Evaluation of forest thinning materials for TMP production

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ABSTRACT: **We used SilviScan analysis and tracheid measurement to evaluate the effect of suppressed growth on the fundamental properties of wood fiber. Suppressed growth reduced cell tracheid length, but the high content of mature wood may translate into longer fibers overall. In pilot-scale refining experiments, blending 25% chips from small-diameter trees (SMD) with 75% mill wood chips produced slightly better quality pulp compared with pulp from a control mill wood chip sample. The pulp from the SMD mix had slightly lower shives and fines content than that of the control pulp. Handsheets from the SMD mix pulp had improved tensile strength and optical properties compared with the control. We conclude that suppressed growth trees are superior to normal growth trees for thermomechanical pulp production because of uniformity in cell geometry, thin cell walls, and higher content of mature wood. Moreover, the thin cell walls of suppressed growth trees may require less refining intensity or energy to produce good quality pulp.**

Application: **The results of this study may help mills improve pulp production through better use of potentially neglected fiber resources.**

Millions of acres of forest and rangeland in the United States are at high risk for forest fire and disease as a result of an overabundance of smalldiameter and underutilized trees [1]. Despite the high fuel loading:, controlled burning is not an option for many forest lands near communities. Thinning of the forest is a critical solution to healthy forest management and reduction of wild fire risk. Forest thinning is an expensive operation because of strict environmental regulations and the volume of small diameter trees (defined as trees with breast height diameter, DBH, of less than 25.4 cm) involved. Efficient forest operation practices can reduce the cost of thinning. However, high value use of thinned materials is the key to making healthy forest management economical and successful.

One high-value [2] and large-volume [3] use for small-diameter trees and underused tree species is the production of pulp and paper. Wood fiber is typically the largest single cost for pulp and paper mills [4]. Previous studies conducted at the U.S. Department of Agriculture (USDA) Forest Products laboratory [5-8] using laboratory bench-scale kraft and mechanical pulping apparatuses indicated that pulp produced from forest thinnings are acceptable for commercial production of various grades of paper. However, the performance of pulp from forest thinning materials must first be demonstrated in scaled-up experiments to convince the pulp and paper industry to use these materials as an alternative wood fiber source. This is especially true for the production of mechanical pulps because laboratory bench-scale refiners do not generally produce pulp with commercial quality properties. Consequently, any conclusions drawn from laboratory bench-scale mechanical pulping experiments cannot be directly applied to commercial production with high confidence. Furthermore. it is not usually feasible to use 100% forest thinnings in commercial pulp production because of the available quantities of the materials relative to the 400–600 ovendry (o.d.) ton/day production capacity of a typical pulp mill. Therefore, one of our objectives was to demonstrate that equivalent quality mechanical pulp can be obtained when regular pulp mill wood chips are blended with chips from forest thinnings at an industrial pilot scale.

Forest thinning materials consist mainly of trees grown under a suppressed growth environment as a result of overpopulation. Understanding of the effect of suppressed growth on wood and fiber properties is very limited. Therefore, another objective of our study was to understand basic wood and fiber properties of trees under a suppressed growth environment and their potential effect on pulp and paper production. By conducting both basic wood and fiber property analysis and pilot-scale pulp production using pulp mill wood chips blended with chips from forest thinning materials, this study paves the way for mill-scale demonstration of the use of forest thinning materials in pulp and paper production.

EXPERIMENTAL

Materials

In this study, normal growth trees (from eastern Washington) were defined as trees about 25 years old, with growth ring width of about 4 mm. Suppressed growth trees were defined as trees more than 50 years old, with very narrow growth rings of less than 2 mm thickness as a result of growing in a severe environment. Ring widths of less than 0.5 mm arc common for suppressed growth trees. Small-diameter (mainly suppressed growth thinnings) lodgepole pine and Douglas-fir from eastern Washington were selected for the study on the basis of (a) frequency of the species as small-diameter trees in the intermountain region of northwest United States and (b) ease of thermomechanical pulp (TMP) production. Our discussions with foresters in the region revealed that lodgepole pine and Douglas-fir are highly represented as small-diameter trees. However, local TMP mill technical experts indicated that they had no experience in producing TMP pulp using this type of small-diameter thinnings. Lodgepole pine typically produces the whitest pulp with the least amount of electrical energy for refining. In contrast, Doughs-fir typically produces a dark pulp as a result of its reddish heartwood and so it requires rela-

	WEIGHT, %						
	MILL CHIP SAMPLE		CONTROL	SMALL-DIAMETER THINNING SAMPLES		TMP WITH 25% SMALL-DIAMETER CHIPS	Est. total small-diameter
Species	**HF[a]**	**Pine**	**Est TMP, HF + Pine**	**DF[a]**	**LPa**	**75% HF + Pine[c] 25% DF + LP[d]**	
Lodgepole pine[b]	2.9	91.1	47	0.7	86.4	46	11
Fir	82.6	1.2	42	—	—	32	—
Douglas-fir	1.4	0.4	1	99.3		13	12
Spruce	1.4	2.7	2		13.6	3	2
Hemlock	11.7	3.7	8	—	—	6	—
Larch	—	0.8	—	—	—	—	—
Bark	—	0.1	—	—	—	—	—
Total	100	100	100	100	100	100	25

[a] HF = hemlock–fir =(Abies genus, not Douglas-fir),DF, Douglas-fir; and LP =lodgepole pine. [b] Mainly lodgepole pine; traces of ponderosa pine. [c] 1:1 mix of hard pine and pine. [d] 1:1 mix of DF and LP.

I. Weight of chip species and TMP pulp furnish[a].

tively high bleaching loads; the sapwood is much lighter. Douglas-fir also requires the highest electrical energy demand for refining.

To optimize their economic value, the trees were sent to an integrated sawmill for manufacture into nominal 2-by-4 inch (38-by-89 mm) lumber from the heartwood. The rest of the wood (With a high proportion of sapwood) was chipped. This practice also solved the problem of the reddish heartwood in Douglas-fir. Regular wood chip furnish was also obtained from a U.S. newsprint mill in the Pacific Northwest. Wood chip furnish from smalldiameter forest thinnings was obtained from an integrated sawmill that also supplied regular chips to the mill.

Both chip furnishes consisted of two separate portions. The regular mill chips consisted of a shipment of a hemlock-fir mixture and a shipment of pine chips. Representative chip samples from each of these shipments were subjected to species analysis (TAPPI T263 sp-02) (Table 1) by a commercial laboratory (Integrated Paper Service, Inc., Appleton, WT). Chips from smalldiameter forest thinnings (after removing any small-dimension lumber) were also received as two separate shipments, labeled Douglas-fir and lodgepole pine. Representative samples from each of these samples were also submitted for species analysis (Table 1).

The two mill chip samples were blended to represent a typical mill furnish and the species were estimated from the results given for the two samples before mixing. Likewise, the two smalldiameter thinning samples were blended equally and the species ratios estimated from the testing of the separate samples (Table 1).

SilviScan and tracheid length analysis

Typical normal growth and suppressed growth (smalldiameter) thinnings of lodgepole pine and Douglas-fir were selected in the sawmill. Four wood disks about 2.5 cm in thickness were obtained at breast height from four selected trees. Figure 1 compares the ring structure (log cross section) of normal and suppressed growth lodgepole pine disks used in SilviScan analysis [9-11] in this study. A strip was cut across the entire diameter of each disk, as shown in Figure 1, with the least differentiation in radius between the two radii from the pith to bark (for example, the two radii are more likely in the east-west direction rather than the north-south direction where they may vary significantly due to variation in sunlight). After sanding, the four strips were sent to the Tasmanian Forest Research Center (CSIRO), Forestry and Forest Products, Australia. for SilviScan analysis.

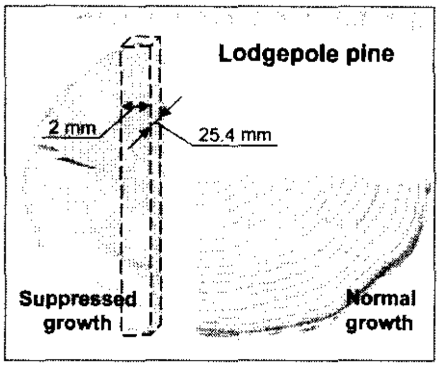
Only four test samples were used because SilviScan measurement is expensive in terms of time and cost. The results presented in this study are not intended to draw quantitative conclusions, but rather to reveal some distinct difference between normal and suppressed growth trees.

Another strip (for clarity, not shown in Fig. 1), cut from each disk next to the strip for SilviScan analysis, was mascerated to measure the tracheid length of the selected section of the tree. This strip was divided into several blocks along the radial direction. A 2 mm thick (radial direction) chip was cut from each block and further cut into matchsticksized pieces. A sample weighing about 0.33 g was obtained.

The match-stick-sized wood sample was macerated by the method of Brisson et al. [12]. The volumetric composition of the macerating solution was 1 part hydrogen peroxide (30% reagent solution), 4 parts deionized water, and 5 parts glacial acetic acid. All chemicals were from commercial sources. Approximately 35 mL of macerating solution was added to a 40 mL vial to macerate the 0.33 g (approximate) wood sample. The vial was then capped and placed in an oven at 60°C. After 7 days, the sample appeared as a white translucent material and the maceration solution became clear. The vial was removed from the oven and allowed to cool to room temperature. The macerated fiber sample was gently removed with a forceps and placed in a clean vial. The fiber sample was mixed with deionized water for a several minutes to separate any fiber bundles. The fiber sample was then analyzed by a Kajaani FS-100 fiber analyzer to determine the tracheid length distribution. The same fiber length analyzer was used to determine the fiber length distribution of the refined pulp.

Mechanical pulping

The blended mill wood chips and the blended thinning materials were mixed at a 3:1 ratio to produce the study sample (hereafter called smalldiameter [SMD]) mix.) We shipped 500 kg (dry basis) of a typical mill sample and 500 kg (dry basis) of the SMD mix sample to Andritz Research and Development Laboratory (Springfield, Ohio, USA) for evaluation. The wood chips were first refined (primary pulp) in an Andritz 36-1CP pressurized single-disc refiner (0.91 m diameter). The chips were presteamed in a pressurized steaming tube for 3 min at 2.18 kPa. The presteamed chips were then refined at 4.35 kPa. A Durametal plate pattern (36604, Andritz Ag. Graz, Austria) operating in the holdback direction was selected to best simulate commercial-scale operation. The primary pulp was then secondary and tertiary refined in an Andritz 401 atmospheric double-disc refiner (0.91 m diameter).



1. Annual ring structure of suppressed and normal growth lodgepole pine.

Pulp and paper evaluation

Canadian standard freeness (CSF) was measured by TAPPI T-227, pulp fines content by Bauer McNett, TAPPI T-233, and shives content by Pulmac screen (0–10 mm) analysis. Handsheets were prepared according to TAPPI T-201; physical and optical properties were evaluated according to TAPPI T-220 and T-425.

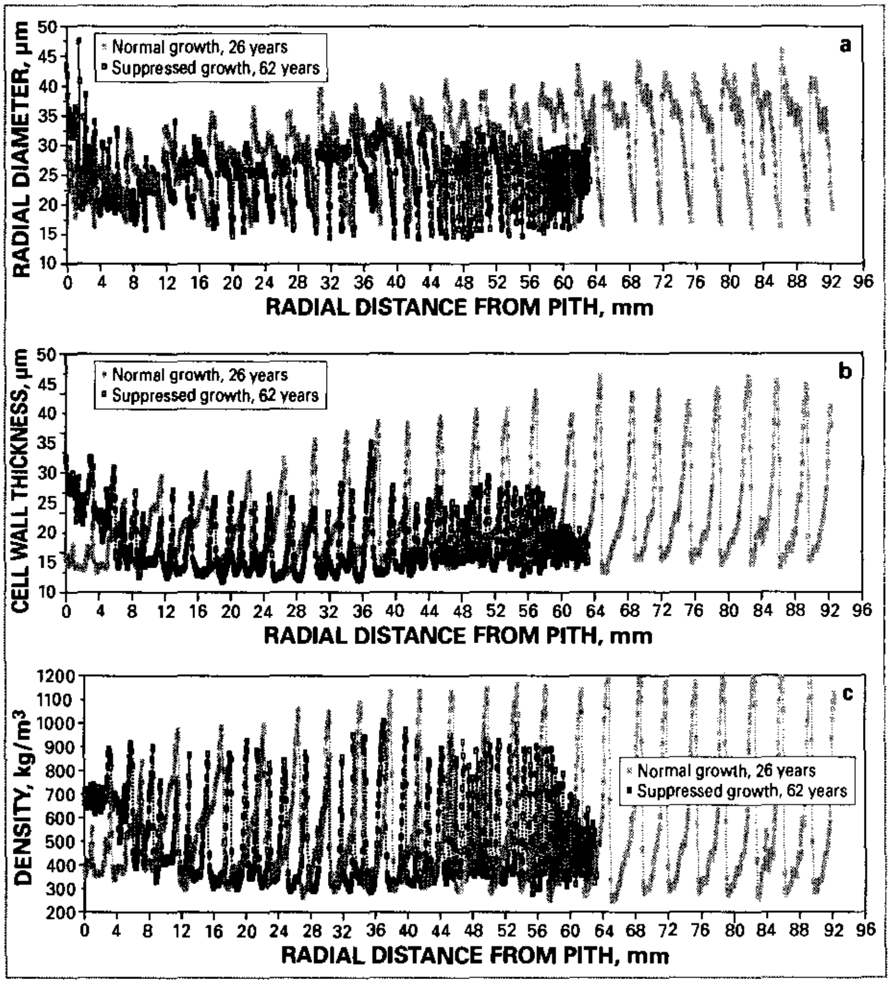
RESULTS AND DISCUSSION

Wood species analysis

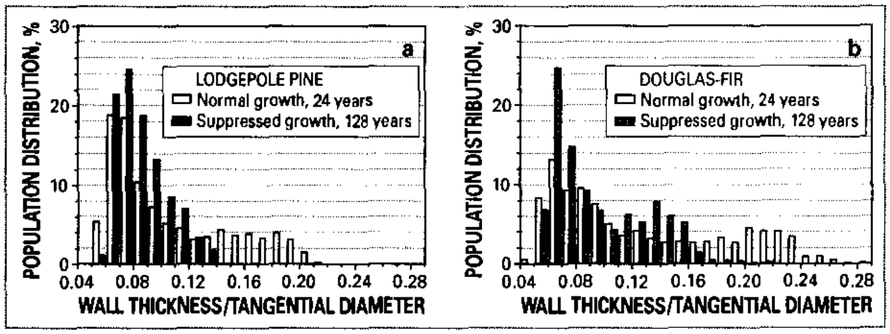
Table I shows results of the analyses of the four samples. Chip analysis of the two forest thinning samples showed that the lodgepole pine's growth was very suppressed, as evidenced by the narrow rings. Douglas-fir and lodgepole pine were the main species in the small-diameter chip furnish. The chip sample with 25% thinning material consisted of 12% Douglas-fir, 11% lodgepole pine, and 2% spruce smalldiameter species.

Effect of suppressed growth on physical properties and mechanical pulping

Among the four trees selected for SilviScan analysis (normal and small-diameter lodgepole and Douglas-fir). the small-diameter lodgepole pine was severely suppressed, as shown in Figure 1. This tree was 128 years old and had a diameter of about 64 mm. Severe growth suppression was indicated by tight ring structure throughout the cross section. The growth of the 62 year old small-diameter Douglas-fir (Fig. 2) had been mildly suppressed for about 35 years and then severely suppressed. The two normal growth trees (Fig. 3), lodgepole pine and Douglas-fir, were 24 and 26 years old, respectively.



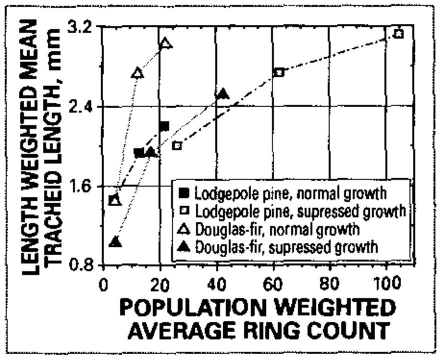
2. SilviScan measured radial profiles of normal and suppressed growth Douglas-fir: (a) cell radial diameter, (b) cell wall thickness, (c) wood density.



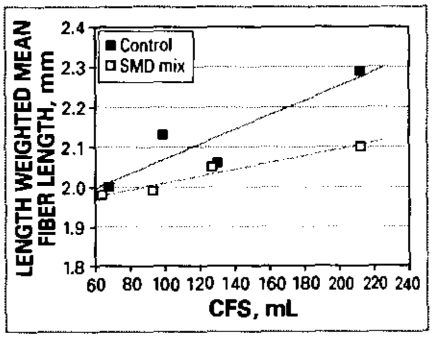
3. Effect of suppressed growth on cell population distribution of ratio of cell wall thickness to tangential diameter: (a) lodgepole pine, (b) Douglas-fir.

Few studies have reported the effect of suppressed growth on the physical properties of wood and fiber. SilviScan analysis of the two Douglas-fir trees indicated that the suppressed growth environment affected the diameter of the cell (ring width < 0.5 mm as opposed to normal of about 4 mm) and the cell wall thickness, compared with a normal growth environment (Fig. 2). Furthermore, the suppressed growth environment produced a tree with less distinction between latewood and earlywood than that observed in trees under normal growth. This is evident in the measured cell geometry and density profiles in Fig. 2, especially in the latter years of growth. Similar results were obtained for the two lodgepole pine logs tested.

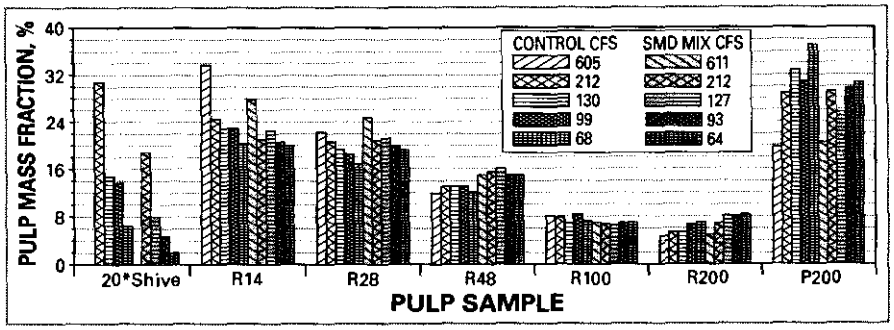
SilviScan has a spatial resolution of 50 µm. Therefore, the accuracy of the measured cell radial and tangential diameter is compromised due to spatial averaging, which is pronounced for suppressed growth rings. Cell wall thickness was derived from density and cell diameter; therefore, its accuracy is dependent on the accuracy of cell diameter measurements. However, the cell geometry results presented in Fig. 2 are in agree-



4. Effect of suppressed growth on measured mean tracheid length of lodgepole pine and Douglas-fir



5. Effect of blended mill wood chip/thinning materials (SMD mix) on measured mean fiber length of refined thermomechanical pulp.



6. Comparison of pulp fractions of SMD mix and thermomechanical pulp.

ment with qualitative image analysis, as will be reported in a future study.

For producing TMP, less distinction between earlywood and latewood means a more uniform material for refining. That may produce a more uniform pulp and reduce the degree or extent of cutting and damage of earlywood fibers. Rudie et al. [13] attributed the poor quality of loblolly pine TMP pulp to that species' high latewood content (about 30%) and a clearer distinction (i.e., sharper transition) in cell wall thickness, elastic modulus, and energy absorption potential between earlywood and Latewood. This translates into a bimodal distribution of fiber mechanical properties. Because of this nonuniformity, significant cutting and damage of earlywood fibers may occur when the applied refining energy or refining intensity is approximately the right level for fiberizing latewood.

The SilviScan data reveal that, although the latewood content of suppressed growth trees (both Douglas-fir and lodgepole pine) is higher than that of normal growth trees, there is less distinction in fiber cell structure and physical properties between earlywood and latewood. That means the properties of fibers from suppressed growth trees are more uniform. Figure 3 shows the composite cell population distribution of the ratio of cell wall thickness to tangential diameter. The composite is integrated over the entire cross-section of a tree and assumes axisymmetric distribution of cell population, wall thickness, and tangential diameter. (The tangential diameter is a measure of cell collapsibility under bending or torsion in refining.) The results clearly show that a suppressed growth tree is more uniform in terms of cell wall thickness than a normal growth tree.

Effect of suppressed growth on tracheid length

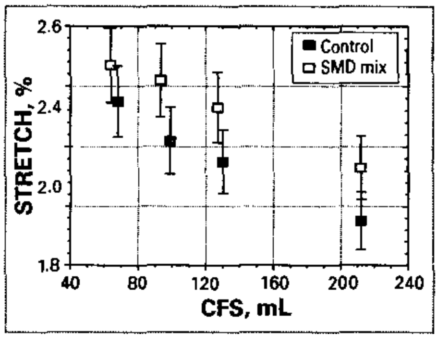
Figure 4 shows the measured tracheid length of the four trees. A suppressed growth environment may hinder cell growth in the longitudinal direction as it does in the radial direction, which shortens the tracheid, as confirmed by the results shown in Figure 4, which compares tracheids at about the Same age. However, a suppressed growth tree may have longer tracheids length in a comparison of tracheids from about the Same radial distance. For example, the measured mean tracheid length of the lodgepole pine tree under suppressed growth was greater than that of the lodgepole pine under a normal growth environment. This may be because the suppressed growth lodgepole pine was much older than the normal growth lodgepole pine (128 years compared to 24 years). Therefore, the suppressed growth lodgepole pine had a higher percentage of mature wood (fibers of mature wood are longer than those of juvenile wood), which further suggest that suppressed growth trees can be better material for TMP production.

Pilot-scale TMP refining

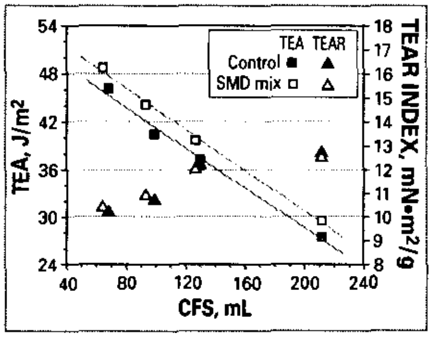
Refining energy is a very important parameter because electric energy used by the refiner is one of the largest single costs in TMP production. The pilot-scale refining experiments indicated that refining energy inputs (kJ/oven-dry ton wood) were almost the Same for the control and SMD mix samples; i.e., the refining energy inputs for both runs could be correlated to pulp Canadian standard freeness (CSF) by the same inverse relationship, $y = 21350/x^{0.47}$, with $r^2 = 0.968$. We conclude that blending forest thinning materials in TMP production will not affect refining energy usage.

Pulp fiber length is directly related to sheet tear strength, an important parameter for newsprint papers. Figure 5 indicates that the length weighted mean fiber lengths of pulps from the SMD mix sample were shorter than those of pulps from the control sample at all freeness levels. However, the difference in mean fiber length decreased as refining increased.

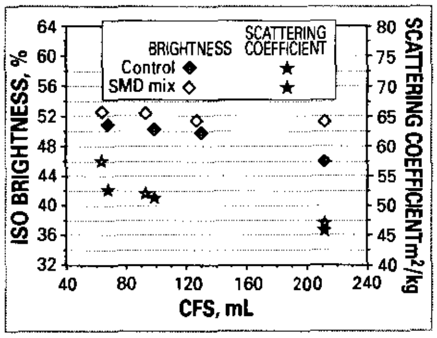
Pulp fractionation analysis (Fig. 6) indicated that the pulp produced from the SMD mix sample had lower shives and fines (P200) contents than that of the pulp of the control sample at all freeness levels. Furthermore, pulp produced from the SMD mix had a slightly more uniform distribution in various fractions, i.e., lower R14 and P200 fractions and slightly higher R48 and R200 fractions compared with pulp from the control wood chip sample (Fig. 6). The uniformity of the SMD pulp can be explained by the uniformity of the raw materials in terms of cell wall thickness as revealed from SilviScan analysis. That is, the suppressed growth environment produces a tree with less distinction between earlywood and latewood in terms of cell wall thickness (Fig. 3). The results in Figure 6 indicate that blending small-diameter



7. *Stretch of handsheets made from SMD mix and normal pulp.*



8. *Effect of SMD mix on strength properties of handsheets from refined thermomechanical pulp.*



9. *Effect of SMD mix on optical properties of handsheets from refined thermomechanical pulp.*

wood in TMP production produces a better pulp in terms of Low fines and shives content.

The conformability of the two pulp samples was about the same; the apparent density of handsheets made from the two pulp samples could be correlated to their respective pulp freeness (CSF) by the same exponential decay function $y = 413\exp(-x/937)$. with $r^2 = 0.976$. The variation in pulp fractions between the two pulp samples resulted in different fiber network structure as evidenced by handsheet stretch. The stretch Of the handsheet made from the SMD mix pulp sample was consistently higher (about 8 percentage points; the standard deviation of the measurements was 5 percentage points) than that of the sheet made from the control pulp sample, as shown in Figure 7. The low shives content and uniform distribution of pulp fractions in SMD pulp may also have translated to slightly better strength properties than those of the sheet made from the control sample.

The tear indices of handsheets made from the two pulp samples were about the same (Fig. 8) despite the fact that length weighted mean fiber lengths of the SMD mix pulp samples were consistently shorter than those of the control pulp samples (Fig. 5). The tensile energy absorption (TEA) values of the SMD mix handsheets were slightly higher than those of the control as a result of greater (about 8%) stretch measured, despite the fact that the tensile indices were slightly lower at equivalent freeness levels. No difference was observed in the burst strength of handsheets made from the SMD mix and control samples.

Optical properties (paper scattering coefficient and ISO brightness) of handsheets from the SMD mix pulp were also slightly better than those of control handsheets (Fig. 9). The improved brightness of handsheets from the SMD mix pulp was due in part to the fact that the wood chips contained less reddish heartwood of small-diameter Douglas-fir.

CONCLUSIONS

This study used SilviScan technology to analyze the fundamental fiber properties of suppressed and normal growth lodgepole pine and Douglas-fir trees. Tracheid measurements were obtained through macerating wood samples from the four types of trees. We found that fibers of the suppressed growth trees had a smaller cell radial diameter and thinner cell wall compared with those of normal growth trees. The suppressed growth trees also had higher latewood content compared with that of normal growth trees. Furthermore, the suppressed growth trees showed less distinction between earlywood and latewood properties in terms of cell radial geometry (cell wall thickness and radial diameter), cell population, and density.

The data also suggest that a suppressed growth environment reduces wood tracheid length. However, the overall mean tracheid length from a suppressed growth tree in the field can be greater than that of a normal growth tree because a typical suppressed growth tree is much older and has more mature wood than a typical normal growth tree used for pulp production. The fundamental data suggest that suppressed growth trees from forest thinning are more uniform than normal growth trees and may be more suitable for TMP production.

In pilot-scale refining experiments, a blend of 25% small-diameter trees from forest thinning (primarily suppressed growth trees) and 75% mill wood chips produced a slightly better quality TMP paper than the control run, which supports our hypothesis that suppressed growth trees are superior to normal growth trees for TMP production. An integrated sawmill operation that produces 2-by-4 lumber from Douglas-fir can reduce juvenile wood content, increase fiber length, and increase pulp brightness when much of the dark heartwood, such as that of Douglas-fir, is removed for lumber production. Further studies are required to validate the hypothesis that suppressed growth trees are superior to normal growth trees for TMP production and to find optimal conditions for pulping wood from suppressed growth trees.

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INSIGHTS FROM THE AUTHORS

Millions of acres of forest and rangeland in the United States are at high risk for forest fire and disease as a result of an overabundance of small-diameter and underutilized trees.

One high-value and large-volume use for small-diameter trees and underutilized tree species is the production of pulp and paper. That is why we chose this topic foroout research.

Previous studies conducted at the USDA Forest Products Laboratory incicated that pulp produced from forest thinning trees using laboratory bench-scale kraft and mechanical pulping apparatuses are acceptable for commercial production of various grades of paper. However, the performance of pulp from the forest thinning materials must first be demonstrated in scaled-up experiments to convince the pulp and paper industry to use these materials as an alternative wood fiber source. This is especially true for the production of mechanical pulps because laboratory bench-scale refiners do not generally produce pulp with commercial quality proerties. Demonstrating on scaled-up experiments was reported.

Furthermore, it is not usually feasible to use 100% forest thinning materials in commercial pulp production because of the available quantities of the materials relative to the 400-600 o.d. ton/day production capacity of a typical pulp mill. Therefore, another objective of our research was to demonstrate that mills can obtain equivalent quality mechanical pulp when regular pulp mill wood chips are blended with chips from forest thinning trees at an industrial pilot scale.

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We conclude that suppressed growth trees are superior to normal growth trees for thermal mechanical pulp production because of uniformity in cell geometry, thin cell walls, and higher content of mature wood. Moreover, the thin cell walls of suppressed growth trees may require less refining intensity or energy to produce good quality pulp.

The fundamental data suggest that suppressed growth trees from forest thinning are more univorm than normal growth trees and may be more suitable for thermo-mechanical (TMP) production. Further studies are required to validate the hypothesis that suppressed growth trees produce superior TMP.

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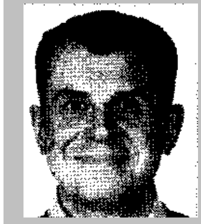
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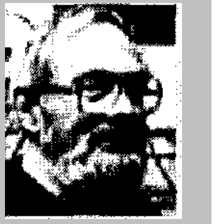
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