FACTORS INFLUENCING BENDING PROPERTIES OF WHITE SPRUCE LUMBER

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ABSTRACT

Influences of drying treatments, slope of grain, knots, juvenile wood percentage and other factors on strength properties of lumber were studied.

Conventional drying schedules, knots, warp, and juvenile wood significantly influenced the bending strength and stiffness of the lumber. Both modulus of rupture (MOR) and modulus of elasticity (MOE) decreased with any increase in the projected knot area (PKA). The mean MOR of specimens with PKA > 50% was only half of the mean MOR of specimens with PKA < 20%. The corresponding ratio for MOE was about 0.6. Both MOR and MOE decreased with an increase in warp or juvenile wood percentage. A clear dependence of strength on general slope of grain was not evident under the test conditions in this project.

Keywords: Bending properties, softwood lumber, drying defects, knot area.

INTRODUCTION

A fundamental requirement for efficient utilization of timber resources is basic understanding of the behavior of wood having natural growth defects. The inherent anisotropy, heterogeneity, and occurrence of knots and other defects emphasize the complexity of wood as a structural material and point out the importance of understanding its properties.

The traditional method of determining wood strength properties is to test small clear specimens, and to estimate the effects of specimen size and defects using empirical procedures. The unreliability of this method has been noticed by many researchers. Recently the traditional method has been replaced by the "in-grade" approach, in which large representative samples of full size lumber are tested to destruction. Studies of the strength and stiffness of full size lumber specimens have not confirmed species rankings obtained from small clear specimen tests (Hoffmeyer 1980). The ultimate bending strength of small specimens increases as a result of drying, but the bending strength of full size lumber may decrease during drying (Madsen 1975a, b). Differences in drying characteristics of lumber and small clear specimens may be attributed to the effects of factors such as drying defects, drying stresses, and presence of knots, slope of grain, and splits in the structural size members. Relatively little quantitative information on how these factors influence the lumber quality is available for white spruce.

The two most detrimental growth characteristics affecting lumber strength are knots and variations in grain orientation. According to Rochester (1938), in bending tests on 1,215 pieces of seasoned white spruce [*Picea glauca* (Moench) Voss] joists of nominal sizes ranging from 2-by-4 to 3-by-9 inches, 76% of the failures were caused by knots and 10% were caused by grain variation. Knots present a weakened zone in lumber that causes higher stresses in adjacent material. The influence of a knot on mechanical properties of a wooden member is due to the interruption of continuity and change in direction of wood fibers associated with the knot. The influences of knots depend on their sizes, locations, shapes, soundness, attendant local slopes of grain, and the type of stress to which members are subjected (Cramer et al. 1988).

Any form of grain deviation from the straight-grained condition is considered to be a defect in structural lumber. Since truly straight-grained lumber is the exception, the extent of grain deviations is an important consideration when using wood for structural purposes. The extreme orthotropy of clear wood strength properties makes grain orientation very critical in controlling wood strength. The ratio of parallel-to-grain tensile strength to perpendicular-to-grain tensile strength for clear wood of a structural softwood species can be as high as 40 to 1.

Forest practices and the trees themselves are changing as a result of more intensive forest management efforts. In Canada, the total area planted in white spruce during 1980–1986 was 430,236 ha, includes Engelmann spruce (*Picea engelmannii* Parry), which represents 35% of the total area planted (Kuhnke 1989). As the mechanical properties of lumber depend on the growth conditions for trees and the age at which they are harvested, new information relevant to lumber from the commercially important plantations of young white spruce is required.

A recent comprehensive review of literature on the influence of juvenile wood on properties of softwood lumber from fast grown and plantation material is given by Zhou (1989). Her review revealed that no systematic study had been made of important questions such as the influence of juvenile wood content on drying degrade when conventional kiln schedules are used.

Based on the background described, a project studying the influences of drying treatments, knots, and slope of grain on short-term bending strength of lumber was instigated with the following objectives:

1. to study the influence of knots on MOR and MOE of 2-by-4 lumber;
2. to study the influence of slope of grain on MOR and MOE of 2-by-4 lumber, and the relationship between slope of grain and drying defects, especially distortions;
3. to study the effects of different conventional drying schedules on bending strength of 2-by-4 lumber;
4. to determine the static bending properties of lumber from young plantation fast-grown white spruce trees;
5. to study the influences of other variables, such as relative density (RD), ring width, and proportion of juvenile wood on MOR and MOE, as well as their interactions.

TABLE 1. *The record of sample trees.*

Tree ref.	DBH (cm)	Height of tree (m)	Crown length (m)	Crown width (m)	Tree class	Defects	Number of logs
4	30	19.3	10	3	codominant	sweep	4
5	32	19.5	12	3	codominant		4
6	40	21	15	4	dominant	forked	5
7	29	15.8	10	3	codominant		4
9	28	19	8	3.5	intermediate		4
10	25	16.7	11	3	intermediate		3
11	20	16.3	4	2.5	suppressed		3
14	24	17.6	8	2	intermediate		3
20	41	20.8	15	3.5	dominant		4
22	27	19.7	8	2.5	intermediate		4
23	26	19.9	6	2	intermediate		3
25	30	21	8	2.3	codominant		4
27	23	15.5	6	2	suppressed		3
28	26	16.9	8	2.5	intermediate		3

It is intended to provide information for improving quality control during production of lumber, for structural wood design, and for commercial kiln drying. The study contributes to quantitative methods of evaluating the influence of drying stress and other drying variables on strength.

MATERIAL AND METHODS

The sample white spruce stand was located in the University of New Brunswick (UNB) research forest, southwest New Brunswick, and was planted in 1935. Thinning operations were carried out in 1959, 1965, 1973, and 1980, reducing the stand density from 2,500 to 1,000 stems per hectare between planting and harvesting. Trees in the range from dominant to suppressed were chosen (Table 1).

The trees were cut down in November 1987, and were cut into 3-m-long logs at the site. Logs were designated as bottom logs, lower middle logs, upper middle logs, and top logs. A total of 51 logs were obtained from 14 trees.

The logs were converted into 2-by-4-inch rough-sawn lumber at the Maritime Forest Ranger School training sawmill. This allowed very careful control of the sawing process. Before conversion, the logs were trimmed to 2.4-m standard length and marked, and the diameter of the small end of each log was measured.

According to the experimental design, the test material was divided into four matched groups. To minimize the inherent variations of wood and get good comparisons among groups, a series of grouping and sawing patterns based on the small end log diameter were designed. Where possible, each group had a specimen from each log of each tree. For small logs, specimens were taken from a similar position in a similar-sized tree. Each specimen was marked immediately after cutting with the tree number, position, and group reference information. As a result of conversion, 208 specimens were obtained from the 51 logs, approximately 50 specimens per group. After conversion, all specimens were stored in a cold room at 0 C to retard drying.

For the purpose of the study, the first 15 rings from the pith were counted as juvenile wood for bottom, lower middle, and upper middle logs. Twelve rings from the pith were counted as juvenile wood for top logs. Choice of 15 and 12 rings as demarcations of juvenile-mature transitions was mainly based on previous work by Sebastian (1969). Before conversion, the area of juvenile wood at both ends of each log was marked by painting. In this way, the proportion of juvenile wood in each piece of lumber could be easily estimated after conversion. The average painted area of the ends was used to represent the proportion of juvenile wood of a particular piece of lumber.

One of the groups of specimens was designated for testing in the green condition, the other three groups were kiln-dried. Kiln schedules for drying experimental material were carefully selected based on recommendation in "Kiln Operator's Manual for Eastern Canada" (Cech and Pfaff 1977). Drying schedules with different dry-bulb temperatures, wet-bulb depressions, and rates were designed for the three groups of specimens. The slow rate and mild drying schedule with temperatures ranging from 120 to 150 F was designed as a dry control (slow-mild). Two schedules with different drying rates and relatively severe drying conditions, which may cause different degrees of damage to material, were also designed. A schedule with a low initial temperature (140 F) (medium-severe) and a more rapid schedule (fast-severe) with a high initial temperature (160 F) were chosen. Both "severe" schedules had larger initial wet-bulb depressions (30 F) than the slow-mild schedule (7 F). The target moisture content (MC) for the three groups of dry specimens was 12%. More details about drying schedules are given by Zhou (1989).

Each group of specimens was dried in one batch of approximately 50 pieces of lumber. No top weight was used during drying, so that the distortional defects could occur.

A four-point-bending-test arrangement and short-term duration (approximately 5 minutes to failure) were chosen for this study. Before testing, both green and dry specimens were surfaced to a size of 38 by 89 mm.

Knots were subsequently evaluated using the projected knot area (PKA) in the zone of constant bending moment; PKA was determined according to British Standard BS4978-1988 (BSI 1988).

General slope of grain was determined from:

$$1/x = [(1/a)^2 + (1/b)^2]^{0.5}$$

where:

$1/x$ = slope of grain expressed as 1 in x.
a, b = the slope distances on the two adjacent faces.

Slope of grain was measured on all four faces of each specimen using a grain scribe. This produced two values of slope of grain for each piece. The average of the two values was used to represent the slope of grain of a piece.

The proportion of juvenile wood was estimated on both ends to the nearest 5%. The average for the two ends was used to represent the piece. Warp was measured immediately after planing.

Each specimen was stress-graded by the first author according to NLGA (National Lumber Grades Authority) (1987) visual grading regulations for Structural Light Framing.

Each specimen was tested twice as a joist to find MOE for the two possible specimen orientations (weakest edge up and weakest edge down), then retested to find MOR with the weakest edge down. The weakest edge was defined based on the following assumptions: 1) juvenile wood is weaker than mature wood when subjected to tensile stress, because of greater fibril angle and shorter tracheid length; 2) edge knots are a major weakening factor in specimens and should be placed in tension. Therefore, the juvenile wood portion or the large knots were always placed on the tension side of the specimen. If the two criteria could not be satisfied at the same time, the juvenile wood was the first factor to be considered.

Specimens were tested in bending following procedures consistent with ASTM-D4761-88 (1989). The span between the two supports was adjusted to the standard length of 1,513 mm, which was 17 times the depth of the specimen, with loads at the third points.

The failure pattern of a specimen was recorded, including the order of occurrence of any sub-failures. The failure patterns were grouped as shown in Fig. 1. Small clear cross sections were cut near the failure area to determine MC, RD, and ring width. The MC was determined using the oven-drying method, and RD was determined using the oven-dry weight and volume at test. Ring width was determined over a 50–90 mm portion of a radial line representing the average growth on the cross section.

DATA ANALYSES

The smaller of MOE values for the two orientations, weaker face up or weaker face down, was chosen as the MOE to represent any piece. Slope of grain was converted to degrees for further analysis.

Actual moisture content of specimens at the time of testing showed minor variations from the target value of 12%. All results were corrected to an equivalent value at 12% moisture content by procedures according to ASTM-D2915-88 (1989). Green et al. (1986, 1988) and Green and Evans (1988) have pointed out that the moisture adjustment procedures given in ASTM-D2915 may not be accurate for MOR. A new adjustment procedure is proposed by Green and coworkers based on calibration to their Douglas-fir and southern pines data. Information about other species was not available, so the ASTM-D2915 method was used in this project. A further consideration was that adjustments made in this project were in a moisture content range where the alternate methods do not diverge.

RESULTS AND DISCUSSION

The average green moisture content of three charges of dried material varied from 70 to 80%, while individual piece moisture contents varied from 32 to 150%. The slow-mild group was dried for approximately 90 hours and developed the least internal stresses and defects due to drying. The fast-severe group, which was dried for only about 50 hours, developed the most severe drying defects and stresses. Since a shorter conditioning time was used for this group, severe casehardening and stress remained in the specimens. The medium-severe group was dried for about 70 hours, and the severe drying condition resulted in extensive drying stresses and defects. After conditioning, some stress and casehardening still remained in these specimens.

A summary including mean values and standard deviations for specimen properties is contained in Table 2. The results of MOE and MOR showed an expected

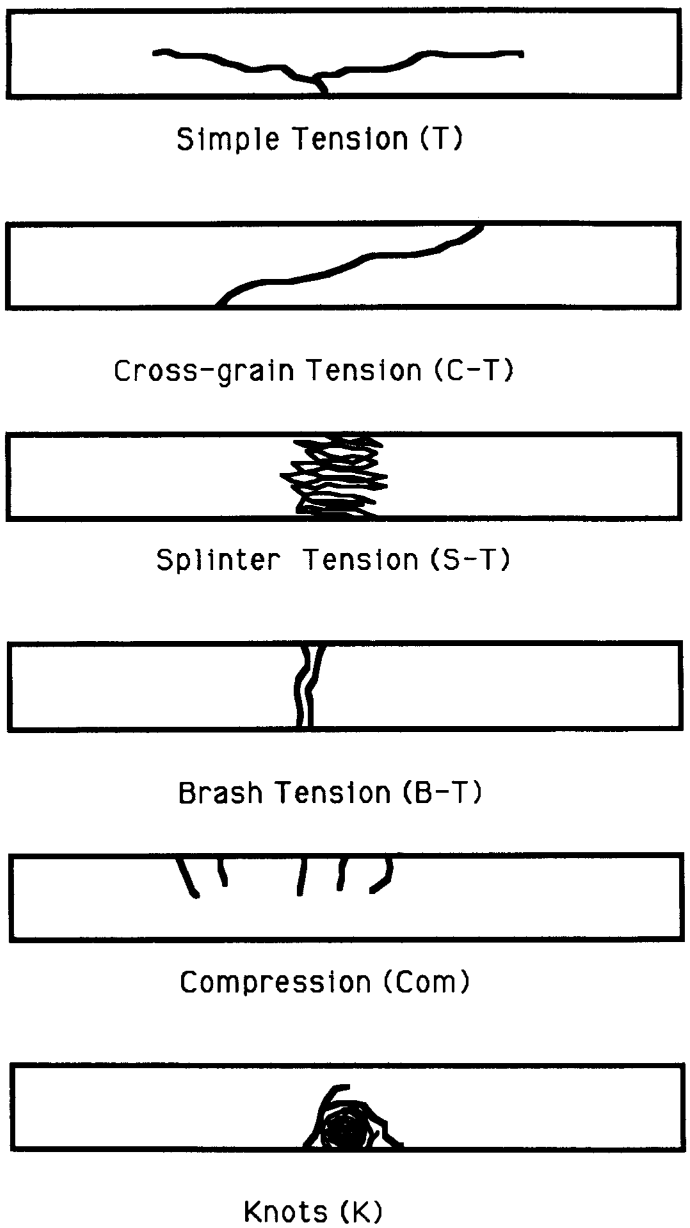

FIG. 1. Types of failures in static bending.

trend of decreasing from slow-mild to severe groups. The average ratios of dry to green values for MOR were 1.55, 1.15, and 1.34 for slow-mild, medium-severe, and fast-severe, respectively. The ratios of dry to green values for MOE were 1.44, 1.29, and 1.22, respectively. The RD and ring width values were quite similar among groups, but there was slight variation in slope of grain, juvenile wood percentage, and PKA among groups. The method used for grouping is thought to explain such discrepancies, i.e., it only guaranteed geometrical matching with

TABLE 2. *Summary of physical and mechanical properties.*[1]

Group		Green	Slow-mild	Medium-severe	Fast-severe	All dry groups
MOE (MPa)	mean	6,047	8,720	7,816	7,730	7,954
	SD	2,220	2,894	2,468	2,213	2,576
MOR (MPa)	mean	19.8	30.7	22.7	26.5	26.6
	SD	5.8	11.4	8.4	10.6	10.6
Test MC (%)	mean	65.8	13.1	10.3	12.1	11.8
	SD	29.6	0.9	0.6	1.3	1.5
RD	mean	0.333	0.348	0.344	0.346	0.346
	SD	0.021	0.031	0.027	0.031	0.029
Slope (degree)	mean	2.65	2.96	3.87	3.28	3.38
	SD	1.70	1.08	2.26	1.82	1.82
Juve (%)	mean	55	51	61	53	55
	SD	34	32	31	36	33
Ring width (mm)	mean	4.35	4.67	4.64	4.58	4.63
	SD	1.60	1.65	1.45	1.48	1.52
PKA (%)	mean	36	33	37	29	33
	SD	20	21	19	19	20
Warp (mm)	mean[2]	N/A	7.4	9.1	9.3	8.7
	SD		6.6	5.8	7.2	6.6

[1] MOR and MOE adjusted to a standard MC of 12% for dry groups.
[2] Mean of all specimens in the group.

respect to stem cross-section. Taper in tree trunks, eccentricities in the pith, and positions and the randomness of branches were neglected in the matching.

The mean MOR and MOE values of both green and dry materials were apparently lower than values reported by other researchers (Forestry Branch, Forest Products Laboratories Division 1981) for white spruce. The overall average of percentages of juvenile wood in specimens for the work reported here was 55%. Mean RD for dry specimens was 0.346 and mean ring width was 4.6 mm, while the values reported in Canadian Woods (Forestry Branch, Forest Products Laboratories Division 1981) were 0.37 and 2.0 mm, respectively.

A comparison of alternative estimates of MOE for dried groups is presented in Table 3. There are no significant differences between descriptive statistics for MOE between the orientation tested only for stiffness (EMOE) and the orientation that was tested to failure (FMOE). This suggests that minimum MOE may not

TABLE 3. *Comparison of alternative estimates of MOE with MC adjustment.*

	Property	EMOE[1] (MPa)	FMOE[2] (MPa)	MOE[3] (MPa)
Slow-mild group	mean	9,036	8,885	8,720
	SD	2,855	2,933	2,894
Fast-severe group	mean	7,498	7,701	7,370
	SD	2,283	2,198	2,213
Medium-severe group	mean	7,980	8,030	7,816
	SD	2,455	2,594	2,468

[1] EMOE: MOE value obtained from the orientation which was tested only for stiffness.
[2] FMOE: MOE value obtained from the orientation which was tested to failure.
[3] MOE: minimum of either EMOE or FMOE for a piece.

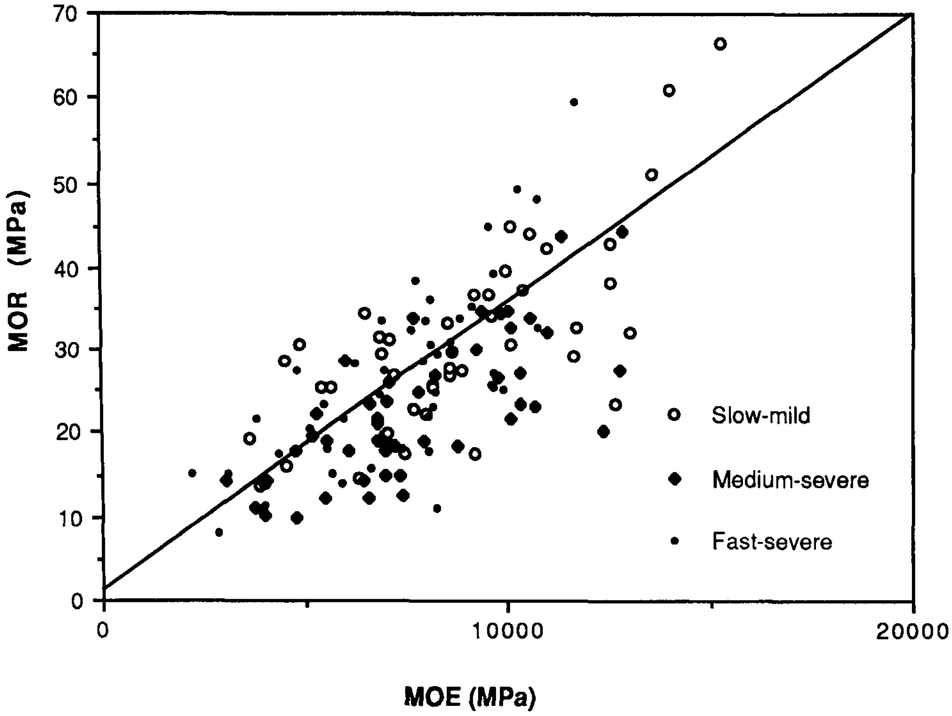

FIG. 2. Linear regression of MOR against MOE for all dry specimens (n = 140). Fitted equation: MOR = 3.1 + 0.003 × MOE (R^2 = 0.516)

be a good indicator of the orientation in which a piece of lumber will be weakest in bending. Such an observation should not be confused with deduction of a low strength zone from lengthwise variation of MOE within a piece.

The SAS Univariate Analysis (SAS Institute Inc. 1985) of data distribution showed that MOE, MOR, and RD distributions within a group were basically normal for all groups. This gave a necessary basis for other statistical analyses.

Linear regression analysis was made for MOR against MOE. The results of all dry specimens are presented in Fig. 2. Generally the MOR increased with any increase in MOE. The correlations observed between MOR and MOE were very good for both green and dry material.

The results of grading and the percentage of each group in a particular grade are shown in Table 4. Approximately 60% of material was No. 3 grade or reject according to current visual grading rules for Structural Light Framing (NLGA 1987). This suggests that there may be an adverse effect in the future on yields of high grade structural lumber when a higher proportion of sawlogs come from plantations. The average bending and physical properties of all dry specimens, in each grade, are given in Table 5. The average values of MOE, MOR, and RD increase with the better grades. The slope of grain, juvenile wood percentage, ring width, PKA, and warp are reduced with the better grades. Results shows that visual grading can be reliable as long as the visual defects are carefully observed and measured. This suggests that any problems with respect to application of the visual grading as a quality control technique relate to the rigor with which it is

TABLE 4. *Lumber grade distribution by groups.*

Group		Slow-mild	Medium-severe	Fast-severe	Green	Total
SS and No. 1	No.[1]	7	4	10	9	30
	(%)[2]	(14.3)	(8.0)	(20.0)	(18.0)	(15.1)
No. 2	No.	11	12	11	10	44
	(%)	(22.5)	(24.0)	(22.0)	(20.0)	(22.1)
No. 3	No.	18	21	15	24	78
	(%)	(36.7)	(42.0)	(30.0)	(48.0)	(39.2)
No. 3 & above	No.	36	37	36	43	152
	(%)	(73.5)	(74.0)	(72.0)	(86.0)	(76.4)
Rejected	tested	9	10	12	7	38
		(18.4)	(20.0)	(24.0)	(14.0)	(19.1)
	untested	4	3	2	0	9
		8.2)	(6.0)	(4.0)	(0.0)	(4.5)
	total	13	13	14	7	47
		(26.5)	(26.0)	(28.0)	(14.0)	(23.6)
Total specimens		49	50	50	50	199

[1] No. = Number of specimens in the grade.
[2] (%) = Percentage of the group in the grade.

applied. The wide ranges in properties within a grade indicate that surface features alone may not constitute an ideal means of material segregation. Individual dry groups showed similar trends for the various grades.

Concerning failure pattern, knots directly contributed to the failures of 46% of specimens (88 pieces), and indirectly contributed to the failures of 27% of specimens (51 pieces). Altogether, 73% of failures in specimens were connected with knots. Some 19% of failures were caused by cross-grain and other grain deviations. These findings are in good agreement with the results of Rochester (1938) and McGowan (1968). Details of physical and strength properties sorted on the basis of failure patterns are given by Zhou (1989).

Specimens that failed because of knots had the highest mean PKA and relatively

TABLE 5. *Summary of physical and mechanical properties by NLGA Structural Light Framing grade.*

Grade	Number[1]		MOE (MPa)	MOR (MPa)	RD	Slope degree	Juve (%)	Ring (mm)	PKA (%)	Warp (mm)
			Dry groups only							
SS and No. 1	21	mean	9,965	39.0	0.353	2.199	38.8	3.83	14.3	3.10
		SD	2,346	12.7	0.035	0.805	32.2	1.22	8.3	3.71
No. 2	34	mean	9,358	30.4	0.351	3.215	44.3	3.90	24.3	6.18
		SD	2,002	8.3	0.028	1.55	34.3	1.17	8.7	4.41
No. 3	54	mean	7,707	24.1	0.345	3.785	62.3	4.89	35.4	9.57
		SD	2,087	6.6	0.027	2.11	30.6	1.42	13.9	4.87
Reject	31	mean	5,480	18.2	0.337	3.632	65.5	5.52	51.7	13.53
		SD	1,865	7.3	0.030	1.735	29.3	1.62	24.3	8.56
No. 3 and above	109	mean	8,657	29.0	0.349	3.302	52.2	4.38	27.9	7.27
		SD	2,306	10.2	0.029	1.845	33.4	1.39	14.1	5.15
No. 2 and above	55	mean	9,590	33.7	0.352	2.827	42.2	3.87	20.5	5.0
		SD	2,139	10.9	0.030	1.402	33.3	1.18	9.8	4.39
No. 3 and below	85	mean	6,895	22.0	0.342	3.729	63.5	5.12	41.4	11.02
		SD	2,270	7.4	0.028	1.974	30.0	1.52	19.9	6.69

[1] Number of specimens per grade group.

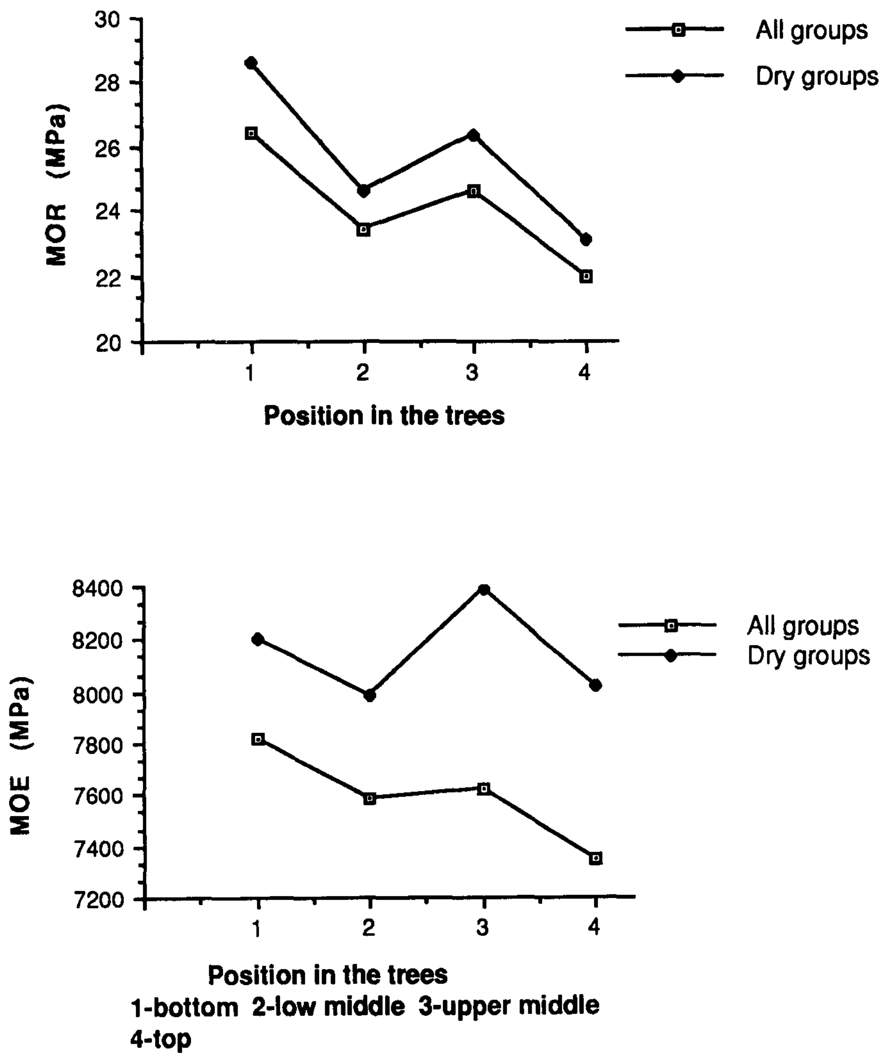

FIG. 3. Average bending properties of specimens at different positions in stems.

low strength. Specimens that failed in a tension pattern had higher strength and lower slope of grain and PKA than other failure modes except the compression pattern. Specimens that failed in cross-grain tension had the highest mean slope of grain. Brash tension only took place in dry specimens. This class had the lowest mean MOE and MOR values, the widest ring width, and the highest juvenile wood percentage among all failure patterns. This is a very interesting result, which may give some information about fracture behavior of juvenile wood. The dry specimen compression failure class showed the highest MOR, MOE, and RD, and the lowest mean juvenile wood percentage and PKA values for dry specimens. There were no special features associated with compression failures in green specimens.

Figures 3, 4, and 5 show the variation of average physical and mechanical

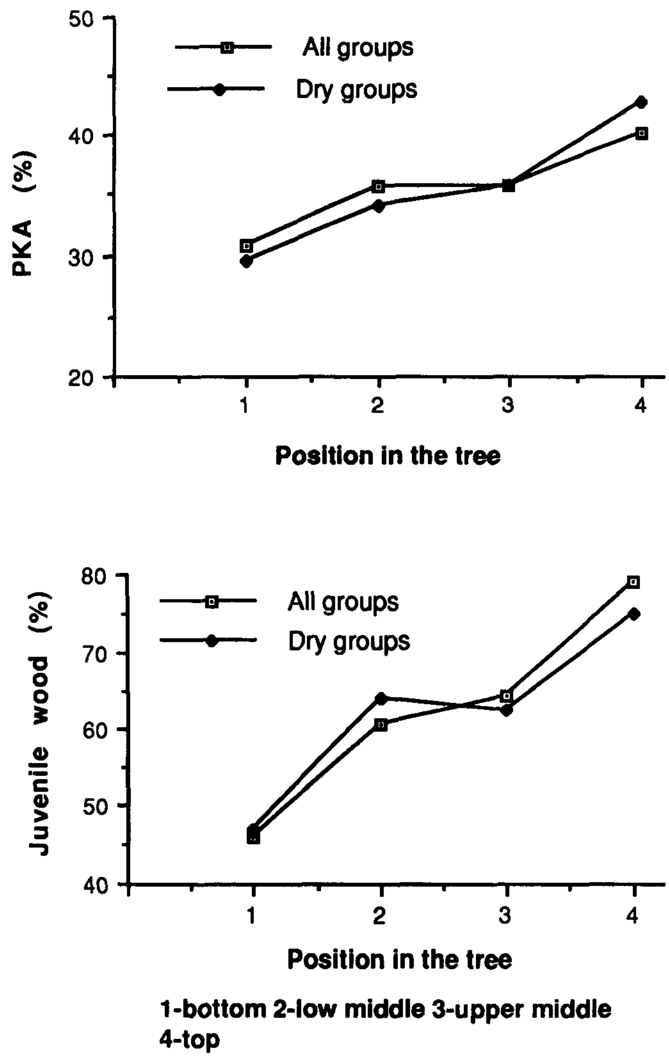

FIG. 4. Average PKA and juvenile wood percentage at different positions in stem.

properties of specimens with change in the stem position from which lumber is cut. Stem positions were grouped as bottom, lower middle, upper middle, and top. The RD increased with increasing height in the tree. Similar results were reported by Taylor et al. (1982). Juvenile wood percentage in test specimens increased with increasing height in the tree, and increased more quickly than the apparent juvenile wood volume percentage in the tree trunk. Conversion of small diameter logs from plantations of white spruce will give a high proportion of lumber containing mostly juvenile wood. The mean ring width and PKA also increased with the height in the tree. The strength properties observed in this study showed a different trend in comparison with some research reports. The bottom logs did not produce the weakest lumber as was the case for the loblolly pine studied by Pearson and Gilmore (1971). Instead they produced the strongest

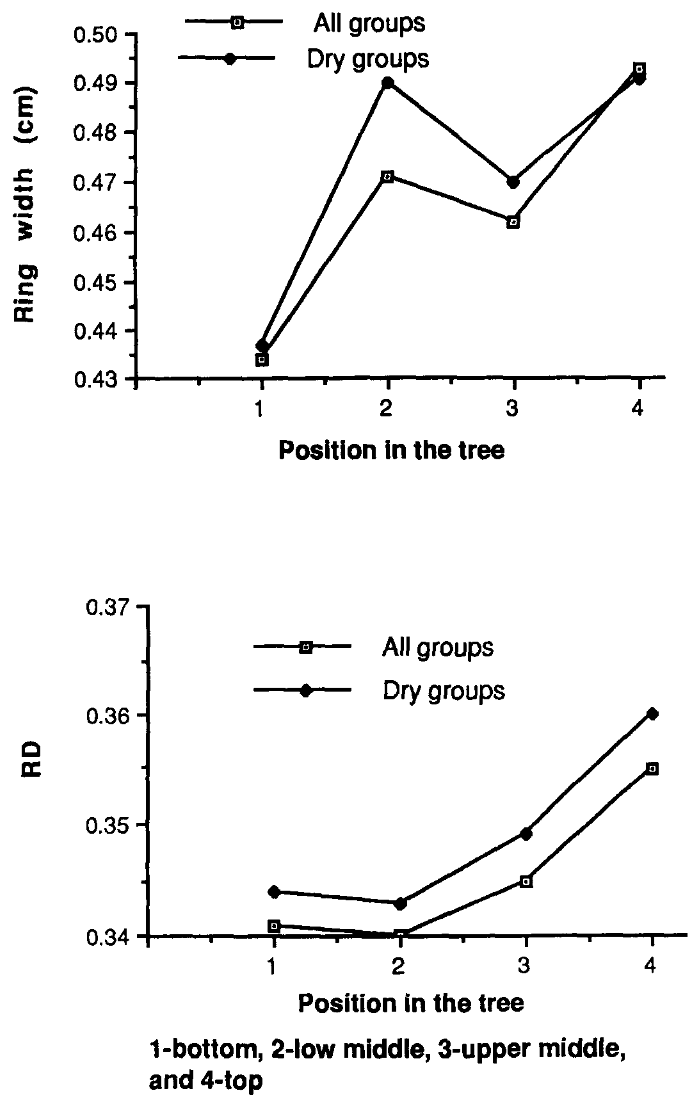

FIG. 5. Average RD and ring width at different psitions in stem.

lumber, and the top logs of the trees produced the weakest lumber. This indicates that extreme caution is required when extrapolating conclusions from one species to another.

Analyses reported in detail by Zhou (1989) showed that suppressed trees (DBH < 24 cm) and dominant trees (DBH > 35 cm) were relatively weak and had low density, and that dominant trees contained wide annual rings. Most codominant and intermediate trees had higher RD, more moderate growth rate, and higher strength than suppressed and dominant ones. Figure 6 shows mean MOE and MOR of each tree against its RD. Both MOE and MOR trends showed an increase in the property when RD increased.

No strong relationship was found between average slope of grain within a piece of lumber and MOR or between average slope of grain and MOE. Compared with

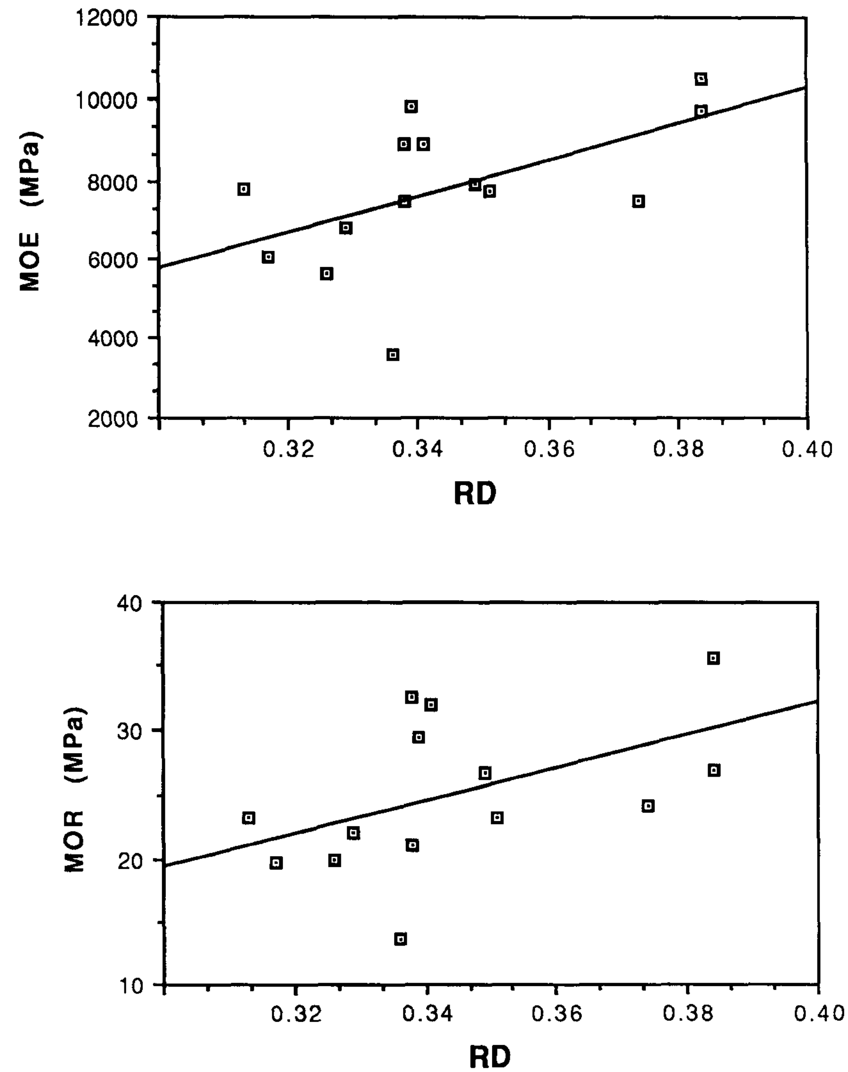

FIG. 6. MOR and MOE versus RD (average in-tree values of each variable). Fitted equations: MOE = −7,516 + 44,323 × RD (R^2 = 0.30); MOR = −18.3 + 126 × RD (R^2 = 0.23).

other factors, such as knots, RD, juvenile wood, and ring width, the general influence of slope of grain is quite weak under the testing conditions used by the authors. The influences of other factors may have masked the influences of slope of grain. A high average slope of grain value was associated with specimens that failed in cross-grain tension, indicating it does have some effect.

Linear regressions of PKA against MOR and MOE for all dry specimens are given in Fig. 7. There are strong decreasing trends for both MOR and MOE when the percentage PKA increases. The influence of knots on MOR is much stronger than on MOE. The correlation coefficients are 0.595 and 0.465 for MOR and MOE, respectively. Table 6 summarizes physical and mechanical properties of each group based on PKA classes. The mean MOR of high percentage PKA

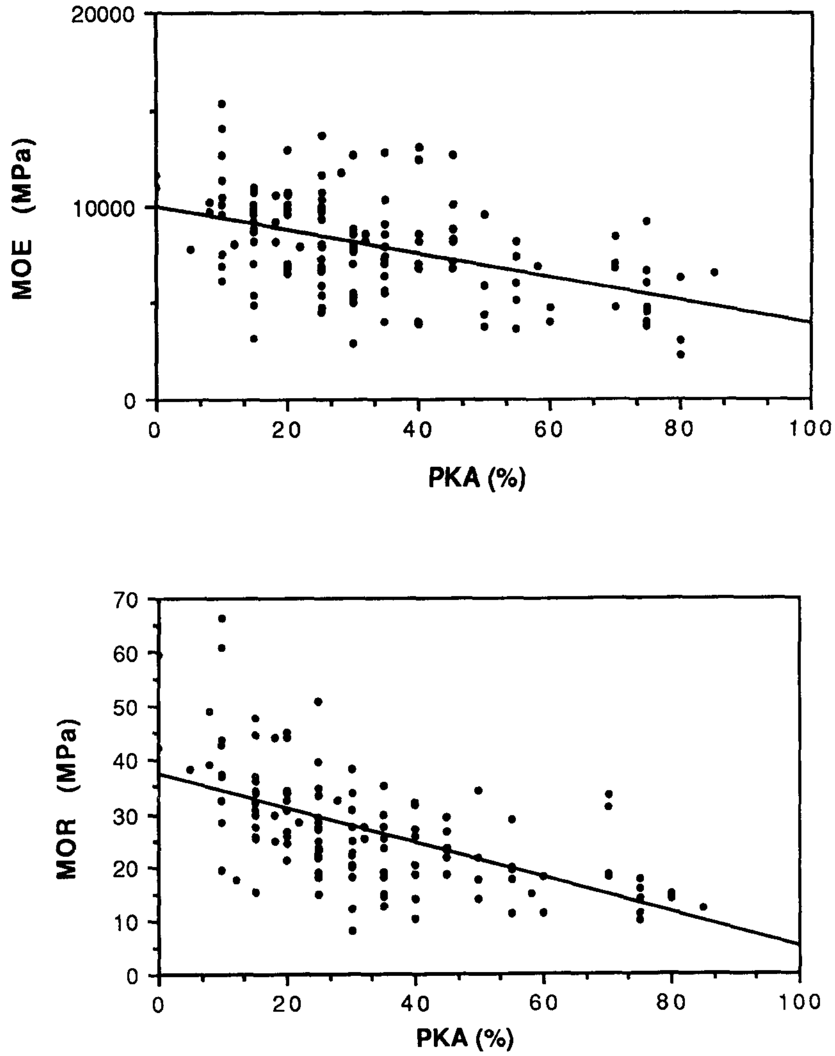

FIG. 7. Linear regression of MOR and MOE against PKA for dry specimens (n = 140). Fitted equations: MOE = 9,987 − 61.35 × PKA (R^2 = 0.22); MOR = 37.3 − 0.323 × PKA (R^2 = 0.35).

(>50%) material is only half that of low percentage PKA (<20%) material, while the ratio for MOE is about 0.6. Other interesting trends from Table 6 are reduction in RD and increase in juvenile wood proportion and ring width associated with any increase in PKA.

Average strength and physical properties of each group based on four classes of juvenile wood content are listed in Table 7. In all groups both MOR and MOE decrease with increasing proportion of juvenile wood. Statistically significant differences were found among different classes at the 0.05 significance level. As found by other researchers, decreasing RD and increasing ring width are associated with an increase in the proportion of juvenile wood in lumber. The mean PKA and warp also increase with increased percentage of juvenile wood.

TABLE 6. *Average physical and mechanical properties based on PKA classes.*

Property	PKA <20%	PKA 20–50%	PKA >50%	Total
		Green group		
Number	12	28	10	50
MOE	7,608	5,954	4,436	6,047
MOR	25.8	19.4	13.8	19.8
RD	0.349	0.331	0.320	0.333
Slope	3.377	2.436	2.355	2.646
Juve[1]	32.7	61.9	61.2	54.8
Ring width	3.58	4.47	4.92	4.35
		Slow-mild group		
Number	14	23	8	45
MOE	9,796	8,883	6,368	8,720
MOR	39.5	28.9	20.4	30.7
RD	0.353	0.346	0.345	0.348
Slope	2.879	2.785	3.587	2.957
Juve	43.9	52.2	62.3	51.4
Ring width	4.37	4.58	5.45	4.67
Warp	8.4	6.6	8.1	7.4
		Medium-severe group		
Number	10	28	9	47
MOE	9,887	7,899	5,256	7,816
MOR	32.5	21.3	16.3	22.7
RD	0.351	0.343	0.341	0.344
Slope	3.932	3.697	4.361	3.874
Juve	42.4	63.2	75.0	61.0
Ring width	3.64	4.80	5.27	4.64
Warp	7.8	9.1	10.4	9.1
		Fast-severe group		
Number	19	23	6	48
MOE	8,577	6,869	5,467	7,370
MOR	33.4	23.9	15.0	26.5
RD	0.357	0.340	0.336	0.346
Slope	3.281	3.437	2.653	3.277
Juve	43.5	58.8	59.2	52.8
Ring width	4.11	4.60	6.02	4.58
Warp	10.5	8.6	8.4	9.3

[1] Juve = percentage of cross-section in juvenile core.

CONCLUSIONS

On the basis of a study of properties of eastern Canadian white spruce lumber as described here, some conclusions can be drawn.

Drying schedules of different levels of severity, at conventional temperature levels, significantly influence strength properties of white spruce lumber. Mildly and carefully dried material represents a condition for the maximum average strength increase as a result of drying.

Knots are a major harmful factor in full size lumber. They accounted for 73% of bending specimen failures in the project reported. The ratio of mean bending strength of specimens with large or numerous knots, PKA > 50%, to that for

TABLE 7. *Average physical and mechanical properties based on juvenile wood content classes.*

Group	Property	Juvenile wood content <25%	26–50%	51–75%	76–100%
Green	Number	13	12	7	18
	MOE	6,711	6,187	5,729	5,598
	MOR	20.3	20.2	19.8	19.3
	RD	0.337	0.329	0.332	0.334
	Slope	3.18	2.96	2.26	2.19
	Ring width	2.87	4.33	4.71	5.28
	PKA	27.2	32.8	42.9	42.7
Slow-mild	Number	11	12	10	12
	MOE	10,126	8,884	8,154	7,777
	MOR	32.9	33.7	27.2	28.5
	RD	0.357	0.349	0.344	0.341
	Slope	2.57	2.91	3.47	2.93
	Ring width	3.34	4.07	5.77	5.55
	PKA	26.1	29.3	39.0	39.7
	Warp	2.55	6.33	10.6	10.42
Medium-severe	Number	8	6	16	17
	MOE	9,029	8,655	7,517	7,229
	MOR	26.8	27.7	23.0	18.8
	RD	0.359	0.358	0.335	0.340
	Slope	5.04	3.92	3.35	3.81
	Ring width	3.30	3.82	4.73	5.49
	PKA	28.1	32.2	34.1	44.9
	Warp	5.50	4.50	9.94	11.65
Fast-severe	Number	15	10	7	16
	MOE	8,885	7,686	5,785	6,445
	MOR	33.8	22.7	25.6	22.4
	RD	0.366	0.342	0.330	0.338
	Slope	4.35	3.11	2.71	2.63
	Ring width	3.49	3.72	5.59	5.71
	PKA	24.0	35.3	24.3	33.1
	Warp	6.87	5.93	13.0	12.2

specimens with small knots, PKA < 20%, is only 0.5. The corresponding ratio for MOE is 0.6. Average MOR and average MOE decrease with any increase in PKA.

The relationship of slope of grain to bending strength properties was weak under the test conditions in this study, even though cross-grain caused 19% of failures. The influence of other factors appeared to mask the influence of slope of grain. Specimens with high slope of grain are more easily distorted during drying than straight-grained specimens. Herein lies the more direct need to limit the general slope of grain in lumber.

The results of this study show that, largely due to the high proportion of juvenile wood, plantation fast-grown white spruce harvested in 50–60 years will have a low RD, wide annual rings, and low strength properties. On average, juvenile wood volume in specimens may be as high as 55% of total volume for this rotation age under growing conditions in southwest New Brunswick. More than 23% of specimens would be rejected, and about 40% would fall into Structural Light Framing No. 3 visual stress grade if NLGA rules were to be applied. Therefore, low grade material accounted for 63% of all specimens. This means plantation fast-grown wood in future markets is likely to produce more low value material than is traditional, so planning for the production and use of these materials should be based on a new understanding. From the research reported here, white spruce trees with high RD and moderate growth rate show satisfactory strength properties.

More quantitative and theoretical studies about the relationship between drying condition and strength properties and the influence of drying stress on strength are needed. Both presence or absence of the pith and the ring width should be considered in visual stress grading of white spruce lumber.

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