Wood Sci Technol 37 (2004) 531–537
DOI 10.1007/s00226-003-0202-8

Original

Stress wave sorting of red maple logs for structural quality

Xiping Wang, Robert J. Ross, David W. Green, Brian Brashaw,

Karl Englund, Michael Wolcott

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 for which MOE is of primary concern. The purpose of this study was to investigate the use of stress wave nondestructive evaluation techniques to sort red maple logs for the potential quality of lumber obtained from them. Ninety-five red maple logs were nondestructively evaluated using longitudinal stress wave techniques and sorted into four stress wave grades. The logs were then sawn into cants and lumber. The same procedure was used to obtain stress wave times in the cants and lumber. The lumber specimens were then dried and graded using a transverse vibration technique. The results of this study showed that good relationships existed between stress wave times measured in logs, cants, and the lumber produced from the logs. It was found that log stress wave grades have positive relationships with the lumber grades. Logs with high stress wave grades produced high-grade

Published online: 18 February 2004

X. Wang (✉), R.J. Ross, D.W. Green
Forest Products Laboratory,
USDA Forest Service,
One Gifford Pinchot Drive,
Madison, WI 53726-2398, USA
E-mail: xwang@fs.fed.us

B. Brashaw
Natural Resources Research Institute,
University of Minnesota-Duluth,
5013 Miller Trunk Highway,
Duluth, MN 55811-1442, USA

K. Englund, M. Wolcott
Wood Materials and Engineering Laboratory,
Washington State University,
Pullman, WA 99164-1806, USA

lumber. These findings indicate that the longitudinal stress wave technique has potential in sorting logs and cants for the production of high MOE products.

Introduction

Nondestructive evaluation (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 (Forest Products Laboratory 1999). 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 (Bodig and Jayne 1982).

Machine stress rating (MSR), a nonvisual 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 (Galligan et al. 1977). Annually, nearly 2.12 million m^3 (900 million board feet) of softwood lumber are graded in this manner (Ross et al. 1998). 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 (Sharp 1985).

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 (Green and Ross 1997). These procedures do not incorporate estimates of the modulus of elasticity (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 for 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 (Hailey and Morris 1987), which can have limited applications in the field. Techniques that have been investigated include x-ray and neutron radiography, computer tomography (CT), as well as magnetic resonance (MR) (Benson–Cooper et al. 1982; Burgess 1985; Chang et al. 1987; Funt and Bryant 1987; Hailey and Morris 1987; Holoyen and Birkeland 1987; Taylor et al. 1983).

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. (1992) utilized longitudinal vibration characteristics to estimate the quality of lumber obtained from 59 Japanese cedar logs and observed a strong relationship between the natural frequency of logs and log MOE. Ross et al. (1997) 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 and found that this relationship was exceptionally strong for eastern spruce logs. Green and Ross (1997) described the results from a series of studies using the same technique with Douglas-fir, western hemlock, and southern pine logs. Results were comparable with Ross et al. (1997).

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

Materials and methods

Ninety-five red maple logs were evaluated at a local sawmill in Buchanan, West Virginia, USA. Longitudinal stress wave transmission time was determined for each log. The stress wave measuring system 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 procedures used is given in Ross et al. (1994), and a discussion of the application to large wood specimens is included in Schad et al. (1995).

After this testing, each log was sawn into 152- by 203-mm (6- by 8-in.) cants. Each cant was then sawn into four pieces of 51- by 152-mm (2- by 6-in.) lumber. Special care was taken to ensure that individual lumber specimens could be traced to the cant and the log from which they were sawn. Stress wave transmission times in cants and lumber were then determined in green condition. After stress wave tests, the green lumber was placed in a dehumidification kiln and dried to approximately 12% moisture content. Stress wave time in lumber was also obtained in dry condition. Flatwise MOE was then determined for each dry lumber specimen using a transverse vibration NDE technique (Ross et al. 1991).

Results and discussion

Stress wave times in logs, cants, and lumber

Stress wave transmission times have been recognized as good indicators of wood strength and stiffness (Rippy et al. 2000; Ross et al. 1999). In this paper, the stress wave times (SWT) measured in red maple logs and corresponding cants and lumber were reported on the unit per length basis (time/length). Lower SWT, which corresponds to higher stress wave speed (length/time), indicates higher strength and stiffness.

Table 1 summarizes the stress wave transmission times measured in red maple logs and corresponding cants and lumber produced from the logs. The SWT of logs ranged from 254 to 355 μs/m with a mean of 289 μs/m, which was about 3% higher than that of cants and green lumber. The SWT value for lumber

Table 1. Stress wave transmission times (SWT) of red maple logs and corresponding cants and lumber produced from logs

Material	SWT (μs/m)			
	Mean	Standard deviation	Minimum	Maximum
Log	289	20.1	254	355
Cant	281	19.9	247	342
Green lumber	279	19.8	238	347
Dry lumber	230	15.1	199	270

was the average value of all four pieces of lumber obtained from each cant. It was found that the SWT of green lumber was very close to that of the cants. Statistical analysis indicated that there was no significant difference between SWT of cants and SWT of green lumber. However, due to the loss of moisture content, the SWT measured on dry lumber decreased about 18–20% compared with that measured in green lumber, cants, and logs.

Stress wave time relationships

Regression analyses were conducted to examine the relationships between SWT of logs and SWT of corresponding cants and lumber obtained from them. Specifically, stress wave times were compared for logs and cants, cants and lumber, and logs and lumber. Figure 1 shows the relationship between SWT of logs and SWT of cants. The relationships between SWT of logs and lumber and SWT of cants and lumber are shown in Figures 2 and 3.

Results obtained from regression analyses are summarized in Table 2. The results indicated that strong relationships existed between SWT of logs, cants, and green lumber (r=0.75–0.92). A good relationship was also found between SWT of logs and cants and SWT of dry lumber. As expected, the correlation coefficient was not very high for dry lumber and logs (r=0.68). This could be caused by several factors that were involved in the conversion from logs to dry lumber, such as loss of moisture, removal of outer materials, and drying defects. However,

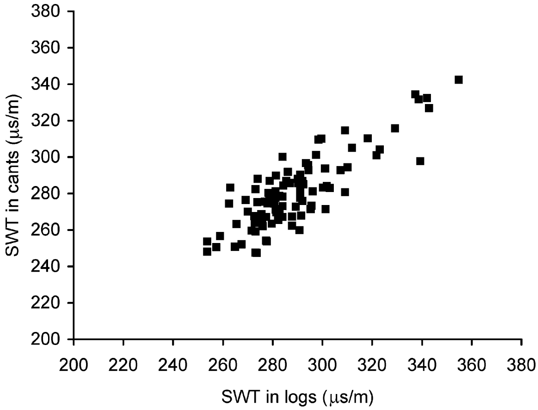

Fig. 1. Relationship of stress wave time (SWT) in logs and SWT in cants

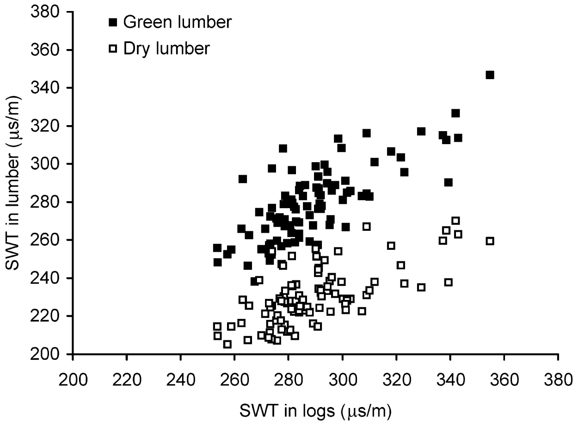

Fig. 2. Relationship of stress wave time (SWT) in logs and SWT in lumber

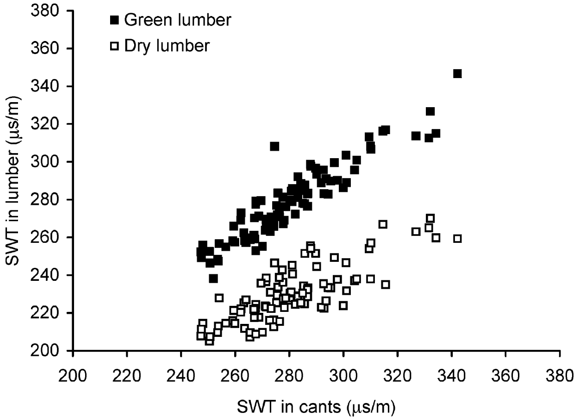

Fig. 3. Relationship of stress wave time (SWT) in cants and SWT in lumber

Table 2. Regression analysis of stress wave times (SWT) for red maple logs and corresponding cants and lumber produced from the logs

y	x	Linear regression model $y=a+bx$	Correlation coefficient r	Standard error of estimate S_{yx}
SWT of cant	SWT of log	$y=40.4+0.8316x$	0.82	10.93
SWT of green lumber	SWT of log	$y=60.5+0.7560x$	0.75	12.81
SWT of green lumber	SWT of cant	$y=21.1+0.9187x$	0.92	7.63
SWT of dry lumber	SWT of log	$y=82.3+0.5107x$	0.68	11.17
SWT of dry lumber	SWT of cant	$y=58.7+0.6096x$	0.80	9.06

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.

Log stress wave grades and lumber yield

Based on the results obtained from stress wave measurements, the red maple logs were sorted into four grades (G1, G2, G3, and G4) as follows:

G1	<272 μs/m
G2	272–298 μs/m
G3	298–328 μs/m
G4	>328 μs/m

The majority (78%) of the logs fell into the G1 and G2 grades. Only 15% of logs were in G3 grade, and 7% of logs were in G4 grade. Figure 4 shows the average lumber MOE for different log stress wave grades. The lumber produced from G1 logs had the highest average MOE of 12.82 GPa, followed by the lumber produced from G2 logs, which had an average MOE of 12.34 GPa, and the lumber from G3 logs with an average MOE of 11.03 GPa. The lumber from G4 logs had the lowest average MOE of 9.86 GPa.

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

g1	>13.79 GPa
g2	11.10–13.79 GPa
g3	8.27–11.02 GPa
g4	<8.27 GPa

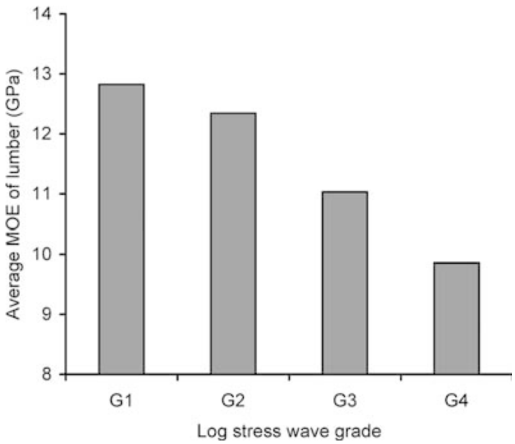

Fig. 4. Average lumber modulus of elasticity (MOE) for different log stress wave grades

Table 3. Lumber yields of stress-wave-graded red maple logs

Log grade	Number of logs	Average MOE of lumber (GPa)	Lumber yield in each lumber grade (%)			
			g1	g2	g3	g4
G1	17	12.82	30	56	14	0
G2	56	12.34	23	50	23	5
G3	15	11.03	7	36	51	6
G4	7	9.86	0	29	54	17

Table 3 shows lumber yields for four different log stress wave grades. The yield values for each log grade were the percentages of the total lumber produced from the logs that fell into that stress wave grade. Table 3 shows that 71% of lumber from G4 grade (SWT >328 μs/m) of logs fell into g3 and g4 grades, and no g1 lumber was produced in this log grade. In G3 grade (298< SWT <328 μs/m) of logs, 87% of lumber produced were g2 and g3 grades, 7 and 6% of lumber fell into g1 and g4, respectively. In G2 (272< SWT <298 μs/m) and G1 (SWT <272 μs/m) grades of logs, the percentages of high-grade lumber (g1 and g2) were 73 and 86%, respectively. Clearly, log stress wave grades have a positive relationship with the grades of lumber produced from the logs. Logs that have a high stress wave grade contain high-grade lumber. If we use a log cut-off value of 298 μs/m in this case, we can expect a 76% yield of g1 and g2 lumber from logs with a SWT value ≤ 298 μs/m, while the logs with a SWT value >298 μs/m can only yield 39% g1 and g2 lumber. 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.

Conclusions

The results of this study showed that good relationships existed between stress wave times measured in red maple logs, cants, and the lumber produced from the logs. Log stress wave grades have a positive relationship with the grades of lumber produced from the logs. We found that logs with high stress wave grades produced high-grade lumber. Longitudinal stress wave technology has potential in sorting logs for the production of high MOE structural products. The results of this study are promising; therefore, further development of a broader database is warranted.

References

Aratake S, Arima T, Sakoda T, Nakamura Y (1992) Estimation of modulus of rupture (MOR) and modulus of elasticity (MOE) of lumber using higher natural frequency of log in pile of logs. Possibility of application for Sugi scaffolding board. Mokuzai Gakkaishi 38(11):995–1001

Benson-Cooper DM, Knowles RL, Thompson FJ, Cown DJ (1982) Computed tomographic scanning for the detection of defects within logs. Bull. No. 8. Forest Res. Inst. Rotorua, New Zealand Forest Service, New Zealand

Bodig J, Jayne BA (1982) Mechanics of wood and wood composites. Van Nostrand Reinhold, New York

Burgess AE (1985) Potential application of medical imaging techniques to wood products. In: Proceedings of the 1st international conference on scanning technology in sawmilling, 8–11 Oct., San Francisco, Calif., pp vii-1/vii-13

Chang SJ, Wang PC, Olson JR (1987) Nuclear magnetic resonance imaging of hardwood logs. In: Proceedings of the 2nd international congress on scanning technology in sawmilling, Oakland/Berkely Hills, Calif., Pap. IX

Forest Products Laboratory (1999) Wood handbook – wood as an engineering material. Gen. Tech. Rep. FPL–GTR–113, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI

Funt BV, Bryant EC (1987) Detection of internal log defects by automatic interpretation of computer tomography images. For Prod J 37(1):56–62

Galligan WL, Snodgrass DV, Crow GW (1977) Machine stress rating: practical concerns for lumber producers. Gen. Tech. Rep. FPL–GTR–7, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI

Green DW, Ross RJ (1997) Linking log quality with product performance. In: Proceedings of the IUFRO all division 5 international conference, 7–12 July, Pullman, WA, International Union of Forestry Research Organizations, Rome, Italy

Hailey JR, Morris PI (1987) Application of scanning and imaging techniques to assess decay and wood quality in logs and standing trees. Forintek Canada Corp, Vancouver, Canada

Holoyen S, Birkeland R (1987) Industrial methods for internal scanning of log defects: a progress report on an ongoing project in Norway. In: Proceedings 2nd international congress on scanning technology in sawmilling, San Francisco, Calif., Pap. X1-X18

Rippy RC, Wagner FG, Gorman TM, Layton HD, Bodenheimer T (2000) Stress-wave analysis of Douglas-fir logs for veneer properties. For Prod J 50(4):49–52

Ross RJ, Geske EA, Larson GL, Murphy JF (1991) Transverse vibration nondestructive testing using a personal computer. FPL–RP–502, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI

Ross RJ, De Groot RC, Nelson WJ (1994) Technique for nondestructive evaluation of biologically degraded wood. Exp Tech 18(5):29–32

Ross RJ, McDonald KA, Green DW, Schad KC (1997) Relationship between log and lumber modulus of elasticity. For Prod J 47(2):89–92

Ross RJ, Brashaw BK, Pellerin RF (1998) Nondestructive evaluation of wood. For Prod J 48(1): 15–19

Ross RJ, Willits SW, Segen WV, Black T, Brashaw BK, Pellerin RF (1999) A stress wave based approach to NDE of logs for assessing potential veneer quality. Part 1. Small-diameter ponderosa pine. For Prod J 49(11/12):60–62

Schad KC, Kretschmann DE, McDonald K, Ross R, Green DW (1995) Stress wave techniques for determining quality of dimensional lumber from switch ties. FPL–RN–0265, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI

Sharp DJ (1985) Nondestructive testing techniques for manufacturing LVL and predicting performance. In: Proceedings of the 5th nondestructive testing of wood symposium. Washington State University, Pullman, WA, pp 99–108

Taylor FW, Wagner FG, McMillin CW, Morgan IL, Hopkins FF (1983) Locating knots by industrial tomography – a feasibility study. For Prod J 34(5):42–46