

Stratification of paper grades

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The ability to create a multilayered sheet will open a new world of options for the papermaker.

Stratified or multilayer products have been around for many years. Manufacturers of the heavier packaging and linerboard grades adopted the stratified concept because it allowed them to substitute less costly furnishes in the center or bottom of the sheet. These grades were typically produced by combining separately formed layers (multi-former machines) or by forming one layer on top of another (secondary headboxes and top formers) (1). Some machines are now producing multilayered products from a single headbox (2). More recently, tissue grades are being made as two- or three-ply sheets from a single headbox (3).

Progress toward stratification of printing paper grades has been slower. Many studies have been conducted using handsheets to produce multi-ply sheet grades. The results indicate that certain sheet properties can be improved by stratification (4, 5). The problem has been to produce a multi-ply sheet in uniform layers with adequate coverage purity while obtaining significant improvements in sheet properties. New developments in headboxes and formers now provide the technology to produce three-layer paper grades with high surface purity and uniform coverage over the center layer. This report examines the physical structure and properties of paper grades produced using this new technology.

Why stratify?

The concept of producing stratified paper for printing, coated, or copy grades looks very promising. These grades typically comprise two or more furnish components of various freeness levels, along with fillers and chemicals. Each component has different properties, and it is clear that sheet quality can be optimized through preferential placement of these materials in either the center of the sheet or on the surface.

There are two incentives for wanting to produce a stratified paper grade:

1. **Economic:** Less costly fibers can be utilized. For example, chemi-thermomechanical pulp (CTMP) could be substituted for hardwood (HW) or softwood (SW) pulps in the center of the sheet.

2. **Quality:** Sheet properties can be improved. For example, printability can be enhanced by placing a better furnish on the surface to provide a smoother finish with less linting. It is also possible to alter refining, improve bulk, or increase sheet strength through stratification.

Methods and procedures

Sheet stratification can be quantitatively determined in several ways. Splitting the sheet in the z-direction and counting the fiber species of each layer is one method used to measure the surface purity of the sheet as well as the extent of mixing between the plies. The surface purity is defined as the percentage of desired fiber in the surface layer. The sheet is split and resplit into many layers using tape until the layers are thin enough to count the fibers under a microscope. Then the tape can be dissolved, leaving the fibers to be tested by other means such as fiber classification.

Another method of visually determining the degree of stratification is to embed a sheet sample in epoxy and use a microtome to cut a cross section 14 μm thick. The fibers in the sample are then dyed using Selleger's stain, and the cross section is photographed under 200X magnification. If the fiber layers dye to different colors, this provides a good visual indication of the individual ply integrity.

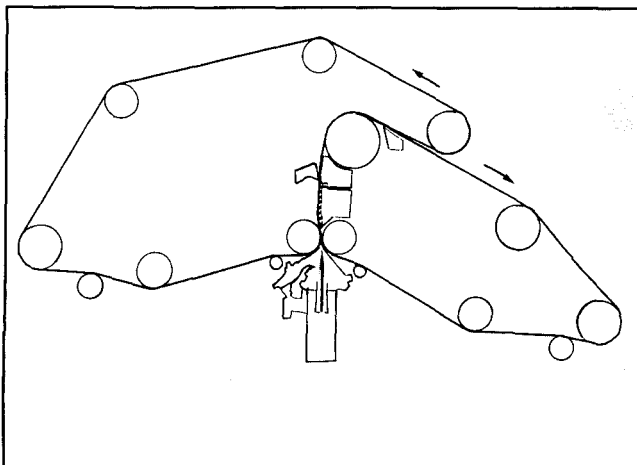
These methods use small sample sizes, so they do not indicate the uniformity of coverage over a large area. Coverage of a surface layer over a center layer can be evaluated by dyeing one of the layers. An ultraviolet dye can be used on the center layer. If the center furnish contains mechanical fibers, a sample of the stratified sheet can be dipped into a mixture of phloroglucinol stain and HCl to highlight the center layer.

Trial conditions

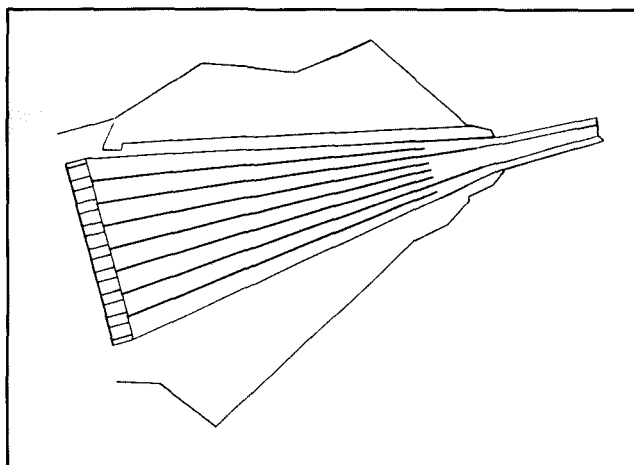
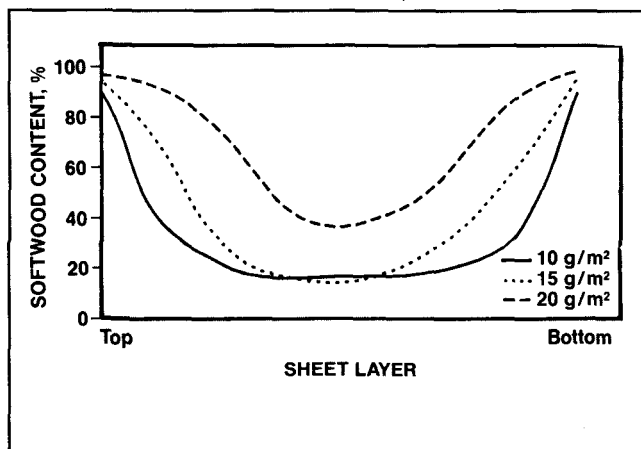
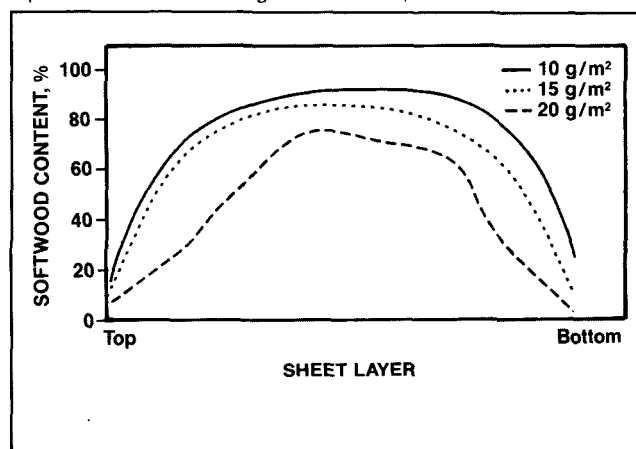
The results discussed in this report are based on samples produced during trials made on a twin-wire pilot machine equipped with a multilayer headbox. The paper machine and headbox are illustrated in **Figs. 1 and 2**, respectively. The basis weight of the samples ranged from 60 g/m² to 100 g/m². Machine speed was around 800 m/min.

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1. Twin wire former



2. Multilayer headbox

3. Surface homogeneity and stratification in 60-g/m² sheets with SW (375 mL CSF) liners over a HW (415 mL CSF) center ply. The three curves represent different basis weights for the liner plies.4. Surface homogeneity and stratification in 60-g/m² sheets with HW (415 mL CSF) liners over a SW (375 mL CSF) center ply. The three curves represent different basis weights for the liner plies.I. Basis weight of individual plies in 60-g/m² samples, g/m²

Top liner	Center	Bottom liner
10	40	10
15	30	15
20	20	20

II. Level of refining for the softwood and hardwood furnishes used to produce the samples examined in Figs. 9-18

Trial	Level of refining, mL CSF*		Figures
	Softwood	Hardwood	
1	475	305	9, 11, 13, 15, 17
2	365	415	10, 12, 14, 16, 18

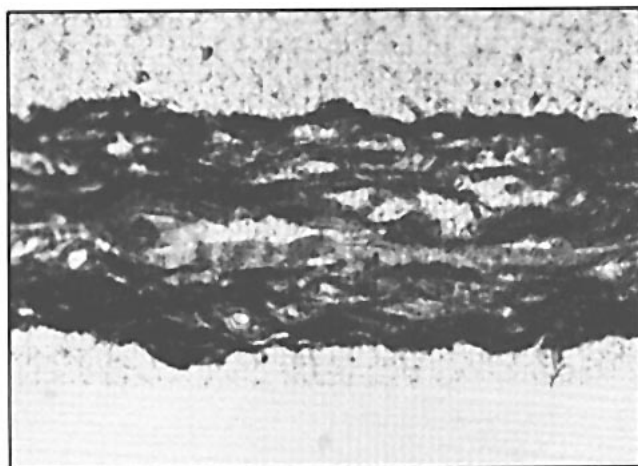
*Canadian Standard Freeness

Layer purity and uniformity of coverage

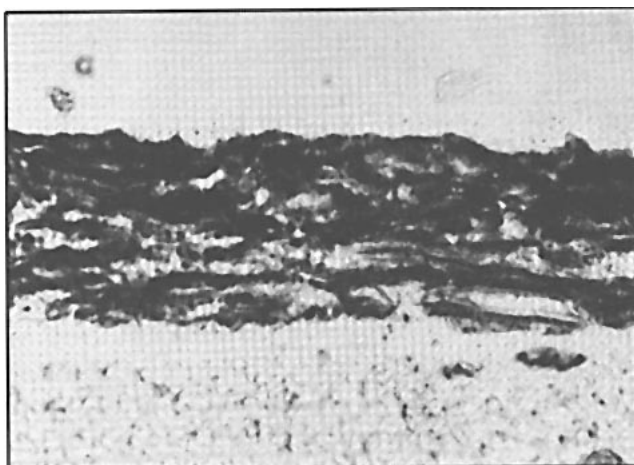
Before examining the surface properties of the stratified sheets, it was necessary to verify the purity of the three layers and the uniformity of coverage for the outer layers. This ensured that any changes in surface or strength properties would be uniform across the width of the machine.

The purity of a given layer depends mainly on its ply weight. The heavier the ply, the greater is its purity. **Figures 3 and 4** show that the surface purity of a 60-g/m² sheet with top and bottom liner ply weights of 10 g/m² ranges from 80% to 90% at each surface but falls off rapidly toward the interior of the sheet. At liner ply weights of 15 g/m² and 20 g/m², the surface purity is over 90%, and the purity is maintained to a greater depth. The

5. Stratified sheet with bleached HW kraft surfaces and a CTMP center layer



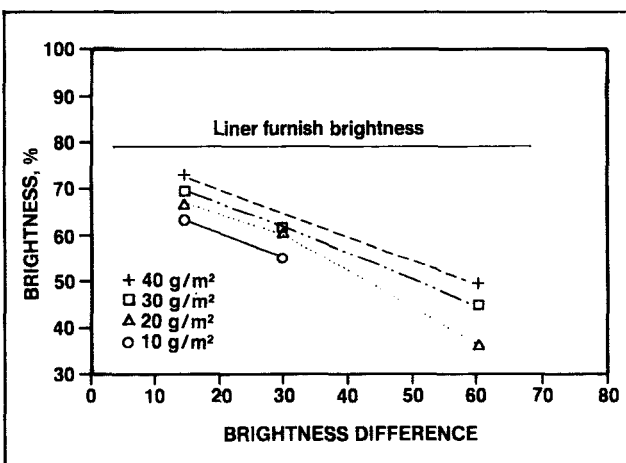
6. Nonstratified sheet made from the same furnish as the sample in Fig. 5



8. Top: stratified sheet with HW fibers on surface and SW fibers in center. Bottom: stratified sheet with SW fibers on surface and HW fibers in center.



7. Sheet brightness as a function of the difference in brightness between the inner and outer plies. The four curves represent various basis weights for the brighter liner ply.

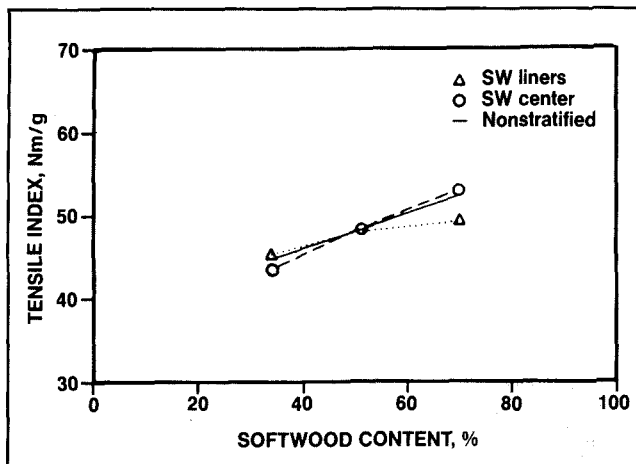


individual ply weights of these 60-g/m² samples are listed in Table I. The 60-g/m² basis weight is maintained by decreasing the weight of the center ply as the weight of the liner plies increases. This explains why the purity of the center ply decreases with increasing weight of the liner plies.

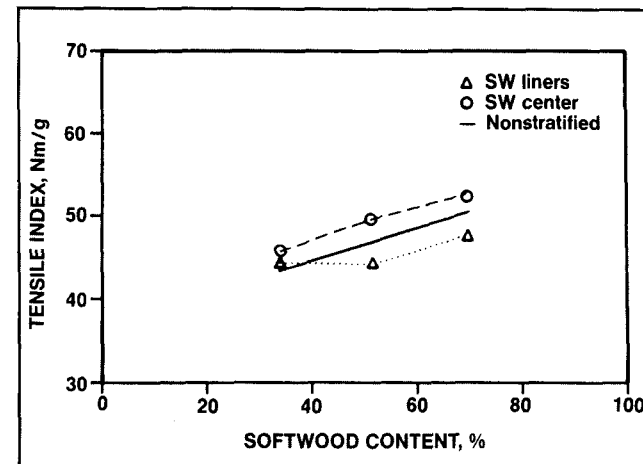
The cross-section photographs in Figs. 5 and 6 show the different fibers to be fairly well layered. The mechanical fibers in the center ply of the stratified sample in Fig. 5 are a light yellow color when stained, while the chemical fibers at the sheet surfaces are a dark blue color. The nonstratified sample in Fig. 6 was made from the same furnish. It has a mixed appearance, with mechanical fibers present at the surface.

The uniformity of the coverage across the web can be evaluated by using dyed fibers as part of the furnish or, if mechanical fibers are used in the center ply, by using phloroglucinol stain. Both of these techniques have been used to confirm the uniformity of coverage that can be obtained through stratification.

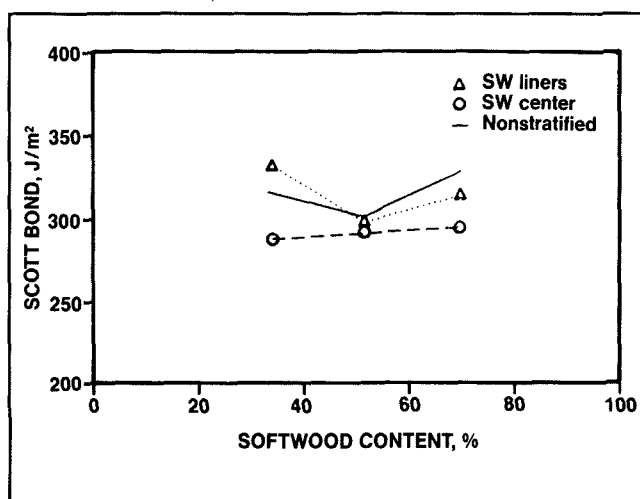
9. Tensile index $[(MD \times CD)^{1/2}]$ for stratified sheets with SW liners/HW center, stratified sheets with HW liners/SW center, and nonstratified sheets. SW furnish refined to 475 mL CSF; HW furnish refined to 305 mL CSF.



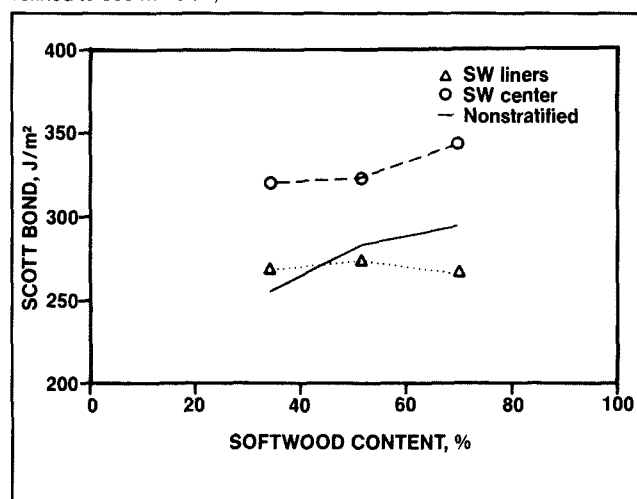
10. Tensile index $[(MD \times CD)^{1/2}]$ for stratified sheets with SW liners/HW center, stratified sheets with HW liners/SW center, and nonstratified sheets. SW furnish refined to 365 mL CSF; HW furnish refined to 415 mL CSF.



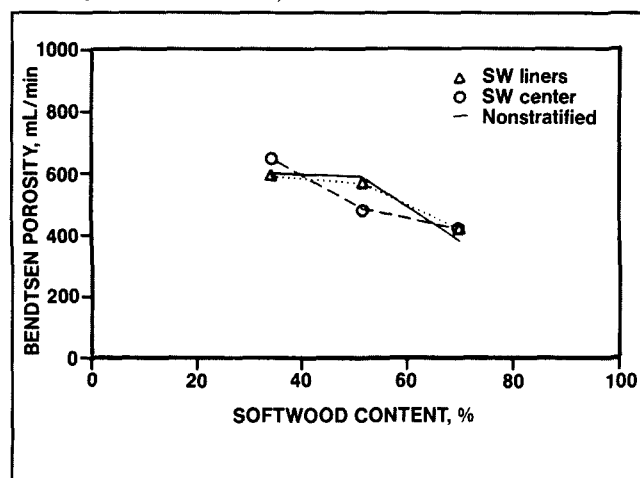
11. Scott bond for stratified sheets with SW liners/HW center, stratified sheets with HW liners/SW center, and nonstratified sheets. SW furnish refined to 475 mL CSF; HW furnish refined to 305 mL CSF.



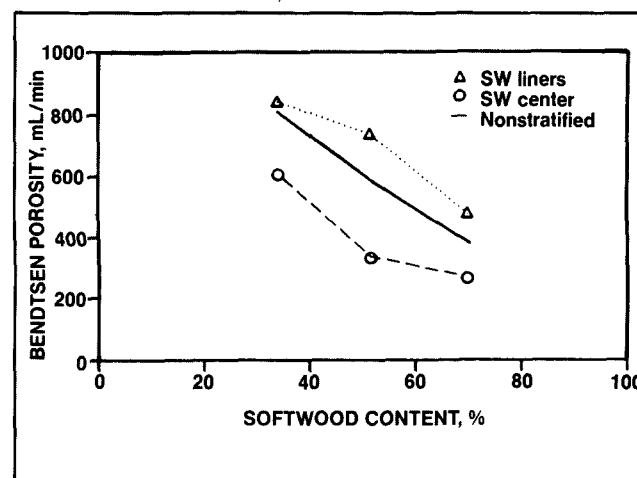
12. Scott bond for stratified sheets with SW liners/HW center, stratified sheets with HW liners/SW center, and nonstratified sheets. SW furnish refined to 365 mL CSF; HW furnish refined to 415 mL CSF.



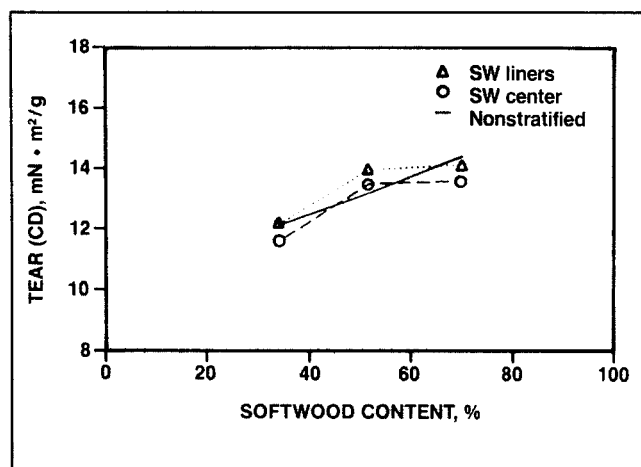
13. Bendtsen porosity for stratified sheets with SW liners/HW center, stratified sheets with HW liners/SW center, and nonstratified sheets. SW furnish refined to 475 mL CSF; HW furnish refined to 305 mL CSF.



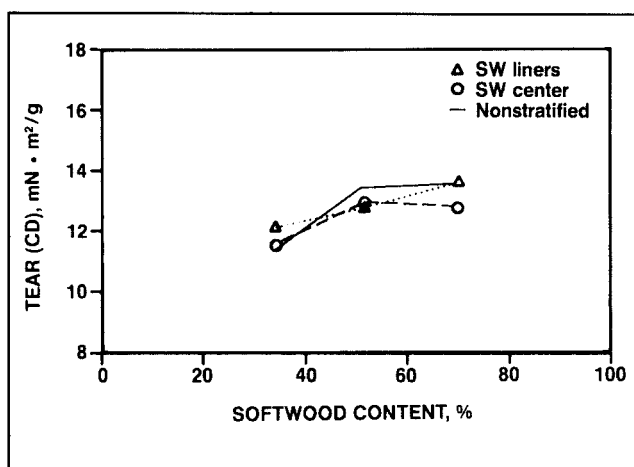
14. Bendtsen porosity for stratified sheets with SW liners/HW center, stratified sheets with HW liners/SW center, and nonstratified sheets. SW furnish refined to 365 mL CSF; HW furnish refined to 415 mL CSF.



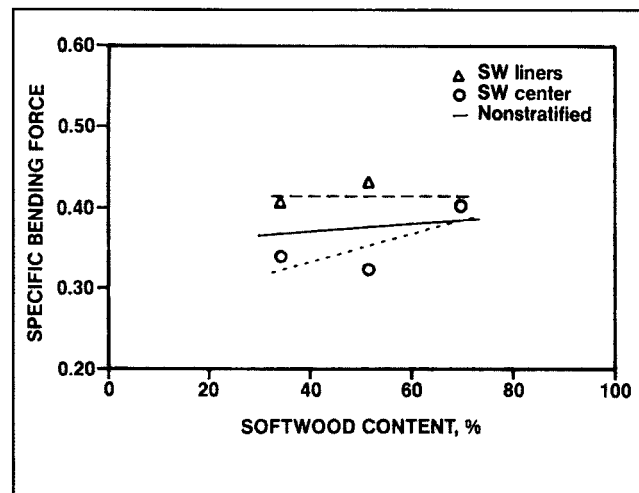
15. CD tear for stratified sheets with SW liners/HW center, stratified sheets with HW liners/SW center, and nonstratified sheets. SW furnish refined to 475 mL CSF; HW furnish refined to 305 mL CSF.



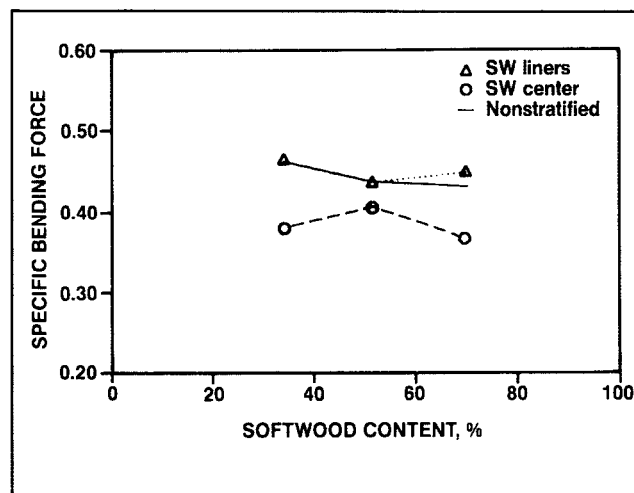
16. CD tear for stratified sheets with SW liners/HW center, stratified sheets with HW liners/SW center, and nonstratified sheets. SW furnish refined to 365 mL CSF; HW furnish refined to 415 mL CSF.



17. Specific bending force for stratified sheets with SW liners/HW center, stratified sheets with HW liners/SW center, and nonstratified sheets. SW furnish refined to 475 mL CSF; HW furnish refined to 305 mL CSF.



18. Specific bending force for stratified sheets with SW liners/HW center, stratified sheets with HW liners/SW center, and nonstratified sheets. SW furnish refined to 365 mL CSF; HW furnish refined to 415 mL CSF.



The ability to cover a lower-brightness or colored furnish in the center of the sheet is dependent on the liner ply weight and on the difference in brightness between the liner and center-ply furnishes. Lab work with handsheets indicates that no optical effects are observed with stratification on sheet weights under 85–100 g/m² (4, 5). Figure 7 shows the brightness that can be attained by increasing the weight of the liner ply. The figure also shows that the attainable brightness is a function of the difference in brightness between the liner and center plies. While increasing the weight of the liner plies leads to an increase in brightness, it is not possible to completely hide or cover the color of the center ply on paper-grade weights.

Physical properties

The trial work to date has concentrated on fine paper grades with two or more distinctly different furnish components, such as SW and HW. It seems reasonable to assume that the properties of the individual components

would have to be different in order to observe any changes in physical properties upon stratification of the sheet.

Surface characteristics such as smoothness, linting, or other printability-type properties could be improved by putting the “better” fiber on the surface (4, 6, 7). Figure 8 demonstrates the significantly different surfaces that can be obtained by stratifying the HW and SW fibers.

Many different types of stratified trials have been conducted. This report considers two models. One model uses bleached HW and SW kraft furnishes. The other model uses bleached CTMP in combination with bleached HW and SW kraft.

Softwood/hardwood pulps

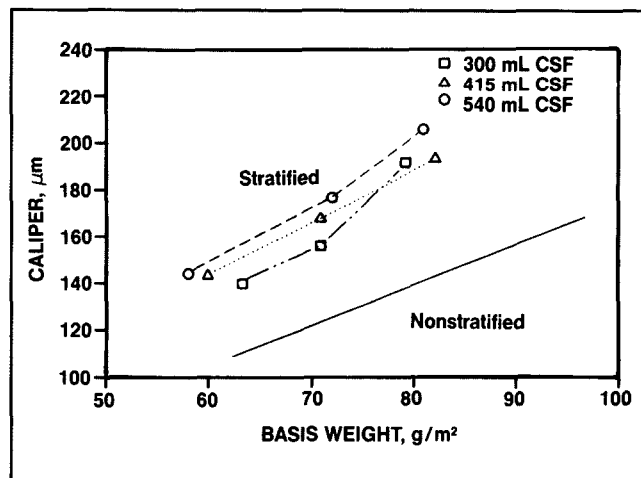
If we consider the model using SW and HW pulps, it is apparent that mere stratification of these two furnishes does not guarantee any improvements in sheet properties. For example, tensile index, shown in Fig. 9, is similar regardless of whether the SW pulp is used in the liner plies, the center of the sheet, or mixed with the HW to

III. Comparison of sheet properties for stratified and nonstratified sheets containing softwood and hardwood pulps. Softwood content of stratified sheets was much lower than nonstratified sheets.

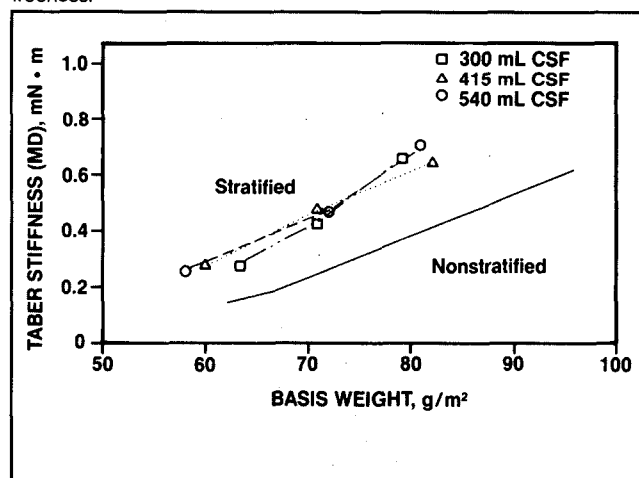
	Stratified	Nonstratified	Nonstratified
Furnish	67% HW (415 mL CSF) 33% SW (365 mL CSF) Softwood in center ply	50% HW (300 mL CSF) 50% SW (500 mL CSF)	50% HW (415 mL CSF) 50% SW (260 mL CSF)
Basis weight, g/m ²	61.7	64.0	63.7
Tensile index, Nm/g			
MD ^a	84.8	94.0	89.5
CD ^b	24.4	24.3	24.8
(MD × CD) ^{1/2}	45.5	47.8	47.1
Tear index, mN·m ² /g			
MD ^a	7.5	8.1	8.7
CD ^b	11.6	13.2	13.3
Burst index, kPa·m ² /g	3.4	3.5	3.3
Density, g/cm ³	0.596	0.619	0.604
Porosity, mL/min	600	590	575
Scott bond, J/m ²	321	300	279
Specific bending force	0.38	0.43	0.43
Tensile energy absorption, J/kg			
MD ^a	1401	1390	1334
CD ^b	1068	1033	1154

^aMachine direction.
^bCross-machine direction.

19. Caliper as a function of basis weight for stratified sheets with liners of 75% HW/25% SW and center plies of 80% CTMP and 20% SW. A nonstratified sheet made of 75% HW/25% SW is included as a reference. The three stratified curves represent different levels of CTMP freeness.



20. MD stiffness as a function of basis weight for stratified sheets with liners of 75% HW/25% SW and center plies of 80% CTMP and 20% SW. A nonstratified sheet made of 75% HW/25% SW is included as a reference. The three stratified curves represent different levels of CTMP freeness.



create a nonstratified sheet. Figure 10, however, shows that the sheet is stronger if the SW is in the center of the sheet, and the difference becomes greater as the amount of SW increases. The only distinction between the samples examined in Figs. 9 and 10 is the degree to which the individual furnishes were refined. The freenesses of the HW and SW furnishes for the two trials are listed in Table II.

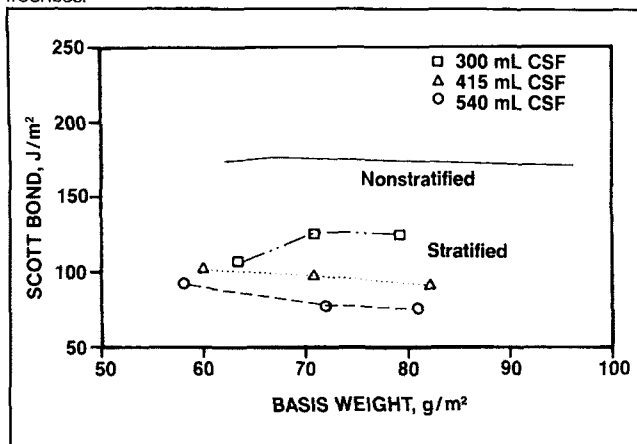
Refining the SW to a lower freeness and the HW to a higher freeness (Trial 2 in Table II) led to significant differences for the stratified sheets compared with nonstratified or mixed sheets. This was also true for Scott

bond, as seen in Figs. 11 and 12, as well as porosity, as seen in Figs. 13 and 14. Tear index was not affected by stratification, as seen in Figs. 15 and 16. Placing the lower-freeness SW in the center gave a stronger, lower-porosity sheet than a nonstratified sheet.

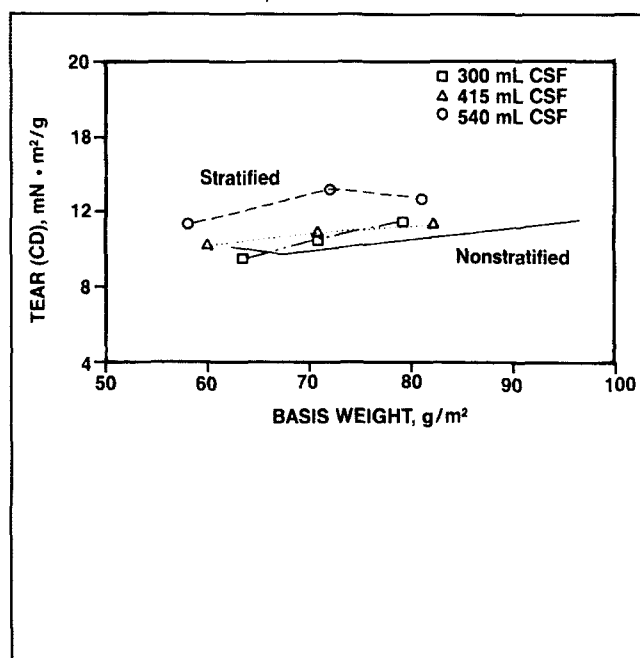
Figures 17 and 18 indicate that stiffness can be improved by using the SW in the liners and the HW in the center. This is similar to results reported in other studies, where mechanical fibers were used in the center instead of HW (4, 5).

Table III compares a stratified sheet containing 33% SW and two nonstratified sheets containing 50% SW. The

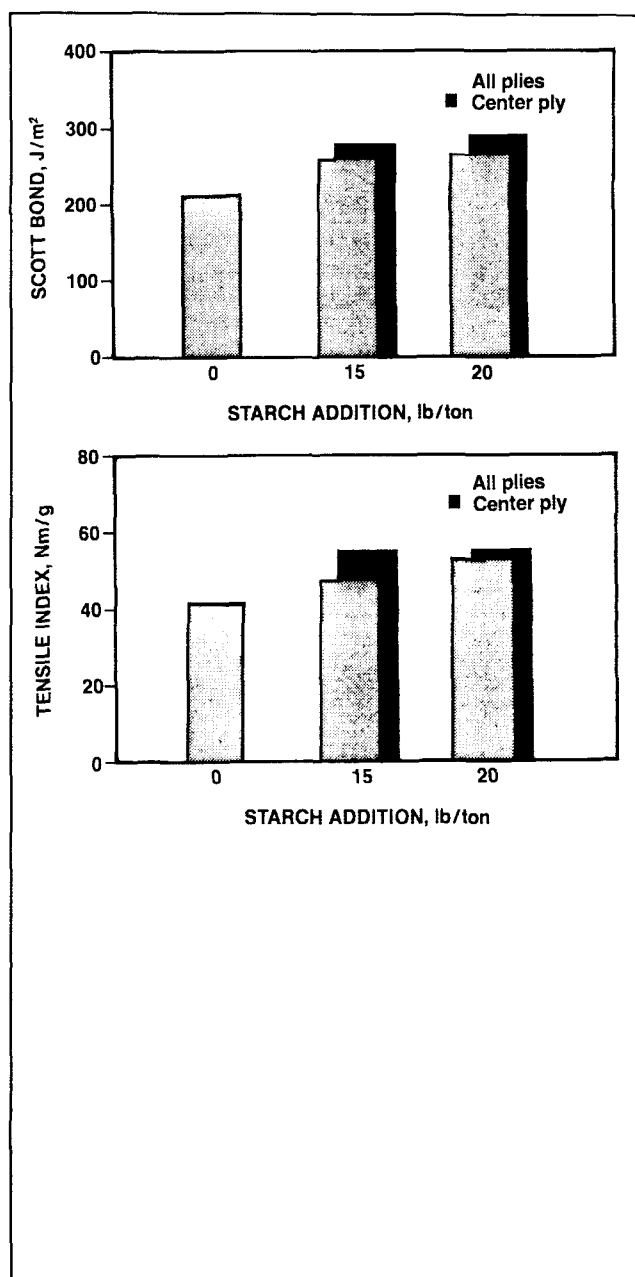
21. Scott bond as a function of basis weight for stratified sheets with liners of 75% HW/25% SW and center plies of 80% CTMP and 20% SW. A nonstratified sheet made of 75% HW/25% SW is included as a reference. The three stratified curves represent different levels of CTMP freeness.



22. CD tear as a function of basis weight for stratified sheets with liners of 75% HW/25% SW and center plies of 80% CTMP and 20% SW. A nonstratified sheet made of 75% HW/25% SW is included as a reference. The three stratified curves represent different levels of CTMP freeness.



23. Influence of starch addition point. Top: Scott bond as a function of starch addition for stratified sheets with HW liners and SW center. Bottom: Tensile index $[(MD \times CD)^{1/2}]$ as a function of starch addition for stratified sheets with HW liners and SW center.



data indicate that certain sheet properties, such as Scott bond, burst, and porosity, can be improved or maintained through stratification and modified refining, even with less SW. Some losses in tensile ($\approx 5\%$) and tear ($\approx 10\%$) were seen, but these losses were in a sheet containing 33% SW as compared with a sheet containing 50% SW.

The comparison made here does not represent an optimum set of refining conditions. However, it does indicate the importance of refining when considering stratification, and it demonstrates the real benefits to be gained through stratification. The refining requirements

will depend on which sheet properties are to be optimized and the type of furnish.

Softwood/hardwood pulps with CTMP center ply

The second model involved the use of bleached CTMP (80%) and bleached SW kraft (20%) in the center ply of the sheet. The liner-ply furnish consisted of bleached HW kraft (75%) and bleached SW kraft (25%). Three levels of CTMP freeness were tested: 540, 415, and 300 mL CSF. The liner ply weight was held at 15 g/m² per side, and the center ply weight was varied from 30 g/m² to 70 g/m². This gave

final sheet basis weights from 60 g/m² to 100 g/m². Machine speed was 800 m/min.

The primary reasons for using CTMP are its bulk and lower cost. **Figures 19 and 20** illustrate the added caliper (bulk) and stiffness obtained using CTMP. The drawbacks of using a bulky furnish such as CTMP include reduced Scott bond, as seen in **Fig. 21**, and diminished tensile strength. Refining the CTMP from 540 mL CSF to 300 mL CSF helped to recover some of the strength difference without affecting stiffness much. The CD tear of the stratified sheets was higher than that of the nonstratified sheet, as seen in **Fig. 22**. Either additional refining, more SW, or a wet-end strength chemical such as starch could further improve the strength.

Additives

Different amounts of starch, filler, size, and retention aids can be added selectively to the various plies of a stratified sheet. There are some indications that the filler distribution in the sheet can be influenced by adding the filler in the center. The effectiveness of size or starch can be increased by adding these materials to a specific sheet layer rather than dispersing them across all three layers. **Figure 23** shows that starch addition to the center ply increased tensile and bond strength compared with adding it to all plies.

Conclusion

The technology now exists for manufacturing a stratified paper grade with good surface purity and uniform coverage. Stratification provides the papermaker with the flexibility to optimize surface properties or to maintain the same level of quality while reducing raw-material costs. As the demand for higher-quality products continues, the potential benefits of stratifying fine papers and printing grades will become more appealing. □

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