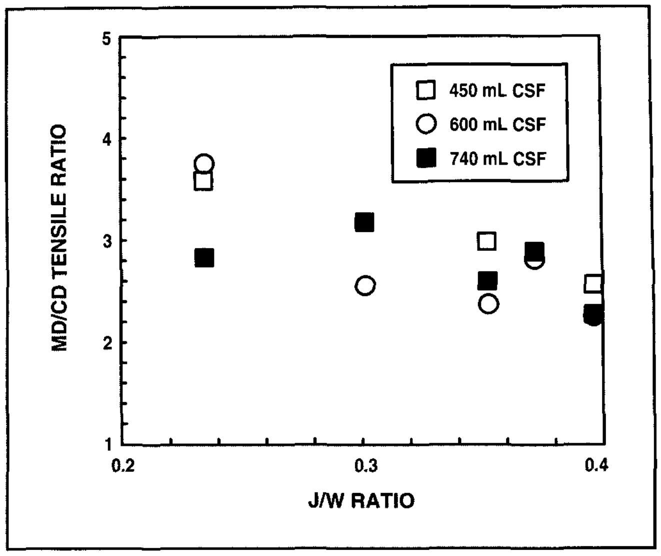
Recycled fiber has an additional disadvantage in its unacceptable physical appearance. To improve the appearance of liner made with recycled fiber, U.S. manufacturers form a multi-

Orloff is a professor of engineering and director of Engineering and Paper Materials Division at the Institute of Paper Science and Technology, 500 10th St. NW, Atlanta, GA 30318.

2. Hydrodynamic specific surface as a function of jet-to-wire velocity ratio for single-ply sheets produced from HKSP at three levels of freeness. (Sheets pressed to 52% solids.)



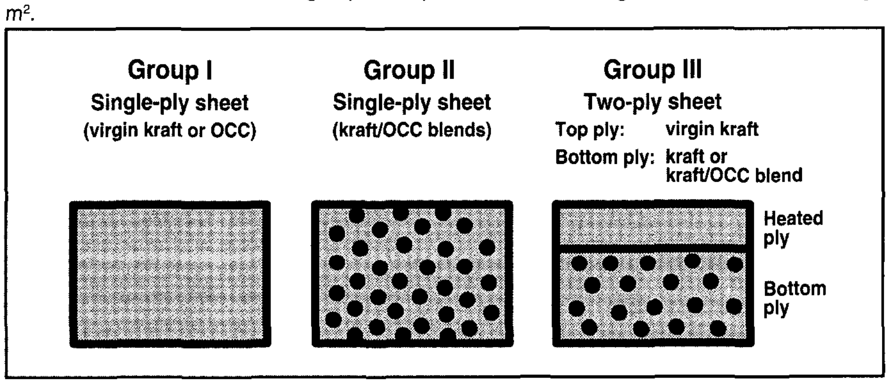
3. MD-to-CD tensile ratio as a function of jet-to-wire velocity ratio for single-ply sheets produced from HKSP at three levels of freeness. (Sheets pressed to 52% solids and cylinder dried.)



ply sheet, where recycled fiber is contained in a bottom or inner ply, with outer plies made from virgin kraft refined sufficiently to impart an attractive appearance to the product.

The present research was designed to extend impulse drying to sheet constructions that correspond to commercial sheet structures.

1. Sheet structures for the three groups of experiments. Basis weight for all sheets was 205 g/m^2.



Experimental design

The experimental program was conducted in three groups, based on the sheet structures illustrated in **Fig. 1.** The composition of sheets in each grouping is given in **Table I.**

The first group of experiments focused on the effects of pulp species and lignin content (kappa number). The second group of experiments examined the effects of blends of virgin kraft and recycled OCC. The third group of experiments investigated the influence of the composition and freeness of both the heated top ply and the bottom ply. In all cases, the total basis weight of the sheets was held constant at 205 g/m^2.

Previous research has shown that sheet delamination begins at a critical temperature (T_c) and that T_c depends on the hydrodynamic specific surface of the sheet to be impulse dried. Hydrodynamic specific surface, in turn, is expected to be a function of fiber dimensions and extent of prepressing *(10)*. Fiber dimensions and hydrodynamic specific surface were determined from sheet samples for each of the sheet compositions listed in Table I. These measurements were obtained with the intent that they would be useful in predicting T_c.

Experimental methods

Sheet forming

The Formette Dynamique was used to fabricate handsheets because of its ability to produce multi-ply sheets with fibers oriented in the MD (machine direction). Preliminary experiments were conducted with unbleached high-kappa southern pine to determine the correct ratio of jet-to-wire (J/W) velocity that would produce handsheets with a two-to-one MD/CD tensile ratio, which is typical for commercial linerboard. Toward this end, the jet velocity was fixed at 316 m/min, while the wire velocity was varied to obtain J/W ratios ranging from 0.2 to 0.4. To simplify the pressing procedures, sheets were drained at a constant wire speed of 1050 m/min.

High-kappa southern pine pulps were refined to three levels of freeness (450 mL CSF, 600 mL CSF, 750 mL CSF). These pulps were then formed at various J/W ratios, drained at constant speed, and conventionally

I. Composition of sheets in Groups I–III that were impulse dried in the laboratory*

Top (heated) ply				Bottom ply			
Pulp type	Sheet content, wt.%	Kappa number	Freeness, mL CSF	Pulp type	Sheet content, wt.%	Kappa number	Freeness, mL CSF
Group I—single ply, one component							
Southern pine	100	High (109.2)	High (750)	...	...	...	...
Southern pine	100	Low (63.4)	High (710)	...	...	...	...
Douglas-fir	100	High (89.6)	High (720)	...	...	...	...
Douglas-fir	100	Low (74.2)	High (710)	...	...	...	...
OCC	100	High (114.6)	High (600)	...	...	...	...
OCC	100	High (114.6)	Low (450)	...	...	...	...
Group II—single ply, two components							
Southern pine	25	High (109.2)	High (750)	...	...	...	...
OCC	75	High (114.6)	High (600)				
Southern pine	50	High (109.2)	High (750)	...	...	...	...
OCC	50	High (114.6)	High (600)				
Southern pine	50	High (109.2)	High (750)	...	...	...	...
OCC	50	High (114.6)	Low (450)				
Southern pine	75	High (109.2)	High (750)	...	...	...	...
OCC	25	High (114.6)	High (600)				
Group III—two plies							
Southern pine	20	High (109.2)	High (750)	Southern pine	40	High (109.2)	High (750)
				OCC	40	High (114.6)	High (600)
Southern pine	20	High (109.2)	Med. (600)	Southern pine	40	High (109.2)	High (750)
				OCC	40	High (114.6)	High (600)
Southern pine	20	High (109.2)	Low (450)	Southern pine	40	High (109.2)	High (750)
				OCC	40	High (114.6)	High (600)
Southern pine	20	High (109.2)	High (750)	OCC	80	High (114.6)	High (600)
Southern pine	20	High (109.2)	Low (450)	OCC	80	High (114.6)	High (600)

*Basis weight of all sheets was 205 g/m^2 (42 lb); for two-ply sheets, top ply was 41 g/m^2 and bottom ply was 164 g/m^2.

pressed to 52% solids. Sheet samples were tested to determine their Darcian permeability, which is reported here in terms of hydrodynamic specific surface. **Figure** 2 shows that specific surface decreased with decreasing refining (i.e., with increasing freeness), while being relatively insensitive to J/W ratio.

Samples were also cylinder dried, conditioned, and tested for MD and CD tensile strength. The MD/CD tensile ratio of these specimens is plotted as a function of J/W ratio in **Fig. 3**. Commercial liner typically has an MD/CD tensile ratio of about 2. The J/W ratio corresponding most closely to this MD/CD ratio was 0.4. Consequently, all subsequent experiments were conducted with sheets formed at a constant J/W ratio of 0.4, corresponding to a wire speed of 800 m/min.

Measurement of fiber dimensions

Samples of sheets prepared for impulse drying and double-felted pressing were coded and sent to a consultant

II. Fiber identification for various pulp samples

Pulp type	Fiber content, % Softwood	Fiber content, % Hardwood	Species Softwood	Species Hardwood
Southern pine				
High kappa (109.2)	98	2	Southern yellow pine (hard cook)	Mixed—poplar
Low kappa (63.4)	100	Trace	Southern yellow pine (soft, medium, & hard cook)	Mixed—gum
Douglas-fir				
High kappa (89.6)	99	1	40–50% Douglas-fir 40–50% Ponderosa or Lodgepole pine 5–10% balsam fir 1% western hemlock 1% Engelmann spruce 1% western pine 1% western red cedar (hard cook)	Alder
Low kappa (74.2)	99	1	70–80% Douglas-fir 5–10% Ponderosa or Lodgepole pine 5–10% balsam fir 5% western red cedar 5% Engelmann spruce 1% western white pine 1% western larch (hard cook)	Mixed—alder & maple
OCC				
High kappa (114.6)	76	24	80–90% southern yellow pine 5–10% Douglas-fir 1% balsam fir 1% white and/or red pine 1% hemlock (53% hard cook, 18% medium soft cook)	Mixed—20–30% gum 20–30% oak 10–20% *Populus sp.* 10–20% yellow poplar, 5% maple 5% elm 5% basswood 5% cherry 5% sycamore

(John D. Hankey & Associates, Appleton, WI), who identified the fiber species and measured fiber length, fiber width, cell-wall thickness, and coarseness. **Table II** shows the species identification for the furnish components used in the present research. **Tables III and IV** summarize the average fiber dimensions for Group I sheets and Group III sheets, respectively. Each furnish was refined to various freeness levels and then formed into 205-g/m^2 sheets.

Measurement of hydrodynamic specific surface

Transverse permeability measurements were made using equipment and techniques that have been described previously *(10)*. In this method, Darcian permeability coefficient vs. porosity data are used to determine the hydrodynamic specific surface of a saturated sheet. While the resulting hydrodynamic specific surface is related to fiber geometry, it is also influenced by formation, basis weight, and pressing effects. Basis weight, formation, and prepressing (to 50% ingoing solids) were held constant in the experiments of this study. Hence, the hydrodynamic specific surface data were expected to be directly related to fiber geometry.

Simulation of double-felted pressing and impulse drying

Figure 4 is a schematic of the electrohydraulic press used to simulate the transient mechanical and thermal conditions experienced during either double-felted pressing or impulse dry-

III. Fiber dimensions for Group I sheets*

Sheet properties			Fiber dimensions						
			Length, mm					Cell-wall	
Pulp type	*Kappa no.*	*Freeness, mL CSF*	*Arithmetic*	*Length weighted*	*Weight weighted*	*Width, mm*	*Perimeter, mm*	*thickness, mm*	*Coarseness, mg/100 m*
S. pine	High (109.2)	Low (450)	1.66	2.29	2.90	38.4	88.4	2.9	34.6
		Med. (600)	1.77	2.47	3.11	40.7	93.0	2.9	35.6
		High (750)	2.48	3.19	3.74	40.3	92.6	3.0	34.0
S. pine	Low (63.4)	Low (450)	1.88	2.64	3.31	38.3	88.6	3.0	30.4
		Med. (600)	1.86	2.54	3.17	39.7	91.0	2.9	29.6
		High (710)	2.60	3.29	3.78	41.5	92.2	2.3	30.8
D.-fir	High (89.6)	Low (450)	1.20	1.59	2.00	35.8	80.4	2.2	23.2
		Med. (600)	1.28	1.75	2.19	37.5	83.4	2.1	24.0
		High (720)	2.02	2.69	3.20	38.3	85.8	2.3	23.8
D.-fir	Low (74.2)	Low (450)	1.44	2.05	2.59	37.0	84.0	2.5	25.6
		Med. (600)	1.75	2.38	2.89	39.1	87.8	2.4	25.2
		High (710)	2.15	2.80	3.32	39.3	87.4	2.2	25.6
OCC	High (114.6)	Low (450)	1.33	1.88	2.57	27.8	66.0	2.6	25.8
		High (600)	1.54	2.20	2.93	29.2	68.8	2.6	24.8

*Single-furnish, single-ply, 205-g/m² (42 lb) sheets

IV. Fiber dimensions for Group III sheets*

Sheet properties				Fiber dimensions						
Bottom ply		Top (heated) ply		Length, mm					Cell-wall	
$HKSP_{highCSF}$ content, wt.%	*$OCC_{highCSF}$ content, wt.%*	*HKSP content, wt.%*	*HKSP freeness, mL CSF*	*Arithmetic*	*Length weighted*	*Weight weighted*	*Width, mm*	*Perimeter, mm*	*thickness, mm*	*Coarseness, mg/100 m*
40	40	20	Low (450)	1.81	2.56	3.28	34.9	81.0	2.8	31.4
40	40	20	Med. (600)	1.63	2.51	3.38	32.9	77.8	3.0	32.0
40	40	20	High (750)	1.95	2.78	3.46	31.9	76.2	3.1	31.8
...	80	20	Low (450)	1.51	2.24	2.99	30.0	71.6	2 9	27.0
...	80	20	High (750)	1.58	2.47	3.34	32.1	75.8	2.9	26.2

*Two-furnish, two-ply, 205-g/m² (42 lb) sheets; top ply 41 g/m² and bottom ply 164 g/m².

ing. A newly installed programmable signal generator allowed the electrohydraulic press to simulate a pressure history that the sheet would experience in a commercial impulse dryer configured on a long-nip shoe press. For impulse-drying simulations, thermal conditions were simulated using a ceramic-coated platen heated to the operating temperature of the process.

In impulse-drying experiments, wet sheets of paper on felts were placed onto a wire support attached to a steaming ring. A radiation shield was automatically positioned between the heated platen and the sheet to reduce dry-out of the sheet's top surface. Steam exiting from the ring flowed upward through the felt and the sheet. The initial temperature in the sheet was raised to 85°C by controlling steam pressure and adjusting the steaming time. Once the sheet was heated, the hydraulic system was activated to give a pressure pulse of 40-ms duration, simulating an 8500-pli load on an "O" pivot shoe press.

Double-felted pressing experiments were conducted in a similar manner, except that the platen was maintained at 100°C, and the wet sheet was sandwiched between two identical felts. For both double-felted pressing and impulse drying, the initial wet weight of the paper sheet was adjusted so that the ingoing dryness of the sheet after steam preheating was 52 ± 2% solids. This required that water weight loss during steam preheating be calibrated as a function of initial platen temperature for each furnish. Ingoing felt moisture was kept at 16%.

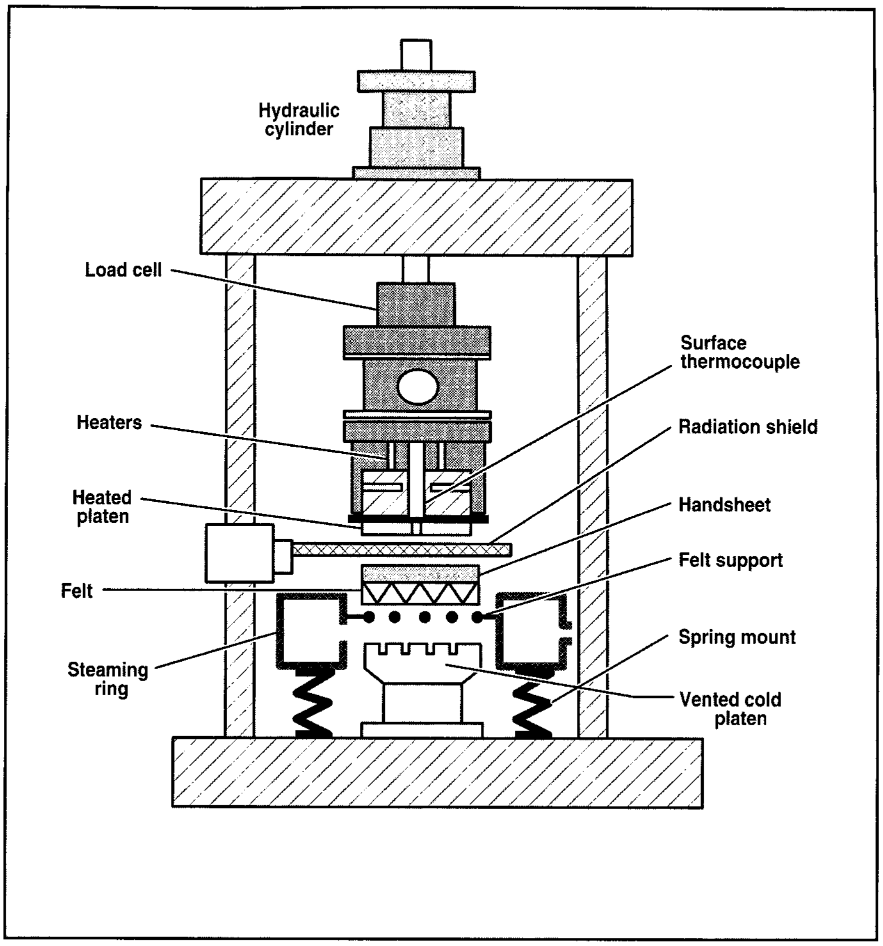
Experimental results

Hydrodynamic specific surface

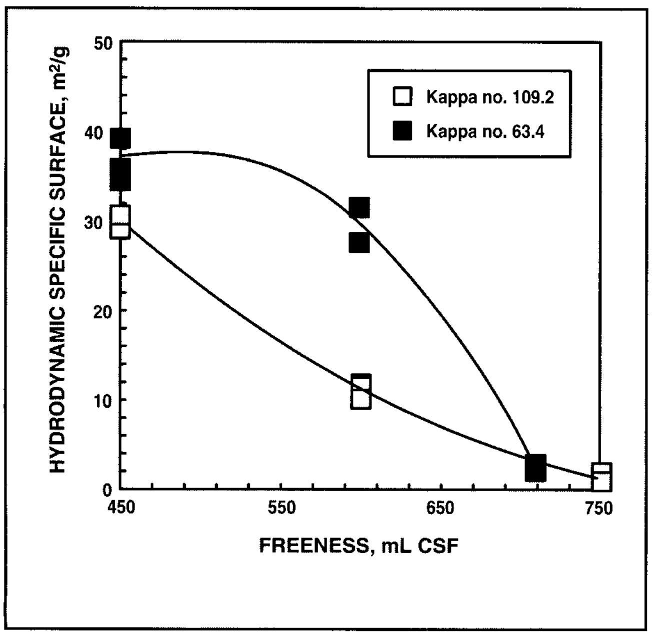
We examine here the out-of-plane permeability of single- and two-component single-ply sheets. **Figures 5 and 6** show the hydrodynamic specific surface of single-component single-ply sheets as a function of pulp freeness for, respectively, southern pine (SP) kraft and Douglas-fir (DF) kraft. Figure 5 shows that high-kappa southern pine (HKSP) tended to be more permeable at a given freeness than low-kappa southern pine (LKSP). In contrast, the low-kappa Douglas-fir (LKDF) shown in Fig. 6 was more permeable than high-kappa Douglas-fir (HKDF). Comparison of the southern pine and Douglas-fir at high freeness shows that the southern pine tends to be more permeable. Similarly, hydrodynamic specific surface vs. freeness is shown for the OCC furnish in **Fig. 7.**

The specific surface of two two-component blends of HKSP with OCC is shown as a function of the OCC con-

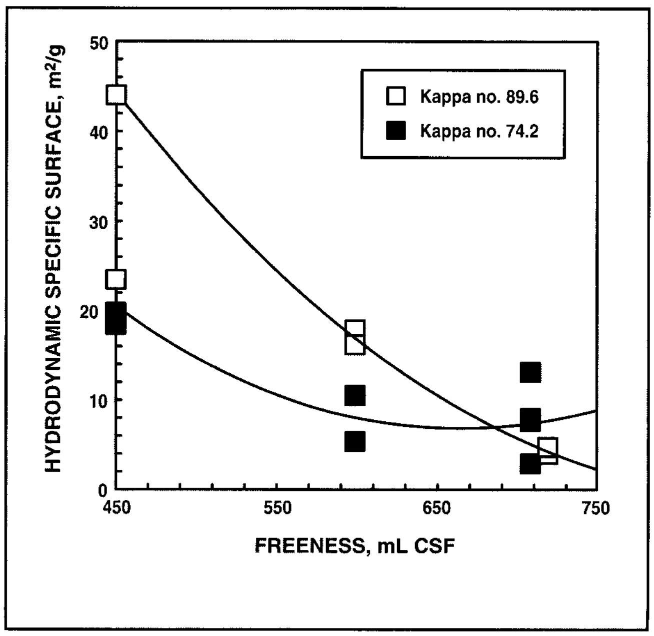
4. Electrohydraulic press



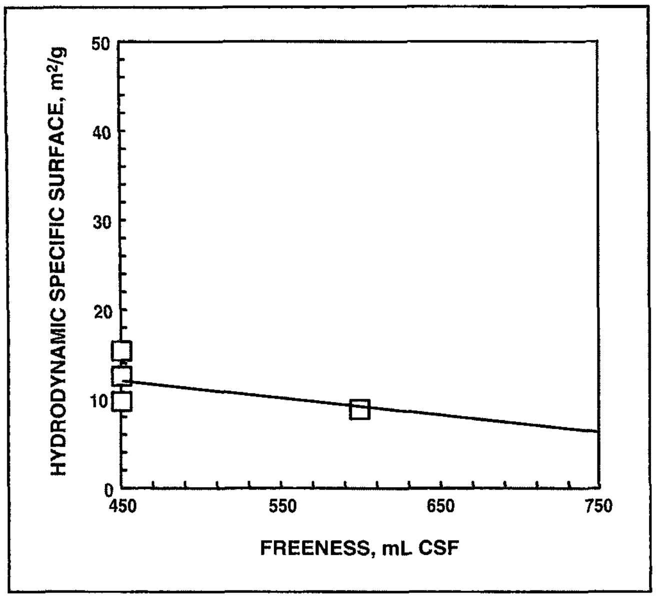
5. Hydrodynamic specific surface as a function of freeness for single-ply sheets produced from southern pine kraft at two levels of lignin content



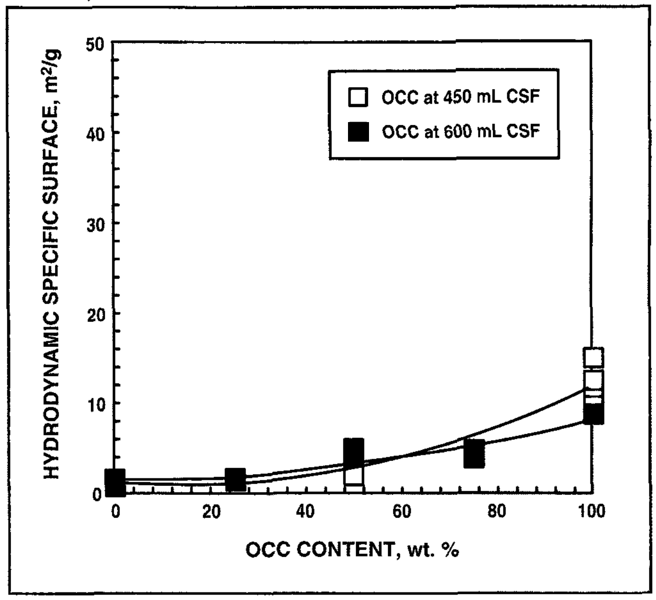
6. Hydrodynamic specific surface as a function of freeness for single-ply sheets produced from Douglas-fir kraft at two levels of lignin content



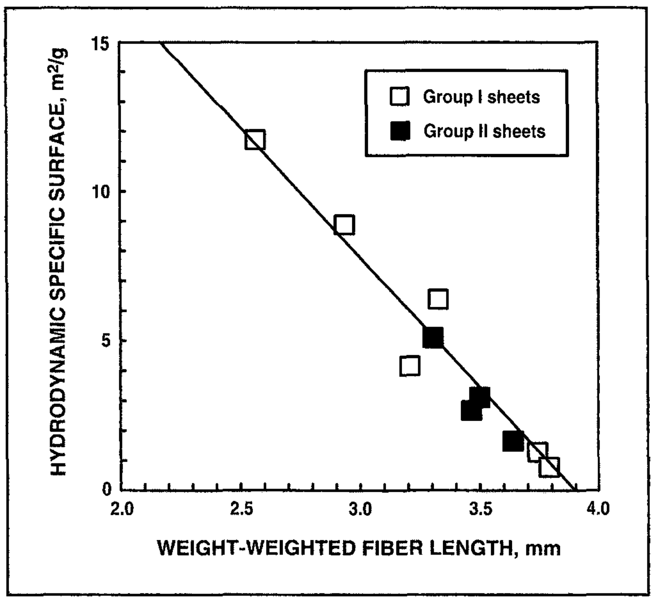
7. Hydrodynamic specific surface as a function of freeness for single-ply sheets produced from OCC (kappa no. 114.6)



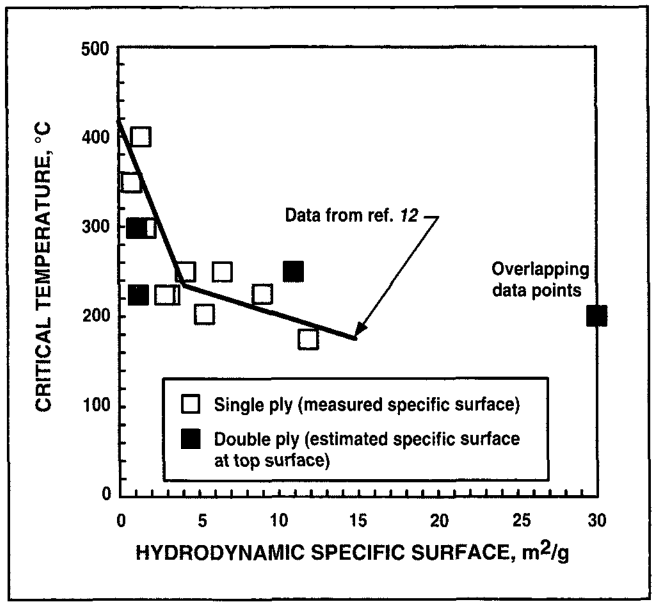
8. Hydrodynamic specific surface as a function of OCC content for single-ply sheets produced from $HKSP_{highCSF}$ and OCC (at high or low freeness)



9. Hydrodynamic specific surface as a function of weight-weighted fiber length for impulse-dried single-ply sheets. (Sheets pressed to 52% solids. Sheet compositions given in Table I.)



10. Critical impulse-drying temperature as a function of hydrodynamic specific surface for single-ply and two-ply sheets



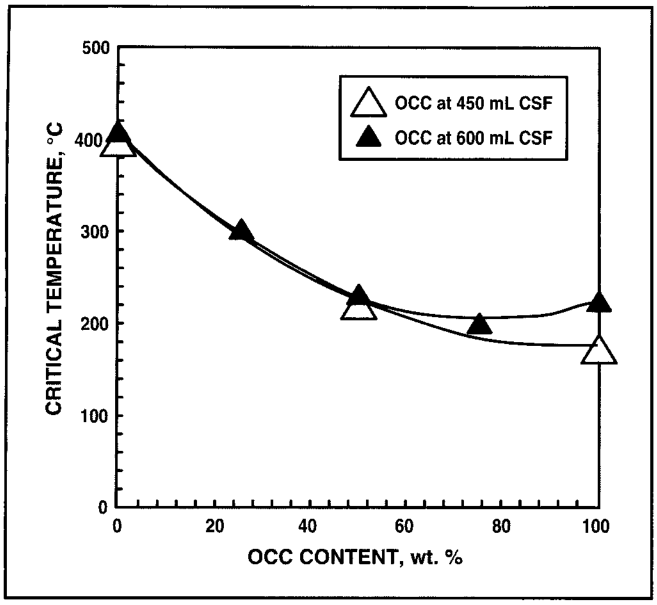
tent in **Fig.** 8. The results show that specific surface was not a linear function of OCC content. As seen in Fig. 8, as much as 60% OCC by weight can be added to the blend without increasing the hydrodynamic specific surface beyond 5 m²/g.

It was also observed that, for the impulse-dried single-ply linerboards (Groups I and II), hydrodynamic specific surface was a linear function of the weight-weighted length for the fibers in the sheet. This relationship is shown in **Fig. 9**. Weight-weighted fiber length is primarily a function of the fines concentration. Hence, sheet permeability was primarily influenced by fines concentration.

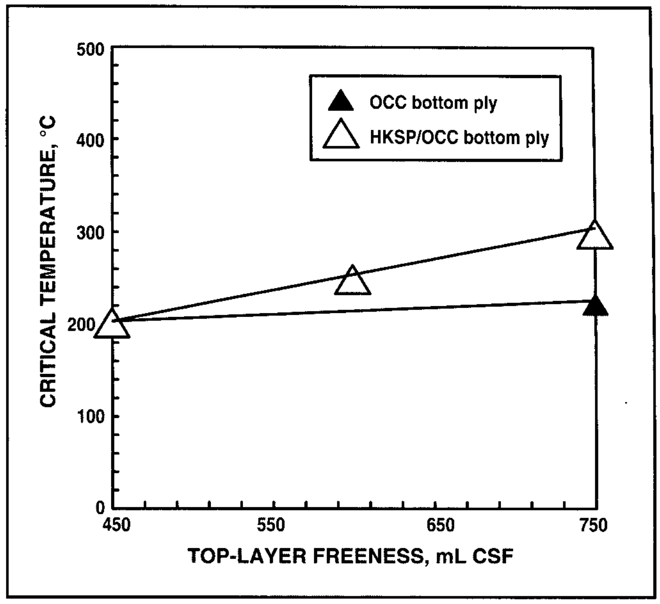
Critical temperature

Previous research has shown that the impulse-drying T_c—defined as the platen temperature above which sheet delamination occurs—decreases with increasing hydraulic specific surface. That work, with single-ply sheets made from a single furnish, also showed that

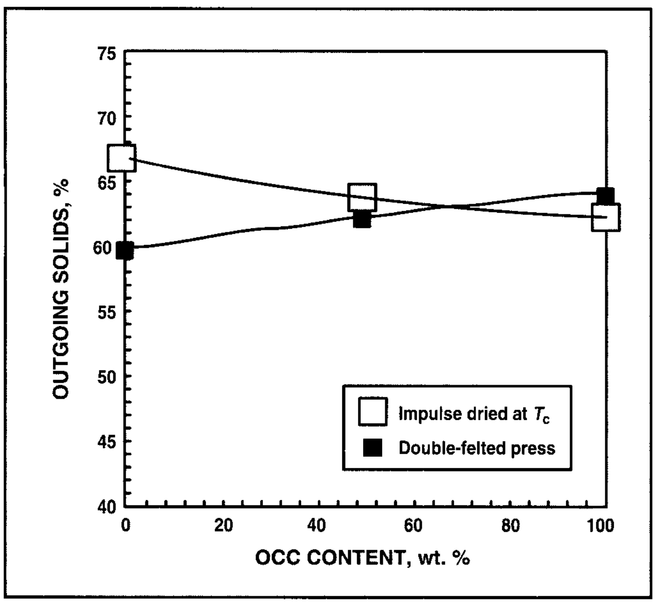
11. Critical impulse-drying temperature as a function of OCC content for single-ply sheets produced from $HKSP_{highCSF}$ and OCC (at high or low freeness)



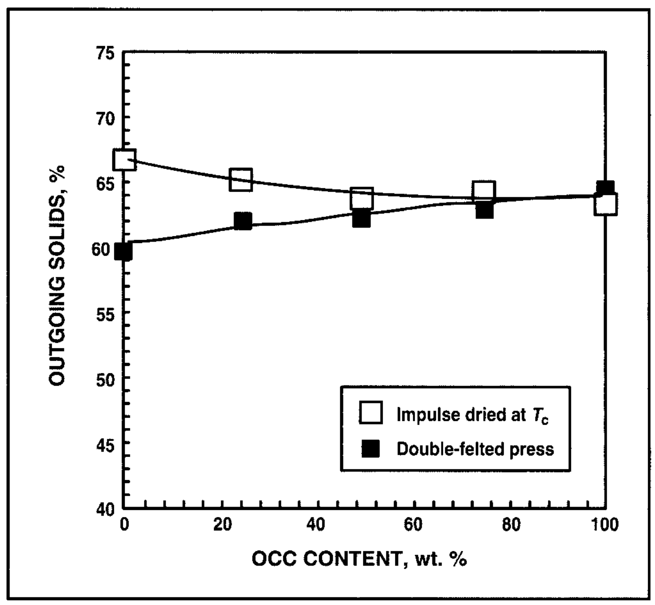
12. Critical impulse-drying temperature as a function of top-ply freeness for two-ply sheets



13. Outgoing solids as a function of OCC content for single-ply sheets after impulse drying or double-felted pressing. Sheets produced from $HKSP_{highCSF}$, OCC_{lowCSF}, or a blend of the two pulps.



14. Outgoing solids as a function of OCC content for single-ply sheets after impulse drying or double-felted pressing. Sheets produced from $HKSP_{highCSF}$, $OCC_{highCSF}$, or blends of the two pulps.



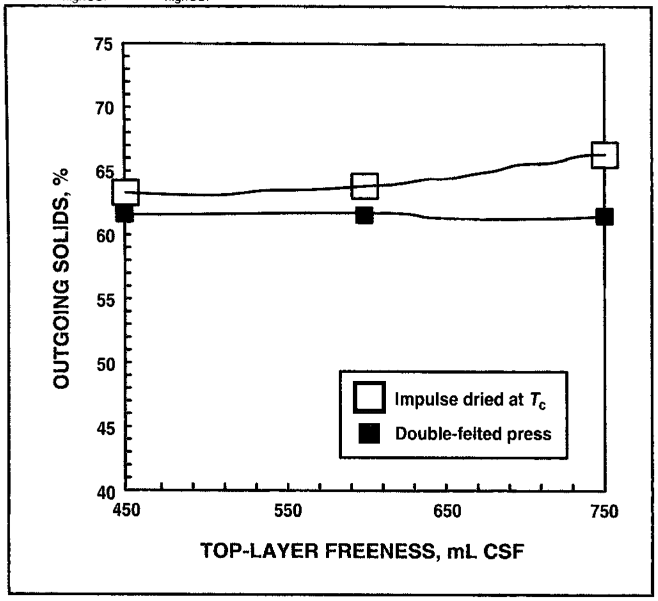
the benefits of impulse drying decreased with decreasing T_c.

As in previous work, T_c was determined by visual inspection and by interpretation of out-of-plane ultrasound (specific elastic modulus) data and STFI compression-strength data. The procedure was to define T_c as the highest temperature that showed no signs of delamination.

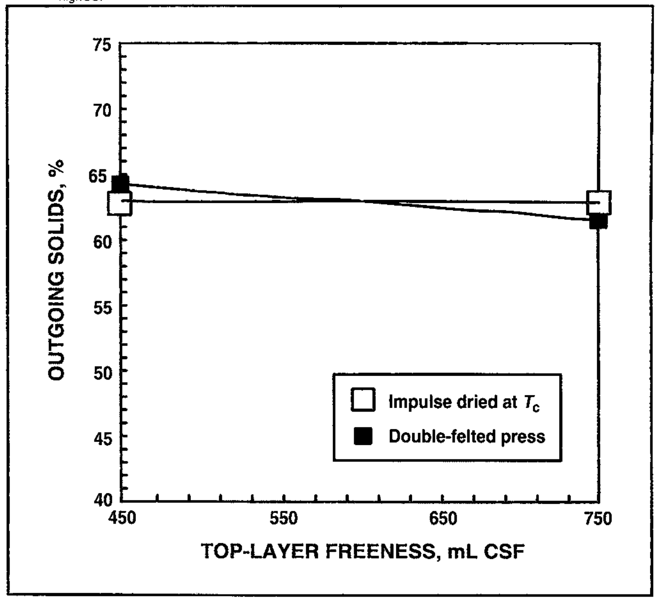
The specific elastic modulus and its coefficient of variation are typically the most sensitive indicators of delamination. The coefficient of variation of the elastic modulus and its mean value were plotted against initial platen surface temperature. Delamination occurs when the coefficient of variation suddenly rises or when the modulus suddenly drops with increased initial platen temperature.

In **Fig. 10**, T_c for the present experiments is plotted as a function of hydrodynamic specific surface. For single-ply sheets, the hydrodynamic specific surface was the measured value, as per Figs. 5–8. For two-ply sheets, the hydrodynamic specific sur-

15. Outgoing solids as a function of top-ply freeness for two-ply sheets after impulse drying or double-felted pressing ($HKSP_{highCSF}$ top ply; $HKSP_{highCSF}/OCC_{highCSF}$ bottom ply)



16. Outgoing solids as a function of top-ply freeness for two-ply sheets after impulse drying or double-felted pressing ($HKSP_{highCSF}$ top ply; $OCC_{highCSF}$ bottom ply)



face was taken to be that of the surface of the sheet in contact with the heated platen. Data from previous work on IPST's pilot roll press *(12)* are also shown for comparison in Fig. 10. The fact that the two-ply and single-ply data are consistent demonstrates that it is the hydrodynamic specific surface of the layer in contact with the heated platen (the top ply) that controls delamination.

The effect on T_c of increasing the OCC concentration in a blend with HKSP is shown in **Fig. 11**, where T_c decreases with increasing OCC content. The influence of the permeability of the layer in contact with the heated platen surface is again observed in **Fig. 12**, where T_c increases when the extent of refining is reduced.

Impulse drying vs. double-felted pressing

Impulse drying at T_c was compared with double-felted pressing and with a control that was pressed to 52% solids and cylinder dried. **Figures 13 and 14** show outgoing solids vs. OCC content for single-ply sheets made from blends of high-freeness HKSP ($HKSP_{highCSF}$) and, respectively, OCC_{lowCSF} or $OCC_{highCSF}$. The results show that impulse drying has a press-dryness advantage over double-felted pressing for OCC content up to 60%.

Figures 15 and 16 show outgoing solids vs. top-ply freeness for two-ply sheets with different bottom plies. As seen in Fig. 15, when the bottom ply was made from a 50/50 blend of $HKSP_{highCSF}$ and $OCC_{highCSF}$, impulse drying was superior to double-felted pressing, independent of top-ply freeness. Figure 16 shows that when the bottom ply was made from 100% $OCC_{highCSF}$, impulse drying was superior when the top-ply freeness was more than 600 mL CSF.

Many linerboard manufacturers measure STFI compression strength in the CD as the target strength parameter used to adjust their processes. **Figures 17 and 18** show CD STFI index vs. OCC content for single-ply sheets made from blends of $HKSP_{highCSF}$ and, respectively, OCC_{lowCSF} or $OCC_{highCSF}$. In Figs. 13 and 14, it was observed that dryness for impulse-dried sheets was superior to double-felted pressing for OCC content up to 60%. In Figs. 17 and 18, CD STFI index for impulse-dried sheets was superior to that of double-felted pressing for OCC content up to 50%. Figures 17 and 18 show that impulse drying provides superior CD STFI index compared with conventional papermaking (control), independent of OCC content.

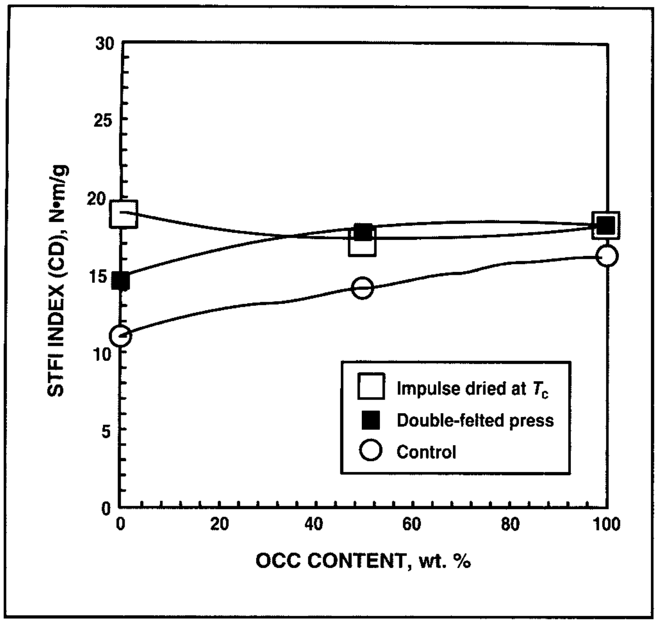
Figures 19 and 20 show CD STFI index vs. top-ply freeness for two-ply sheets with different bottom plies. As seen in Fig. 19, when the bottom ply was made from a 50/50 blend of $HKSP_{highCSF}$ and $OCC_{highCSF}$, impulse-drying CD STFI index was superior to that of double-felted pressing when top-ply freeness was greater than 550 mL CSF. When the bottom ply was made from 100% $OCC_{highCSF}$, impulse-drying CD STFI index was equal or superior for the entire range of top-ply freeness. In all cases, impulse drying provided superior strength than the control, which represented conventional papermaking.

Conclusions

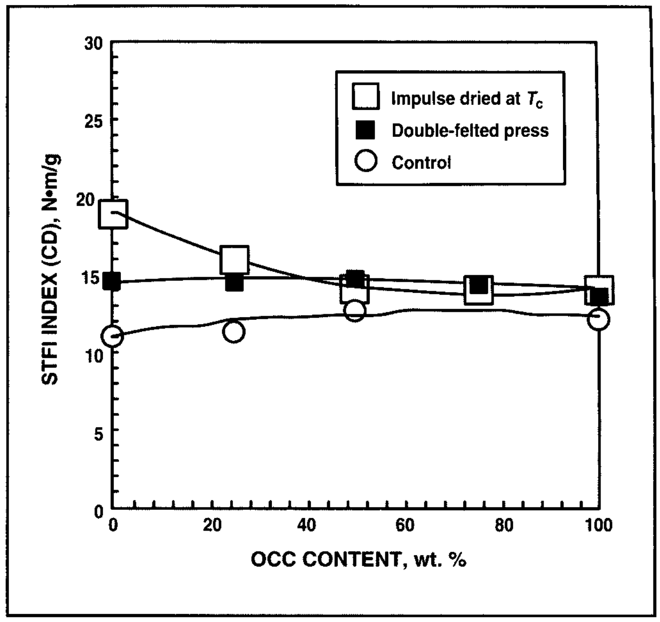
Impulse-drying was simulated in the laboratory in an effort to quantify its benefits in drying multi-ply linerboard manufactured with recycled fiber from old corrugated containers (OCC).

Preliminary experiments were carried out (a) to identify procedures for operating a Formette Dynamique to produce samples with fiber orienta-

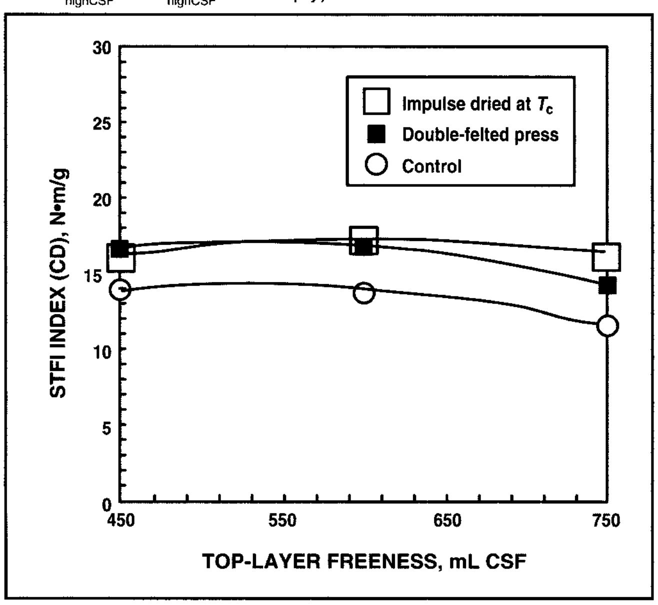
17. CD STFI index as a function of OCC content for single-ply sheets after impulse drying or double-felted pressing. Sheets produced from $HKSP_{highCSF}$, OCC_{lowCSF}, or a blend of the two pulps. Control sheets pressed to 52% solids and cylinder dried.



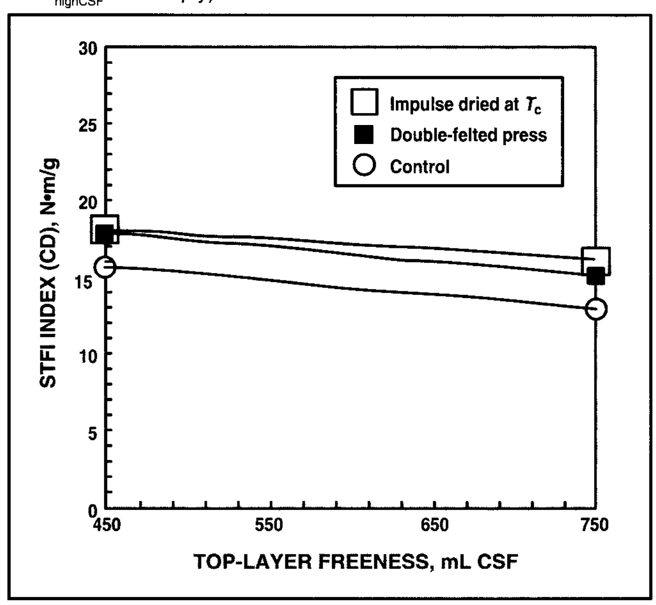
18. CD STFI index as a function of OCC content for single-ply sheets after impulse drying or double-felted pressing. Sheets produced from $HKSP_{highCSF}$, $OCC_{highCSF}$, or blends of the two pulps. Control sheets pressed to 52% solids and cylinder dried.



19. CD STFI index as a function of top-ply freeness for two-ply sheets after impulse drying or double-felted pressing ($HKSP_{highCSF}$ top ply; $HKSP_{highCSF}/OCC_{highCSF}$ bottom ply)



20. CD STFI index as a function of top-ply freeness for two-ply sheets after impulse drying or double-felted pressing ($HKSP_{highCSF}$ top ply; $OCC_{highCSF}$ bottom ply)



tion similar to that of commercially produced linerboard and (b) to map out the influence of refining on fiber morphology and sheet permeability. The preliminary experiments revealed that *z*-directional permeability is (a) nearly independent of fiber orientation in the sheet and (b) strongly dependent on refining. The refining effect on permeability was found to be species dependent. At high freeness levels, Douglas-fir was less permeable to water transport than southern pine. This behavior was traced to the higher fines concentration of the Douglas-fir pulp.

Subsequent experiments were conducted on 42-lb linerboard sheets in three broad categories:

Single-ply sheets made from a one-component furnish. Sheets were produced from lightly refined 100% virgin fiber (southern pine or Douglas-fir) or 100% OCC. This group of experiments was carried out to identify the effects of pulp species and lignin content. Pulp lignin content (kappa number) had little influence on impulse-drying performance. Pulp species, on the other hand, did affect performance. The southern pine kraft pulp—which had a lower fines concentration at high freeness than the Douglas-fir pulp—could be impulse dried at higher temperatures, resulting in higher outgoing dryness and enhanced physical properties.

Single-ply sheets made from a blend of virgin kraft and OCC. Sheets were produced from blends of lightly refined virgin southern pine and either lightly refined OCC or heavily refined OCC. This group of experiments was designed to determine how much recycled fiber could be blended with virgin kraft and still be successfully impulse-dried. The criterion for success was that the strength and dryness imparted by impulse drying be superior to that achievable by conventional double-felted pressing at the same impulse as used during impulse drying. The strength advantage of impulse drying was observed at OCC concentrations up to 50%, while a dryness advantage was observed for blends having OCC concentrations up to 75%.

Two-ply sheets with a virgin top ply and a bottom ply containing either 100% OCC or a blend of OCC and virgin kraft. These experiments were carried out to determine how the composition of the top and bottom plies influences impulse-drying operating conditions and the resulting sheet dryness and strength. The composition of the portion of the sheet in contact with the heated surface controls the impulse-drying critical temperature, T_c. (T_c is the threshold temperature above which delamination occurs.) When the bottom ply was composed of 50% virgin kraft and 50% OCC, we observed superior impulse-drying dryness and physical property development when the freeness of the top-ply pulp was 450 mL CSF or more. When the bottom ply was composed of 100% OCC, enhanced dryness and strength were apparent when the freeness of the virgin top ply was 600 mL CSF or more. TJ

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