Influence of Juvenile Wood on Bending Properties of Softwood Lumber

C. S. Shivnaraine[1]
Industrial Domestic & Electrical Appliances Ltd., Guyana, South America
and I. Smith,
University of New Brunswick, Fredericton, New Brunswick, Canada

ABSTRACT

Starting from the questions of the appropriateness of the term juvenile wood and the uncertainty in predicting its location in a given stem of a typical Northern American conifer, some predictions are made concerning the impact of the proportion of juvenile wood on bending properties of softwood lumber.

Results of a recent study which looks at the relative merits of proportion of juvenile wood and position in the tree stem as alternative indicators of bending strength of plantation White spruce lumber are used to expand the discussion. This work is related to changing harvesting and log transportation practices to those which make it possible to cut and segregate logs from tree stems in the relatively controlled environment of a sawmill rather than in the forest.

Key Words: *Lumber properties, juvenile wood, log conversion, bending strength.*

INTRODUCTION

In recent years there has been an increase in the proportion of Canadian forests that are in coniferous plantations. It is estimated that between 1983-1986, the area planted as a percentage of the area harvested rose to 27.2 percent, up from 16.8 percent during 1975-1980 [15]. Similar trends are observed in USA, and European countries. Elsewhere, for example, in New Zealand and Chile virtually all of the commercial softwood forest is in plantations of exotic species.

Along with increased utilisation of plantation material and intensive forest management comes a shortening of the rotation period associated with conifers from a given geographic location. Plantation grown material tends to have a high proportion of wood from growth rings formed during the initial stages of development at any particular height in a tree stem. Structural softwood lumber from plantations has been found to exhibit undesirable features such as high knot area ratios, high degree of spiral grain, excessive drying degrade, [3] [26]. An example of the problems that can occur due to presence of juvenile core material in building structures is seasonal arching in trusses made from softwood lumber. Gorman[11] studied King-post southern pine trusses and concluded that there should be a reduction in the amount of "juvenile" material allowed in bottom chords if seasonal arching is to be avoided.

Moody [18] analysed ninety finger jointed tension specimens of 2" x 6" Southern pines, to compare their strengths with those of sixty unjointed control specimens. Thirty of the control specimens and sixty of the jointed specimens contained a significant amount of "pith-associated" (juvenile core) wood. It was found that the tensile strength of control specimens with significant amounts of pith-associated wood had an average strength 34 percent less than that of specimens without significant amounts of pith-associated wood. Pith-associated wood reduced the tensile strength of finger jointed specimens by an average of 22 percent. Based on Moody's work, use of short rotation plantation grown Southern pines, may require reductions in allowable design capacities for elements such as tension chords in trusses, and glulam beams and ties compared with similar elements made from mature wood from Southern pines.

From experience with softwood lumber from other species of trees, it seems likely that juvenile core material will have a significant influence on the strength and stiffness properties of White spruce (Picea glauca (Moench) Voss) lumber from short rotation plantations. Studies were initiated at the University of New Brunswick during 1987 on two aspects of mechanical properties of plantation grown White spruce from the University's woodlot. In the work reported here the influence of variation in position in a tree stem on the bending strength and stiffness of lumber was studied, with the objective of optimising quality control and "grade" recovery in a sawmill environment. A second study has shown that significantly different levels of drying degrade

1. The authors are respectively, Wood Products Manager, Industrial Domestic & Electrical Appliances Ltd., Soesdyke, East Bank Demerara, Guyana, South America; and Director, University of New Brunswick Wood Science & Technology Centre, Fredericton, New Brunswick, Canada.

can result from alternate conventional drying schedules [30]. Further projects are extending consideration to Red pine (Pinus resinosa Ait.).

Juvenile Wood Content of Lumber

Researchers have used different terms when referring to immature wood near the piths of tree stems. Using position in the tree stem as an indicator of physical properties, this material has been termed pith wood [21], core wood [33], and inner wood [21]. Based on the concept of wood formation, it has been termed crown-formed wood [14] [7] [17] [24]. Study of anatomical features and their variation within trees has led to the term juvenile wood[22] [23] [31] [1] [16] [17] [5] [28] [20] [32] [29] [13].

The term juvenile wood refers to a phase in the life of a cross-section in the stem or branch being considered. Establishing that a particular piece of wood is "juvenile" does not by itself tell anything about the age of the tree from which it was cut. Juvenile wood is produced by a young cambium in close proximity to the foliage (crown-formed wood). Mature wood in a tree stem is formed below the crown, and as the height of the tree increases and the crown moves upward, the juvenile core at a cross-section below the crown remains constant but the ring of mature wood surrounding it thickens with the formation of each new annual ring.

Location of an exact boundary between juvenile and mature wood in the vertical and horizontal planes of a tree stem is not possible. According to Yank et al [29], "the mechanism that mediates the transition from juvenile to mature wood is still unknown". Rendle [23] attributed this to the range of variables concerned (tracheid or fibre length, vessel diameter, summerwood density, percent cellulose, etc.). Several researchers have attempted to clearly define the juvenile-mature wood boundary:[9] [12] [26] [6]. Unfortunately the inconsistent results obtained using the variables outlined by Rendle [23] make it difficult to locate a boundary.

Table 1 gives an indication of how various physical properties have been found to vary between juvenile and mature wood.

Table 1 - Physical properties indicating transition from juvenile to mature wood, Yank et al [29]

Greater for juvenile wood than mature wood	**Smaller for juvenile wood than mature wood**
microfibril angle, longitudinal shrinkage, cell lumen, lignin content, reaction wood, spiral grain, knottiness of lumber,	relative density, tracheid length, latewood content, cell wall thickness, tangential cell dimensions, cellulose content, strength of clear wood

No clear guidance has been found in the literature concerning definition of the juvenile core in plantation grown White spruce. Some guidance is available from a literature review by Barbour [4], but this emphasises variations in physical properties in trees from mature natural stands.

The primary information used by the authors to select an assumed boundary between juvenile and mature wood was work by Dr. L.P. Sebastian, University of New Brunswick (UNB) on some anatomical and physical properties of White spruce sapwood and heartwood, [25]. Tracheid length was selected as the most reliable indicator, and this led to adoption of the outer surface of the fifteenth annual ring as the boundary of the juvenile core.

For species other than White spruce the juvenile wood-mature wood boundary has been estimated to lie between five and twenty growth rings from the pith and has generally been assumed to depend upon species. However, a recent study on loblolly and slash pine suggests that the length of juvenility is related to environmental factors associated with geographic location rather than to species differences [8]. The role of silvicultural treatments also appears important [19].

Barrett and Kellogg [3] in their work on Douglas fir lumber defined specimens with up to 50 percent of the cross-section contained in the first twenty annual rings as mature wood, and those with more than 50 percent of the cross-section contained in the first twenty annual rings as juvenile wood. By contrast, in the UNB studies on White spruce, lumber has been categorised as shown in the first column of Table 3.

MATERIALS AND METHODS

A total of 14 trees were harvested from the University woodlot located on the outskirts of Fredericton, New Brunswick, Canada. These trees were from two pure White spruce stands approximately 300m apart that were planted in 1935 on old fields abandoned in late 1920's. Both stands are on gently sloping sites with soil type Queens clay loam. Sample trees were selected to have a diameter at breast height (D.B.H.) of greater than 240mm and for straightness of the bole. The average D.B.H. was 282mm and the coefficient of variation for D.B.H. was 8.36 percent. Table 2 gives details of the history of the two stands harvested.

Table 2 - History of plantation stands yielding sample trees

Year	Activity
1935	Planting with 3 year old seedings on 2m x 2m grid, (approximately 2500 stems/hectare).
1959	First thinning.
1965	Second thinning.
1973	Third thinning.
1980	Fourth thinning to approximately 1000 stems/hectare.
1987	Harvesting of sample trees (age 55 years).

The trees were cut into bole samples 3m long, commencing with base samples cut from as close to the ground line as practical, (stump heights approximately 150mm). A 3m length allowed for cutting disks used to measure moisture content at harvest and average relative density at various heights in each stem, and production of 2.4m long pieces of lumber. The cutting yielded 14 base logs (0-3m above stump level), 14 lower middle logs (3-6m above stump level), 14 upper middle logs (6-9m above stump level), and 5 top logs (9-12m above stump level). Sampling of logs, moving up a tree, ceased if the minimum measured diameter fell below 150mm. All logs were numbered then removed from the sites in the green condition for conversion in the Maritime Forest Ranger School Training Sawmill, Fredericton. Disks for moisture content and density measurements were removed at the sawmill.

Prior to conversion both ends of each log were carefully inspected to locate the fifteenth annual ring and the area at either end falling within that ring painted. By this means the juvenile wood content at each end of a piece of lumber could be easily established following conversion of the logs into lumber. Logs were processed to maximise the yield of nominal 50 x 100mm pieces of lumber, which when dried and surfaced would be reduced to final section dimensions of 38 x 89mm at approximately 12 percent moisture content. The parent tree number and position in stem from which it was cut was recorded on each lumber specimen.

A total of 184 pieces of lumber were produced from the 14 sample trees, and dried to approximately 12 percent moisture content in two batches using a conventional commercial drying schedule. Following drying specimens were surfaced and tested mechanically. Mechanical tests included symmetrical third point bending using a span of 1512mm. This test arrangement was used to measure modulus of elasticity in bending about the major axis with the narrow face cut from nearest to the pith loaded in tension. The specimen was then turned over and modulus of elasticity measured again with the narrow face cut furthest from the pith loaded in tension. Modulus of elasticity was estimated over the middle third of the specimen in which region the bending moment was constant. Finally modulus of rupture was measured with the narrow face cut from nearest the pith loaded in tension. This was assumed to give the minimum strength for the two possible specimen orientations in bending about the major axis. Average time to failure was in the region of five minutes.

Subsidiary tests included measurement of relative density and moisture content, and modulus of elasticity for bending about the minor axis. Also detailed records were made of the physical features of each specimen, including the nature of the failure resulting from the test to measure modulus of rupture. The subsidiary information is reported by Shivnaraine [27].

Figure 1. Percent juvenile wood of White spruce as a function of average bole diameter and position in the stem - Sites 1 and 2.

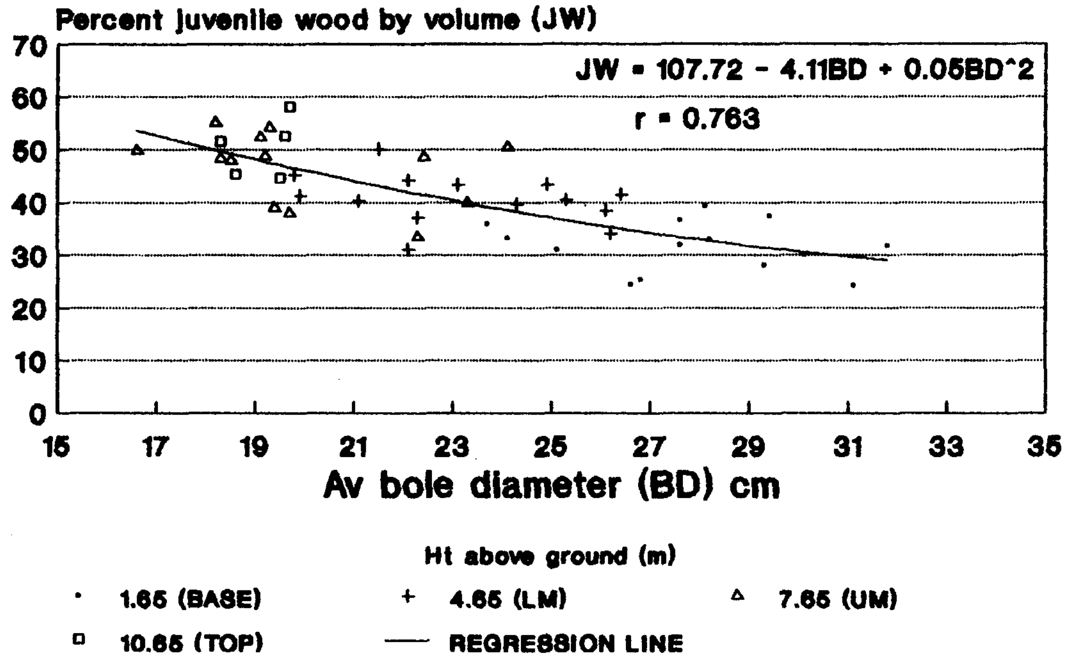
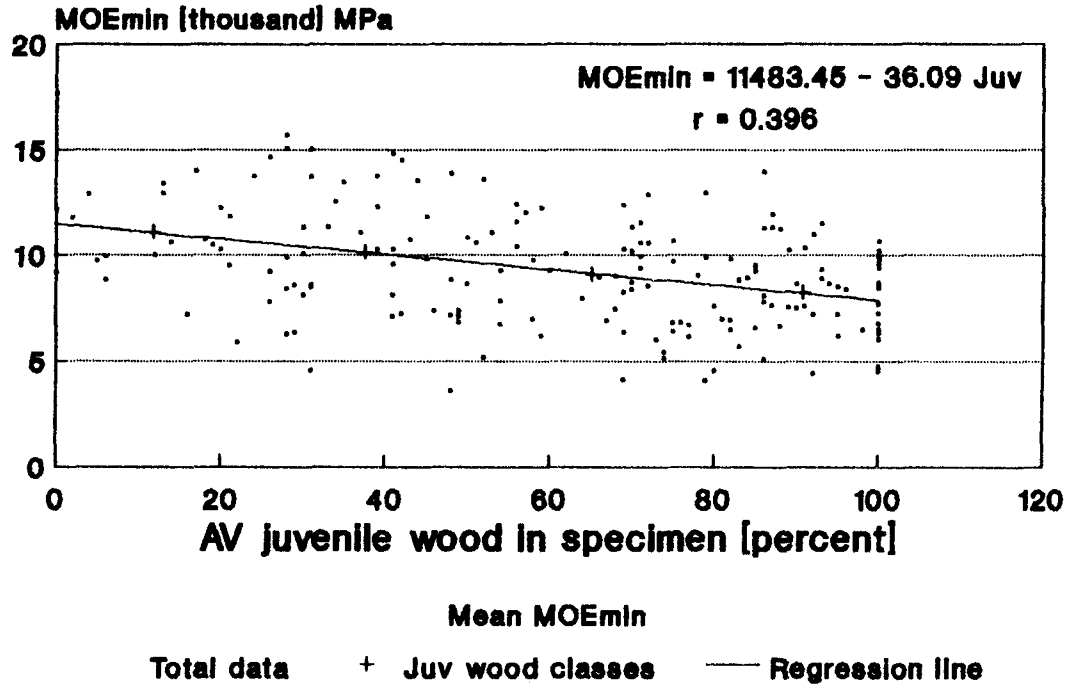


Figure 2. MOE_{min} vs Average percentage juvenile wood



RESULTS

Influence of minor variation in moisture contents between specimens were eliminated by adjusting all results to 12 percent moisture content according to the procedures of ASTM D2915 (1987). Moisture variations were those normally observed between pieces of lumber in a kiln batch and between batches of nominally the same material. Unadjusted properties of lumber corresponded to moisture contents between 8.5 and 14.4 percent.

Figure 1 shows the observed percentages of juvenile wood for each of the 47 bole samples. Individual values were determined by averaging the proportion at either end of a 3m long bole sample. It can be seen that the trend is for the juvenile wood content to reduce with an increase in absolute bole diameter and increase with height above stump level. The proportions of the lumber samples falling into different categories based on juvenile wood content are given in Table 3.

Table 3 - Proportion of lumber specimens in each category based on juvenile wood content

Percentage of cross-section contained in first fifteen annual rings	Number of pieces	Proportion of lumber samples (%)
0-25 (Mature)	23	12.5
26-50 (Mildly juvenile)	46	25.0
51-75 (Moderately juvenile)	45	24.5
76-100 (Juvenile)	70	38.0

Results of this table are discussed in more detail in the next section of the paper.

Table 4 summarises the variation in bending stiffness and strength properties of the lumber specimens according to the height above the ground from which the lumber is cut. Also shown in Table 4 is variation in relative density based on dry weight and volume.

Table 4 - Variation in average bending stiffness and strength properties, and relative density according to position in the stem (Values are for 12% moisture content).

Position in tree stem	MOE_{max} 1/ (MPa)	MOE_{min} 1/ (MPa)	MOR 2/ (MPa)	Relative density (= Mo/Vo x 10^{-3})	No. of specimens
Base (1.65m)	9969 (28.8) 3/	9648 (29.5)	32.7 (37.5)	0.335 (7.9)	77
Lower middle (4.65m)	9810 (27.7)	9446 (28.0)	29.6 (36.3)	0.333 (7.6)	60
Upper middle (7.65m)	8775 (26.7)	8340 (27.5)	25.0 (39.2)	0.335 (7.1)	37
Top (10.65m)	9342 (18.6)	8754 (17.9)	26.7 (22.2)	0.326 (5.6)	10
Total	9642 (27.9)	9270 (28.6)	9.8 (38.1)	0.334 (7.5)	184

Notes: 1/ MOE_{max} and MOE_{min} refer to modulus of elasticity in bending about major axis. Subscripts denote values for two specimen orientations tested per specimen.

2/ MOR signifies modulus of rupture in bending about major axis.

3/ Bracketed values are coefficients of variation expressed as percentages.

The influence of percentage of juvenile wood on modulus of elasticity and on modulus of rupture of the lumber are shown in Figures 2 and 3, and Table 5. It can be seen that there is an influence of percentage of juvenile wood on both modulus of elasticity or modulus of rupture. Although not reported in detail here, it was also found that only weak relationships exist between parameters such as general slope-of-grain, rings per inch and relative density, and bending stiffnesses and strengths of the lumber specimens tested. Related work by Zhou has demonstrated a strong correlation of both modulus of rupure and modulus of elasticity with projected knot area [30]. Thus both proximity of the pith and projected knot area should be considered in visual stress grading of White spruce lumber.

DISCUSSION

If it had been decided to adopt a similar philosophy to that of Barrett and Kellogg [3] concerning classification of lumber as juvenile or mature wood, approximately 63 percent of pieces of lumber would have been classified as juvenile, and 37 percent would have been classified as mature. Presuming that this is a realistic reflection of expectations for products from plantation grown softwoods, significant effort will have to be directed towards avoidance of problems associated with juvenile core material, e.g. drying degrade, if high quality solid wood products are to be produced from plantation material 50 to 60 years old.

Table 4 shows that modulus of rupture of lumber tends to be reduced the higher up the tree stems the lumber is cut. Table 5 shows that modulus of rupture of lumber tends to be reduced if the proportion of juvenile wood is increased. For example, the mean bending strength of lumber from base bole samples was 131 percent of that for lumber from upper middle bole samples. Similarly, the mean bending strength of lumber from class 1 samples (0-25 percent juvenile wood) was 153 percent of that for lumber from class 4 samples (76-100 percent juvenile wood). Variability in bending strength was found to be approximately constant at different heights above the stump at which lumber was cut (ignoring lumber from top bole samples). From Figure 3, Table 4 and statistical analysis, the percentage of juvenile wood in a piece of lumber and "height" in the tree stem from which lumber was cut are both good predictors of bending strength. Therefore, they can be used as indicators of likely quality of the lumber, in terms of bending strength. For practical purposes, lengthwise position in the tree stem is a more useful segregation criterion than percentage juvenile wood.

Table 5 - Variation in average bending stiffness and strength properties, and relative density according to juvenile wood class (Values are for 12%moisture content)

Juvenile wood classe	MOE_{min} 1/ (MPa)	MOR2 (MPa)	Relative density (= Mo/Vo x 10^{-3})	No. of specimens
Class 1 (0-25)*	11092 (22.4)3	39.95 (33.5)	0.352 (8.1)	23
Class 2 (26-50)*	10117 (30.0)	30.63 (45.9)	0.340 (8.30)	46
Class 3 (51-75)*	9082 (25.7)	29.55 (31.2)	0.326 (5.60)	45
Class 4 (76-100)*	8237 (25.7)	26.13 (28.0)	0.329 (6.7)	70

Notes: 1/ MOE_{min} refer to modulus of elasticity in bending about major axis. Subscript denotes value for most flexible orientation of specimen.
2/ MOR signifies modulus of rupture in bending about major axis.

From Table 4 it can be seen that there is a general trend of reduction in modulus of elasticity of lumber in bending the higher up the tree stems the lumber is cut. Similarly from Table 5 the reduction in modulus of elasticity of lumber is associated with the proportion of juvenile wood in the samples.

The variability in stiffness of lumber from a particular category of height above stump does not differ greatly from corresponding values averaged across all specimens. (A possible exception is lumber from "top bole sections", but the number of samples from top bole sections is too small for such an exception to be suggested with any certainty.) Based on Figure 2, Table 5, and more detailed analysis not reported here, the percentage of juvenile wood in a piece of lumber is a good predictor of modulus of elasticity of White spruce lumber cut from a plantation.

The above results indicate that it might be possible to employ lengthwise position in a tree stem as a simple means of segregating saw logs into classes yielding different ranges of lumber "quality". It is envisaged that lumber from a given class of logs should be machine stress graded using a machine controlled process such as that described by Fewell [10], where lumber is typically sorted into two structural grades and rejects. Combinations of grades sorted simultaneously would be selected to be appropriate to each class of logs. This two tier method of sorting (stress grading) material should be capable of significantly reducing the range of mechanical properties in each stress grade compared with a case where there is no segregation of material on the basis of position in a tree stem. As a result, the proportion of material going into higher value grades could be increased relative to current practice.

In Canada and other countries some companies transport coniferous wood to the sawmills in full tree form for reasons of economy. This practice makes the sequence of sorting described above viable as full-length stems arriving at the sawmill can be segregated into log classes under a more easily controlled system than might be possible in the forest.

Clearly there is a significant amount of work that would have to be done before the ideas outlined above could be put into practice. Further study is needed to answer questions such as the influence of position in the tree stem on mechanical properties of plantation lumber loaded in tension or compression parallel to grain, and how results vary if the size and length of the lumber is varied. As discussed in the introduction, the proportion of coniferous forest in plantation is going to be increasing on a world-wide basis. Now seems an appropriate time to devise ways of gaining a maximum benefit from this resource.

CONCLUSIONS

Based on the work discussed here, some preliminary conclusions are:

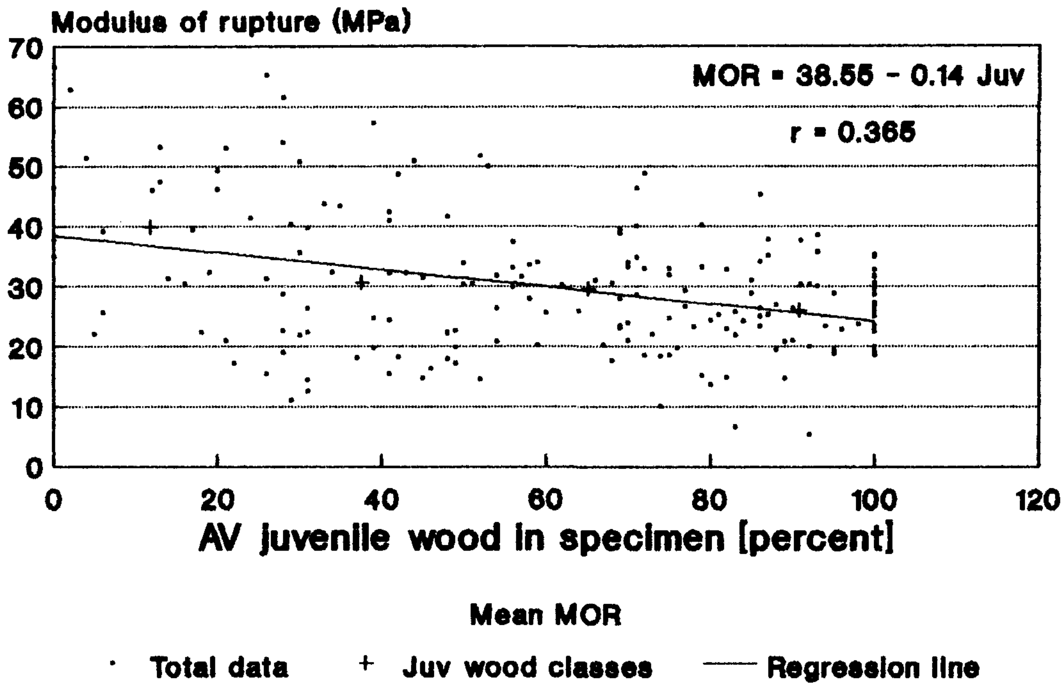
1. Over the next ten to twenty years the proportion of wood from coniferous forests in plantation will increase significantly. The proportion of solid wood products for which direct allowance must be made for presence of juvenile core material during processing of logs will also increase significantly.

2. Position in the tree stem from which it is cut has only a moderate influence on bending stiffness of 38 x 89mm lumber from plantation grown Eastern Canadian White spruce 50 to 60 years old.

3. Height in the tree stem from which it is cut is a good indicator of bending strength of 38 x 89mm lumber from plantation grown Eastern Canadian White spruce 50 to 60 years old.

4. Percentage juvenile wood in a piece of lumber is a good indicator of bending strength of 38 x 89mm lumber from plantation grown Eastern Canadian White spruce 50 to 60 years old. However this seems to be a less practical means of segregating material than using height in the tree stem as an indicator of strength.

Figure 3. MOR vs Average percentage juvenile wood



5. Potential exists for increasing the yield of higher value grades of lumber if the two tier approach to sorting (stress grading) described in this paper is adopted. The two tiers consist of sorting logs into classes on the basis of lengthwise position in the tree stem, and machine stress grading with log class specific machine settings. It is not clear whether this conclusion applies to parent material other than Eastern Canadian plantation grown White spruce.

REFERENCES

[1] Aldridge, F. and R.H. Hudson, 1959. Growing softwoods. Quarterly Journal of Forestry. Vol. 53: 210-219.

[2] American Society for Testing Materials, 1985. Standard methods for evaluating allowable properties of structural lumber. ASTM D2915-84. ASTM, Philadelphia.

[3] Barrett, J.D. and R.M. Kellogg, 1984. Strength andstiffness of second-growth Douglas-fir dimension lumber. Contract No. 50-69-559. Forintek Canada Corp., Vancouver, vi + 66.

[4] Barbour, J., 1988. A review of the literature on the wood quality of white spruce (Picea glauca) (second of two reports). Project No. 04-55-12X-002. Forintek Canada Corp., Ottawa, v + 68pp.

[5] Bendtsen, B.A., 1978. Properties of wood from improved and intensely managed trees. Forest Products Journal. Vol. 28 (10): 61-72.

[6] Bendtsen, B.A. and J. Senft, 1986. Mechanical and anatomical properties in individual growth rings of plantation grown eastern cottonwood and loblolly pine. Wood and Fiber Science. Vol. 18 (1): 23-38.

[7] Brunden, M.N., 1964. Specific gravity and fiber length in crown formed and stem formed wood. Forest Products Journal. Vol. 14: 13-17.

[8] Clark, A. (III) and J.R. Saucier. 1989. Influence of initial planting density, geographic location, and species on juvenile wood formation in southernpine. Forest Products Journal. Vol. 39: 42-48.

[9] Erickson, H.D. and T. Arima, 1974. Douglas fir wood qualities studies part II: Effects of age and simulated growth on fibril angle and chemical constituents. Wood Science and Technology. Vol. 8: 255-265.

[10] Fewell, A.R., 1986. Derivation of settings for stress grading machines: A brief description of the approach used to derive settings in the U.K. Building Research Establishment, United Kingdom.

[11] Gorman, T.M., 1985. Juvenile wood as a cause of seasonal arching in trusses. Forest Products Journal. Vol. 35 (11/12): 35-40.

[12] Isebrands, J.G., and C.M. Hunt, 1975.Growth and wood properties of rapid grown Japanese Larch. Wood and Fiber. Vol. 7 (2): 119-128.

[13] Keith, C.T. and G. Chauret, 1988. Basic wood properties of european larch from fast-growth plantations in eastern Canada. Canadian Journal for Forestry Research. Vol. 18: 1325-1331.

[14] Knigge, W., 1960. The natural variability of wood as it affects selection of test material and structural application of wood. Proceedings: World Forestry Congress 5th. Vol 3: 1362-1367.

[15] Kuhnke, D.H., 1989. Silviculture Statistics for Canada: An 11-Year Summary. Information report MOR-X-301, 81 pp.

[16] Larsen, P.R., 1962. A biological approach to wood quality. Tappi. Vol. 45 (6): 443-448.

[17] Larsen, P.R., 1969. Wood formation and the concept of wood quality. Yale University School of Forestry. Bulletin # 74: 1-54.

[18] Moody, R.C., 1970. Tensile strength of finger joints in pith-associated and non-pith associated southern pines 2 by 6's. USDA Forest Service Research Paper. FPL 138. Forest Products Laboratory, Madison, Wisconsin. 20 pp.

[19] Oliver, C.D. 1985. Silviculture and juvenile wood. Proceedings of Forest Products Research Society Workshop on Juvenile Wood. Proceedings 47309. FPRS, Madison, Wisconsin. 29-34.

[20] Panshin, A.J., and C. de Zeeuw, 1980.Textbook of wood technology. Structure, identification, properties and uses of the commercial woods of the United States and Canada, 4th ed. McGraw-Hill Book Co., Toronto, XIV +722 pp.

[21] Perry, T.O. and W.C. Wang, 1958. Variation in the specific gravity of slash pines and its genetic and silvicultural implications. Tappi Vol. 41 (4): 178-180.

[22] Rendle, B.J., 1959. Fast-grown coniferous timber - some anatomical considerations. Quarterly Journal of Forestry. Vol. 53: 116-122.

[23] Rendle, B.J., 1960. Juvenile wood and adult wood. Journal of Institute of Wood Science. Vol. 1 (5): 58-61.

[24] Sanwo, S.K., 1987. The characteristics of the crown-formed and stem-formed wood in plantation grown teak (tectona Brandis L.f) in Nigeria. Journal of Institute of Wood Science. Vol 11 (2): 85-88.

[25] Sebastian, L.P., 1969. Investigation of some anatomical and physical properties of White spruce sapwood and heartwood. Annual progress report. For. Prod. Lab of Canada. Project at University of New Brunswick. Project No.: EMR-F-29. 44 pp.

[26] Senft, J.F., B.A. Bendtsen, and W.L. Galligan, 1985. Weak wood - Fast grown trees make problem lumber. Journal of Forestry. Vol. 83 (8): 476-484.

[27] Shivnaraine, C.S. 1989. Within stem variation in bending strength and stiffness of lumber from plantation grown white spruce. MScFE Thesis, University of New Brunswick.

[28] Taylor, F.W., 1979. Property variation within stems of selected hardwood growing in the mid south. Wood Science. Vol. 11 (3): 193-199.

[29] Yank, K.C., C.A. Benson and J.K. Wong, 1986. Distribution of juvenile wood in two stems of Larix Laricina. Canadian Journal of Forestry Research. Vol. 16: 1041-1049.

[30] Zhou, H. 1989. The influence of drying, knots and slope of grain on bending properties of white spruce. MScFE Thesis, University of New Brunswick.

[31] Zoble, B.J., and R.L. McElwee. 1958. Natural variation in wood specific gravity of loblolly pine, and an analysis of contributing factors. Tappi Vol. 41 (4): 158-161.

[32] Zoble, B.J., 1984. The changing quality of the world wood supply. Wood Science and Technology. Vol. 18: 1-17.

[33] Zoble, B.J., C. Webb, and F. Henson, 1959. Core of juvenile wood of loblolly and slash pine trees. Tappi Vol. 42 (5): 345-356.