THERMOMECHANICAL PULPING OF LOBLOLLY PINE JUVENILE WOOD

Gary C. Myers

Research Forest Products Technologist
USDA Forest Service
Forest Products Laboratory[1]
Madison, WI 53705

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ABSTRACT

Intensive forest management, with a heavy emphasis on ecosystem management and restoring or maintaining forest health, will result in the removal of smaller diameter materials from the forest. This increases the probability of higher juvenile wood content in the harvested materials. The purpose of this study was to compare the performance of loblolly pine juvenile and mature wood unbleached thermomechanical pulp (TMP). The TMPs were prepared without screening (unscreened TMP) and after screening (screened TMP). Pulp and paper properties were tested. Paper made from screened juvenile and mature wood TMP had better properties than those of paper made from unscreened juvenile and mature wood TMP. The results also show that screened juvenile wood TMP consumed a large amount of electrical energy to produce a long-fibered pulp with low fines content and low coarseness. It might be possible to substitute the screened juvenile wood TMP for some of the reinforcing kraft pulp needed to manufacture newsprint and printing and writing papers. This could lower production costs of these paper grades.

Keywords: Loblolly pine, *Pinus taeda,* mature wood, juvenile wood, mechanical pulping, thermomechanical pulping, pulp properties, paper properties.

INTRODUCTION

Forest management is becoming more intensive, with a heavy emphasis on ecosystem management and restoring or maintaining forest health. Fast-growing seedlings are being planted, controlled burns are being used to reduce ground fuels, forests are being thinned, and trees are being harvested on a much shorter rotation. These measures increase the probability of higher juvenile wood content in the harvested materials. The percentage of juvenile wood in a plantation can be controlled by rotation length, ranging from 15% in a 40-year rotation to 50% in a 25-year rotation. Shorter rotations would yield even higher juvenile wood content (Kirk et al. 1972).

Juvenile wood is different from mature wood in that it has lower specific gravity, thin-walled cells, shorter tracheids, higher lignin and hemicellulose content, and low cellulose content (Thomas 1984; Zobel and van Buijtenen 1989). Juvenile wood occupies the center of a tree stem, varying from 5 to 20 growth rings in size; the transition from juvenile to mature wood is gradual. This core extends the full tree height, ending as top wood. Juvenile wood is not desirable for solid wood products because of warpage during drying and low strength properties.

Chemical pulp quality is affected when juvenile wood is a majority of the chip supply (Zobel and van Buijtenen 1989). Under identical chemical pulping conditions, pulp yield for juvenile wood is about 10% to 15% lower than pulp yield for mature wood. Paper made from juvenile wood chemical pulp has lower tear strength but higher tensile strength (Kirk

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et al. 1972). However, Carpenter (1984) reported that southern pine juvenile wood is desirable for producing stone groundwood and refiner mechanical pulp for newsprint.

The objective of this work was to study the feasibility of utilizing loblolly pine juvenile wood to produce unbleached TMP.

EXPERIMENTAL

Raw materials

Freshly cut loblolly pine (*Pinus taeda* L.) logs were obtained from the Talladega National Forest in Alabama. The first 12 rings, starting at the pith, were designed as juvenile wood and marked on both ends of each log. Each log was slabbed on a sawmill at the Forest Products Laboratory (FPL) into juvenile and mature wood; these two raw materials were kept separate for all subsequent processing and mechanical pulping trials. Since the mature pieces still contained bark, they were hand-peeled to remove all bark. The bark-free pieces of mature and juvenile wood were chipped to 19 mm long in a four-knife, commercial-size chipper. Chips were screened to remove all pieces greater than 38 mm and less than 6 mm long. Screened chips were placed in polyethylene-lined barrels and stored at 4°C until processing. Each barrel of juvenile or mature wood was thoroughly mixed in a large V-mixer. The material was then weighed into 5-kg samples, placed in polyethylene bags, and stored at 4°C until pulping.

Thermomechanical pulp preparation

An Andritz Sprout–Bauer (Andritz, Muncy, PA) Model 12–1CP 305-mm-diameter pressurized refiner, fitted with plate pattern D2B505, was used for fiberization. The pressurized refiner was preheated by starting and operating empty with 206.8 kPa steam for a minimum of 30 min. All chips were steamed for 10 min at 206.8 kPa before fiberization. Similar equipment operating parameters were used to fiberize all raw materials. Plate clearance was set at 0.254 mm for thermomechanical pulps (TMP) not screened after fiberization (unscreened TMP) and at 0.305 mm for pulps screened after fiberization (screened TMP). Pulp was screened in a 0.3-mm-slot flat screen. It was assumed that high density latewood fibers do not separate as readily as do low density earlywood fibers and would remain as screen rejects. Refining the two fractions separately would lessen the damage of the low density earlywood fibers. The separately refined accepts and rejects were recombined when Canadian Standard Freeness (CSF) values dropped to less than 200 ml (screened TMP). Other batches of juvenile and mature woods were not screened and were refined as who1e pulp (unscreened TMP). All refining was performed in a Sprout–Waldron (Andritz, Muncy, PA) Model 105–A 305-mm-diameter atmospheric refiner, also fitted with plate pattern D2B505. The atmospheric refiner was preheated by starting and operating empty with 90°C water for a minimum of 30 min. The initial pass was at 0.254-mm plate clearance; subsequent passes were reduced to a final pass at approximately 0.152 mm. A constant volume of shredded pulp was delivered to the atmospheric refiner inlet by a constant-speed belt conveyor, and 90°C dilution water added to the shredded pulp to adjust refiner consistency to approximately 20%. Multiple passes were necessary to reduce pulp freeness to above and below 100 ml; samples were withdrawn at these freeness levels for pulp testing, handsheet making, and paper testing.

Energy consumed during fiberization and refining was measured using an Ohio Semitronic (Hilliard, OH) Model WH30–11195 integrating watt-hour meter attached to the power supply of a 44.8-kW electric motor, measuring amperes, volts, and power factor. Energy consumption values for fiberizing and refining were reported in watt-hours per kilogram (oven-dry weight basis), with the idling energy subtracted. Latency was removed from the pulp after fiberization and each refining step by soaking the pulp in 90°C water for a minimum of 30 min, with occasional stirring. All pulp samples were dewatered to approximately 30% solids content after each fiberization and refining step. Three replicates were prepared for the juvenile and mature unscreened TMP, and four replicates for the juvenile and mature screened TMP.

Refining intensity was calculated according to Miles (1991) for all chip fiberization and pulp refining steps.

Pulp testing and handsheet formation and testing

Pulp freeness was measured according to TAPPI Test Method T227. Shive contents were determined with a Pulmac shive analyzer, using a disk with 0.10-mm slot openings. Average fiber length, fines content, and fiber coarseness were determined using a Kajaani FS–100 analyzer. Handsheets weighing 60 g/m^2 were made according to TAPPI Test Method T205. Burst, tear, tensile, and smoothness properties were measured according to TAPPI Test Methods T403, T414, T494, and T538, respectively. Brightness, printing opacity, and light-scattering coefficient were measured with a Technidyne Corp. (New Albany, IN) Technibrite Model TB–1 diffuse brightness apparatus according to TAPPI Test Method T525.

Statistical analyses

Each TMP was processed to a freeness level above and below the 100-ml target. A set of 10 handsheets were made and tested for each pulp. The individual test results were used to perform a Dunnett's multiple comparison procedure, which provided statistical significance at a 95% confidence level. Mean, standard deviation, and coefficient of variation were computed for each property tested in a handsheet set. Mean values from the replicates were combined and averaged to provide a value above and below 100 ml CSE which were interpolated to estimate a value for 100 ml CSE

A separate statistical analysis was performed to determine the significance of pulp feed rate and energy consumption as predictors of pulp and paper properties.

RESULTS AND DISCUSSION

The main objective of this study was to compare the performance of juvenile and mature loblolly pine TMP. Estimated values at 100 ml CSF for juvenile and mature wood are presented in Table 1. Changes in pulp properties are shown in Figs. 1 to 4. Strength and optical properties of handsheets from juvenile and mature wood pulps are shown in Figs. 5 to 8. Statistical analysis results were added to Figs. 1 and 2 and Figs. 5 through 8; "S" indicates that the specific property for juvenile wood was significantly different from that for mature wood.

Pulp preparation and pulp properties

Pressurized and atmospheric disk refiner operating conditions were very similar for all raw materials. This was a deliberate attempt to reduce variables while looking for differences between properties of juvenile and mature loblolly pine pulp and paper. This could have led to some operating conditions that were not optimized for a specific raw material.

Fiberization in the pressurized refiner was nearly identical for all raw materials. Chip feed rate into the refining zone was –900 oven-dry grams per minute (od g/min), energy consumed was ~477 WH/od kg, and coarse pulps were ~755 ml CSE Large differences occurred during refining, which will be presented and discussed in the following paragraphs.

Energy consumption is traditionally high in preparing mechanical pulp and higher for juvenile wood than for mature wood (Corson 1999a; Murton 1998). In the study reported here, juvenile wood consumed more total energy than did mature wood and significantly more energy when screened juvenile wood TMP was prepared (Table 1, Figs. 1 and 2). There were essentially no differences in fiberization energy intensity between juvenile and mature wood (Fig. 3). Slightly higher refining energy intensity occurred when juvenile wood was refined as unscreened TMP, and refining energy intensity was much higher when ju-

TABLE 1. *Loblolly pine test results interpolated to 100 CSE.*

Processed pulp and wood type	Total energy (WH/od kg)	Shive content[a] (%)	Kajaani analysis[b] Average (mm)	Kajaani analysis[b] Fines (%)	Coarseness (mg/m)	Apparent density (kg/m³)	Burst index (kPa-m²/g)	Tear index (mN-m²/g)	Tensile index (N-m/g)	Stretch index (%)	TEA index (J/m²)	Smoothness (SU)	ISO brightness (%)	Printing opacity (%)	Scattering coeff. (m²/kg)
Unscreened TMP															
Juvenile	2,003	0.56	0.94	7.31	0.443	397	0.66	2.63	19.9	1.16	10.50	274.3	40.0	98.0	44.8
Mature	1,909	0.82	0.87	8.73	0.446	387	0.57	2.40	17.0	1.07	8.17	313.2	39.9	97.9	44.5
Screened TMP															
Juvenile	4,647	0.71	1.24	6.23	0.350	444	1.12	3.88	27.1	1.42	17.38	183	38.5	99.0	47.1
Mature	2,049	0.41	1.10	6.98	0.447	415	0.74	2.95	19.3	1.18	10.01	287	39.3	98.2	40.3

[a] Pulmac shives < 0.004 mm.
[b] Kajaani FS-100 analysis, length-weighted values.

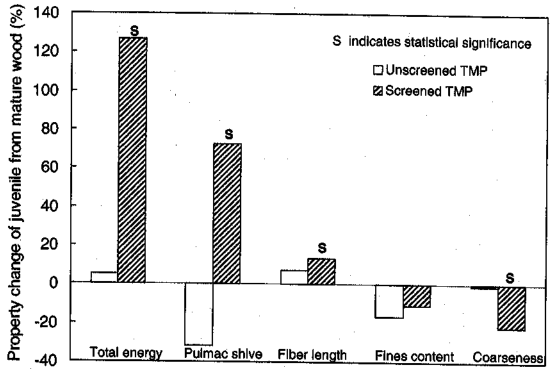


FIG. 1. Change in properties of unscreened and screened juvenile wood TMP compared with mature wood TMP.

venile wood was refined as screened TMP. Pulp feed rate (od g/min) was the probable cause of differences in refining intensity since all other operating conditions were very similar. Chip feed rates during fiberization were nearly identical, as were refining intensities. When refining the unscreened TMP, the weighted average feed rate for juvenile wood was 435 od g/min and for mature wood 484 od g/min. The slower feed rate for juvenile wood corresponds to its higher refining intensity (Fig. 3). When refining the screened TMP, the weighted average feed rate for juvenile wood was 251 od g/min and for mature wood 374 od g/min. Again, the slower weighted average feed rate for juvenile wood corresponds to its higher refining intensity (Fig. 3). Since the pulp feed system for the atmospheric re-

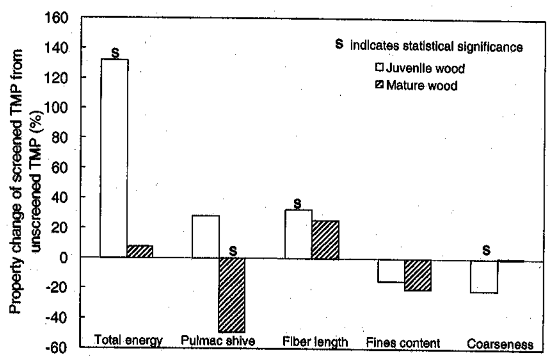


FIG. 2. Change in properties of screened juvenile and mature wood TMP compared with unscreened TMP.

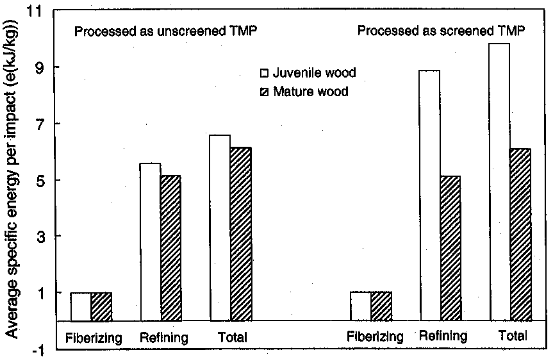


FIG. 3. Refining intensity of screened and unscreened TMP from juvenile and mature wood.

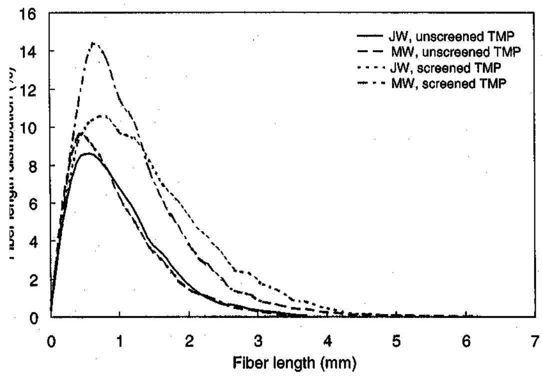


FIG. 4. Weighted length distribution of fibers in screened and unscreened juvenile wood (JW) and mature wood (MW) TMP as determined by Kajaani FS100 analysis.

finer was at a constant volume, the screened juvenile wood pulp apparently had a lower bulk density.

Pulp feed rate to the atmospheric refiner appeared responsible for differences in all pulp and paper properties measured, not just total energy and refining intensity. At first glance, this appeared to be a valid consideration, worthy of a statistical analysis. However, the analysis revealed that average fiber length and diffuse brightness were the only properties with statistically significant relationships to pulp feed rate. Total energy was found to be the better predictor of properties, in which all but fiber coarseness and diffuse brightness were statistically significant.

Shive content was low for juvenile wood when processed as unscreened TMP, but significantly higher when processed as screened TMP (Fig. 1). Shive content for juvenile wood increased and that for mature wood decreased when each wood was processed as screened TMP instead of unscreened TMP (Fig. 2). Fiber length was longer for both unscreened and screened juvenile wood TMP, but significantly longer for the screened TMP (Fig. 1). When both juvenile and mature wood were processed as screened pulp, fiber length was significantly longer for juvenile wood (Fig. 2). When compared against mature wood, both unscreened and screened juvenile wood TMP had lower fines content (Fig. 1); when compared against unscreened TMP, juvenile wood had lower fines content than mature wood (Fig. 2). Coarseness was significantly lower when juvenile wood was processed as screened TMP, but only slightly lower when processed as unscreened TMP (Fig. 1). Figure 2 shows a significant reduction in coarseness when juvenile wood was processed as screened rather than unscreened TMP, but no change for mature wood.

The weighted fiber length distributions also show some differences between juvenile and mature loblolly pine TMP (Fig. 4). When juvenile and mature woods were processed as unscreened TMP, differences in fiber length were slight. The juvenile wood had a slightly lower percentage of very short fibers and slightly more middle-length fibers, but both juvenile and mature wood had the same distribution of long fibers. However, when juvenile and mature woods were processed as screened TMP, fiber length distributions were much different from that for unscreened TMP. When the coarse pulps were flat screened, the mature wood separated into 93% accepts and 7% rejects, and the juvenile wood separated into 50% accepts and 50% rejects. Comparison of juvenile and mature screened TMP showed that juvenile wood had fewer shorter fibers and more longer fibers than did mature wood. The fiber length distribution patterns in Fig. 4 help visualize why the juvenile wood

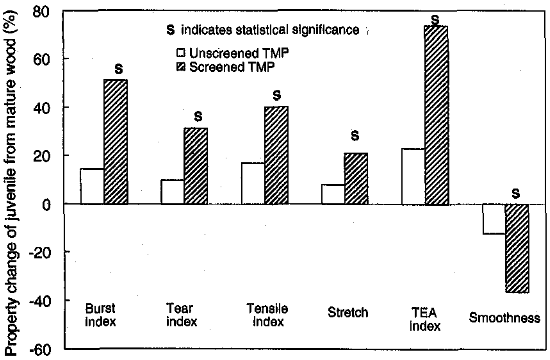
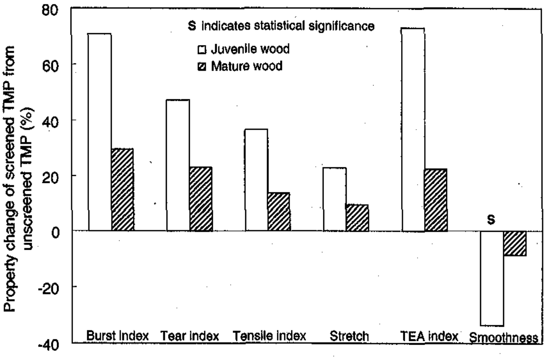


FIG. 5. Change in strength properties of handsheets from unscreened and screened juvenile wood TMP compared with mature wood TMP.



FIG, 6. Change in strength properties of handsheets from screened juvenile and mature wood TMP compared with unscreened TMP.

had higher shive content, longer fibers, and less fines contents (see Figs. 1 and 2).

Juvenile wood consumed more electrical energy than did mature wood, and, except for shive content, yielded a long-fibered, low fines, less coarse pulp than did mature wood. The larger mature wood fibers experienced more reduction in length than did the smaller juvenile wood fibers during fiberization and refining, which agrees with Corson's findings for radiata pine (Corson 1999b).

Strength properties

Table 1 and Figs. 5 and 6 show that paper made from juvenile wood had better strength properties than those of mature wood, for both unscreened and screened TMP. Smoothness was improved, as shown by the lower smoothness unit number (Table 1) and reductions (Figs. 5 and 6). Figure 5 shows that all paper properties from unscreened and screened juvenile wood TMP were better than those from mature wood TMP. Only the properties of screened juvenile wood TMP were significantly better than those of screened mature wood TMP.

Paper made from screened juvenile and mature wood TMP had better properties than those of paper from unscreened juvenile and mature wood TMP (Fig. 6). Figure 6 indicates that only smoothness was significantly better for screened juvenile wood TMP. Contrary to the results found by Semke (1984), we found that tear index increased for screened and unscreened juvenile wood TMP (Figs. 5 and 6).

The higher apparent density of unscreened and screened juvenile wood TMP probably caused the higher paper strength properties, compared with those of mature wood TMP. Paper strength properties correlated very well with apparent density, where R^2 ranged from 0.87 to 0.98. The only significant difference in density was between screened and unscreened TMP, but there was no significant difference between juvenile and mature wood. Improved pulp quality, as partially presented in Fig. 4, was the probable cause of the higher apparent density of paper from juvenile wood TMP. More of the original fiber length was retained, coarseness was reduced, and fines content was reduced, which probably promoted better fiber-to-fiber conformability and bonding. Better paper smoothness also suggests better sheet consolidation and bonding. The improvement in pulp quality presented earlier correlates with the improvement in strength properties presented in Figs. 5 and 6. Better tear index was probably due to the longer fiber length. Screened juvenile wood TMP appeared to produce a better quality pulp, which then produced a stronger paper.

Optical properties

Table 1 and Fig. 7 show no significant effect of pulp screening on optical properties of ju-

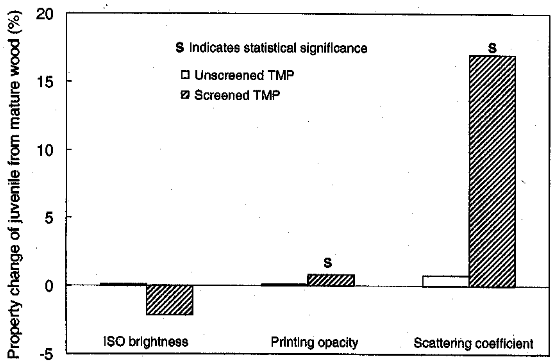


FIG. 7. Change in optical properties of handsheets from unscreened and screened juvenile wood TMP compared with mature wood TMP.

venile and mature wood TMP. Handsheets from screened juvenile wood TMP had slightly lower brightness but significantly better opacity and scattering coefficient than did handsheets from screened mature wood TMP. Hatton and Johal (1994) found that handsheets from juvenile wood chemithermomechanical pulp (CTMP) had a higher scattering coefficient than did those from mature wood.

Processing mature and juvenile wood loblolly pine as screened TMP was more detrimental to optical properties than processing as unscreened TMP (Fig. 8). These trends were opposite to the improvement seen in strength properties of screened TMP when compared with unscreened TMP (Fig. 6). The traditional

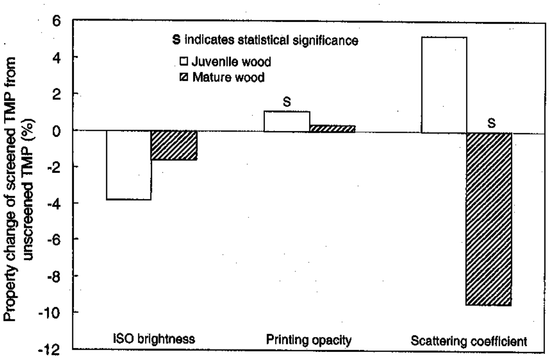


FIG. 8. Change in optical properties of handsheets from screened juvenile and mature wood pulps compared with unscreened TMP.

scenario in mechanical pulping is that strength improvements are offset by optical property reductions.

CONCLUSION

Because of the superior strength and optical properties of paper made from loblolly pine juvenile wood thermomechanical pulp, it is possible that using this pulp would allow a paper mill to reduce the amount of reinforcing kraft pulp needed to manufacture newsprint and printing and writing papers.

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