Profiling the wood and pulping properties of southern pine thinning resources

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ABSTRACT: This study established the chemical and physical properties of chips and kraft pulps made from southern softwood thinnings and mature wood. Differences in physical pulp properties were established and shown to be due to the effects of the wood furnish. Carbohydrate analysis demonstrated distinct differences in wood carbohydrates, including increased levels of glucose and reduced levels of xylan for mature wood samples. When we used constant kraft pulping conditions, the mature wood samples provided a 1% increase in screened pulp and 12% reduction in pulp kappa number. Mixtures of thinnings and mature wood provided pulps that were a composite average between the two extremes of 100% mature and 100% thinning wood fiber resources. The differences in wood carbohydrates were shown to influence pulp carbohydrate profiles, hexenuronic acids, and fiber charge. Fiber quality analysis indicated that the kraft pulps prepared from wood thinnings were ~30% shorter; this yielded handsheets that were denser and had higher tensile strengths.

Application: This study provides a road map for kraft pulping southern softwood thinnings and mature wood. It shows the effects of using different mixtures of this valuable wood resource to produce pulps of differing physical properties.

The ample supply of pine woodlands in the southern portions of the United States remains a competitive advantage for the pulp and paper industry. This resource is converted into softwood kraft pulp, which is used for assorted paper, packaging, and sanitary applications.[1]

Over the past two decades, our knowledge of how wood properties influence physical paper properties for mechanical and chemical pulps has developed substantially. Among the key physical assets of southern softwood kraft pulp fibers are their renowned strength, stiffness, drainage, and dimensional stability. Pulping, bleaching, and refining operations have a considerable influence on the overall end-product properties. However, many of the properties for softwood kraft board and bleached products are determined by the properties of the native wood fibers.[2] Although pulping, bleaching, and refining operations can reduce fiber length, coarseness, and cell wall dimensions, the raw wood properties establish upper limits for each of these parameters.[3]

The southern United States has one of the largest collection of non-industrial private forest (NIPF) landowners in the nation and their resource assets are a primary source of wood for many of the region's pulp mills.[4] Many of these NIPF owners have begun to explore and practice short-rotation management options to improve the feasibility, profitability, and cash flow of production forestry enterprises. A valuable component in forestry management is to cut immature tree stands and clumps of trees to stimulate growth of the remaining trees and to increase the total yield of useful material from the stand. Studies undertaken at the University of Georgia have demonstrated that thinning loblolly and slash pine stands increased the internal rate of return for NIPF landowners by 1%-2% over unthinned stands. The practice also increased total cash flow for southern pine resources compared to the unthinned counterparts. Given these economic incentives, it is most likely that southern forest landowners will continue to use thinning programs to help maximize the value of their forestry investments. In turn, these thinning programs will generate substantial amounts of pine fiber available for kraft pulping operations.

Despite these economic considerations, the full effects of using southern pine thinnings on mill operations and pulp quality are not adequately established. Early studies by Zobel [5,6], Koch [7], and others [8,9,10] documented that wood from fast-grown plantations is different from that from older, natural stands of the same species because of age, tree form, and quality. These fast-grown trees have a large proportion of juvenile wood, which can have significant effects on total wood quality and use and on product standards.

Studies performed by Hatton et al. have demonstrated that kraft pulps prepared from black, Norway, red, and white spruce thinnings exhibited reduced tear properties, but excellent tensile properties, which were attributed to the thinner cell walls from the juvenile wood.[10] In subsequent studies, Drost et al. reported on variations in fiber characteristics from mature and juvenile wood from whole-log and sawmill chips. Their results demonstrated that pulps from juvenile wood had superior beatability resulting from lower coarseness, while pulps from mature wood exhibited higher tear as a result of greater fiber lengths. Of the wood species examined, jack pine fibers was found to be the longest and exhibited the highest fiber coarseness, yielding kraft pulps with the highest tear strength values, but significantly lower tensile strength.[11]

An earlier study by Kibblewhite and Bawden also demonstrated significant fiber and physical property differences for thinned logs and 38-year-old top logs.[12] The authors determined that the wood and kraft pulp properties from radiata pine thinnings were dependent upon when the thinnings were cut. These results clearly demonstrate that the wood and fiber properties of thinnings differ from mature wood.

	Chip Size Distribution, %				
	Fines	Pins	Accepts	Overthick	Oversize
Mature	2.6	5.4	78.8	12.2	1.0
Thinnings	1.2	7.7	80.9	9.0	1.2

I. Chip size distribution (based on green weight) for mature and thinnings softwood chips used.

Cook Type	Softwood Chips Thinning:Mature	Final H-factor	Residual EA, g/L
Conventional Kraft	100:0	1436	9.1
	0:100	1445	10.4
	80:20	1438	10.0
	60:40	1434	10.9
	40:60	1433	10.9
Modified Continuous Kraft	100:0	1717	—
	0:100	1713	—
	60:40	1709	—

II. Softwood kraft pulping conditions.

Wood Source	Pins	Accepts	Overthick	Oversize
Thinnings	13.7	3.5	2.2	3.0
Mature	1.8	1.3	0.8	2.3

III. % Bark content of southern softwood thinnings and mature wood chips.

As southern U.S. pulp mills begin to use greater amounts of southern softwood thinnings, it is critical to provide pulp mills an updated guide to the fundamental papermaking properties of this resource to ensure the economic vitality of the industry.

EXPERIMENTAL

Materials

Commercial samples of thinnings (~15 years old) and mature softwood pine wood chips (~38 years old) were acquired from a southeastern U.S. wood logging operation, chipped on site. The green wood chips were classified according to chip size and subsequently blended together to ensure all pulping studies used the same chip size distributions. **Table I** summarizes the observed chip size distribution of the mature and thinnings wood samples.

Kraft Pulping

Laboratory Kraft Cooks. We performed conventional batch kraft cooking trials using a 10-L digester with external liquor circulation.[13] The chip charge was either 1.5 or 1 o.d. kg. White liquor was added at 18.5% active alkali with 30% sulfidity on wood. The rise time to a cooking temperature of 170°C was 90 min. The cooks were maintained at temperature to an H-factor target of 1400.

Modified kraft cooks were simulated with a 10-L digester, two liquor accumulators, a dual-head liquor metering pump, and a mass flow meter.[14] The total white liquor charge was 22.1% active alkali (AA) on wood at 30% sulfidity. The white liquor addition was split into three stages: impregnation (55% of AA), co-current (25% of AA), and countercurrent/wash (20% of AA). For the impregnation stage, we added pre-heated white liquor to the chips, which we circulated at 120°C for 30 min. The co-current liquor was injected and the temperature was raised to 160°C and held for 60 min. For the counter-current stage, white liquor was injected at a rate of 8 mL/min while black liquor was extracted at the same rate. The counter-current stage was held at 160°C until a final H-factor of 1700 was reached.

Following pulping, chips were disintegrated in an agitation tank and screened on a 0.006-inch slotted flat screen. We collected the rejects and accepts and determined the screened yield and percent rejects. Kappa numbers were measured on the screen accepts. **Table II** shows the pulping conditions.

Wood Source	Density	Klason Lignin	Extractives Content, %	Earlywood: Latewood
Thinnings	0.423	29.8	2.77	1.0:0.89
Mature	0.448	28.5	1.93	1.0:1.53

IV. Density, Klason lignin, extractives content, and earlywood:latewood of southern softwood thinnings and mature wood chips.

	Thinnings		Mature	
Metal, ppm	Wood	Bark	Wood	Bark
Na	9	18	9	1
K	420	1380	390	1040
Ca	672	5910	552	5710
Ba	1	3	5	11
Mg	177	685	162	600
Mn	55	94	68	167
Fe	15	62	23	20
Al	17	1390	8	282
S	55	317	83	448

V. Nonprocess elements present in thinnings and mature wood and bark samples.

Wood and Pulp Characterization

We analyzed the wood chips for density, nonprocess elements, carbohydrate composition, bark, extractives, and lignin content, following literature methods.[15,16] Kraft pulps were analyzed for yield viscosity, kappa number, earlywood:latewood, TAPPI brightness, absorption, and scattering coefficients, again following published methods. Fiber properties, including percent fines, mean fiber length, mean curl, and kink values were determined using an Optest Fiber Quality Analyzer, Model LDA96. Hexenuronic acids and fiber charge were measured following standard methods. [13,17,18] Experimental errors associated with these measurements were within published values. All kraft pulps were PFI refined (4000 revolutions) and physical pulp properties including TEA, zero span tensile, tensile, and tensile index, were determined according to published methods.[15]

RESULTS AND DISCUSSION

Paper machine operations for a given product line require a unique set of fiber properties that, under the best of conditions, should remain relatively constant. Therefore, for improved quality of the final product, variations in wood supply should remain nominal, or at least predictable. Recently, higher wood costs and increasing demand for improved wood quality have resulted in greater management of woodlands, especially in the southeast United States. Another important consideration is recent federal

policies directed at removing forest thinnings to aid forest health and prevent catastrophic wildfires.[19] These initiatives will result in the generation of additional amounts of thinnings, which are a valuable wood resource for many pulp mills that want to lower their overall wood costs. This study evaluated the wood and pulp properties resulting from commercially available southeast U.S. softwood thinnings and mature wood chips.

Samples of softwood mature and thinning wood were acquired from a mill located in the southeast and segregated by chip size (see Table I).

All subsequent studies employed blended samples to ensure that the wood samples had reproducible chip size distributions. Wood chips were analyzed for routine physical properties including density, Klason lignin, bark, and extractives content, as summarized in **Tables III-VI**. This data indicated clear differences in the physical and chemical components of the two wood sources.

The differences in bark content between thinnings and mature wood have been reported elsewhere.[20,21] For pulp mills practicing closed mill operations, the additional bark from thinnings will introduce further nonprocess elements into the mill (Table V).

The trends in Klason lignin content for thinnings and mature wood were comparable to the studies reported by Hatton, although greater in magnitude.[22,23] The magnitude of the differences in extractives was less than previously reported, resulting at least in part because this study used mill chips, whereas Hatton's studies frequently used freshly stored wood samples. Nonetheless, these differences in extractives suggest that this could provide an added benefit to kraft pulp mills that use thinning, as the extractives could yield enhanced tall oil.

The differences in wood properties were also seen in the carbohydrate composition of the two samples (Table VI). The higher yield of glucose in the mature wood sample suggested the potential for higher kraft pulping yields.

Kraft Pulping

We examined the pulping properties of these two wood samples under laboratory conventional and modified continuous kraft pulping conditions. Pulping conditions are summarized in Table II and pulp properties are presented in **Tables VII-XII**.

Wood Source	% Carbohydrates in Pulp				
	Glucose	Galactose	Mannose	Xylanose	Arabinose
Thinnings	64.9	4.5	16.9	10.6	3.1
Mature	67.9	3.5	17.7	8.8	2.1

VI. Carbohydrate profile for softwood thinnings and mature wood chips.

Conventional Kraft	Pulp Kappa #	Screened Yield, %	Rejects, %	Scattering Coefficient, m²/kg	Absorption Coefficient, m²/kg
100% Thinnings (T)	27.4	44.6	0.13	14.8	9.8
100% Mature (M)	24.2	45.6	0.25	13.9	7.6
80:20 (T:M)	26.4	45.0	0.16	14.5	8.9
60:40 (T:M)	25.7	45.1	0.14	14.4	8.8
40:60 (T:M)	27.9	45.6	0.18	14.5	8.6
Modified Kraft					
100% Thinnings (T)	24.4	42.9	0.2	14.2	9.2
100% Mature (M)	24.4	45.5	0.1	12.7	9.1
60:40 (T:M)	26.3	44.0	0.1	14.4	12.4

VII. Pulp kappa # and yields for conventional and simulated modified continuous kraft pulping of thinnings and mature southern softwoods.

Kraft Pulp	% Carbohydrates in Pulp				
Conventional	Glucose	Galactose	Mannose	Xylanose	Arabinose
Thinning	81.6	0.4	7.5	9.7	0.8
Mature	84.9	0.3	7.2	7.1	0.5
Modified Continuous					
Thinning	83.5	0.6	6.0	9.1	0.8
Mature	86.4	0.6	5.4	7.1	0.5

VIII. Carbohydrate profile for conventional and modified continuous kraft pulps prepared from thinnings and mature southern softwoods.

The higher glucose level and lower lignin content of the mature wood is reflected in the resulting pulp yields and lignin content of the kraft pulps under conventional and simulated modified continuous kraft cooking conditions. As expected, the mixtures of thinnings and mature wood exhibited yield properties between the results observed for the mature and thinnings wood chips. Many southern kraft mills acquire value from tall oil production. The weight % tall oil in the black liquor from conventional kraft pulping studies was shown to be 3.2% and 1.7% when thinnings and mature wood were used, respectively.

Table VIII summarizes the carbohydrate distribution of selected kraft pulps.

Kraft Pulp, conventional	Hexenuronic Acid Content, µmol/g pulp	Fiber Charge, µmol/g pulp
Thinnings	25.3	55.5
Mature	19.8	50.8

IX. Hexenuronic acid and fiber charge content for conventional kraft pulps prepared from thinnings and mature southern softwoods.

The pulp carbohydrate analysis demonstrates that the use of thinnings or mature fiber affects the chemical constituents of the fiber regardless of the pulping technology employed.

The hexenuronic acid [13,24] and the fiber charge [25] content of kraft pulps play an important factor in determining pulp bleachability and physical strength properties. These fundamental fiber properties were determined for the kraft pulps prepared from the thinnings and mature wood resource and are shown in Table IX.

Metal, ppm	Conventional Pulp		Modified Continuous Pulp	
	Thinnings	Mature	Thinnings	Mature
Na	168	146	166	82
K	380	37	28	25
Ca	2310	1620	1830	1290
Ba	3	3	4	3
Mg	370	288	296	223
Mn	29	34	21	28
Fe	31	20	104	48
Al	24	7	12	7

X. Nonprocess elements present in kraft pulps prepared from thinnings and mature softwood chips.

	Fiber Length		Fiber Coarseness, mg/m
Conventional Kraft	Length Weighted, mm	Weight Weighted, mm	
100% Thinnings (T)	2.51	3.07	0.18
100% Mature (M)	3.51	4.21	0.24
80:20 (T:M)	2.52	3.21	—
60:40 (T:M)	2.66	3.45	—
40:60 (T:M)	2.70	3.50	—
Modified Continuous Kraft			
100% Thinnings (T)	2.51	3.04	0.21
100% Mature (M)	3.62	4.26	0.25
60:40 (T:M)	2.90	3.58	—

XI. Fiber quality analysis of conventional and modified continuous kraft pulps prepared from thinnings and mature southern softwoods.

Conventional Kraft	Tear Index, mNm^2/g	Tensile Index, N/mm	TEA, J/m^2	Zero-Span Tensile Index, N/mm
100% Thinnings (T)	13.6(±0.2)	91.1(±3.7)	2098(±186)	163(±4)
100% Mature (M)	16.8(±0.2)	88.2(±1.9)	1748(±120)	174(±5)
80:20 (T:M)	14.6(±0.4)	92.2(±2.5)	1968(±79.5)	164(±5)
60:40 (T:M)	14.4(±0.5)	88.7(±2.5)	1707(±98.5)	173(±4)
40:60 (T:M)	15.7(±0.3)	90.1(±3.8)	1862(±98.9)	172(±4)
Modified Continuous Kraft				
100% Thinnings (T)	15.6(±0.5)	85.4(±3.3)	1870(±172)	164(±4)
100% Mature (M)	19.9(±0.8)	73.2(±3.8)	1170(±136)	174(±3)
60:40 (T:M)	16.6(±0.4)	86.8(±2.4)	1860(±145)	171(±6)

XII. Physical strength properties (with 95% CI) for conventional and modified continuous kraft pulps prepared from thinnings and mature southern softwoods after 4000 revolutions of PFI refining.

The increased amounts of xylan in the thinnings wood presumably provide an increased amount of glucuronic acid groups that yields an increased amount of fiber charge and hexenuronic acid groups in the resulting kraft pulp. The increased fiber charge of the thinnings pulps suggests that those pulps could exhibit increased metal binding capacity. Hence, the nonprocess elements of the kraft pulps were determined (Table X). An examination of the content of nonprocess elements in these pulps suggests that the thinning pulps have a slightly higher affinity to metals, presumably due in part to the increased fiber charge. [26,27]

The screened fiber length properties were analyzed with a Fiber Quality Analyzer™ (Table XI). These results clearly demonstrate that the difference in wood age can contribute to differences in fiber length and coarseness for the resulting pulp fibers. As expected, the most significant differences in fiber length were observed when either 100% thinnings or mature wood was used as the furnish for kraft pulping. Mixtures of the two wood sources provided composite results.

The physical strength properties of the kraft pulps were evaluated after 4000 revolutions in a PFI refiner. Table XII shows results of standard physical strength testing.

The differences in fiber properties for kraft pulps prepared using thinnings and mature fiber are exhibited in the resulting physical strength properties of the refined pulps. As previously documented, the thinning pulps provided a sheet that has reduced tear and increased tensile properties, which can be attributed to the shorter fiber length and lower coarseness values. These differences are less than those reported for some northern wood species.

CONCLUSIONS

The data reported here clearly show that southern softwood kraft pulps will differ with the proportion of thinnings and mature wood used. As thinnings become increasing available to southern pulp mills, this data will be useful as a convenient roadmap to predict potential changes that increased use of thinnings wood may have on kraft pulping and papermaking operations. **TJ**

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INSIGHTS FROM THE AUTHORS

This research project addressed a high priority subject identified through discussions with pulp and paper manufacturers located in the southeastern United States.

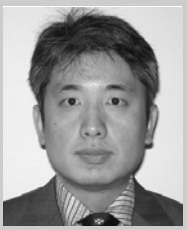
The study continues our ongoing, industry-sponsored programs directed at fiber modification and fiber-fiber bonding, which is directed at developing new, innovative means of developing tailor-made paper properties through a variety of technologies.

Establishing the most relevant physical testing and analysis protocols to provide relevant technical data to our sponsoring industrial partners was the most challenging component of this overall program. We addressed this issue by carefully listening to our sponsors and developing their ownership in the program.

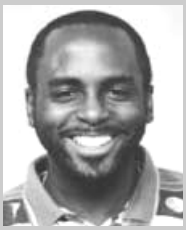
We established the chemical and physical properties of mature and thinnings southern softwood wood chips and kraft pulps. Differences in physical pulp properties were established and shown to be due to the effects of the wood furnish. Carbohydrate analysis demonstrated distinct differences in wood carbohydrates including increased levels of glucose and reduced levels of xylan for mature wood samples. Under constant kraft pulping conditions, the mature wood samples provided a 1% increase in screened pulp and 13% reduction in pulp kappa number. The differences in wood carbohydrates were shown to influence pulp carbohydrate profiles, hexenuronic acids, fiber charge, and physical properties

As southern U.S. pulp mills begin to use greater amounts of southern softwood thinnings, it is critical to provide pulp mills an updated road map of the fundamental papermaking properties of this resource to ensure the economic vitality of the industry. This manuscript begins to address this need. Future studies will examine the properties of elemental chlorine free, fully bleached pulps.

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