RELATIONSHIP BETWEEN LOG AND LUMBER MODULUS OF ELASTICITY

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ABSTRACT

Past nondestructive evaluation (NDE) research efforts have paved the way for the successful use of NDE for determining the quality of finished wood products. However, little effort has been expended on developing nonvisual NDE techniques for use in grading or sorting logs for intemal soundness and structural quality. This paper describes the results of a study that addressed this problem. Longitudinal stress wave NDE techniques were used to evaluate the quality of 193 balsam fir and eastern spruce logs prior to processing into lumber. Longitudinal speed-of-stress wave transmission was used to determine the modulus of elasticity (MOE) for each log. The MOE of each piece of structural lumber cut from the logs was then determined using transverse vibration NDE techniques. A strong relationship was observed between the MOE of the logs and the lumber obtained from the logs.

Historically, the wood products community has used nondestructive evaluation (NDE) techniques almost exclusively for sorting or grading of structural products. Two excellent examples of the use of nonvisual NDE techniques are machine stress rating (MSR) of lumber and ultrasonic veneer grading in laminated veneer material production. As currently practiced in North America, MSR couples visual sorting criteria with nondestructive measurements of the stiffiness of a piece of lumber to assign it to an established grade (7). Similarly, laminated veneer lumber production facilities use stress wave NDE techniques to sort incoming veneer into strength categories, which are established through empirical relationships between stress wave velocity and strength (13).

Although research efforts have paved the way for the successful use of NDE with finished products, little effort has been expended on developing NDE techniques for use in grading or sorting logs for structural quality. Conventional log grades are developed from product recovery information based on grades of the end product. It is questionable whether the visual grading procedures currently used for logs adequately assess the potential quality of structural products manufactured from them, especially those in which MOE is of primary concern. In addition, the research that has been conducted on log NDE has focused on the use of relatively costly scanning techniques (2-5,8, 14), which can have limited applications in the field. Techniques that have been investigated include NMR and x-ray-based tomography. Some promising work was performed by Aratake et al. (l). They utilized longitudinal vibration characteristics to estimate the quality of lumber obtained from a small sample of logs. Galligan et al. (6) conducted a similar study with six Douglas-fir logs and were able to rank the lumber obtained from the logs, with reasonable accuracy, based on the log NDE information.

Considerable savings in material and processing costs might be realized if precise log sorting technologies, based on anticipated final product quality, can be achieved. The addition of NDE techniques to visual assessment procedures could also ease industrial adaptation to a changing resource base that may result from an increasing emphasis on ecologically based forest management strategies.

The goal of the research reported herein was to investigate the use of longitudinal stress wave NDE techniques to evaluate log quality based on the potential structural quality of products obtained from them. Specific objectives were to 1) determine if a relationship exists between visual log grade and the MOE of lumber obtained from it; and 2) examine the relationship between the MOE of a log and that of the lumber obtained from the log.

MATERIALS AND METHODS

A schematic diagram outlining our experiment is shown in **Figure 1.** Ninety-five balsam fir and 98 eastern spruce logs were evaluated at a mill yard, For each log, longitudinal speed-of-sound transmission was determined using the setup shown in **Figure 2.** The setup consisted of an accelerometer fixed to one end of the log. A stress wave was introduced to the specimen through a hammer impact on the opposite end, and the stress wave was recorded on an oscilloscope to obtain the time between

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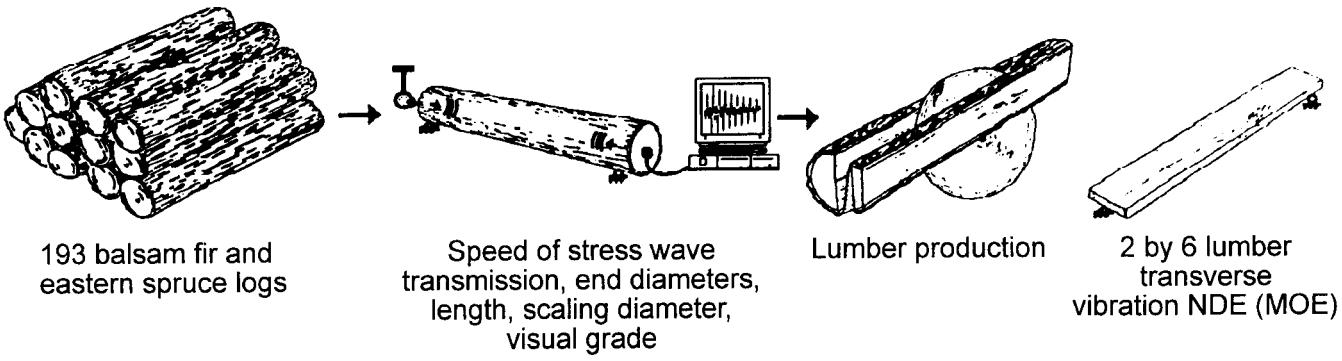

Figure 1. — Flowchart of study.

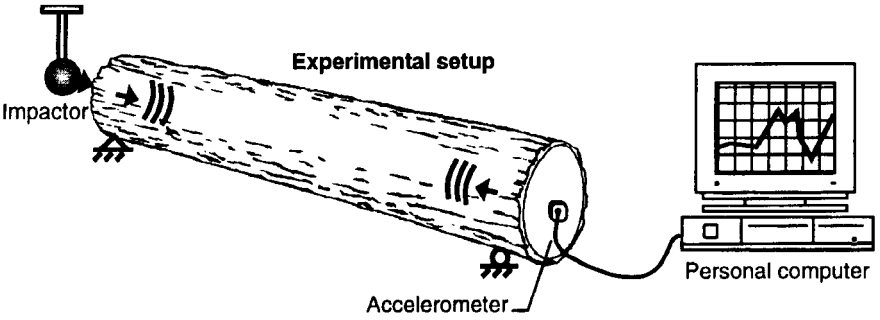

Figure 2. — Experimental test setup.

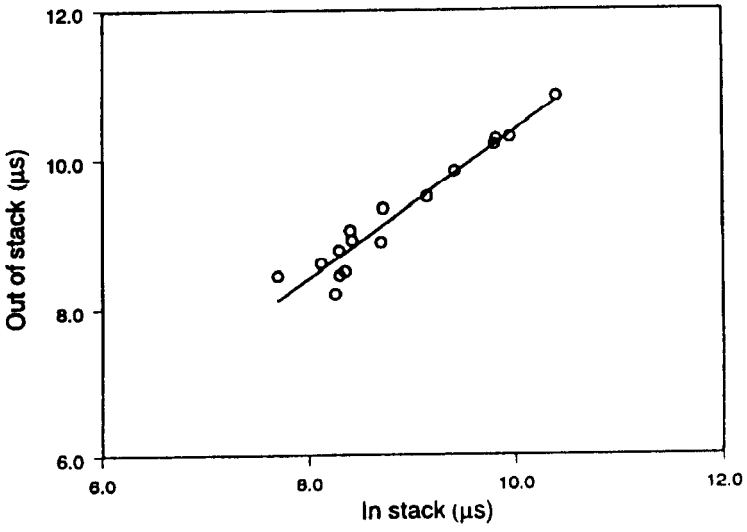

Figure 3. — Results obtained from stress wave transmission measurements made on logs in the stack and out of the stack.

TABLE 3. — Relationship between log MOE and mean MOE of boards cut from the log.

Species	Sample size	A + B = (MOE log) A	B	r^2
Mean board MOE				
Balsam fir	95	0.857	0.638	0.33
White spruce	98	-0.133	1.228	0.82
Individual board MOE				
Balsam fir	324	0.863	0.634	0.17
Eastern spruce	418	-0.138	0.230	0.50

peaks. A detailed description of the instrumentation and analysis procedures used is given by Ross et al. (10), and a discussion of the application to large wood specimens is included in Schad et al. (12). Although most NDE tests performed on the logs were done with the logs removed from a stack, preliminary results **(Fig. 3)** revealed that an equivalent measurement could be made while they were in a stack. The irregular shapes resulted in enough space between individual logs to facilitate an accurate measurement. End diameters, length, and scaling diameter were measured for each log. In addition, moisture content (defined as the weight of water in wood expressed as a fraction, usually a percentage, of the weight of ovendry wood), largest knot in the log, and visual log grade based on eastern pine sawlog grading criteria (9) were determined for each log.

The logs were then sawn into lumber. Special care was taken to ensure that individual lumber specimens could be traced to the log from which they were sawn. Flatwise MOE was then determined for each green lumber specimen using transverse vibration NDE techniques (1 1). Average and individual lumber MOE values for each log were then compared with MOE values of the log.

RESULTS AND DISCUSSION

PHYSICAL CHARACTERISTICS

Table 1 summarizes the various physical characteristics of lumber obtained from the logs as a function of a visual sawlog grade. Note that for both species, the average moisture content exceeded the fiber saturation point (about 30%). The individual values ranged from 56 to 153 percent for the balsam fir logs and from 66 to 149 percent for the eastern spruce logs. Density values for the balsam fir logs ranged from 48.2 to 52

pcf (772.2 to 833.04 kg/m^3), and those for eastern spruce ranged from 33.5 to 38.1 pcf (536.67 to 610.36 kg/m^3).

Results obtained from the NDE measurements of both the logs and individual lumber specimens are summarized in **Table 2.** The MOE for the balsam fir logs ranged from 0.96 to 2.20 × 10^6 psi, (6.619 to 15.167 GPa) and the range for eastern spruce was 0.91 to 2.31 × 10^6 psi (6.274 to 15.925 GPa). It is interesting to note that little correlation was found to exist between MOE values of the log and corresponding visual sawlog grade as applied. For example, little difference was noted in MOE values for visual grades 1 and 2 of eastern spruce logs. Similarly, little or no relationship was observed between average lumber MOE and visual log grade. The MOE values for lumber obtained from the balsam fir logs ranged from 1.00 to 2.92 × 10^6 psi (6.895 to 20.13 GPa) and lumber obtained from the eastern spruce logs ranged from 0.68 to 2.65 × 10^6 psi (4.689 to 18.27 GPa).

MOE RELATIONSHIPS

Statistical analysis procedures were used to investigate the relationships between lumber MOE values and MOE of the log **(Table 3).** As expected, results of a linear regression analysis revealed that MOE of the log correlated reasonably well to the average MOE of the lumber. **Figures 4** and **5** illustrate these relationships. A weaker relationship was observed between MOE of the log measurements and individual MOE values of the lumber specimens, illustrated in **Figures 6** and **7.**

CONCLUSIONS

Based on our results, we conclude the following:

- For eastern spruce and balsam fir logs, little relationship exists between the visual sawlog grade of a log and the MOE of lumber obtained from the log.
- The MOE of a log correlates well with the average MOE of lumber obtained from the log.
- A relationship exists between the MOE of individual lumber specimens obtained from the log and the MOE of the log.

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TABLE 1. — Moisture content and density of individual lumber specimens taken from balsam fir and eastern spruce logs.[a]

Species and visual log grade	Number of logs	Moisture content Average	Moisture content Minimum-Maximum	Density Average	Density Minimum-Maximum
		(%)		(pcf)	
Balsam					
1	0	--	--	--	--
2	30	98	56-40	49.3	37.8-61.7
3	63	103	66-153	76.0	71-80
4	2	76	71-80	52.0	45.1-58.1
Eastern spruce					
1	17	68	23-131	38.1	25.6-58.0
2	18	74	34-129	38.0	28.1-63.0
3	60	75	16-149	37.9	27.2-59.3
4	3	59	38-91	33.5	28.4-39.4

[a] 1 pcf = 16.01 kg/m^3.

TABLE 2. — MOE of balsam fir and eastern spruce logs and indivudal lumber specimens.[a]

Species and visual log grade	MOE of log Average	MOE of log Minimum-Maximum	MOE of lumber Average	MOE of lumber Minimum-Maximum
	(× 10^6 psi)			
Balsam fir				
1	--	--	--	--
2	1.56	1.19-2.20	1.87	1.24-2.92
3	1.37	0.96-1.79	1.72	1.00-2.80
4	1.56	1.30-1.83	1.71	1.47-1.98
Eastern spruce				
1	1.52	1.13-2.31	1.69	0.90-2.40
2	1.49	1.18-1.81	1.71	1.03-2.65
3	1.34	0.91-1.93	1.47	0.68-2.35
4	1.21	1.10-1.39	1.36	0.99-2.06

[a] 1 psi = 6.894 × 10^6 GPa.

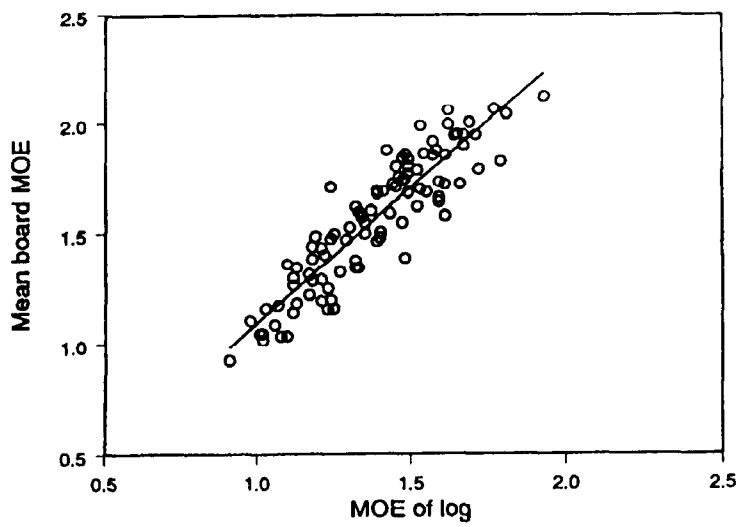

Figure 4. — Mean board MOE as a function of MOE of logs for eastern spruce (MOE is × 10^6 psi; 1 × 10^6 psi = 6.894 GPa).

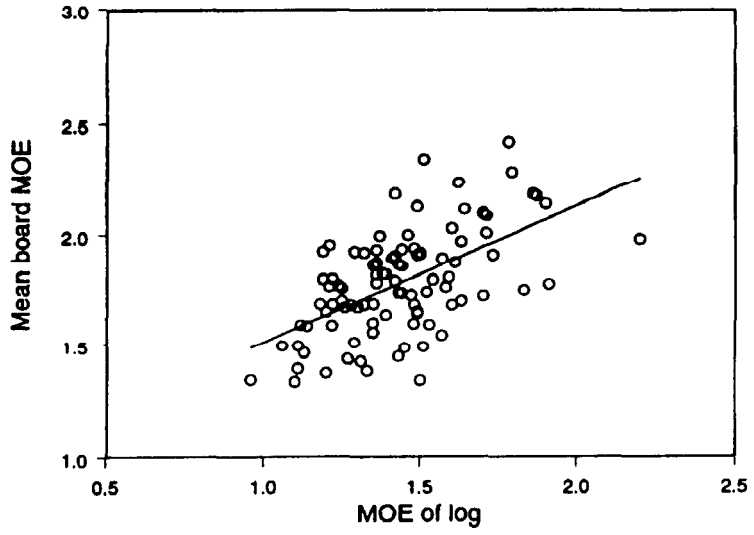

Figure 5. — Mean board MOE as a function of MOE of log for balsam fir (MOE is × 10^6 psi; 1 × 10^6 psi = 6.894 GPa).

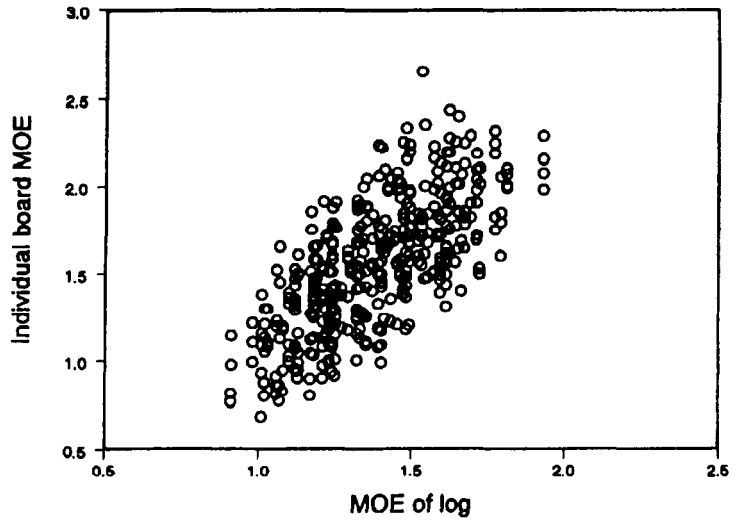

Figure 6. — Individual board MOE as a function of MOE of log for eastern spruce (MOE is × 10^6 psi; 1 × 10^6 psi = 6.894 GPa).

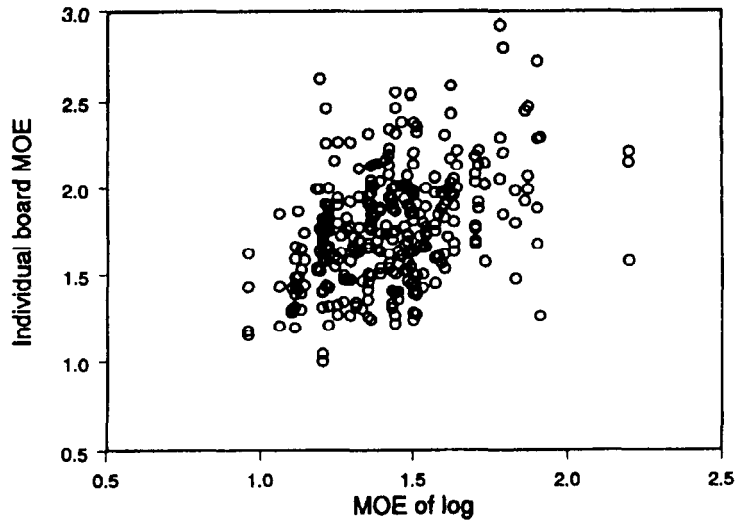

Figure 7. — Individual board MOE as a function of MOE of log for balsam fir (MOE is × 10^6 psi; 1 × 10^6 psi = 6.894 GPa).

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