Evaluation of Forest Thinning Materials for TMP Production

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Abstract

The effect of suppressed growth on the fundamental properties of wood fiber was evaluated by SilviScan analysis and tracheid measurement. 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 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 require less refining intensity or energy to produce good quality pulp.

Introduction

Billions 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 [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 that need to be thinned. Efficient forest operation practices can reduce the cost of thinning. However, high value utilization of thinned materials is the key to making healthy forest management economical.

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One high-value [2] and large-volume [3] use for small-diameter trees and underutilized 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 USDA Forest Products Laboratory [5-8] indicated 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 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 thinning materials in commercial pulp production because of the location of the materials relative to the 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 thinning trees 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. SilviScan has proven to be a very useful tool for nondestructive and rapid characterization of wood and fiber properties [9-11]. Application of SilviScan could reveal some unique fiber characteristics of suppressed growth trees. Some fundamental understanding of the suitability of suppressed growth trees for pulp and paper production can be obtained from the combination of SilviScan data with measurements of tracheid length. 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 utilization of forest thinning materials in pulp and paper production.

**Experimental**

**Materials**

Small-diameter (mainly suppressed growth) lodgepole pine and Douglas-fir trees 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 thermal mechanical pulp (TMP) production. Our discussions with foresters in the region revealed that lodgepole pine and Douglas-fir are highly represented as small-diameter trees. Local TMP mill technical experts consider these species as being on the extreme ends of the spectrum for ease in pulping. Lodgepole pine typically produces the whitest pulp with the least amount of electrical energy for refining. In contrast, Douglas-fir typically produces a dark pulp as a result of its reddish heartwood and so requires relatively 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 (38- by 89-mm) lumber from the heartwood. The remainder of the wood (with a high proportion of sapwood) was chipped. This practice also solved the problem of the reddish heartwood in the Douglas-fir. Regular wood chip furnish was also obtained from a northwestern U.S. newsprint mill. Wood chip furnish from small-diameter forest thinning 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 T 401) (Table 1). Chips from small-diameter forest thinning (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 (Table 1). Likewise, the two small-diameter 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 (small-diameter) trees of lodgepole pine and Douglas-fir were selected in a sawmill. Normal growth trees were defined as trees about 25 years old, with growth rings of normal width for that age. Suppressed growth trees were defined as trees more than 50 years old, with very narrow
growth rings as a result of living in a severe environment. A total of four wood disks about 2.5 cm in thickness were obtained at breast height from four selected trees. A strip was cut across the entire diameter of each disk, with the least differentiation in radius between the two radii from the pith to bark. After sanding, the four strips were sent to the Tasmanian Forest Research Center (Commonwealth Scientific and Industrial Research Organization (CSIRO), Forestry and Forest Products, Australia) for SilviScan analysis.

Another strip, cut from each disk next to the strip for SilviScan analysis, was macerated 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 matchstick-sized pieces. A total of about 0.33 g sample was obtained.

The matchstick-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 approximately 0.33 g 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 75% to 25% ratio to produce the study sample (hereafter called small-diameter (SMD) mix; 500 kg (dry basis) of a typical mill sample and 500 kg (dry basis) of the SMD mix sample were shipped to Andritz Research and Development Laboratory (Springfield, Ohio) 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 pre-steamed in a pressurized steaming tube for 3 min at 2.18 kPa. The pre-steamed 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).

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 (0–10mm) 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 Chip Analysis

Results of the analysis of the four samples are given in Table 1. Chip analysis of the two forest thinning samples showed that the lodgepole pine 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.

Effect of Suppressed Growth on Wood and Fiber Physical Properties and Mechanical Pulping

Among the four trees selected for SilviScan analysis, the small-diameter lodgepole pine was severely suppressed. 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 had been mildly suppressed for about 35 years and then severely suppressed. The two normal growth trees, lodgepole pine and Douglas-fir, were 24 and 26 years old, respectively, and were typical of trees used for mill pulpwod.

Limited studies have been reported on 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 not only the diameter of the tree (ring width < 0.5 mm as opposed to 4mm) but also the cell wall thickness,
compared with a normal growth environment (Fig. 1). Furthermore, the suppressed growth environment produced a tree with less distinction between latewood and earlywood than that observed in trees under normal growth, as evident in the measured cell geometry and density profiles in Figure 1, 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 Om. 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 Figure 1 are in agreement 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 and 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 TMF pulp to the fact that loblolly pine has a 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 though 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, which makes suppressed growth trees a more uniform material.

Figure 2 shows the composite (integrated over entire cross section of a tree, assuming axisymmetric distribution of cell population, wall thickness, and tangential diameter) cell population distribution of the ratio of cell wall thickness to tangential diameter (measure of cell collapsibility under bending or torsion in refining). The composite data also suggest that less refining energy or refining intensity may be needed for suppressed growth trees than that used to refines wood chips from normal growth trees. This may explain the slightly lower strength obtained in an early study of TMF production from suppressed trees compared to the strength of pulp from normal growth trees when the same refining intensity and energy were applied [6].

Effect of Suppressed Growth on Tracheid Length

Figure 3 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 (Fig. 3, Douglas-fir). However, the measured mean tracheid length of the lodgepole pine tree under suppressed growth was greater than that of the loblolly pine under a normal growth environment. This may be due to the fact that the suppressed growth lodgepole pine was much older than the normal growth lodgepole pine (128 compared to 24 years). Therefore, the suppressed growth lodgepole pine had a higher percentage of mature wood. It is well known that the fibers of mature wood are longer than those of juvenile wood. These conclusions are verified by the slope of the mean tracheid length curve for the suppressed growth lodgepole pine, which is much steeper than that for the normal growth lodgepole pine. The mean length of tracheids from the very old suppressed growth tree was greater than that of tracheids from the regular growth tree, which further suggest that suppressed growth trees can be better material for TMP production.

Pilot-Scale TMP Refining

The SilviScan data and measured tracheid length data were used to estimate fundamental data for the two wood chip samples used in refining, i.e., the control and the SME mix sample. Because only lodgepole pine and Douglas-fir data were available, the control sample was modeled using a 50%–50% mix of normal growth lodgepole pine and Douglas-fir (see Table 1, assuming all firs are Douglas-fir and all pines are lodgepole pine and no other species); the SME mix sample was modeled using a 12.5%–12.5% mix of suppressed growth lodgepole pine and Douglas-fir and a 37.5%–37.5% mix of normal growth lodgepole pine and Douglas-fir. From the measured number mean tracheid lengths, the mean tracheid lengths of the two model samples were estimated to be about the same, i.e., 1.79 mm for the control and 1.81 mm for the SME mix. Figure 4 shows the mass distribution of the ratio of cell wall thickness to tangential diameter for the two model wood chip samples. The SME mix did not significantly alter the wood chip sample. One would expect to obtain similar pulp quality when the same refining conditions were applied to both samples. The actual refining energy input for the two samples was almost the same. The CSF (in mL) can be correlated to refining energy (kJ/o.d. ton wood) for both samples using the same exponential decay function, $y = 695 + 2919 \exp(-x/220.3)$, with $r^2 = 0.9997$. 
Further examination of the results shown in Figure 4 reveals some interesting information about the two pulp samples. The SMD mix had a single peak distribution of cell wall thickness and slightly higher percentage of cells with thin walls compared with the control sample. The control sample showed a bimodal distribution of cell wall thickness. These results illustrate that the SMD mix was relatively uniform. We had expected that the SMD mix would have slightly shorter fibers as a result of its slightly higher percentage of thin-walled cells and low shives and fines content [13]. Figure 5 confirms that the fibers of the SMD mix were shorter than those of the control pulp for all the CSF values tested, especially at high freeness levels. This difference became smaller with more refining, which indicates that cutting and damaging of thin-walled fibers mainly occur in the early stage of refining [13].

The lower shives (P200) and fines contents of the SMD mix pulp compared with the control sample, at all freeness levels, were also verified through pulp fraction analysis. 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. The results in Figure 6 indicate that blending small-diameter wood in TMF production produces a better pulp in terms of low fines and shives content.

The low shives content and uniform distribution of pulp fractions in SMD pulp may also have translated to slightly better strength properties. The tear indices of handsheets made from the two pulp samples were about the same (Fig. 7). The TEA values of the SMD mix handsheets were slightly higher than those of the control as a result of greater (about 10%) stretch measured, despite the fact that the tensile indices were slightly lower at equivalent freeness levels.

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. 8). The improved brightness of handsheets from the SMD mix pulp was due in part to the fact that the wood chips did not contain the reddish heartwood of small-diameter Douglas-fir.

Conclusions

The fundamental fiber properties of suppressed and normal growth lodgepole pine and Douglas-fir trees were analyzed by SilviScan. Tracheid measurements were obtained through macerating wood samples from the four trees. 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 thermo-mechanical (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 TMF paper than the control run, which confirmed our hypothesis that suppressed growth trees are superior to normal growth trees for TMF production. An integrated sawmill operation that produces 2 by 4 lumber can reduce juvenile wood content, increase fiber length, and increase pulp brightness if the heartwood is dark, such as that of Douglas-fir.

Because of the differences in the raw material from suppressed growth and normal growth trees, it is necessary to adjust pulping conditions, e.g., reduce refining intensity (or perhaps energy input) to achieve optimal pulp properties from refining wood chips from suppressed growth trees. Further studies are required to validate the hypothesis that suppressed growth trees are superior to normal growth trees for TMF production and to find optimal conditions for pulping wood from suppressed growth trees.

Acknowledgments

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Ohio), accommodated our schedule and conducted the pilot-scale refining experiments. Drs. Regis Miller and Alex Wiedenhoeft of the Center for Wood Anatomy Research of the Forest Products Laboratory provided much technical advice and many helpful discussions.
Literature Cited


<table>
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a HF is Hemlock–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.
Figure Legends

Fig. 1–SilviScan measured radial profiles of normal and suppressed growth Douglas-fir trees: (a) cell radial diameter, (b) cell wall thickness, (c) wood density.

Fig. 2–Effect of suppressed growth on cell population distribution of ratio of cell wall thickness to tangential diameter: (a) lodgepole pine, (b) Douglas-fir.

Fig. 3–Effect of suppressed growth on measured mean length of lodgepole pine and Douglas-fir fibers

Fig. 4–woodmass distribution of ratio of cell wall thickness to tangential diameter of model samples representing control and small-diameter (SMD) mix samples.

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

Fig. 6–Effect of SMD mix on shives and fines content of refined TMF pulp.

Fig. 7–Effect of SMD mix on strength properties of handsheets from refined TMF pulp.

Fig. 8–Effect of SMD mix on optical properties of handsheets from refined TMF pulp.
Fig. 3

[Graph showing the relationship between Radial distance from pith (mm) and Length weighted mean fiber length (mm) with different species and growth conditions represented by distinct symbols and lines.]
Fig. 4

![Mass distribution graph](image)

- Control
- SMD mix

Y-axis: Mass distribution (%)
X-axis: Wall thickness/tangential diameter
Fig. 5

[Graph showing the relationship between CSF (mL) and length weighted mean fiber length (mm) with data points for Control and SMD mix.]
Fig. 6

![Graph showing pulp mass fraction (%)](image)

- **Pulp sample labels:** 20" Shive, R14, R28, R48, R100, R200, P200
- **Y-axis:** Pulp mass fraction (%)
- **Legend:**
  - Control CSF
  - SMD mix CSF
  - 605
  - 611
  - 212
  - 212
  - 130
  - 127
  - 99
  - 93
  - 68
  - 64
Fig. 7
Forest Thinning Materials for TMP Production

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BACKGROUND
- Forest fire risk in western States
- Forest thinning as a solution
- Cost: $70/green ton
- High value utilization
- High volume utilization

TMP from FOREST THINNING - Published Work
- Laboratory Study at FPL 12" refiner
- Short Fiber Length
- Slightly Low Pulp Strength
- More Energy for Mechanical Pulping
OBJECTIVES

- Understand basic properties of thinning materials
  - Fiber length analysis
  - Silviscan analysis
- Commercial pilot scale study
  - Mix thinning materials with mill regular chips
  - Andritz pilot-scale test
- Mill trial

SUPPRESSED GROWTH TREES

- Lodgepole pine

SUPPRESSED GROWTH TREES

- Douglas fir
FIBER MACERATION

- Wood Sample Conditions:
  - cut a radial strip into blocks
  - each block is about 0.33 gram
  - Cut a block into 2 mm thick matchsticks

- Maceration Solution: (1:4:5)
  - hydrogen peroxide (30% reagent solution)
  - deionized water
  - glacial acetic acid

- Reaction Conditions
  - 35 mL solution for 0.33 gram of wood
  - T = 60°C
  - 7 days
**EFiber Length Measurements**

- Remove fibers by a forceps
- Place fibers in deionized water
- Kajaani FS-100 fiber analyzer

**Wood Sample Preparation**

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<td>Lodgepole pine</td>
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**Comparison – Douglas Fir**

![Graph showing fiber length distribution for Douglas Fir samples]
**SUMMARY**

- Suppressed growth produces smaller trees
- Suppressed growth produces smaller cells and thinner walls
- Suppressed growth produce less distinction between earlywood and latewood, or more uniform material
- Suppressed growth produces shorter fibers. But it also produce more mature wood that may result in a longer mean pulp fiber length.

**WOOD SPECIES ANALYSIS**

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**CELL WALL THICKNESS DISTRIBUTION - Model Mixture**

[Graph showing cell wall thickness distribution]
CONCLUSIONS -I

- Forest thinning materials that contains majority of suppressed growth trees have less distinction in wood properties between earlywood and latewood, which translate to a more uniform material.
- Suppressed growth produces shorter fibers. But the forest thinning materials contain more mature wood than trees from normal harvesting, therefore, may result in pulp of longer mean fiber length than regular pulp chips.
- A more uniform materials and a longer mean pulp fiber length are more suitable for TMP production.
CONCLUSIONS -II

- Mixing 25% forest thinning materials produced a slightly better quality TMP paper than the control run (no mix), which confirm our hypothesis that suppressed growth trees are superior to normal growth trees for TMP production.
- The integrated saw mill operation that taken lumber out of the heartwood can effectively reduce juvenile wood content, increase fiber length, and increase pulp brightness if heartwood has color such as douglas fir.

CONCLUSIONS -III

- It is necessary to adjust pulping conditions, e.g., reduce refining intensity or may be energy, to achieve a better pulp from refining wood chips from suppressed growth trees.