PROPERTIES OF VENEER AND VENEER-BASED PRODUCTS FROM GENETICALLY IMPROVED WHITE SPRUCE PLANTATIONS

Robert M. Knudson†

Team Leader, Composite Wood Products

Brad J. Wang

Composite Research Scientist
Forintek Canada Corp., Western Division
2665 East Mall
Vancouver, British Columbia V6T 1W5

and

S. Y. Zhang†[1]

Senior Scientist and Group Leader
Resource Assessment & Utilization Group
Forintek Canada Corp., Eastern Division
319, rue Franquet
Sainte-Foy, Quebec G1P 4R4

ABSTRACT

This study examined the suitability of genetically improved fast-growing and short-rotation plantations for veneer-based products. The materials came from a 36-year-old white spruce (*Picea glauca*) half-sib progeny/provenance trial located in two regions (sites) of Quebec. A total of 270 sample trees were collected for the study, 130 trees from St-Ignace in the Gaspé Region and 140 trees from Valcartier near Quebec City. Veneer from the Valcartier site had a mean wood density of 0.353 g/cm³ and a mean modulus of elasticity (MOE) of 9.48 GPa (1.375 million psi). Veneer from the St-Ignace site had a mean wood density of 0.345 g/cm³] and a mean MOE of 8.05 GPa (1.167 million psi). The differences in veneer wood density and MOE between the two sites were statistically significant. Compared to other Canadian species commonly used for veneer products, the genetically improved fast-growing and short-rotation white spruce yielded considerably lower veneer stiffness.

The plantation-grown white spruce veneer from both sites was knotty. Ninety-eight percent of the veneer was classified as visual grade C. The visually graded veneer would be suitable for sheathing grade plywood. With proper stress grading, 14% of the white spruce veneer was suitable for 12.41 GPa (1.8 million psi) grade laminated veneer lumber (LVL), and another 24% of the veneer was suitable for a lower 10.34 GPa (1.5 million psi) grade of LVL, or as core plies for LVL manufacture. The remaining 62% of the stress-graded veneer was suitable for sheathing grade plywood.

Keywords: White spruce, plantations, genetic improvement, veneer properties, end uses.

INTRODUCTION

Over the last few decades, tree breeding programs across Canada have been focused on tree growth. With the worldwide move towards intensive silviculture and shorter rotation, wood and wood product quality coming out of this changing resource has become a concern for the wood products industry. In recent years, efforts have been made to address this concern in major tree breeding programs in Canada. So far, the focus has been placed almost exclusively on a few basic wood characteristics, especially wood density (Zhang and Morgenstern 1995).

---

† Member of SWST.
[1] Corresponding author (Tony.zhang@QC.Forintek.ca)

It is well known to wood scientists that different end uses have different wood quality requirements. As an index of cell-wall materials, wood density is a very important wood quality attribute as it is closely related to pulp yield. For lumber, higher wood density is usually associated with higher strength; but lumber stiffness is, to a lesser extent, related to wood density (Tsehaye et al. 1995; Zhang 1997). For other end uses, higher density wood does not necessarily mean a higher quality end product. Even for lumber, Forintek's study on balsam fir revealed that while wood density decreased by only 5% in the intensively thinned stands, lumber strength and stiffness were reduced by as much as 20% (Zhang et al. 1998). On the other hand, a negative correlation between growth and wood density in most softwood species prevents tree breeders from even incorporating this easy-to-measure wood quality parameter into tree breeding programs. Therefore, it is necessary to examine end-product quality directly instead of intermediate wood traits like wood density.

White spruce (*Picea glauca* [Moench] Voss) is one of the most important commercial species in Canada (Farrar 1995). This species is used for lumber, pulp and paper, and veneer-based and other solid wood products. White spruce, because of its commercial value, is one of the most important reforestation species in Canada. Each year, more than 150,000 ha of white and black spruce plantations are established in Canada (Canadian Council of Forest Ministers 1996). White spruce breeding programs have been established across eastern Canada since the 1960s. These breeding programs have been focused on tree growth, whereas end-use wood quality attributes have not been considered in the selection. A few studies have examined the genetic variation of wood density and fiber length in this species (Caron 1980; Taylor et al. 1982; Beaulieu and Corriveau 1985; Corriveau et. al 1987; Corriveau et. al 1991; Yanchuk and Kiss 1993) and reported that these basic wood quality attributes are under moderate to strong genetic control. However, no genetic study has examined the quality attributes of major end products. In collaboration with the Canadian Forest Ser-

vice, a major project has been initiated to examine the quality attributes of major end products (e.g. lumber, veneer, pulp) and to investigate the impact of tree genetic variation, growth, and basic wood characteristics on these end products. Also, little is known about the end-use potential of the genetically improved white spruce plantations while superior growth performance has been achieved (Beaulieu and Corriveau 1985; Corriveau et al. 1987; Zhou and Smith 1991). Knowledge of the genetic variations of end-product quality traits and their correlations with growth and basic wood characteristics will help incorporate product quality attributes into growth-based white spruce breeding programs.

The present study, as part of a larger project, focuses on veneer and veneer-based products. Based on the oldest white spruce progeny trial, this study has examined major quality attributes of veneer and veneer-based products to evaluate the suitability of the genetically improved white spruce for veneer and veneer-based end uses. Other studies report on wood and pulp properties (Duchesne and Zhang 2003), lumber properties (Zhang et al. 2003), and wood decay resistance (Yu et al. 2003).

MATERIALS AND METHODS

Materials

In the spring of 1969, 4-year-old seedlings grown at the Petawawa Research Forest, Ontario, Canada (Lat. 45° 59′ N; Long. 77° 24′ W; Elev. 168 m) were used to establish a provenance/progeny test replicated at two sites in Québec. These sites were located at the Valcartier Forest Experiment Station (Lat. 46° 50′ N; Long. 71° 30′ W; Elev. 150 m) and at the Lake St. Ignace Arboretum (Lat. 49° 00′ N; Long. 66° 20′ W; Elev. 500 m). Both sites were abandoned farmlands. The surface deposit at Valcartier is a well-drained sand along the Jacques-Cartier River, while at St. Ignace, it is a shaly till with presence of boulders. The seedlings came from 40 open-pollinated families representing 8 natural populations from the Ottawa River Valley, in Ontario. The experimental lay-

out was a randomized complete block design with four blocks. Each row plot contained thirteen trees at 1.8-x 1.8-m spacing. Cultural treatment of both trials consisted of stem–pruning to a height of 2 m in 1986.

In the fall of 2001, the provenance-progeny test plot was thinned, and one tree per plot was retained to carry out a research project on the genetics of wood products in white spruce. A total of 270 trees from 36 families were harvested, i.e. 140 trees at Valcartier, and 130 at St. Ignace. Each sample tree was further crosscut into two 2.5-m-long logs and transported to Forintek Canada Corp. facilities (Sainte-Foy, Quebec). A 20-cm-disc was collected from the bottom of the second log of each tree to perform decay resistance tests and to estimate wood density and average ring width. Sections 35.5 cm (14 in.) long were cut from each tree at a height of (2.4 m) 8 ft and shipped to the Western Laboratory of Forintek Canada Corp. in Vancouver, BC. for veneer manufacture. Because of wood requirements for the lumber manufacturing part of the overall study, the veneer blocks were taken from a section of the stem immediately above the pruned portion of the trees. Diameters for the veneer blocks ranged from approximately 15.2 to 25.4 cm (6 to 10 in.).

A pie-shaped sample was cut from each fresh disc and weighed immediately. Each sample was then oven-dried at 103°C (217°F) until a constant oven-dry weight was attained. Basic wood density of each sample was calculated as the oven-dry weight divided by the green volume. The green volume of each sample was determined by the water immersion method following the ASTM D 2395 standard (method B). Average ring width or annual diameter growth was calculated for each tree as the disc diameter divided by the number of total rings in the disc at 2.4-m height.

Veneer manufacture

At the Vancouver laboratory, bark was removed from each log section by hand. Immediately prior to peeling, logs were conditioned in 45–50°C (113–122°F) water for a minimum of 4 h. Veneer was peeled on the Forintek mini-lathe. Green veneer thickness was 3.30 mm (0.130 in.). Veneer was peeled using optimum lathe settings determined in earlier peeling studies of white spruce carried out on the mini-lathe using a smooth roller bar (Dai and Wang 2001).

Pitch angle – 89.5°
Vertical gap - 10.80 mm (0.425 in.)
Horizontal gap - 2.54 mm (0.100 in.)

A total of 131 log sections from the St-Ignace source and 161 from the Valcartier source were peeled. The number of log sections peeled was slightly lower than the total number shipped because the diameters for a few of the logs were too small to allow for round-up and peeling on the mini-lathe which has a core size of approximately 92 mm (3.625 in.).

Veneer property evaluation

Four pieces of veneer were sampled from each veneer ribbon to represent the quality of veneer going from the outside of each log to the core. The four samples from each veneer ribbon were: 1) one piece from the outside of the log designated "sap," 2) pieces from the section of veneer ribbon between the sap and core designated "heart," and 3) one piece from the inside of the log next to the core designated "core." Veneer samples measured 355 mm (14 in.) long by approximately 355 mm wide. A total of 503 pieces were sampled from the St-Ignace logs and 579 from the Valcartier logs. The total number of veneer samples was slightly lower than 4 per log section because a few veneer ribbons were not long enough to recover four samples. Veneer sheets were dried in a forced air oven at 80°C (176°F) until a moisture content of 3 to 5% was reached. Dry veneer sheets were stored in plastic bags to maintain moisture content and to equilibrate them to uniform moisture content before the various measurements were taken.

Each dry veneer sheet was weighed, and thickness was measured in nine places, length in three places, and width in three places in order to determine veneer density. Veneer sheets were weighed to the nearest 0.01 g, and thickness,

length, and width were measured to the nearest
0.1 mm. Veneer roughness was measured visu-
ally using a comparative scale developed by
Forintek where 0 equals perfectly smooth veneer
and 9 equals the very roughest veneer. The num-
ber of knots in each veneer sample was counted
and tallied. Knot size was not measured because
with the age and size of the trees nearly all knots
were sound and 25-mm diameter or smaller
measured in the dimension across the grain.

Veneer sheets were visually graded "A," "B,"
or "C" based on the size and number of knots,
roughness, splits, pitch pockets, and other de-
fects as outlined in CSA Standard 0151 (Cana-
dian Standards Association 1978)

Stress wave propagation times were measured
for each piece using a Metrigard stress wave
timer in order to determine the dynamic modulus
of elasticity (MOE). A total of 10 individual
stress wave times were measured for each ve-
neer piece at 25-mm (1 in.) intervals across the
width of the piece. MOE for each veneer piece
was calculated from the mean value of the 10
individual stress wave times. The dynamic MOE
of the veneer was calculated by:

$$MOE = C_T C_M v^2 d/g \qquad (1)$$

where v is the stress wave velocity, which equals
the measured span divided by the stress (ultra-
sonic) wave propagation time, d the veneer mass
density, and g the gravity acceleration. C_T and
C_M are calibration coefficients for temperature
and moisture content, respectively (Metrigard
1998). From formula 1, both stress wave veloc-
ity and density have significant positive effects
on veneer MOE (Dai and Wang 2000).

Stress grading

Veneer was stress graded into three grades
based on the dynamic MOE measured for each
piece, using Forintek VGrader® (Veneer Grad-
ing Optimizer) software (Wang 2001). Grades
were assigned as follows. Grade G1 veneer was
set to have an average MOE of 11.59 GPa (1.68
million psi), which pressed at normal compres-
sion levels would produce 12.41 GPa (1.8 mil-

lion psi) grade laminated veneer lumber (LVL).
Grade G2 veneer was set to have an average
MOE of 10.07 GPa (1.46 million psi), which
pressed at normal compression levels would pro-
duce 10.34 GPa (1.5 million psi) grade LVL.
Grade G3 was set to include all remaining ve-
neer that did not meet the requirements of grades
G1 or G2.

RESULTS

Veneer properties for the Valcartier and St-
Ignace sites are summarized in Table 1.

Veneer density

Wood density values for veneer from the Val-
cartier and St-Ignace sites are shown in Table 2.
Overall mean veneer density from the two sites
was 0.349 gm/cm³. Mean density of veneer from
the Valcartier site (0.353 g/cm³) was higher than
for that from the St-Ignace site (0.345 g/cm³).
The difference in wood density between veneers
from the two sites was statistically signifi-
cant (p < 0.001). Veneer density decreased from
sap to core in samples from both sites (Fig. 1).
Figure 2 shows that densities of veneers from
both sites varied greatly, ranging from 0.275 to
0.455 kg/cm³.

Veneer modulus of elasticity

MOE values for veneer from the Valcartier
and St-Ignace sites are shown in Table 2. Over-
all mean MOE for samples from the two sites
was 8.83 GPa (or 1.28 million psi). Mean veneer
MOE from the Valcartier site (9.48 GPa or 1.375
million psi) was higher than for that from the
St-Ignace site (8.05 GPa or 1.167 million psi).
The difference in veneer MOE between the two
sites was statistically significant (p < 0.001).
Following the pattern observed for veneer den-
sity, MOE decreased from sap to core in veneers
from both sites (Fig. 3). Like wood density, ve-
neer MOE of samples from both sites also varied
greatly, ranging from 0.63 to 2.26 million psi
(Fig. 4). In addition, Fig. 4 shows that veneer
samples from the Valcartier site had a signifi-

TABLE 1. *Summary of white spruce veneer properties of samples from Valcartier and St-Ignace sites*

Stand	Stress grade	Volume (%)	Number of sheets	Sap, heart and core	Sheet breakdown (ratio*)	Roughness grade	Density (g/cm³)		UPT (µs)		MOE (10⁶ psi)		Number of knots
							Average	St. dev.	Average	St. dev.	Average	St. dev.	
Valcartier	G1	22.6	131	Sap	49 (37.4%)	2.7	0.390	0.025	45.4	0.90	1.77	0.143	3.2
				Heart	73 (55.7%)	2.6	0.365	0.028	45.4	0.69	1.66	0.140	3.1
				Core	9 (6.9%)	2.5	0.338	0.029	45.8	0.72	1.51	0.131	1.1
	G2	31.3	181	Sap	50 (27.6%)	2.6	0.388	0.031	47.6	0.75	1.60	0.139	3.4
				Heart	100 (55.2%)	2.5	0.353	0.029	47.7	0.70	1.45	0.126	3.8
				Core	31 (17.1%)	2.5	0.330	0.031	48.0	0.76	1.34	0.147	3.9
	G3	46.1	579	Sap	42 (15.7%)	2.9	0.371	0.031	52.2	2.09	1.28	0.149	5.2
				Heart	130 (48.7%)	2.7	0.341	0.027	52.5	3.07	1.17	0.165	5.5
				Core	95 (35.6%)	2.6	0.322	0.027	53.4	3.53	1.07	0.173	6.1
St-Ignace	G1	3.6	18	Sap	2 (11.1%)	2.6	0.365	0.027	45.4	1.00	1.66	0.143	1.5
				Heart	10 (55.6%)	2.6	0.358	0.032	45.8	0.45	1.60	0.135	2.8
				Core	6 (33.3%)	2.8	0.353	0.043	45.2	1.45	1.62	0.301	1.5
	G2	16.5	83	Sap	10 (12.0%)	2.6	0.388	0.031	47.6	0.75	1.60	0.139	3.4
				Heart	39 (47.0%)	2.5	0.353	0.029	47.7	0.70	1.45	0.126	3.8
				Core	34 (41.0%)	2.5	0.330	0.031	48.0	0.76	1.34	0.147	3.9
	G3	79.9	503	Sap	111 (27.6%)	2.7	0.352	0.028	52.8	4.04	1.20	0.195	4.6
				Heart	207 (51.5%)	2.6	0.343	0.027	54.7	4.55	1.09	0.195	5.3
				Core	84 (20.9%)	2.6	0.336	0.027	56.5	5.43	1.01	0.201	6.1

* Expressed as number of sheets and percentage of sheets of that stress grade coming from sap, heart and core sections of the veneer ribbon.
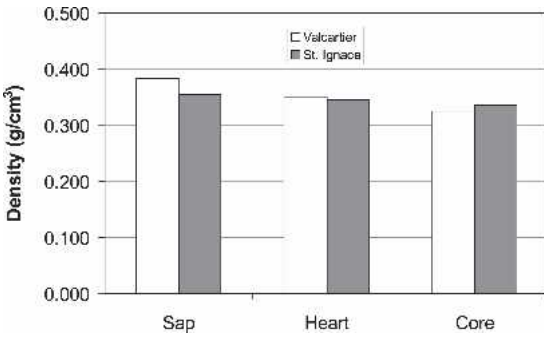
FIG. 1.—Densities of Valcartier and St-Ignace spruce veneers.

cantly higher MOE than did those from the St-Ignace site, although the difference in wood density is not highly evident (Fig. 2). Knot size and placement would also have an influence on veneer (MOE). Knot size, numbers, and distribution patterns were similar for the two sites

(Fig. 8), so much of the MOE difference between the sites was likely a result of the difference in wood density.

MOE is a function of both wood density and UPT (ultrasonic propagation time) as shown previously in Eq. (1). MOE is a key veneer performance property in plywood and LVL constructions, whereas UPT can be considered of intermediate importance in determining MOE. As expected, UPT was shorter for the Valcartier veneer, which had higher MOE and density, than for the St-Ignace veneer (Table 2). The differences in UPT between samples from the Valcartier and St-Ignace sites were statistically significant ($p < 0.001$).

Veneer thickness

Veneer thickness results for samples from the Valcartier and St-Ignace sites are shown in

FIG. 2.—Veneer density distributions for Valcartier and St-Ignace samples.

TABLE 2. *Family mean (± standard error), range and coefficient of variation (CV) for veneer properties and selected basic wood characteristics of the white spruce plantations at Valcartier and St-Ignace.*

| Characters | Lac St-Ignance | | | Valcartier | | |
	Mean	Range	CV (%)	Mean	Range	CV (%)
Veneer density (kg/m^3)	345.11 ± 29.7	290–423	8.61	353.65 ± 36.0	284–424	10.2
Veneer MOE (10^6 psi)	1.17 ± 0.25	0.59–1.83	121.55	1.38 ± 0.28	0.86–1.87	20.15
Veneer roughness	2.61 ± 0.01	2.3–3.25	6.30	2.66 ± 0.04	1.8–4.85	15.61
Veneer knot frequency (knots/sheet)	4.80 ± 0.23	0–12	54.99	4.44 ± 0.23	0–12	61.55
Basic wood density (kg/m^3)	325.21 ± 2.69	269–404	9.17	329.89 ± 2.28	267–412	8.21
Ring width (mm)	5.41 ± 0.07	3.10–7.50	15.12	4.37 ± 0.05	2.90–5.80	14.73
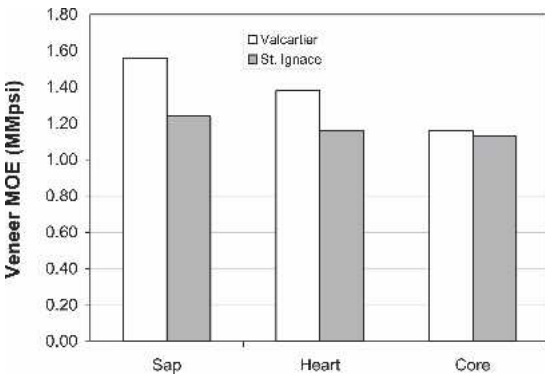
FIG. 3.—MOE of veneer from 3 sampling positions (from sap to core).

Fig. 5, while Fig. 6 shows the combined veneer thickness distribution determined from both sites. There were no significant differences in veneer thickness among the 3 sampling positions (from sap to core in the veneer ribbons) or between the two sites.

Veneer roughness

Veneer roughness data for samples from the Valcartier and St-Ignace sites are shown in Fig. 7. Veneer from both sites had average roughness values in the 2.6 to 2.7 range on the visual scale where 0 equals perfectly smooth veneer, and 9 equals the very roughest veneer. There was little difference in veneer roughness between the outer sapwood and the inner core of the logs. Veneer roughness values for white spruce veneer from the Valcartier and St-Ignace sites were similar to values measured for other Canadian softwood species used for sheathing plywood.

Veneer knots

Data on the number of knots per sample sheet for the Valcartier and St-Ignace veneers are shown in Fig. 8. Sample veneer sheets that measured approximately 355 × 355 mm (14 × 14 in.) typically contained between 4 and 6 knots. Diameters of most knots were 25 mm (1 in.) or smaller measured across the grain, and most knots were tight. As might be expected, the number of knots increased from the outer sap to the core. If the trees had been older so more natural pruning had taken place, or if the trees had been pruned to the height where the veneer samples were taken, larger differences in the number of knots between the sap and core would have been expected.

Veneer stress grading

Stress grade data summarized in Table 3 show that 14% of the veneer sheets were classified as grade G1, 24% as grade G2, and 62% as grade G3. Grade G1 veneer was set to produce 12.41 GPa (1.8 million psi) grade LVL when pressed at normal product compression levels. Grade G2 veneer was set to produce 10.34 GPa (1.5 million psi) grade LVL when pressed at normal product compression levels. Grade G3 was set to include all remaining veneer that did not meet the requirements of grades G1 or G2. Grade G1 had the highest veneer density at 0.369 g/cm^3, followed by grade G2 at 0.353 g/cm^3 and grade G3 at 0.340 g/cm^3.

Veneer visual grading

Visual grading data summarized in Table 4 show that 1.1% of the veneer was classified as visual grade A, 0.6% as visual grade B, and the remaining 98% as visual grade C. Visual grade
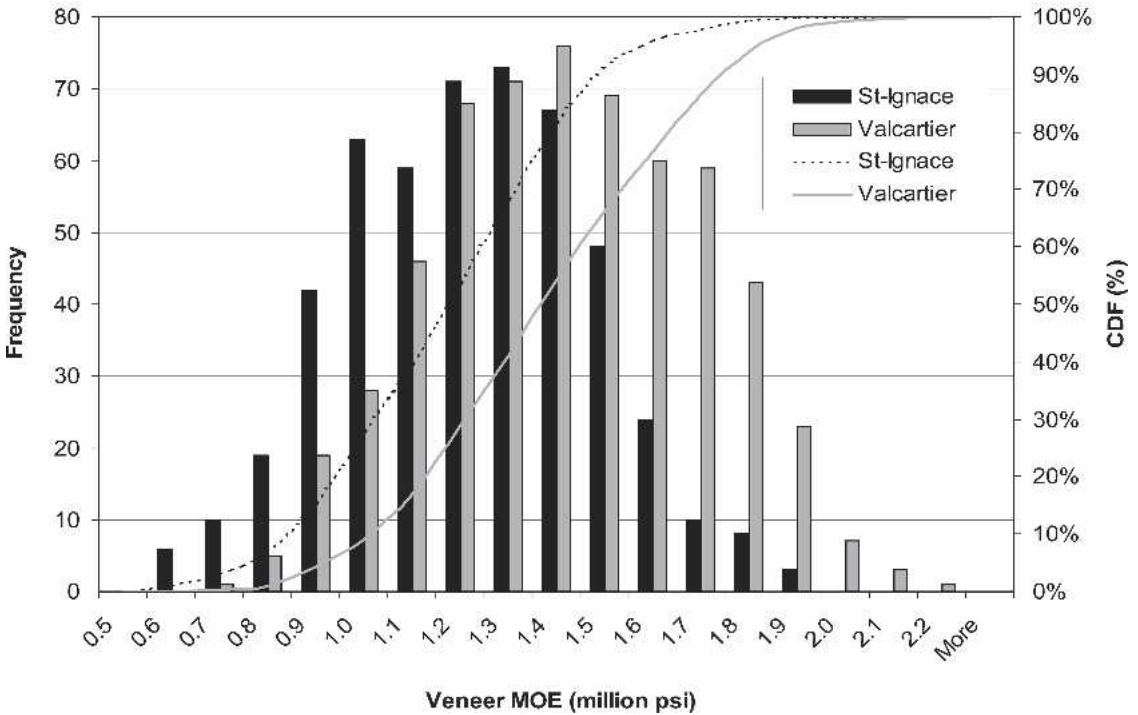
Veneer MOE distribution

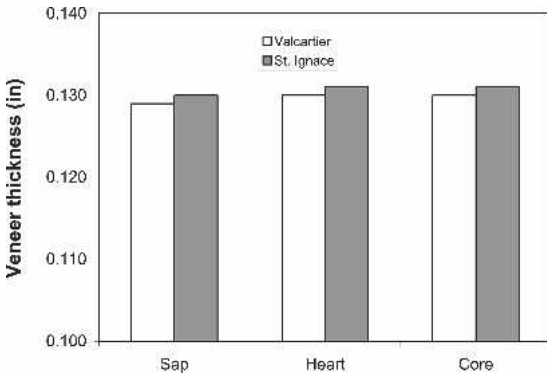FIG. 4.—Veneer MOE distributions for Valcartier and St-Ignace samples.

FIG. 5.—Thickness of veneer from 3 log positions (from sap to core).
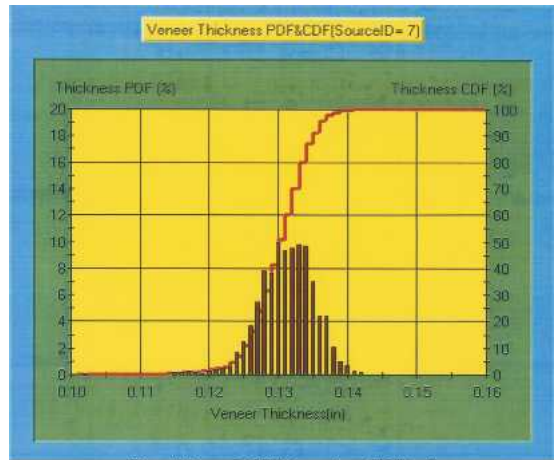

(Mean thickness = 0.130 inch, st. dev. = 0.008 inch)

FIG. 6.—Veneer thickness distribution for combined Valcartier and St-Ignace sites.

DISCUSSION

A had a mean MOE of 8.62 GPa (1.25 million psi), visual grade B a mean MOE of 8.00 GPa (1.16 million psi), and visual grade C a mean MOE of 8.83 GPa (1.28 million psi). Visual grading was not able to separate the veneer in terms of its structural capabilities.

White spruce veneer peeled from the 36-year-old Valcartier and St-Ignace sites would generally be considered as knotty and low density.
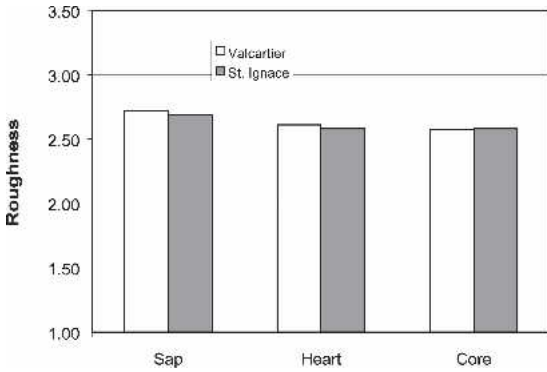
Fig. 7.—Roughness of veneer from 3 log positions (from sap to core) from Valcartier and St-Ignace samples.
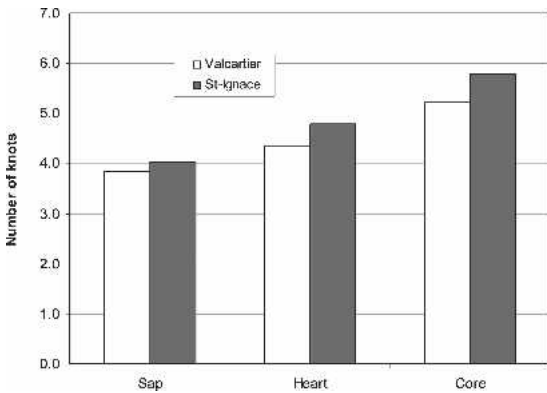

Fig. 8.—Number of knots in veneers from Valcartier and St-Ignace.

Fig. 9.—Cumulative frequency plots of MOE for stress-graded veneer.

TABLE 3. *Summary of white spruce veneer stress grading results.*

Grade	Number of sheets	Volume, %	Density, kg/m³ Mean	Density, kg/m³ St. dev.	Modulus of elasticity, 10⁶ psi Mean	Modulus of elasticity, 10⁶ psi St. dev.
G1	149	13.8	0.371	0.031	1.68	0.16
G2	264	24.4	0.357	0.037	1.46	0.16
G3	669	61.8	0.341	0.029	1.12	0.20

TABLE 4. *Summary of white spruce veneer visual grading results.*

Grade	Number of sheets	Volume, %	Density, kg/m³ Mean	Density, kg/m³ St. dev.	Modulus of elasticity, 10⁶ psi Mean	Modulus of elasticity, 10⁶ psi St. dev.
A	12	1.1	0.355	0.034	1.25	0.28
B	7	0.6	0.348	0.029	1.16	0.25
C	1063	98.2	0.349	0.033	1.28	0.29

When visually graded, 98% of the veneer was classified as grade C, suitable for sheathing grade plywood, either as core or face. When stress graded, 14% could be considered as suitable for 12.41 GPa (1.8 million psi) grade LVL. Another 24% was suitable for either core material in 12.41 GPa (1.8 million psi) grade LVL or for a lower 10.34 GPa (1.5 million psi) grade LVL. The remaining 62% appeared to be best suited for sheathing grade plywood, either as core or face. Silvicultural regimes with natural or artificial pruning would help to improve the visual grade of the Quebec spruce. Pruning would also be expected to have a positive effect on stress grade, but MOE values of the veneer would likely remain low because the basic wood density would remain low.
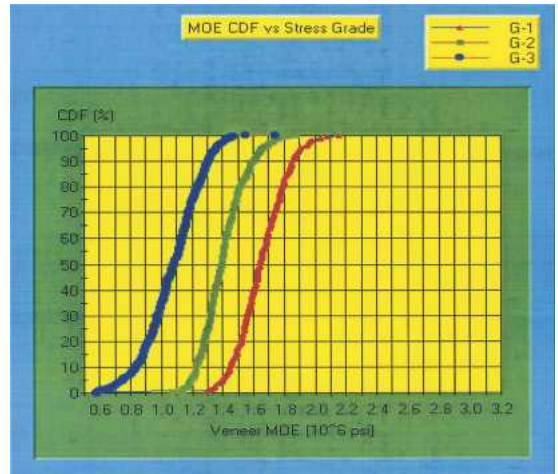
Compared to other Canadian species commonly used for veneer products, the genetically improved, fast-growing, and short-rotation white spruce veneer had lower wood density. The density difference between the genetically improved spruce and naturally grown spruce from British Columbia was marginal (Fig. 10). The 36-year-old plantation-grown white spruce veneer had a considerably lower MOE than BC spruce (Fig. 11). The B.C.-grown spruce in the Forintek Canada Corp. database represents a mixture of natural and mature stands of white spruce and Engelmann spruce (*Picea engelmannii* Parry),
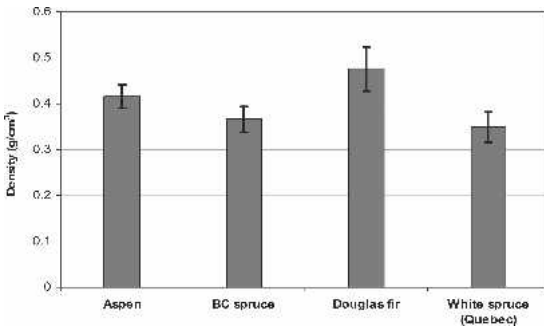
FIG. 10.—Densities of veneers from genetically improved white spruce and other Canadian species (bars (I) equal ±1 standard deviation).
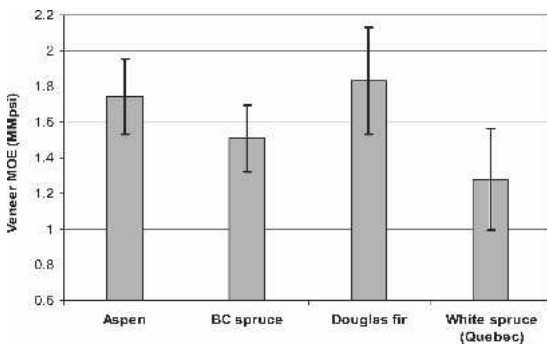

FIG. 11.—MOE of veneers from genetically improved white spruce and other Canadian species (bars (I) equal ± 1 standard deviation).

typically harvested at ages in excess of 200 years. Therefore, it would appear that low wood density, numerous knots, and a high juvenile wood content contribute to the low MOE in the genetically improved short-rotation white spruce. Density and MOE values for the genetically improved spruce were lower than those for Canadian grown Douglas fir and aspen.

CONCLUSIONS

Based on this study, the following conclusions can be drawn:

1. Veneer peeled from the unpruned Valcartier and St-Ignace white spruce was knotty, and 98% of the veneer was classified as visual grade C. This visually graded veneer would be suitable for sheathing grade plywood.
2. Stress grading showed that 14% of the white

spruce veneer was suitable for 12.41 GPa (1.8 million psi) grade of LVL; another 24% of the veneer was suitable for a lower 10.34 GPa (1.5 million psi) grade of LVL or core plies for LVL manufacture; and the remaining 62% was suitable for sheathing grade plywood.
3. Veneer from the Valcartier site was significantly denser and had higher MOE than veneer from the St-Ignace site.
4. White spruce veneer from the Valcartier and St-Ignace sites had lower density and MOE compared with other Canadian species commonly used for veneer products.

A manufacturer considering processing plantation-grown white spruce for veneer products would be advised to carry out an evaluation of veneer properties to estimate the volumes of veneer that : a) are suitable for sheathing plywood, and b) can be extracted for higher value LVL applications by stress grading the veneer. Forest managers should consider the potential benefits of artificial pruning or different planting spacing to achieve natural pruning, as well as a longer rotation age to allow the veneer to achieve higher visual and stress grades.

REFERENCES

BEAULIEU, J., AND A. CORRIVEAU. 1985. Variabilité de la densité du bois et de la production des provenances d'épinette blanche, vingt ans après plantation. Can. J. For. Res. 15:833–838.

CANADIAN COUNCIL OF FOREST MINISTERS. 1996. Forest Regeneration in Canada 1975–1992. Ottawa, Ontario.

CANADIAN STANDARDS ASSOCIATION. 1978. CSA Standard 0151-M1978 Canadian Softwood Plywood, Ottawa, Ontario.

CARON, E. G. 1980. A study of specific gravity variation in white spruce from northwestern New Brunswick. Undergraduate thesis, Fac. For., Univ. New Brunswick, Fredericton, New Brunswick.

CORRIVEAU, A., J. BEAULIEU, AND F. MOTHE. 1987. Wood density of natural white spruce populations in Quebec. Can. J. For. Res. 17:675–682.

———, ———, AND G. DAOUST. 1991. Heritability and genetic correlations of wood characters of Upper Ottawa Valley white spruce populations grown in Quebec. The Forestry Chronicle 67:698–705.

DAI, C., AND B. J. WANG. 2000. Veneer grading strategy for plywood/LVL products. Forintek Project 1967 Report, Vancouver, BC.

——— and ———. 2001. Optimization of veneer peeling parameters with incisor bar and smooth roller bar. Forintek Project 2411 Report, Vancouver, BC.

DUCHESNE, I., AND S. Y. ZHANG. 2003. Variation in tree growth, wood density, and pulp fiber properties of 35 white spruce (*Picea glauca* (Moench) Voss) families grown in Quebec. Wood Fiber Sci. 36(4):467–475.

FARRAR, J. L. 1995. Trees in Canada. Fitzhenry & Whiteside Ltd. and Canadian Forest Service, Ottawa, Ontario. 502 pp.

METRIGARD INC. 1998. Manual of Metriguard Model 239A Stress Wave Timer, Care and Instructions, Theory and Data Reduction.

STELLRECHT, J. W., C. A. MOHN, AND W. M. CROMELL. 1974. Productivity of white spruce seed sources in a Minnesota test planting. Minn. For. Res. Notes No. 251.

TAYLOR, F. W., E. I. C. WANG, A. YANCHUK, AND M. M. MICKO. 1982. Specific gravity and tracheid length variation of white spruce in Alberta. Can. J. For. Res. 12:561–566.

TSEHAYE, A., A. H. BUCHANAN, AND J. C. F. WALKER. 1995. A comparison of density and stiffness for predicting wood quality. J. Inst. Wood Sci. 13:539–543.

WANG, B. J. 2001. Characterizing aspen veneer for LVL/plywood products. Part I: Stress grades of veneer. Forintek Project Report 2019, Vancouver, BC.

YANCHUK, A. D., G. K. KISS. 1993. Genetic variation in growth and wood specific gravity and its utility in the improvement of interior spruce in British Columbia. Silvae Genet. 42:141–147.

2) YU, Q., D. Q. YANG, S. Y. ZHANG, J. BEAULIEU, AND I. DUCHESNE. 2003. Genetic variation in decay resistance and its correlation to wood density and growth in white spruce (*Picea glauca* [Moench] Voss). Can J. For. Res. 33(11):2177–2183.

ZHANG, S. Y. 1997. Wood specific gravity-mechanical property's relationship at species level. Wood Sci. Technol. 31:181–191.

——— AND K, MORGENSTERN. 1995. Genetic variation and inheritance of wood density in black spruce (*Picea mariana*) and its relationship with growth: Implications for tree breeding. Wood Sci. Technol. 30:63–75.

——— Y. CORNEAU, AND G. CHAURET. 1998. Impact of pre-commercial thinning on tree and wood characteristics, product quality and value in balsam fir. CFS Report No. 1108, Sainte-Foy, Quebec. 74 pp.

——— J. BEAULIEU, I. DUCHESNE, AND G. CHAURET. 2003. White spruce breeding for quality products. Canadian Forest Service Report No. 3236, Forintek Canada Corp., Sainte-Foy, Quebec.

ZHOU, H., AND I. SMITH. 1991. Factors influencing bending properties of white spruce lumber. Wood Fiber Sci. 23:483–500.