Stress Wave Sorting of Red Maple Logs for Structural Quality

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ABSTRACT

Existing log grading procedures in the United States make only visual assessments of log quality. These procedures do not incorporate estimates of the modulus of elasticity (MOE) of logs. 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.

The purpose of this study was to investigate the use of stress wave nondestructive evaluation (NDE) techniques to sort red maple logs for the potential quality of lumber obtained from them. Twenty red maple logs were nondestructively evaluated using longitudinal stress wave techniques and sorted into four stress wave grades. The logs were then sawn into lumber. Finally, the lumber specimens were dried and graded a final time using longitudinal stress wave techniques. The results of this study showed that good relationships existed between stress wave times measured in logs and the lumber produced from the logs. It was found that log stress wave grades have a positive relationship with the lumber grades. Logs with high stress wave grades produced high grade lumber. These findings indicate that the longitudinal stress wave technique could be used in sawmills to sort logs/cants for the production of high MOE products.

INTRODUCTION

NDE of wood materials has a long history of application in the wood products industry. Visual lumber grading is perhaps one of the earliest NDE forms. Visual assessment of a piece of lumber requires the grader to estimate a strength ratio on the basis of observed external defects. The ratio is used to estimate the strength of lumber relative to a similar piece without defects. The estimation is based on standard lumber grading rules; however, it is entirely subjective and governed by the judgment of the grader. Furthermore, the value assigned to clear lumber of comparable size is only an estimated minimum based on tests of small, clear specimens.

Machine stress rating (MSR), a non-visual NDE technique, offers an opportunity to eliminate both of these limitations. As currently practiced in North America, MSR couples visual sorting criteria with nondestructive measurements of the stiffness of a piece of lumber to assign it to an established grade based on a pre-established strength MOE relationship (6). Annually, nearly 900 million board feet (BF) of softwood lumber are graded in this manner (11). 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. Existing log grading procedures in the United States make only visual assessments of log quality (7). These procedures do not incorporate estimates of the MOE of the wood in logs. 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. In recent years, some research has been conducted to investigate the feasibility of using longitudinal stress wave/vibration techniques for evaluating log quality. Aratake et al., (1) utilized longitudinal vibration characteristics to estimate the quality of lumber obtained from 59 Sugi logs and observed a strong relationship between the natural frequency of logs and log MOE. Ross and others (10) examined the relationship between log measurements and the quality of lumber obtained from 95 balsam fir logs and 98 eastern spruce logs. They observed useful relationships, with the relationship being exceptionally strong for eastern spruce logs. Green and Ross (7) described the results from a series of studies using the same technique with Douglas fir, western hemlock, and southern pine logs in which comparable results were obtained.

The objective of this study was to investigate the use of longitudinal stress wave NDE techniques to sort red maple logs based on the potential structural quality. Specific objectives were to 1) examine the relationships between the stress wave times measured in logs and corresponding cants and lumber; and 2) determine if a positive relationship exists between log stress wave grades and the grades of lumber obtained from the logs.

MATERIALS AND METHODS

Twenty red maple logs were obtained from Potlatch Corporation in Cloquet, Minnesota. They were evaluated at the Forest Products Laboratory in Madison, Wisconsin. For each log, longitudinal stress wave transmission time was determined using the experimental setup shown in Figure 1. The setup consisted of a specially equipped personal computer, a hand-held hammer, and an accelerometer fixed to one end of the log. A stress wave was induced in the log through a hammer impact on the opposite end, and the resulting stress wave was recorded in the computer. A detailed description of the instrumentation and analysis procedure used is given by Ross et al., (9) and a discussion of the application to large wood specimens is included in Schad and others (12).

One log was removed from the study due to inability to obtain a clear signal. It is unlikely that the log would have been selected for lumber because it had been damaged during logging and was an extremely low grade log. After testing each log, they were sawn into 2- x 4-in (51- x 101-mm) lumber. Special care was taken to ensure that individual lumber specimens could be traced to the log from which they were sawn. The green lumber was placed in an environmentally controlled room and dried to approximately 12 percent moisture content. Stress wave transmission time in the lumber was then measured after equilibration at 12 percent using a Metriguard 239A Stress Wave Timer and a Sylvatest ultrasound timer.

RESULTS AND DISCUSSION

Stress wave transmission times have been recognized as good indicators of wood strength and stiffness. In this paper, the SWT measured in red maple logs and lumber were reported on the unit per length basis (time/length). Therefore, lower SWT, that is higher stress wave speed, indicates higher strength and stiffness.

The SWT of logs ranged from 75.3-92.7 μs/ft with an average of 81.6 μs/ft. The SWT value for dry lumber was the average value of all the lumber (3-7 boards/log) obtained from each log. For the dry lumber, the SWT ranged from 58.4 to 67.6 μs/ft with a mean of 62.5 μs/ft for the Sylvatest and ranged from 61.4 to 69.9 μs/ft with a mean of 65.0 for the 239A Stress Wave

Timer. However, due to the loss of moisture content, the SWT measured on dry lumber decreased about 20 to 23 percent compared with that measured in green lumber and logs. Table 1 summarizes the SWT for the red maple logs and the dry lumber.

Regression analyses were also conducted to compare SWT values obtained from the two pieces of commercial equipment and for logs and corresponding lumber obtained from them. Specifically, SWTs were compared for logs and lumber. Results obtained from those analyses are summarized in Table 2. The results indicated that strong relationships existed between SWT of the lumber as measured using the 239A Stress Wave Timer and the Sylvatest (r=0.98). As expected, the correlation coefficient was as high for dry lumber and logs (r=0.76 using the 239A Stress Wave Timer and r=0.80 using the Sylvatest). This could be caused by several important factors that were involved in the conversion from logs to dry lumber, such as loss of moisture, removal of external materials, and drying defects. However, these relationships are strong enough to indicate that it should be possible to use SWT to sort red maple logs for the production of structural products. Figure 1 shows the relationship between log SWT and the dry lumber SWT obtained from the 239A Stress Wave Timer and the Sylvatest.

Table 1.--Stress wave transmission times of red maple logs and corresponding lumber produced from logs.

Product	Longitudinal Stress Wave Transit Time (μs/ft)			
	Average	Standard Deviation	Minimum	Maximum
Log	81.6	3.9	75.3	92.7
Dry Lumber 239A Stress Wave Timer	65.0	2.6	61.4	69.9
Dry Lumber Sylvatest	62.5	2.6	58.4	67.6

Table 2.--Regression analysis of SWT for red maple logs and corresponding lumber produced from logs.

Stress Wave Time (SWT) in Logs and Lumber (μs/ft)		Linear Regression Model $y = a + bx$	Correlation Coefficient R	Standard Error of Estimate S_{yx}
Y	X			
SWT in dry lumber from Sylvatest	SWT in dry lumber from 239A	y = 4.1 + 0.9756x	0.98	0.52
SWT in dry lumber from 239A Stress Wave Timer	SWT in log	y = 23.8 + 0.5048x	0.76	1.70
SWT in dry lumber from Sylvatest	SWT in log	y = 19.2 + 0.5307x	0.80	1.59

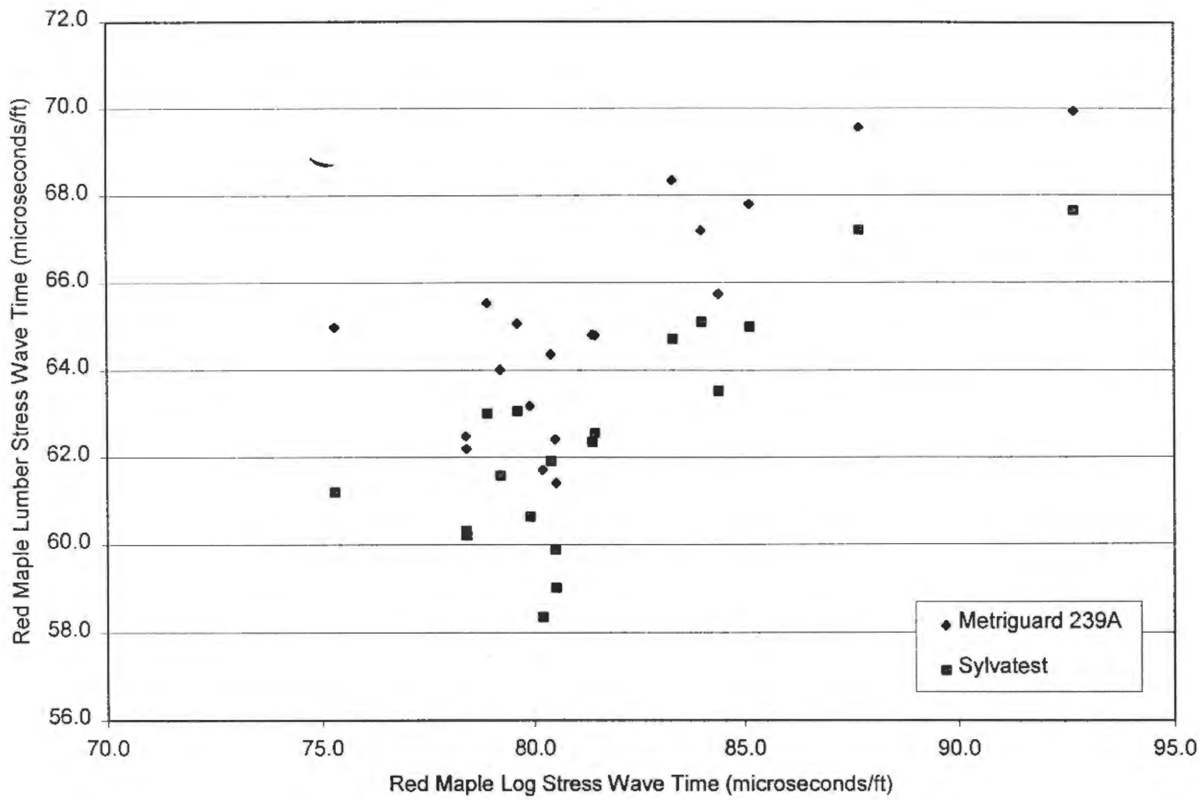

Figure 1.--Red Maple SWT relationship between log and dry lumber.

Based on results obtained from stress wave measurements, the red maple logs were sorted into four grades (G-I, G-II, G-III, and G-IV) as follows:

G-I < 83 μs/ft;
G-II = 83–91 μs/ft;
G-III = 91–100 μs/ft;
G-IV > 100 μs/ft.

It was found that the majority (95 percent) of the logs fell into G-I and G-II grades. Only 5 percent of logs were in G-III grade and 0 percent of logs were in G-IV grade. Table 3 shows the average lumber MOE for different log stress wave grades. Using the 239A Stress Wave Timer as a more conservative MOE estimate, the lumber produced from G-I logs has the highest average MOE of 2.52×10^6 lb/in^2, followed by the lumber produced from G-II logs that has an average MOE of 2.25×10^6 lb/in^2 and the lumber from G-III logs with an average MOE of 2.22×10^6 lb/in^2.

The relationship between log stress wave grades and lumber quality can be further illustrated by comparing log grades to lumber grades. The lumber produced from logs were therefore broken down into four grades (g1, g2, g3, and g4), based on lumber MOE determined from longitudinal stress wave tests:

g1 > 2.00 Mpsi;
g2 = 1.61–2.00 Mpsi;
g3 = 1.20–1.60 Mpsi;
g4 < 1.20 Mpsi.

Table 3 shows the average MOE and the lumber yields for four different log stress wave grades. In G-III grade (91 < SWT < 100 μs/ft) of logs, 100 percent of lumber produced was g1 grade. In G-II (83 < SWT < 91 μs/ft) and G-I (SWT < 83 μs/ft) grades of logs, the percentage of high grade lumber was also 100 percent respectively for g1 and g2 combined. High stress wave grade of logs contains high grade of lumber. If we use a log cut-off value of 91 μs/ft in this case, we can expect a 100 percent yield of g1 and g2 lumber from logs with a SWT value ≤ 91 μs/ft. This indicated that a significant improvement in the mechanical performance of red maple could be achieved with a simple sort-model to segregate "high" and "low" quality stress wave rated logs.

Table 3.--Modulus of Elasticity and lumber yields for the red maple log grades evaluated during this study.

Log Grade	Mean MOE (Mpsi)	Lumber Yield for each Log Grade (%)			
		g1	g2	g3	g4
G-I	2.52	98	2	-	-
G-II	2.25	83	17	-	-
G-III	2.22	100	-	-	-
G-IV	none	-	-	-	-

CONCLUSIONS

The results of this study showed that good relationships existed between SWTs measured in logs and the lumber produced from the logs. Log stress wave grades have a positive relationship with the grades of lumber produced from the logs. It was found that logs with high stress wave grades produced high grade lumber. If we use a log cut-off value of 91 μs/ft in this case, we can expect a 100 percent yield of g1 and g2 lumber from logs with a SWT value ≤ 91 μs/ft. Therefore, it was concluded that this longitudinal stress wave technique could be used in sawmills to sort logs for the production of high MOE products.

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