Wet pressing webs of higher-yield kraft pulp for improved strength

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ABSTRACT *Guidelines are provided for the modification of wet pressing to compensate for strength losses resulting from use of higher-yield pulps. In this study for webs of equal freeness and moisture content, the higher-yield pulps resulted in sheets of lower density and strength after wet pressing A web of a higher-yield pulp (60%) can be wet pressed to achieve burst and tensile strength values equivalent to those of a low-yield pulp (51%). However, higher sheet density is needed with the higher-yield pulp, which requires a longer nip residence time and/or higher press pressure. When higher-yield pulps are refined to lower freeness in order to compensate for strength loss, longer nip residence times may be necessary regardless of press nip pressure. But for higher-yield and higher- freeness pulp webs, where dewatering behavior is pressure limited, increasing press nip pressure is the most effective means of compensating for the sheet strength loss accompanying the use of higher-yield pulps.*

KEYWORDS:
Wet pressing
Pressure
Paper board properties
Mechanical properties
Nip residence time
Pulp yield

Southern pine kraft pulps of yields 50-55% are commonly used in the manufacture of linerboard-grade paperboard. Use of higher-yield pulps (up to 60% yield) is desirable but generally reduces sheet strength. One remedy is more refining of the higher-yield pulps. However, refining results in lower-freeness pulps that retain more water. At a given yield, these lower-freeness Pulps decrease web dewatering rate in the paper machine wet press section *(1-3)*. Therefore, alternative means of increasing sheet strength are required. We have previously shown the importance of sheet density for sheet strength *(4)*. All of our previous work on wet pressing involved pulps of commonly used kraft yields. Although some research has been reported on the effects of pressure on strength when higher-yield pulps are used *(5, 6)*, little has been done on the combined effects of pressure and nip residence time *(7)*.

For this article, we studied web dewatering behavior and sheet strength resulting from wet pressing using loblolly pine kraft pulps ranging in yield from 51 to 60% and in freeness ranging from 350 to 600 mL CSF. We determined (a) how pulp yield affects wet press dewatering behavior and (b) how pulp yield and wet pressing affect the relationship between sheet strength properties and sheet density. We achieved the first objective by measuring the two web properties that characterize the dewatering behavior of the web. These properties are τ, the dewatering time constant, and C', the apparent compressive modulus of the web *(1-4)*. We achieved the second objective by determining the effects of pulp yield, press pressure, and nip residence time on sheet density and strength properties (burst index, tensile index, and compression index).

Results and discussion

Dewatering behavior

Effect of web moisture content. Dewatering behavior in the wet press section of the paper machine is similar for wet webs of equal moisture content made from 51%-, 55%-, and 60%-yield pulp. Dewatering of these webs appears to be analogous to the deformation response of a viscoelastic material as represented by a Kelvin body model *(1)*. The two material properties that characterize the wet web as a Kelvin body material are a dewatering time constant, τ, and a compressive modulus, C'. The dewatering behavior of these viscoelastic webs is influenced by the relative amounts of water, fiber, and air in the webs. For a paperboard web, we have previously found that the amount of water it contains is by far the most influential component of the web affecting τ and C' *(2)*. For loblolly pine pulp webs of freeness ranging from 350 to 600 mL CSF and yields ranging from 51 to 60%, the web moisture content remains the dominant variable influencing dewatering behavior (Fig. 1). As web moisture content decreases, the web material properties τ and C' increase.

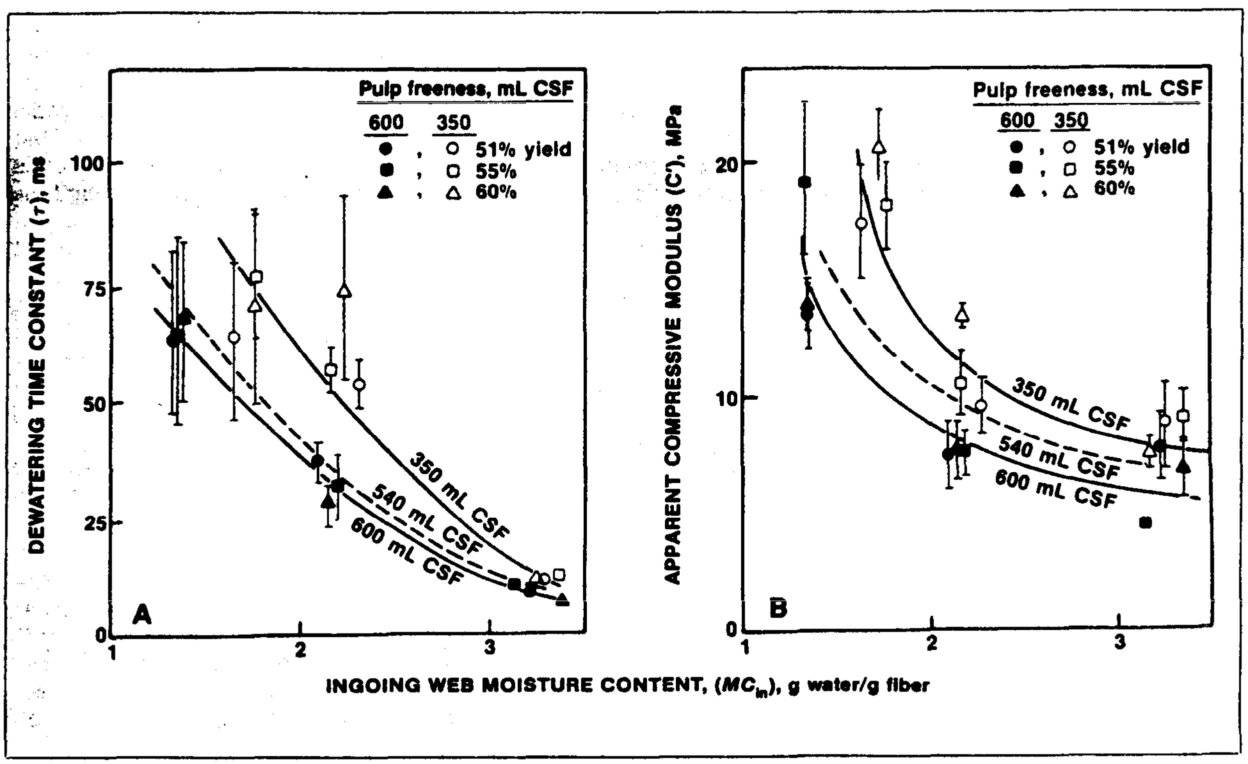
Effect of pulp yield and freeness. Neither pulp yield nor freeness affects web dewatering properties τ and C' as much as does moisture content (Fig. 1). Pulp freeness has only a slightly greater effect than pulp yield. This is reasonable when the water-retaining characteristics of pulps of different yield and freeness are considered. It has been reported that as yield and freeness decrease, the fiber's cell-wall water content increases *(8)*. However, Table I shows that some anomalies occurred in our data of the fiber saturation point (FSP) for the 540-mL CSF pulp. If these anomalies are ignored, the average difference in FSP observed for the change in pulp yield from 51% to 60% is 0.22 g of water/g of fiber (Table I). The average difference in FSP observed for the change in pulp freeness from 600 mL CSF to 350 mL CSF is 0.24 g of water/g of fiber, within each pulp yield group (Table I). The difference between the change in FSP with pulp yield and the change in FSP with pulp freeness is small but apparently significant in its effects on web dewatering behavior (both τ and C'), especially at low web moisture content (Fig. 1). The spread in τ and C' values for webs of each pulp yield and freeness is smaller at the higher moisture contents At low ingoing web moisture content, τ and C' values vary with pulp freeness but not significantly with pulp yield.

Pulp yield effects on sheet strength development. We have previously shown that sheet strength increases as sheet density increases by wet pressing *(4)*. We have shown, for 55%-yield loblolly pine kraft pulp at 630 mL CSF and 51%-yield southern red oak kraft pulp at 580 mL CSF, that increasing the nip residence time in a press nip produces stronger linerboard for nip residence times less than 30 ms. At longer nip residence times, increasing press pressure may produce stronger linerboard than would be produced by increasing nip residence time.

Burst and tensile strength. The burst and tensile strength results depicted in Fig. 2 show that pulp yield has a pronounced effect on the relationship between sheet strength and density. The multiplicity of points shown in Figs. 2a and 2b and some of their scatter can be attributed to the fact that the webs were pressed at different moisture contents over a range of pressures and nip residence times. Points shown at the higher densities generally represent those webs pressed at higher pressures and/or longer nip residence times *(4)*. In general, over the range of press pressures (1.7-3.8 MPa) and nip residence times (2-215 ms), the higher-yield pulps result in sheets of lower burst and tensile strength, even though comparable densities are achievable.

Despite scatter in the data, sheets of each of the different-yield pulps seem to have the same rate of increase in burst index and tensile index with increasing sheet density. This near equivalence of slope allows us to suggest a superposition technique for equating a sheet of lower strength obtained from high-yield pulp to a sheet of lower density obtained from low-yield pulp. By an appropriate shift of the density axes (of plots of strength property vs. density) for the sheets of different yields, all of the data points both for burst index (Fig. 3a) and tensile index (Fig. 3b) can be made to fall close to the same line. A small shift in density axes is needed to make the strength indices of sheets of 55%-yield pulp line up with the strength indices of sheets of 51%-yield pulp. A larger shift in density axes is needed for the sheets of 60%-yield pulp to line up with the sheet strength indices of 51%-yield pulp. In terms of sheet density, therefore, increasing pulp yield has a nonlinear effect in reducing sheet burst and tensile indices. Using

1. The effects of pulp yield and freeness on (a) dewatering time constant and (b) apparent compressive modulus, as a function of ingoing web moisture content. (Data points for the 540-mL CSF case are not shown.)



the sheets from 51%-yield pulp as the benchmark, the loss in sheet strength in going from a 51%-yield to a 55%-yield pulp is equivalent to approximately a 40-kg/m^3 reduction in sheet density. In going from a 51%-yield pulp to a 60%-yield pulp, loss of sheet strength is equivalent to approximately a 150-kg/m^3 reduction in sheet density. These reductions in density for increases in pulp yield appear to be approximately the same for both burst and tensile indices. Although both burst and tensile index increase with decreasing freeness, the rate of decrease in sheet strength with the decrease in sheet density appears independent of pulp freeness for the three different-yield pulps investigated.

I. Fiber saturation points (FSP) for loblolly pulps of various yields and freenesses

Yield, %	FSP, g of water/g of fiber 350 mL CSF	540 mL CSF	600 mL CSF
51	1.95±.01[a]	1.55±.01	1.72±.18
55	1.90±.09	1.64±.04	1.66±.06
60	1.73±.04	1.76±.05	1.49±.07

[a]Values shown are averages ± standard deviation of the mean.

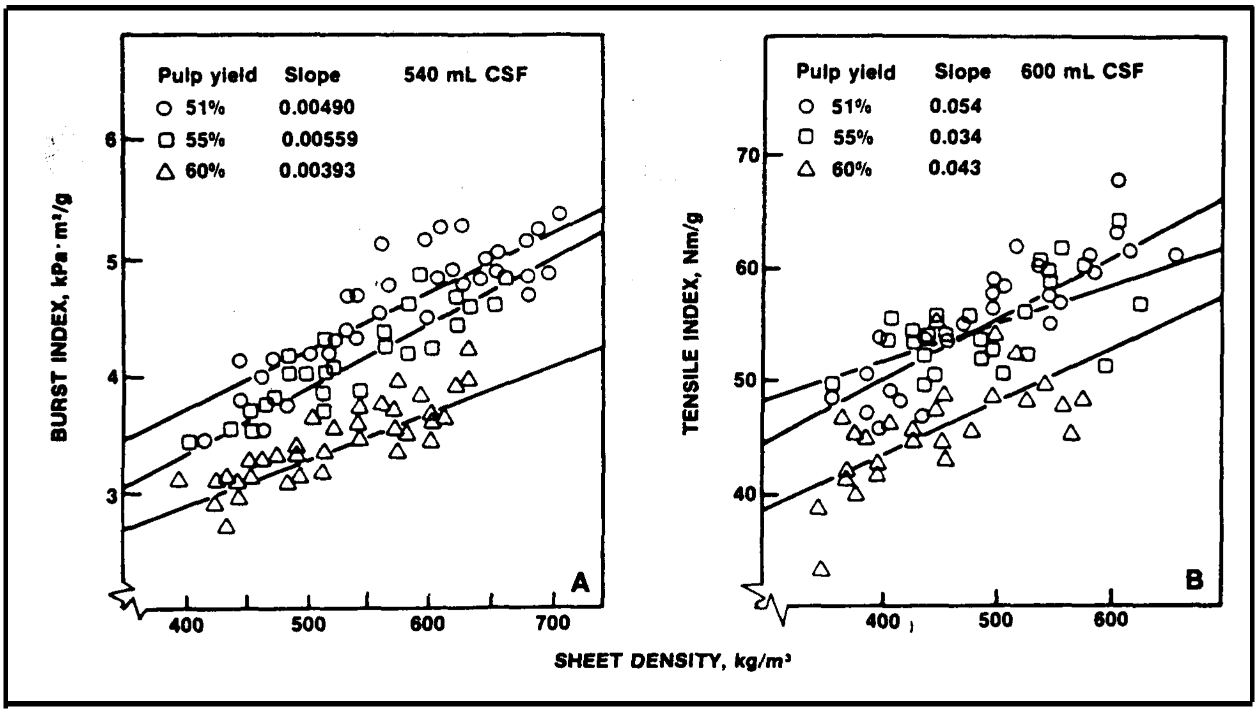
Compression strength. Although both sheet burst and tensile indices decrease similarly with increasing pulp yield, sheet compression index shows no systematic dependence on pulp yield (Fig. 4). The 60%-yield pulp tended to result in sheets weakest in compression index over the range of sheet densities developed. The dependence of sheet compression index on sheet density was not significant. No clear relationship is evident between sheet compression index and pulp yield as a function of sheet density. It may be that in the case of compression, the inherently greater stiffness of the higher-yield pulp fibers partially compensates for the bonding loss and helps mask any sheet compression strength dependence on sheet density.

Wet pressing to achieve high sheet strength properties. Many of the strength indices for the sheets of 60%-yield pulp fall below the range of strength indices for sheets of the lower-yield pulps (Fig. 2, for example). Nevertheless, a web of higher-yield pulp can be wet press-dewatered to achieve higher burst, tensile, and compression indices if a higher sheet density is achieved. This requires a longer nip residence time and/or higher nip press pressure. When higher-yield pulps are refined to low freeness to compensate for sheet strength losses, increases in moisture content of the webs entering the wet press section of the paper machine typically occur. These webs of low-freeness pulp have larger dewatering time constants that cause the wet press dewatering operation to be flow-limited *(9)*. Longer nip residence times are recommended for these refined, higher-yield pulp webs. Increased nip residence time, rather than increased pressure, may be essential in those cases where increased press pressure causes crushing damage. If wet pressing without additional pulp refining is used to compensate for strength losses of higher-yield pulp sheets, the situation is different. When pressing webs of high-freeness pulps and lower moisture content, dewatering tends to be pressure limited *(9)*. For this case, increasing press pressure appears to be the best means of compensating for sheet strength loss.

Conclusions

Webs of 205-g/m^2 grammage, made from loblolly pine kraft pulp of yields ranging from 51 to 60%, did not significantly differ in wet press dewatering behavior when compared at equal moisture content and freeness. The Kelvin body model with parameters τ

2. The effect of pulp yield on (a) sheet burst index and (b) sheet tensile index, as a function of sheet density.



and C′, which characterizes the dewatering behavior of webs made from 51%-yield pulp, also adequately describes the dewatering behavior of webs made from 55%-yield and 60%-yield pulps. Web moisture content entering the wet press has a greater effect on τ and C′ values than either pulp yield or freeness.

Sheet strength properties (burst and tensile indices) generally decrease as pulp yield increases. At a given sheet density, a greater decrease in sheet strength properties occurs as pulp yield increases from 55 to 60% than occurs when pulp yield increases from 51 to 55%. Increased refining of the pulps lowering freeness from 600 mL CSF to 350 mL CSF, did not affect the relationship between sheet density and strength for any given pulp yield; nor did it result in significantly higher sheet densities. Increasing wet press nip residence times and/or press pressures appear to be effective ways to increase web dewatering and sheet strength properties of higher-yield pulps. By increasing sheet density through longer nip residence times and/or higher press pressures, sheets made from 55%-yield or 60%-yield pulps can achieve the burst and tensile strength properties equivalent to sheets made from 51%-yield pulp.

Experimental

Pulp and handsheet preparation

Kraft pulps of 51%, 55%, and 60% yield were prepared from chips of loblolly pine *(Pinus tueda* L.) by varying the active alkali concentration and pulping time in a 0.4-m^3 rotating digester maintained at a temperature of 170°C. After cooking, the low-yield pulp (51%) was blown into a blow tank and washed with 90°C water. With the higher-yield pulps (55 and 60%), greater chip integrity resulted in the cooking liquor being released into the blow tank while pulped chips remained in the digester. In these cases, the pulped chips were washed in the digester using 90°C water and then fiberized.

All fiberizing and refining was done at 90°C at approximately 10% consistency in a 914-mm-diam., double-rotating-disc, atmospheric-pressure refiner. At each yield, nominal 600-mL CSF and 540-mL CSF pulps were produced in a single pass. Nominal 350-mL CSF pulps at each yield were obtained by first-pass refining to 540 mL CSF and then refining to 350 mL CSF in a second pass.

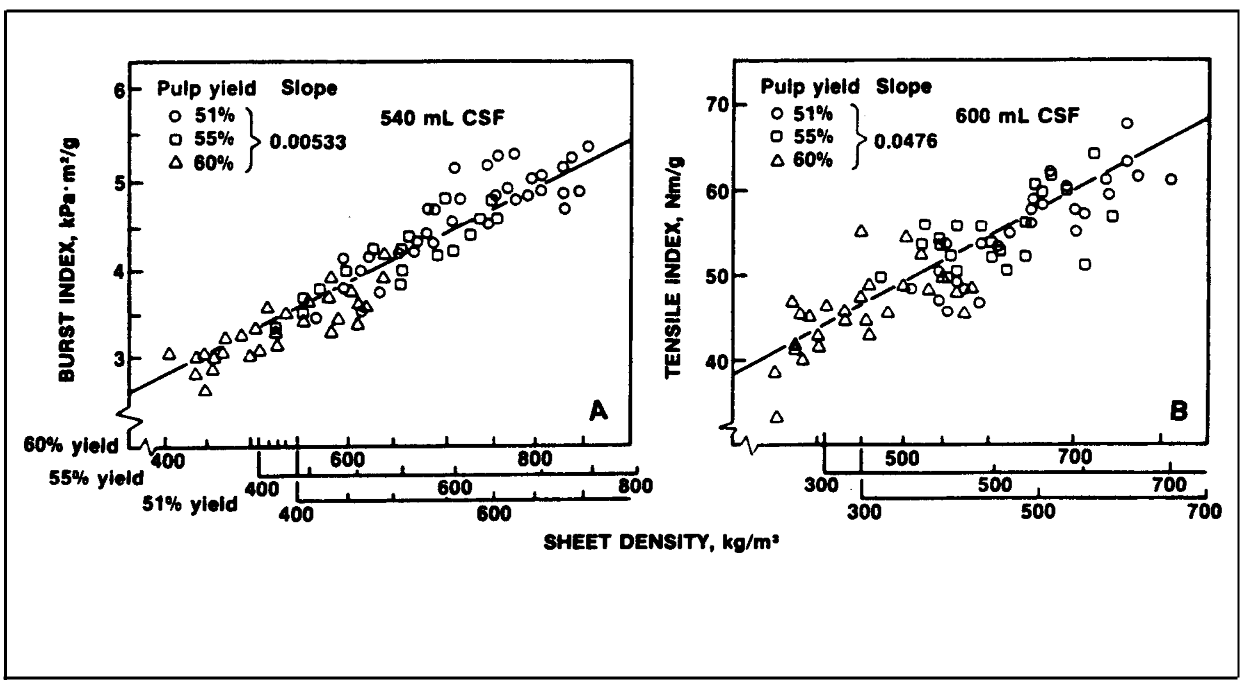
Webs of 205-g/m^2 grammage were formed on a British sheet mold according to TAPPI Test Method T 205. Webs were made from the three different-yield pulps at three freenesses each. At each yield and freeness, webs were moisture-conditioned to three different moisture contents *(MC*in)-3.4, 2.4, and 1.5 g of water/g of fiber, corresponding to web percent solids of 22.7%, 29.4%, and 40.0%, respectively. Webs at *MC*in of 3.4 were moisture-conditioned using blotters. The nominal web moisture contents of 2.4 and 1.5 g of water/g of fiber were reached by passing webs of 3.4 g of water/g of fiber through the first wet press of our laboratory paper machine. By varying press pressure, the desired *MC*in was obtained.

Wet press dewatering and web drying

The moisture-conditioned webs were wet press-dewatered at selected nip residence times and pressures, using the first wet press of the paper machine. The wet press is single felted and consists of a 254-mm-diam., neoprene-covered top roll, a 254-mm-diam. steel bottom roll, and a dry 75% wool/25% synthetic fiber felt. Web nip residence times ranged from 2 to 215 ms, and press pressures ranged from 1.70 to 3.82 MPa.

For this pressing operation, each web was individually taped to a polyester-film carrier along the web side

3. Shifts in sheet density for the different-yield pulps resulting in the same relationship of (a) burst index vs. density and (b) tensile index vs. density.



edges. The use of a carrier much longer and wider than the web ensured that the web would be at machine speed before entering the wet press. The upper press roll was grooved so that the taped edges were not compressed in the nip. These taped edges were trimmed off after passing the rectangular-shaped webs through the press nip. The change in web moisture content (*MC*in minus *MC*out) was measured as a function of nip residence time and press pressure.

After pressing, the webs were restrained in only the x and y direction and dried in a platen press at 177°C. Restraint drying in the x and y directions can increase strength properties.

Sheet strength property measurement

Dried sheets were conditioned at 23°C and 50% relative humidity. Grammage, density, and thickness were measured. Burst index and tensile index were determined as in TAPPI Test Methods T 403 and T 404. Compression index was measured using the method developed by Jackson, Koning, and Gatz *(10)*.

Web dewatering parameters τ and C′

The equation describing the dewatering response of a wet web based on the responaeof a Kelvin body material to a step-applied stress pressure is

$$\Delta MC/MC_{in} = (P/C')(1-e^{-t/\tau}) \quad (1)$$

where:

MC = moisture content

$\Delta MC/MC$ in = $(MC$in - MCout$)/MC$in = web fractional moisture content change

P = press pressure

t = nip residence time

τ = web dewatering time constant

C' = web apparent compressive modulus

The web dewatering time constant, τ, for a web made from pulp of a given yield and freeness is obtained from plots of web fractional moisture content change vs. nip residence time *(1)*. τ is equal to the nip residence time at which 63.2% of the maximum fractional moisture content change is reached for any given web *MC*in.

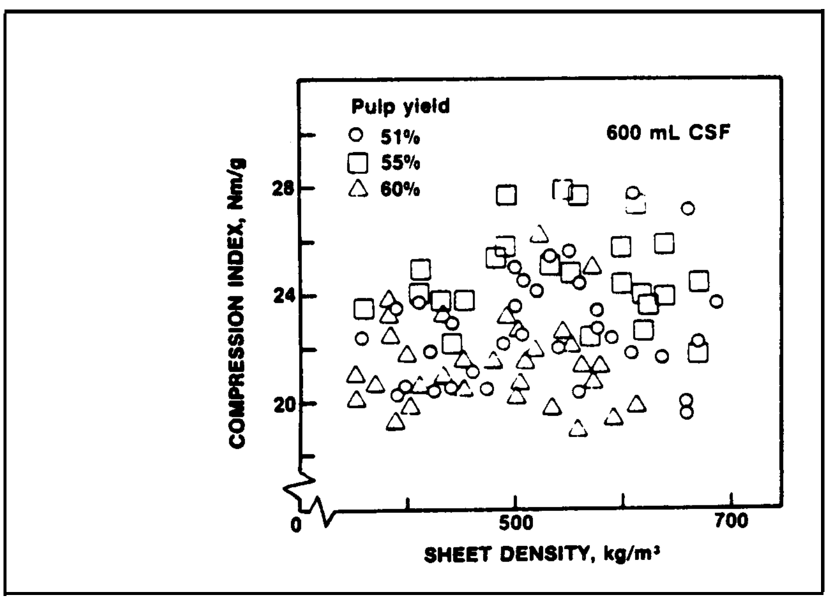
The apparent compressive modulus, C′, can be obtained in either of two ways

1. By plotting $\Delta MC/MC$ in vs. $1-e^{-t/\tau}$ for various nip residence times. C′ is calculated from the slope of the line obtained, which is equal to P/C'. The straight lines obtained in this plot also confirm the validity of the Kelvin body response equation (Eq. 1) for describ ing web dewatering.

2. At long nip residence times, the web fractional moisture content approaches an asymptotic value. For $t\to\infty$, Eq. 1 reduces to:

$$\Delta MC/MC_{in} = P/C' \quad (2)$$

At a given press pressure and long nip residence time, C′ can then be calculated. Because τ and C′ are web material properties, their values are not affected by changes in press pressure.



4. The effect of pulp yield on sheet compression index as a function of sheet density.

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Received for review March 29,1985.

Accepted Sept. 23, 1985.