SMALL-DIAMETER TREES USED FOR CHEMITHERMOMECHANICAL PULPS

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ABSTRACT

During the course of restoring and maintaining forest ecosystem health and function in the western interior of the United States, many small-diameter stems are removed from densely stocked stands. In general, these materials are considered nonusable or underutilized. Information on the properties of these resources is needed to help managers understand when timber sales are a viable option to accomplish ecosystem management objectives. Pulp is a logical use for this small-diameter material. In this study, chemithermomechanical pulps (CTMP) were prepared and evaluated from lodgepole pine and mixed Douglas-fir/western larch sawmill residue chips; lodgepole pine, Douglas-fir, and western larch submerchantable logs; and lodgepole pine, Douglas-fir, and western larch small trees. Douglas-fir/western larch mixture and lodgepole pine sawmill residue chips obtained commercially were used as the control in making comparisons. CTMP prepared from Douglas-fir small trees, Douglas-fir submerchantable trees, and lodgepole pine small trees consumed the most electrical energy during pulp preparation had the best paper strength properties, and the poorest optical properties compared with the control. Lodgepole pine submerchantable logs consumed less electrical energy, had marginal strength properties. and poor optical properties. Western larch submerchantable logs and small trees had the lowest electrical energy consumption, poor strength properties, but some of the better optical properties. The pulp preparation procedures selected for western larch submerchantable logs and small trees were detrimental to the pulp and paper properties.

INTRODUCTION

The focus of forest management on public lands has taken on a more ecological orientation during this decade (1,2,3). Some common ecological concerns in the western United States are lack of diversity at the landscape level, potential for large-scale disturbances such as insect infestations and tire, and development of functional late-successional stand structures within watersheds where they are currently in deficit. In some cases, active management will be required to change the developmental trajectory of stands or landscapes to either hasten the development of desired conditions or reach conditions that might never be achieved without intervention.

Landscape level manipulations can be expensive, and funding for these activities must compete with other priorities in federal and state budgets that may have nothing to do with forest management. Accordingly, whenever possible, government land managers will attempt to use timber sale programs to fund management activities that have more to do with meeting ecological objectives than with providing economic benefits from timber management. In practice, this means that state and federal land managers will offer a different type of resource for sale than they would have under a program oriented more toward timber production. This resource will often be smaller in diameter than the traditional resource (4). Also, forest operations required to implement the silviculture prescriptions associated with meeting ecosystem objectives are often complex and specify equipment with which established operators may have relatively little experience. Often times, the size of the resource and the complexity of the treatments combine to limit the economic feasibility of many proposed treatments (5,6). Managers often find themselves in situations where timber sales being offered do not cover costs, fail to meet the ecological objective, or fail to attract bidders.

The USDA Forest Service has instituted a program to help public land managers understand the complexity and economic difficulty of integrating biological, ecological, silvicultural, and social objectives in a climate where management activities must be self supporting (7,8). The research reported herein is part of that effort. Many of the trees removed under ecosystem management treatments are small diameter, that is, less than 254 mm at breast height therefore, pulp is a logical use for them. This study examines the technical properties of the small-diameter resource through high-yield mechanical pulping. It clarifies quality characteristics of the resource that could add or detract from its value. Such information will help entrepreneurs or corporations make better-informed decisions about whether to bid on marginal sales offered by public land managers. It will also help public land managers understand the economic viability of the sales they design and enable them to offer sales that are more attractive to potential bidders while still achieving their ecological objectives. It also helps identify research needs and opportunities to utilize these materials.

EXPERIMENTAL

Raw Materials

All raw materials used in this study were obtained from the Colville National Forest (eastern Washington) or the Idaho Panhandle National Forest (western Idaho). The species selected were Douglas-fir [*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco], lodgepole pine (*Pinus contorta* Dougl. ex Loud.), and western larch (*Larix occidentalis* Nutt.). A Douglas-fir/western larch mixture and lodgepole pine sawmill residue chips (SRC) were obtained from Vaagen Bros. Lumber (Colville, Washington). The sub-merchantable logs (SML) had less than an 89-mm-end diameter and primarily represent treetops. The small trees (ST) had less than a 127-mm-diameter at breast height and were the entire tree. These small-diameter resources were not removed from young, vigorously growing stands with a high content of juvenile wood (9). They were from densely overstocked mature stands, approximately 40 or more years old, where extreme competition and stressful growing conditions limited diameter growth Consequently, juvenile wood was not an issue. All chips and logs were shipped to the USDA Forest Service, Forest Products Laboratory (FPL), in Madison, Wisconsin for additional processing.

At the FPL, the logs were hand peeled to remove all bark and chipped to a 19-mm length in a four-knife commercial-sized chipper. Chipped logs and sawmill residue chips were screened to remove all particles greater than 38 mm long and less than. 6 mm long. Screened chips were thoroughly mixed in a large V-mixer, weighed into 4- or 5-kg samples, placed in polyethylene bags, and stored at 4°C until used for pulping.

In this study, SRC were obtained commercially and were the controls representing raw materials currently used for pulping. The SML and ST were the small-diameter resources.

CTMP Preparation

TO eliminate an experimental variable, an identical sodium sulfite impregnation procedure was followed for all replicates of all raw materials. Each batch of moist wood chips was placed in a perforated basket that fit inside a 23-L stationary pulp digester. The chips were heated in 138-kPa saturated steam for 20 minutes, commencing when the digester internal pressure stabilized. After pressure relief, the perforated basket and heated chips were removed from the digester and lowered into a tank that contained a 49.0-g/L sodium sulfite solution. Chips were completely covered with the liquor and soaked for 30 minutes. Convection currents kept the liquor circulating through the chip basket, eliminating the need for stirring. Chips were removed from the liquor and allowed to drain 5 minutes before fiberization The volume of liquor absorbed by the wood chips was measured. Sodium sulfite treatment level was calculated from volume of liquor absorbed by the wood chips, liquor concentration, and ovendry weight of wood chips.

An Andritz Sprout-Bauer model 12-1CP 305-mm-diameter pressurized refiner, fitted with plate pattern D2B505, was used for fiberization. All impregnated raw materials were steamed for 10 minutes at 206.8 kPa before commencing fiberization. To minimize the experimental variables, identical fiberization procedures were followed for all raw material replicates. Fiberized pulp was wet screened through a 0.2-mm-slot flat screen. Screen accepts and rejects were refined separately in a Sprout-Waldron model 105-A 305-mm-diameter atmospheric refiner, also fitted with plate pattern D2B505. A constant volume of shredded pulp was delivered to the refiner inlet by a constant-speed belt conveyor, and dilution water was added to the shredded pulp to adjust refiner consistency to approximately 20%. Multiple passes were necessary to reduce pulp Canadian Standard Freeness (CSF) to approximately 200 mL, when accepts and rejects were combined. An additional pass was run on the combined pulp to reduce CSF to less than 100 mL. Energy consumed during fiberization and refining was measured using an Ohio Semitronic model WH30-11195 integrating watt-hour meter attached to the power-supply of the 44.8-kW electric motors, measuring amperes, volts, and power factor. Energy consumption values for fiberizing and refining were reported as watt-hours per kilogram (ovendry 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 minutes, with occasional stirring. A minimum of four replicates was prepared for each of the eight raw materials. Pulp yield was not determined

Pulp Testing, Handsheet Formation, and Testing

The CSF 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 performed using a Kajaani FS-100 analyzer. Pulp sulfonate contents were determined according to a procedure described be Katz, Beatson, and Scallon (10). Handsheets weighing 60 g/m^2 were made according to TAPPI Test Method T205. Burst and tear indexes were measured according to TAPPI Test Methods T403 and T414, respectively. Tensile breaking properties and paper smoothness were measured according to TAPPI Test Methods T494 and T538, respectively. Brightness, printing opacity, and light-scattering coefficient were measured with a Technidyne Corporation Technibrite Model TB-1 diffuse brightness apparatus according to TAPPI Test Method T525.

Statistics

Each CTMP was processed to freeness levels greater and less than 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 interval. Mean standard deviation, and coefficient of variation was computed for each property tested in a handsheet set. Mean values from the four replicates were combined and averaged to provide values greater and less than 100 CSF, which were interpolated to estimate a value for 100 CSF.

RESULTS AND DISCUSSION

Presentation of Results

Instead of presenting data for all CTMP evaluations, the estimated values for 100 ml CSF are presented in Tables I and II for the eight raw materials.

Comparisons between raw materials were accomplished by computing a percentage change from the controls (SRC) (Figs. 2-5). The SML and ST were considered an alternative raw material, and we were interested in bow they compared with a traditional raw material (SRC). The Douglas-fir western larch SRC were the control raw material for comparison with the other Douglas-fir and western larch raw materials, and the lodgepole pine SRC were used for comparison with the other lodgepole pine raw materials. Results of the statistical analysis were added to Figures 2 through 5; the presence of a capital “S” indicates that a specific property was significantly different from the SRC, as determined by the Dunnett’s multiple comparison procedure.

Pulp Preparation and Properties

Chemical impregnation procedure and pressurized and atmospheric disk refiner operating conditions were identical or very similar for all raw materials, to reduce variables as we looked for differences between raw materials. Table I shows considerable variation in the percentage of sodium sulfite absorbed, and the pulp sufonate content for the different raw materials. The correlation between sulfonate content and sodium sulfite absorption is very weak ($R^2 = 0.20$). However. as shown in Figure 1, there is a strong correlation between the amount of liquor absorbed and chip solids content/chip specific gravity. Prior to the 20-minute steaming segment of the impregnation sequence, there was considerable variation in chip solids content between raw materials. Chip moisture content was not measured again after steaming but apparently the differences remained. which affected liquor absorption. Note that the impregnation. fiberization, and refining conditions selected might not be optimum for all raw materials.

Energy consumption is traditionally high in preparing mechanical pulp; therefore. any new raw material that reduces energy consumption would be desirable. The only energy savings occurred with western larch SML and ST. Energy consumption was greater for the lodgepole pine SML and ST and the Douglas-fir SML and ST (Fig. 2). Three energy increases were statistically significant. Pulmac shive decreased for lodgepole pine SML, western larch SML, and western larch ST, but increased for Douglas-fir SML and ST, and significantly increased for the lodgepole pine ST (Fig. 3). Shive reduction implies a more complete fiber-to-fiber separation for the lodgepole pine SML and both western larch small-diameter resources. Fiber length decreased for all raw materials except the Douglas-fir ST (Fig. 3). The fiber length reductions were statistically significant for the lodgepole pine SML and western larch ST. A reduced tines content is desirable and occurred with four raw materials (Fig. 3). The fines reduction in lodgepole pine and Douglas-fir ST was significant. The western larch SML and ST had significant increases in fines content. Coarseness decreased for all raw materials, significantly for the Douglas-fir SML and ST and the western larch SML. Because most western softwood species are rather coarse fibered, coarseness reduction might be desirable.

The western larch SML and ST might have been severely damaged during CTMP preparation because the shive content, fiber length, and coarseness all decreased and the tines content increased significantly. The fibers were apparently being shortened and their diameters reduced. Lodgepole pine SML might also have been damaged. This apparent damage might be partially or totally avoided by process optimization.

Strength Properties

Except for western larch and lodgepole pine ST, the other four raw materials had lower apparent paper density than did their corresponding SRC (Table II). These apparent density differences are statistically significant, except for western larch and lodgepole pine ST. Most handsheet properties are density dependent; therefore, these differences could affect the strength properties.

All strength properties increased for Douglas-fir ST and all decreased for western larch SML and ST (Fig. 4). With one exception, all these changes are statistically significant. Tear index decreased and all other strength properties increased for lodgepole pine ST and Douglas-fir SML. Lodgepole pine SML had burst index and tensile index increases, but tear index and TEA decreases. A smoother paper surface, as indicated by a smoothness decrease. was desirable and did occur with the lodgepole pine SML and Douglas-fir SML and ST.

A potential correlation between individual paper strength properties and pulp sulfonate content was investigated but either none or only very weak correlations were found

Optical Properties

High opacity and light scattering properties are desirable for mechanical pulps, which are heavily used to produce various printing and writing papers. Three of the small-diameter resources had greater brightness than their corresponding SRC, and the others were lower (Fig. 5). Four of the brightness changes were significantly different from the corresponding SRC. The actual printing opacity values (Table II) were very high for all small-diameter resources, and the percentage change from their corresponding SRC was small. Scattering coefficient. which is affected by fiber length fines contents and characteristics. and bonding, had some large and significant decreases for all the small-diameter resources (Fig. 4).

CONCLUSIONS

Douglas-fir ST and SML and lodgepole pine ST consumed the most electrical energy, had the best paper strength properties, but the poorest optical properties. Lodgepole pine SML consumed less electrical energy, had marginal strength properties, and poor optical properties. Western larch SML and ST had the lowest electrical energy consumption, poor strength properties, but some of the better optical properties. The selected pulp preparation procedures were detrimental to the pulp and paper properties of western larch SML and ST.

Results from this study indicate that Douglas-fir and lodgepole pine SML and ST are acceptable raw materials for CTMP production. Western larch SML and ST might become acceptable by optimizing the CTMP process.

ACKNOWLEDGMENTS

We thank the following people for their assistance in conducting this study Dean Parry, USDA Forest Service. Pacific Northwest Station for obtaining the raw materials and arranging shipping; Vaagen Bros. Lumber for the sawmill residue chips and sub-merchantable logs; Colville Ranger District, Colville National Forest, and Priest Lake Ranger District, Idaho Panhandle National Forest, for the logs; David Bormett, Charles Hillary, and Robert Kelly for peeling. chipping. screening, and bagging chip samples; David Pierce for CTMP preparation; Sara Fishwild for pulp testing, handsheet making and testing; and Steve Verrill for statistical analysis.

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Table I. Estimated pulp properties at 100 Canadian Standard Freeness

Input material[a]	Total energy (WH/od kg)	Pulmac shive <0.004 mm (%)	Kajaani FS-100 Analysis: Length-weighted Average (mm)	Fines (%)	Coarseness (mg/m)	Sulfonate content (mmole)
Lodgepole pine SML, impregnated with 7.7% Na_2SO_3	4310	0.13	1.21	4.01	0.270	0.264
Lodgepole pine ST, impregnated with 5.2% Na_2SO_3	4794	0.47	1.28	3.21	0.325	0.230
Lodgepole pine SRC, impregnated with 3.2% Na_2SO_3	4087	0.21	1.43	4.34	0.348	0.189
Douglas-fir SML, impregnated with 5.4% Na_2SO_3	5469	0.33	1.28	3.61	0.319	0.211
Douglas-fir ST, impregnated with 4.7% Na_2SO_3	6939	0.67	1.50	2.95	0.337	0.257
Western larch SML, impregnated with 5.2% Na_2SO_3	3627	0.23	1.28	4.70	0.338	0.331
Western larch ST, impregnated with 4.0% Na_2SO_3	3633	0.18	1.18	4.84	0.369	0.205
Douglas-fir/western larch SRC, impregnated with 2.6% Na_2SO_3	4227	0.31	1.37	3.81	0.408	0.228

[a] SML, submerchantable logs; ST, small trees; SRC, sawmill residue chips.

Table II. Estimated paper properties at 100 Canadian Standard Freeness

Input material[a]	Apparent density (kg/m^3)	Burst index (kPa-m^2/g)	Tear index (mN-m^2/g)	Tensile index (N-m/g)	Stretch (%)	TEA[b] (J/m^2)	Smoothness (SU)	ISO brightness (%)	Priming opacity (%)	Scattering coefficient (m^2/kg)
Lodgepole pine SML, impregnated with 7.7% Na_2SO_3	543	2.03	4.67	43.4	1.81	35.86	125	38.9	97.0	36.6
Lodgepole pine ST, impregnated with 5.2% Na_2SO_3	456	2.06	4.83	43.9	2.08	41.33	157	43.7	97.6	43.7
Lodgepole pine SRC, impregnated with 3.2% Na_2SO_3	505	1.94	5.21	40.3	1.99	37.00	133	42.4	98.0	43.9
Douglas-fir SML, impregnated with 5.4% Na_2SO_3	534	2.10	4.87	42.1	2.09	41.53	116	24.0	99.5	34.1
Douglas-fir ST, impregnated with 4.7% Na_2SO_3	535	2.35	5.66	45.3	2.17	45.48	115	22.6	99.6	31.0
Western larch SML, impregnated with 5.2% Na_2SO_3	474	1.44	4.27	34.5	1.61	24.97	161	31.2	99.0	35.6
Western larch ST, impregnated with 4.0% Na_2SO_3	458	1.26	3.64	29.2	1.55	20.26	205	30.1	99.1	36.4
Douglas-fir/western larch SRC, impregnated with 2.6% Na_2SO_3	469	1.85	5.21	39.2	1.94	33.68	158	27.9	99.4	37.9

[a] SML, submerchantable logs; ST, small trees; SRC, sawmill residue chips.

[b] TEA, tensile energy absorption.

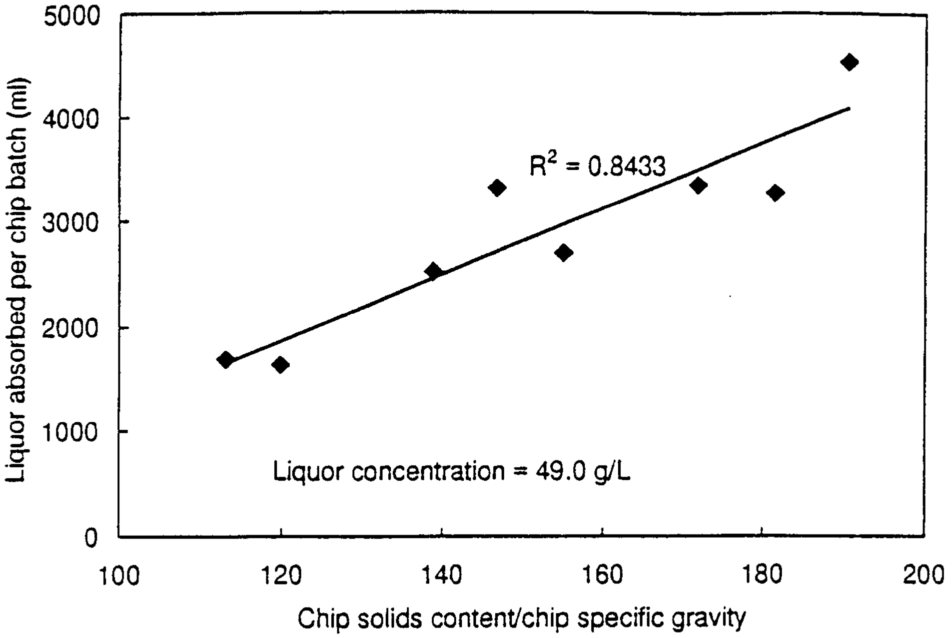

Figure 1. Correlation between sodium sulfite liquor absorption and wood chip properties during chemithermomechanical pulping.

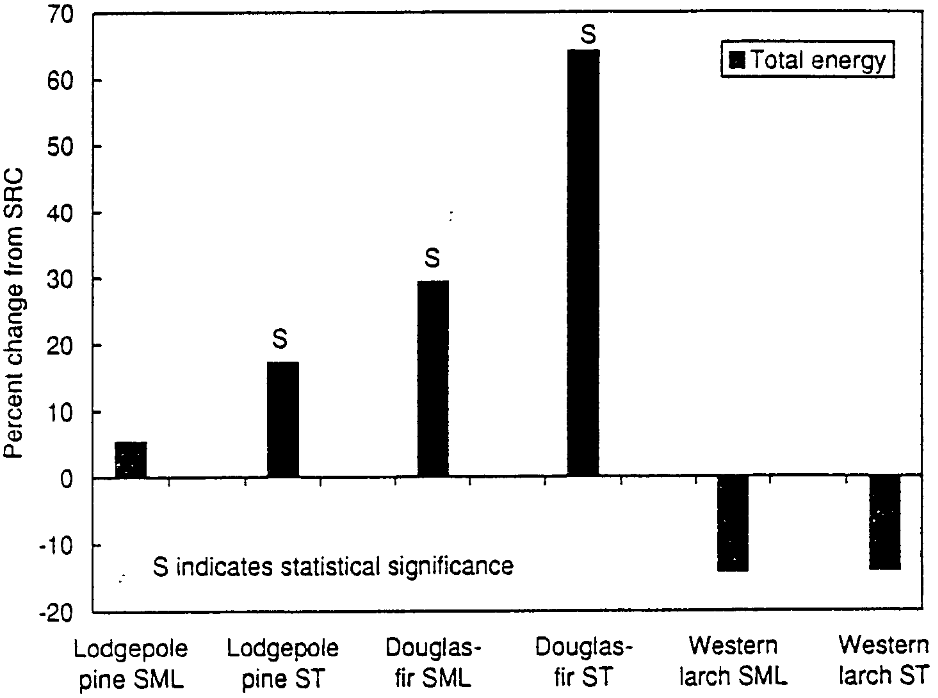

Figure 2. Percent change in energy consumption from sawmill residue chips (SML, submerchantable logs; ST, small trees).

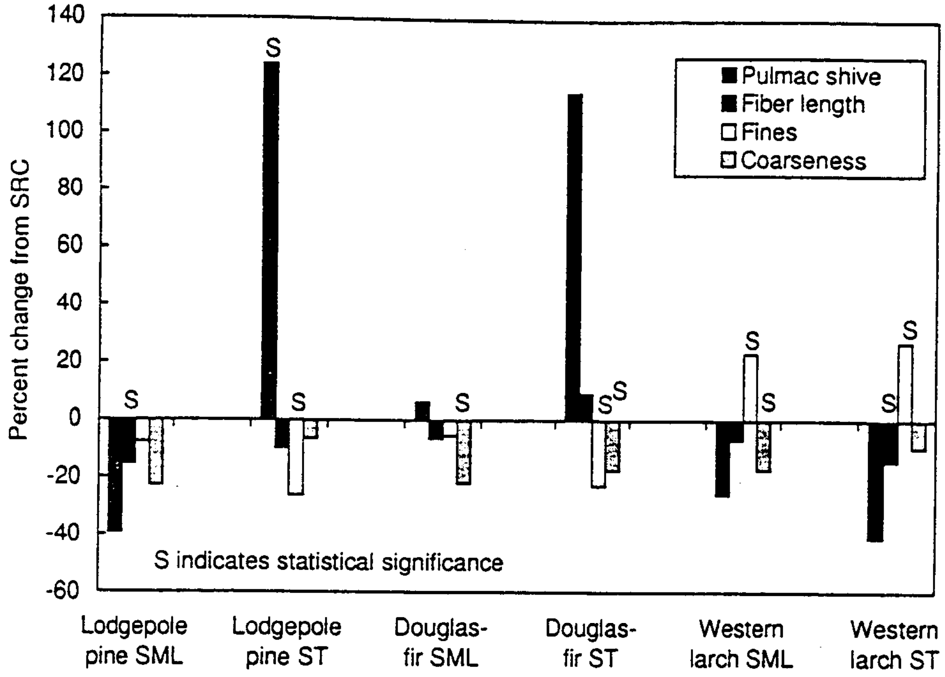

Figure 3. Percent change in pulp properties from sawmill residue chips (SML, submerchantable logs; ST, small trees).

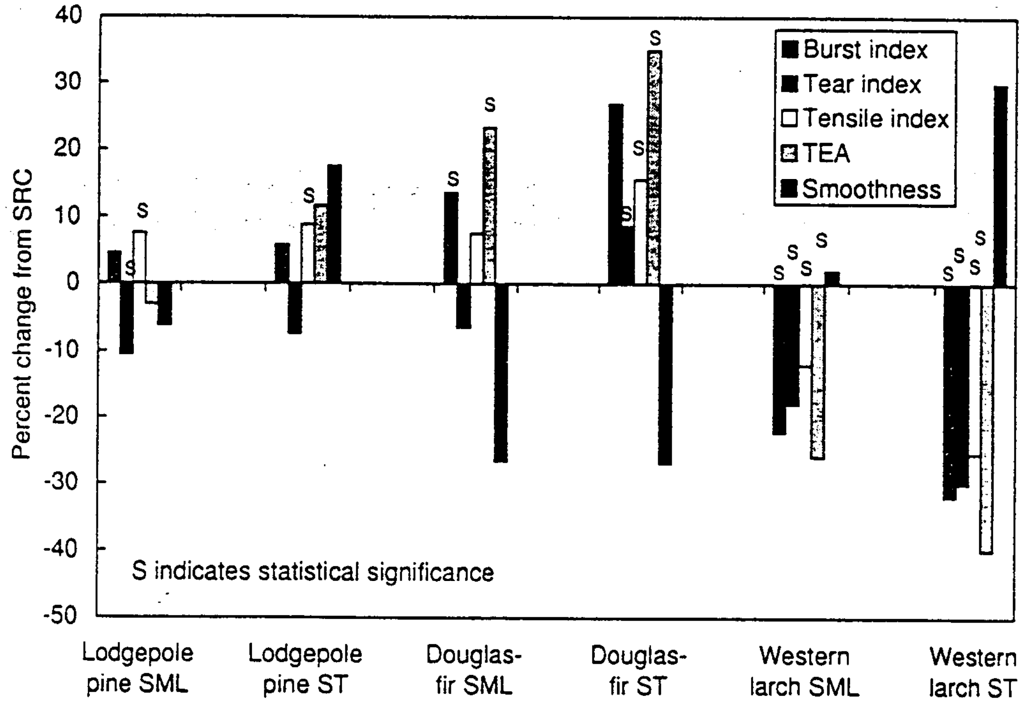

Figure 4. Percent change in paper properties from sawmill residue chips (SML, submerchantable logs; ST, small trees).

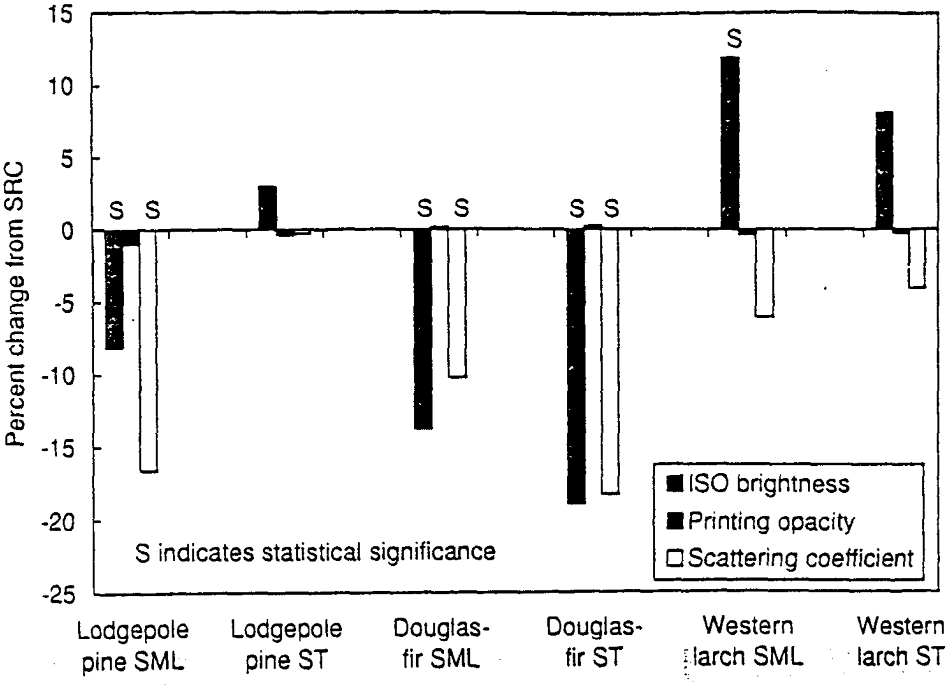

Figure 5. Percent change in optical properties from sawmill residue chips (SML, submerchantable logs: ST, small trees).