Stress wave nondestructive evaluation of green veneer: southern yellow pine and Douglas fir

Brian K. Brashaw

University of Minnesota-Duluth, Natural Resources Research Institute
5013 Miller Trunk Highway, Duluth, Minnesota 55811-1442

Robert J. Ross

USDA Forest Products Laboratory,
One Gifford Pinchot Drive, Madison, Wisconsin 53705

Roy F. Pellerin

Washington State University, Wood Materials and Engineering Laboratory
Pullman, Washington 99164-1806

ABSTRACT

The potential of using stress wave nondestructive evaluation techniques to sort green southern yellow pine and Douglas fir veneer into stress grades was evaluated. Stress wave nondestructive evaluation was used to separate green veneer into several grades for use in manufacturing engineered wood composites, most notably laminated veneer lumber. The effect of moisture content and preservative treatment on stress wave determined properties of green (wet) southern yellow pine and Douglas fir veneer was investigated during the preliminary stages of the project. A digital oscilloscope and a commercial stress wave timer were used to measure the transit time it took for an induced stress wave to travel the longitudinal length of each veneer. Stress wave transit times were measured in each piece in the wet condition, during drying and at a dry equilibrated moisture content of approximately 10 percent Strong con-dative relationships exist between stress wave velocity measured in untreated and preservative heated green (wet) and dry veneer.

Keywords: nondestructive evaluation, stress waves, veneer, southern yellow pine, Douglas fir, green, stress wave timer, transit time, oscilloscope, laminated veneer lumber

1. INTRODUCTION

Longitudinal stress wave technology is used by the forest products industry to determine the dynamic stress wave modulus of elasticity (MOE_{sw}) of structural lumber. It is also used to sort veneer into stiffness and strength classes for laminated veneer lumber (LVL) manufacturing, to identify internal defects in hardwood lumber and to evaluate the integrity of utility poles or existing wood members in building structures.

During the project, longitudinal stress wave techniques were used to evaluate the stress wave velocity *(C)* and MOE_{sw} of southern yellow pine and Douglas fir veneer at several times during the drying process. Stress wave transit times were measured for each specimen in the wet condition, during drying, and at a dry equilibrated moisture content of approximately 10 percent. The veneer was dried in a temperature/humidity-controlled room. The goal was to be able to sort veneer into predetermined strength and stiffness classes before drying, resulting in increased production efficiency and resource utilization for LVL and plywood manufacturers.

The present application of longitudinal stress wave methods to sort wood veneer for LVL manufacture is restricted to dry veneer. Commercially, longitudinal stress wave techniques have allowed LVL manufacturers to translate individual veneer quality (i.e., veneer stiffness and strength) into structural LVL material possessing low variability and predictable strength properties[1]. Following the drying of the veneer, a commercial veneer grader ultrasonically transmits stress waves longitudinally through the veneer[2]. The average *C* is calculated for each veneer and is then categorized into predetermined strength and stiffness classes that correspond to the mean *C* of each piece. Initially, the strength classes were initially determined by empirical relationships between the *C* and stiffness of the veneer and final LVL mechanical properties[3].

 0-8194-2348-31961$6.00

By the time the veneer is sorted into stress grades during the process, significant drying costs have been incurred. If a similar sorting procedure for green veneer could be determined, it would be possible to dry material having similar strengths and stiffnesses together in customized drying schedules. These custom drying cycles, based on veneer strength and stiffness, could lead to increased efficiency, energy savings, and lower costs by reducing or eliminating veneer redrying.

Currently, preservative treatment occurs as a post treatment after the product has been manufactured. The use of NDE on green veneer would improve the feasibility of producing a new family of preservative-treated LVL products. These LVL products would be manufactured by treating green veneer with a preservative, drying the veneer, and laminating the veneer into a final product. A completely treated LVL product can be manufactured by treating each veneer before pressing. Treating green veneer is beneficial because several new preservative systems are water diffusible, short treatment cycles are possible, and dimensional stability is improved by not rewetting the veneer. A reduction in design properties may not be necessary since the final product does not require incising or pressure treatment. Costs associated with treating, drying, and disposing of veneer that is unacceptable for use in LVL material would be reduced. NDE techniques would be vital to accurately identify acceptable strength veneers for processing into pretreated LVL and to allow for the production of engineered products.

Exterior LVL is used for structural applications such as bridge components, sign posts, scaffold planks, utility pole components, and beams and headers for unprotected structures. For some of these exterior uses, LVL is treated with a variety of preservation systems. The primary commercial treatment is chromated copper arsenate (CCA). CCA penetration occurs during pressure treatment due to the presence of veneer checks, thus eliminating traditional incising that is required for many solid lumber products. The potential for incomplete treatment due to varying veneer quality and density does exist. It is also required in the design codes that there be a reduction in strength properties.

To produce an LVL product with a thorough, balanced treatment, studies have been conducted where individual veneers have been preservative treated before adhesive application and pressing. Previous research at the University of Minnesota Natural Resources research Institute has demonstrated the structural feasibility of manufactuing LVL and plywood from southern yellow pine and aspen[4]. This preservative treated LVL underwent extensive durability testing at field sites in Duluth, Minnesota, and Gainesville, Florida. Additionally, soil block tests were made and both had good results.

Investigations of longitudinal stress wave techniques have been primarily restricted to dry wood products. The effect of high moisture content (MC) on stress wave grading of wood has been investigated. *C* in Douglas fir lumber was measured[5] at MC from 0-27 percent. It was found that *C* decreased as the MC increased Burmester[6] evaluated *C* in European pine at various MC. He found that longitudinal *C* decreased 0.2 inches/millisecond for each percent the MC increases above the fiber saturation point.

Gerhards[7] evaluated the effect of MC on *C*, MOE_{sw} and static modulus of elasticity (MOE_s) of sweetgum *(Liquidambar styraciflua)* lumber. The MC of the sweetgum specimens ranged from 15 to 150 percent (oven-dry basis). His results showed the *C* and MOE_{sw} decreased as wood MC increased to a level of 80 percent. At MC above this point, *C* and MOE remained nearly constant, while the MOE_{sw} increased with MC levels. The MOE_{sw} increase was expected because density increases in direct proportion to the amount of free moisture in the specimen. Gerhards[7] concluded that MOE_{sw} is dependent on the MC of the material.

Ross and Pellerin[8] investigated the hypothesis that a relationship would exist between MOE_{sw} and MOE_s of green Douglas fir lumber. Both MOE_{sw} and the *C* are strongly correlated to MOE_s of dry wood materials and they believed that a similar correlation might exist with wood material having a MC above the fiber saturation point. MOE_s and MOE_{sw} of 113 green Douglas fir specimens (nominal 2 in. by 4 in. by 12 ft) were determined. Results of linear regression analyses between MOE_s and *C* revealed a useful relationship between *C* and MOE_s. Sixty percent of the observed behavior was accounted for by the regression analyses (r=0.78). A strong relationship (r=0.95) was evident between MOE_s and MOE_{sw}. Ninety percent of the observed behavior was accounted for by the regresssion model using MOE_{sw} to predict MOE_s. This is only slightly lower than would be observed for dry materials. Recent studies at the USDA Forest Products Laboratory have focused on NDE of green wood materials[9]. Useful correlations between green NDE parameters and final properties have been shown to exist in logs, veneer peeler cores, and railroad switch ties.

2. OBJECTIVES

There were two goals of this research on green veneer. They were:

- To investigate the influence of moisture content and preservative treatment on the longitudinal *C* and the dynamic stress wave modulus of elasticity.

- To utilize longitudinal stress wave NDE to categorize and sort green veneer into strength classes, before drying or treating, using empirical relationships between green stress wave parameters and dry stiffnesses and strengths. The performance of the LVL, composed of preservative-treated veneers, would then be evaluated.

3. METHODS AND MATERIALS

During the research project, green southern yellow pine and Douglas fir veneer were obtained to evaluate the effect of MC and preservative treatment type on the longitudinal stress wave velocity and stress wave MOE. The second phase of this project was to investigate the relationship between the stress wave properties of green veneer and the final mechanical properties of LVL. Currently, only the stress wave NDE of green southern yellow pine and Douglas fir veneer has been completed. The manufacture of LVL from these veneers will occur during the second half of 1996.

3.1 Materials

3.1.1 Southern yellow pine

One hundred southern yellow pine *(Pinus spp.)* veneers, 1/8 in. by 52 in. by 100 in. (3 mm by 132 cm by 254 cm) were obtained from a LVL mill in Georgia. This veneer was rotary peeled from average candidate logs in terms of size, age, and MC. Veneer from all grades was randomly selected and shipped in green form to the Natural Resources Research Institute (Duluth, Minnesota) for further preparation. Each veneer piece was then cut in half lengthwise resulting in 200 specimens. These specimens were divided into four groups of fifty veneers for NDE testing. Each group contained veneer from four veneer visual grades to ensure a wide range of material properties.

The first group served as an untreated group and the other groups were treated with chromated copper arsenate (CCA) and disodium octaborate tetrahydrate (borate) solution. CCA was applied by a local preservative treatment company using traditional pressure treatment techniques. Borate was applied to the veneer using a backpack sprayer since this preservative is water diffusible in green veneer. Each group of veneer was treated to a retention level of 0.40 lb of active ingredient/cubic ft. It is planned that these veneers also will be used in the manufacture of LVL billets in later phases of the project. In summary, the experimental design included the following four groups for each species:

- Untreated - 50 veneers,
- CCA treated to 0.40 retention level - 50 veneers
- Borate treated to 0.40 retention level - 50 veneers

3.1.2 Douglas fir

Thirty Douglas fir (Psedotsuga menziesii) veneers, 1/8 in. by 52 in. by 100 in. (3 mm by 132 cm by 254 cm) were obtained from a LVL mill in eastern Oregon. This veneer was rotary peeled from average candidate logs in terms of size, age, and MC. Veneer from all grades was randomly selected and shipped in green form to the Natural Resources Research Institute (Duluth, Minnesota) for further preparation. Each veneer piece was then cut in half lengthwise resulting in 60 specimens. These veneers served as the control (untreated) group. Additional study of preservative treated Douglas fir veneer will take place during the second half of 1996.

3.2 NDE Measurements

Each veneer specimen (1/8 in. by 25 in. by 100 in. [3 mm by 66 cm by 254 cm]) was stress wave evaluated in the green (wet) condition, during drying, and at a dry equilibrated moisture content of approximately 10 percent. Stress wave transit times were measured using a commercially available stress wave timer and an oscilloscope over a gauge length of 96 inches. The oscilloscope was used because it was hypothesized by the authors that the signal at the stop accelerometer would be damped significantly, resulting in inaccurate transit times captured by the stress wave timer.

NDE measurements were taken along the grain at three places on each veneer to obtain a mean transit time that was used to compute *C*. The transit time was recorded directly from the stress wave timer. The highest stop gain setting was selected to maximize sensitivity to the received wave signal. The wave signal was also captured by a computer data acquisition system that served as a two-channel oscilloscope. The wave signal was then analyzed to determine the transit time. Physical measurements of each veneer were obtained each time the specimen was tested to determine density and MC. The dynamic MOE_{sw} was calculated for each moisture content condition using *C* and mass density (ρ) in the following equation:

$$MOE_{sw} = C^2 \rho \qquad [1]$$

The data was analyzed using linear regression analyses to examine the relationship between stress wave parameters and moisture content for each treatment group. At the time this paper was submitted, only regression analyses using *C* were completed.

4. RESULTS AND DISCUSSION

Each test group of southern yellow pine and Douglas fir veneer was evaluated independently to determine the relationship between stress wave velocity *(C)* and MC. Stress wave velocities were determined for each group of southern yellow pine veneer during the drying process in the green (wet) condition, once or twice during drying, and at a dry equilibrated MC of approximately 10 percent. The stress wave velocities of the Douglas fir veneer were detemined in only the green and dry conditions.

The MC of southern yellow pine green veneer groups ranged from 33 - 154 percent dropping to 21 - 106 percent when the second set of NDE measurements was taken. The MC dropped below the fiber saturation point(17 - 27 percent) when the third set of NDE measurments was taken, and to approximately 10 percent when the final set of NDE measurements was taken. The green Douglas fir veneer groupo MC 39 - 104 percent, dropping to a range of 3 - 10 percent when dry. Each group's MC range and mean at each time NDE was conducted are shown in table 1.

Table 1 Moisture content range and mean for each southern yellow pine and Douglas fir veneer group at time of each NDE measurement.

Southern Yellow Pine Group	Moisture Content at Time of Stress Wave NDE							
	Green Condition		Intermediate Condition #1		Intermediate Condition #2		Dry Condition	
	Range (%)	Mean (%)	Range (%)	Mean (%)	Range (%)	Mean (%)	Range (%)	Mean (%)
Untreated	33 - 106	60.1	21 - 75	39.8	17 - 27	21.4	9 - 13	10.3
CCA-Treated	41 - 128	70.9	n/a	n/a	19 - 24	22.5	7 - 9	7.3
Borate-Treated	82 - 154	105.8	52 - 106	75.3	22 - 27	23.9	8 - 10	9.3
Douglas fir Group								
Untreated	39 - 103	53.8	n/a	n/a	n/a	n/a	3 - 10	8.0

Figures 1-4 show the stress wave velocities for each southern yellow pine and Douglas fir veneer group as determined using a commercially available stress wave timer. The velocities are shown in the green condition and one or two intermediate moisture conditions plotted against the velocity of that group's specimens in the dry condition. Results of the regression analyses of the stress wave velocities using the stress wave timer are shown in Table 2. It became apparent that a strong correlation exists between the stress wave velocities of green and dry veneer for all treatment groups. In the untreated southern yellow pine veneer group, the relationship between the stress wave velocities (acquired with a stress wave timer) in the wet and dry conditions showed a correlation coefficient of 0.91, indicating that 83 percent of observed behavior was accounted for in the regression model. The poorest relationship existed in the borate treated group. This can be attributed to the high MC ranges (82 - 154%) for these specimens, resulting in the introduction of addtional variability. It was evident from reviewing the data that the wettest samples resulted in damped wave strength, causing false readings on the timer. The borate group was also the first group measured, and, hence, might be more prone to experimental error.

Analyses of the Douglas fir data also showed a useful correlation between the green and dry wave velocities, showing that the relationship between wet and dry velocities are not species dependent. Each species will have different slopes of lines fit to their data, as the slopes from the Douglas fir groups were significantly different from the southern yellow pine groups. For the southern yellow pine, the relationships were not dependent on treatment type, as monitored by noting the nearly constant slope of the regression line among all conditions.

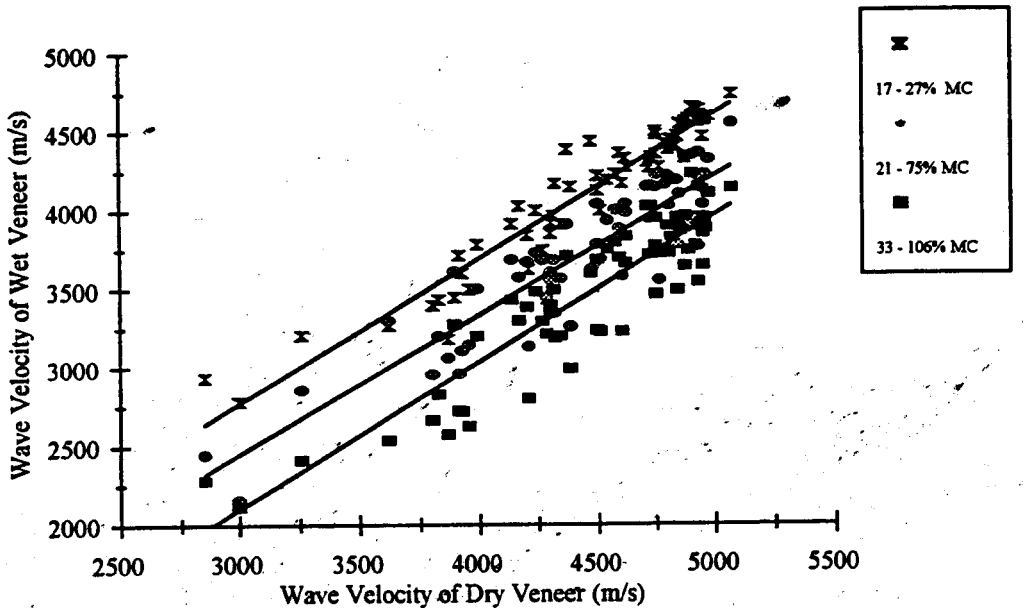

Figure 1. A comparison of longitudal stress wave velocities at several moisture content ranges to the velocity of dry untreated southern yellow pine veneer as measured using a commercial stress wave timer.

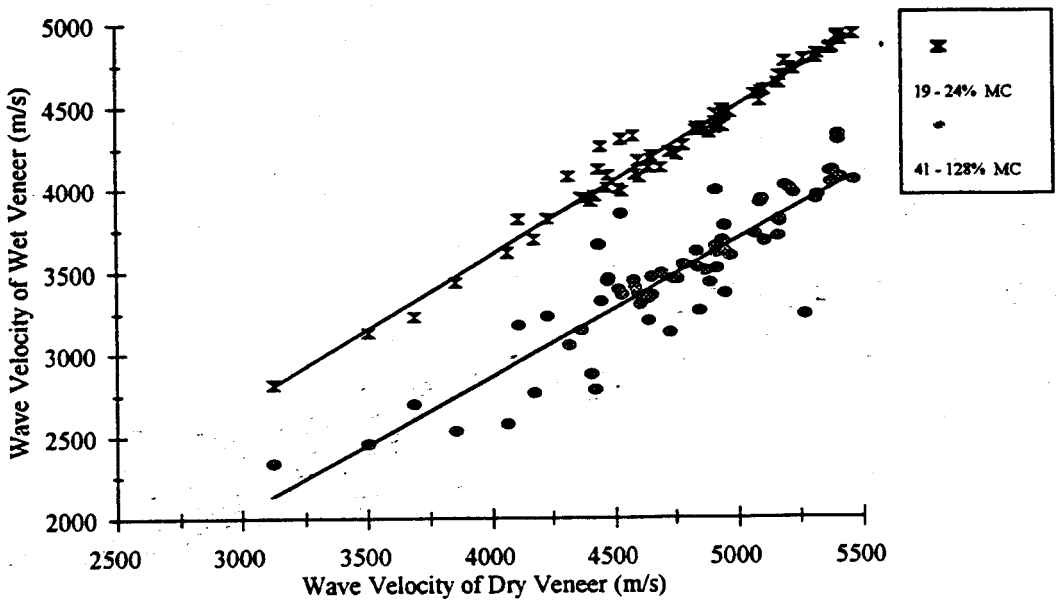

Figure 2. A comparison of longitudinal stress wave velocities at several moisture content ranges to the velocity of dry CCA-treated southern yellow pine as measured using a stress wave timer.

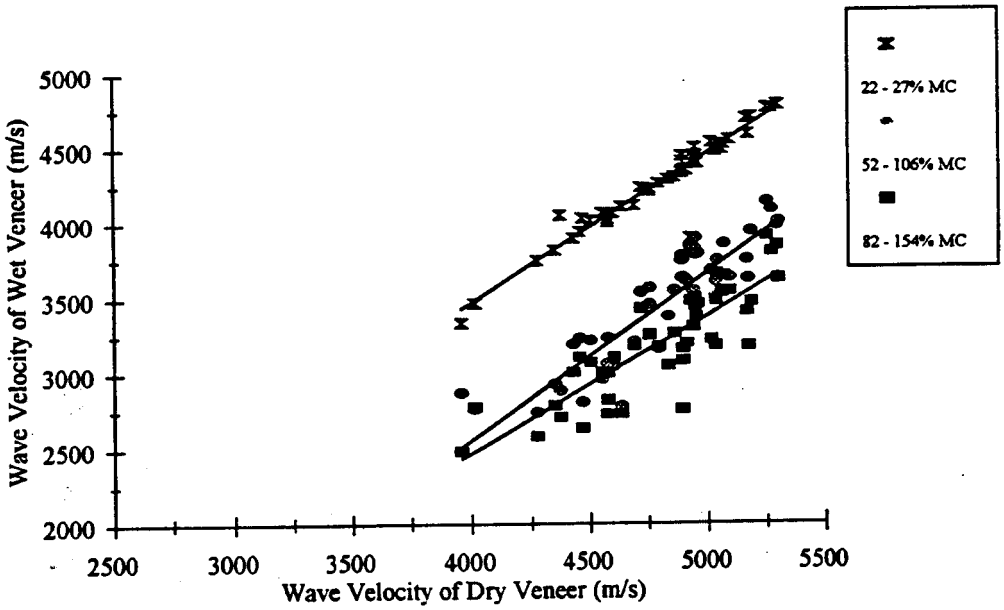

Figure 3. A comparison of longitudinal stress wave velocities at several moisture content ranges to the velocity of dry borate-treated southern yellow pine veneer as measured using a commercial stress wave timer.

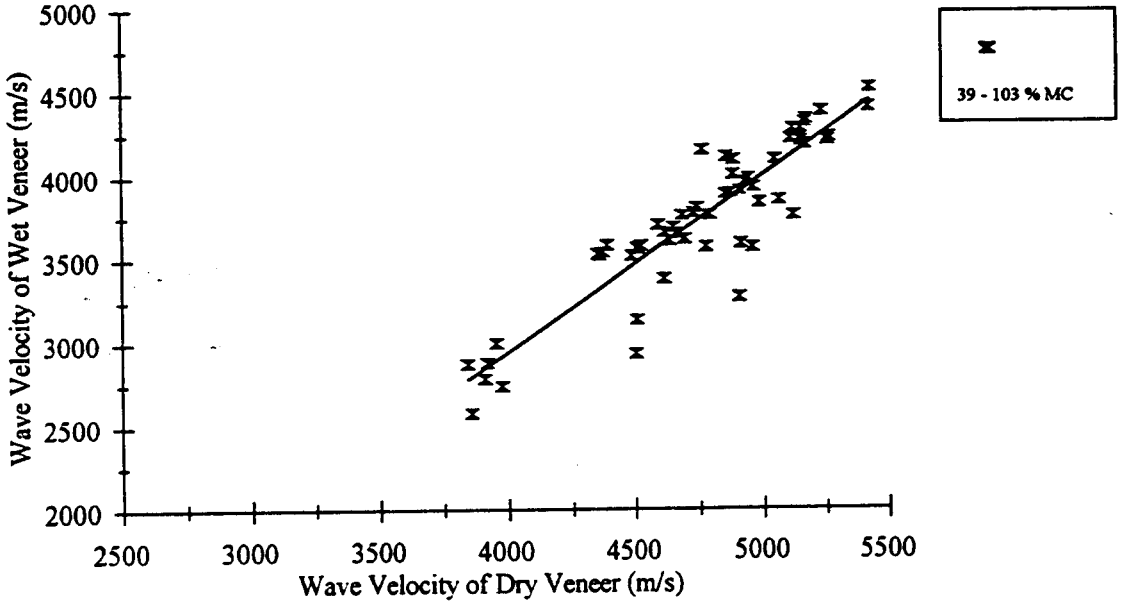

Figure 4. A comparison of longitudinal stress wave velocities at several moisture content ranges to the velocity of dry Douglas fir veneer as measured using a commercial stress wave timer.

Table 2 Results of regression analyses between stress wave velocities of southern yellow pine and Douglas fir veneer in the green and dry conditions as measured using a commercial stress wave timer (general form of the regression equation: Dry $C = m(x) + b$).

Dry versus Green					
Southern Yellow Pine Group	Moisture Content Range (%)	Slope	Y-intercept	Correlation Coefficient (r)	Coefficient of Determination (r^2)
Untreated	33 - 106	0.88	55.7	0.91	0.83
CCA treated	41 - 128	0.96	55.2	0.89	0.79
Borate treated	82 - 154	0.78	90.3	0.84	0.71
Douglas Fir Group					
Untreated	39 - 103	0.46	209.6	0.91	0.83
Dry versus Intermediate # 1					
Southern Yellow Pine Group	Moisture Content Range (%)	Slope	Y-intercept	Correlation Coefficient (r)	Coefficient of Determination (r^2)
Untreated	21 - 75	0.88	55.7	0.90	0.81
Borate treated	52 -106	0.70	93.6	0.88	0.77
Dry versus Intermediate #2					
Southern Yellow Pine Group	Moisture Content Range (%)	Slope	Y-intercept	Correlation Coefficient (r)	Coefficient of Determination (r^2)
Untreated	17 - 27	0.99	15.7	0.95	0.91
CCA treated	19 - 24	1.08	5.6	0.99	0.98
Borate treated	22 - 27	0.94	31.9	0.96	0.92

Figures 5-8 show the stress wave velocities for each southern yellow pine and Douglas fir veneer group as determined using a digital storage oscilloscope. The velocities are shown in the green condition and one or two intermediate moisture conditions plotted against the velocity of that group's specimens in the dry condition. Results of the regression analyses of the stress wave velocities using the oscilloscope are shown in Table 3. As expected, the correlations between the velocities of wet and dry veneer were higher when the oscilloscope was used instead of the stress wave timer. This is due to the ability to evaluate the true wave signal. For example, the r^2 for the untreated Douglas fir goup was 0.96 (oscilloscope) versus 0.91 (stress wave timer). The southern yellow pine borate group had the poorest correlation, due in part to signals that were difficult to analyze and that this group was the first tested.

Additional regression analyses were conducted to examine the relationship between the velocity determined by using the oscilloscope and the stress wave timer. The relationship between the two instruments was explored through regression analyses conducted of the C at the same moisture condition within each group. The correlation coefficient ranged from 0.89 - 0.97 when comparing velocities of wet veneer and 0.98 when comparing velocities of dry veneer using the two instruments. The small differences resulted in the oscilloscope providing a better reading of wave transit time.

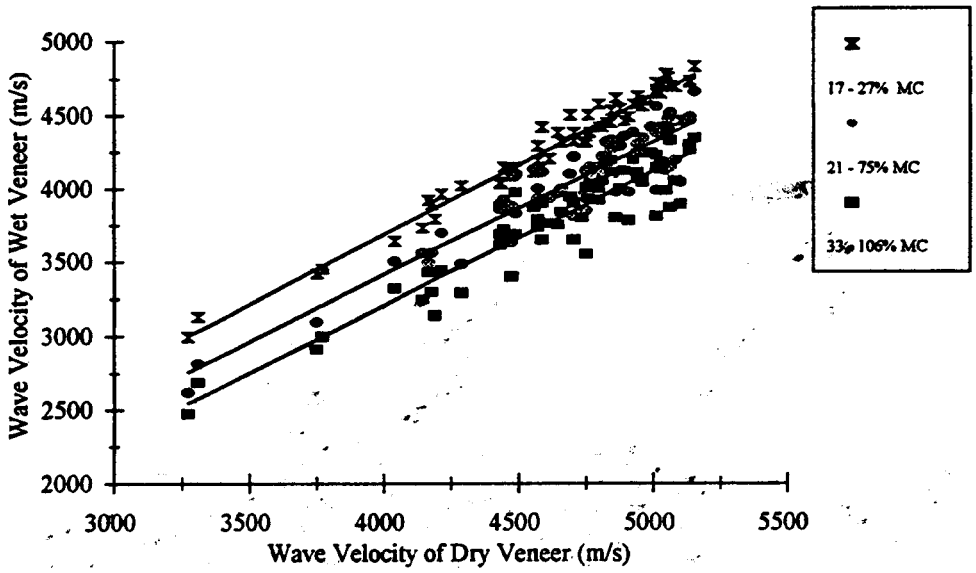

Figure 5. A comparison of longitudinal stress wave velocities at several moisture content ranges to the velocity of dry untreated southern yellow pine as measured using an oscilloscope.

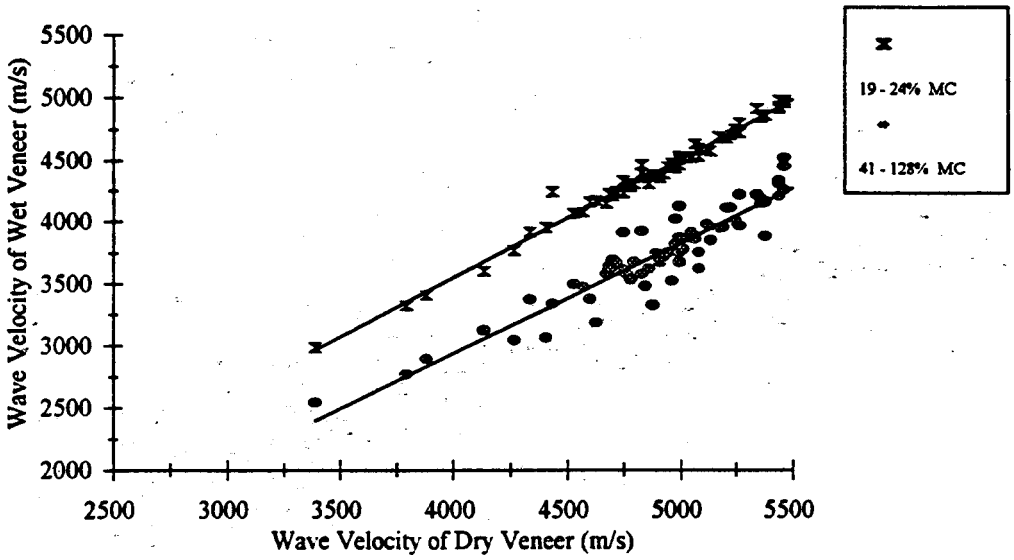

Figure 6. A comparison of longitudinal stress wave velocities at several moisture content ranges to the velocity of dry CCA-treated southern yellow pine veneer as measured using an oscilloscope.

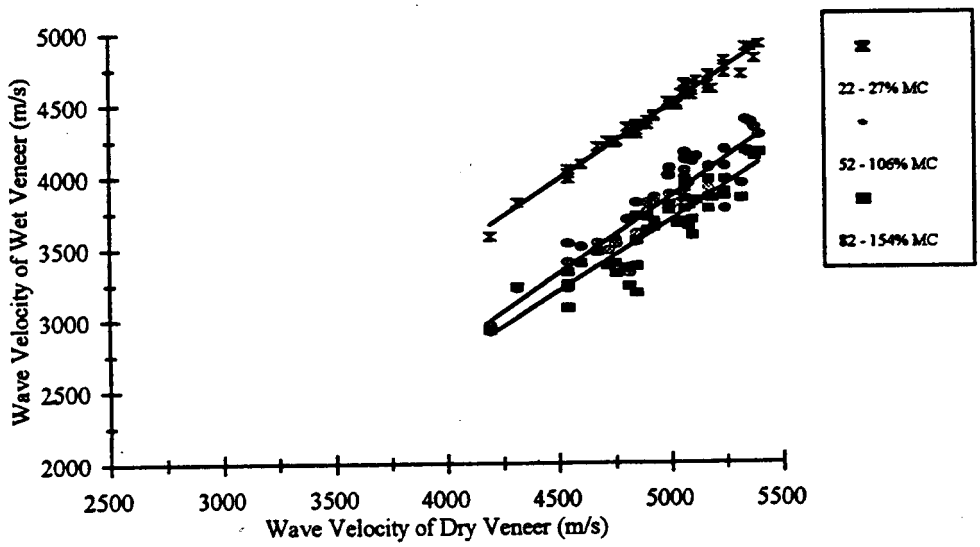

Figure 7. A comparison of longitudinal stress wave velocities at several moisture content ranges to the velocity of dry borate-treated southern yellow pine as measured using au oscilloscope.

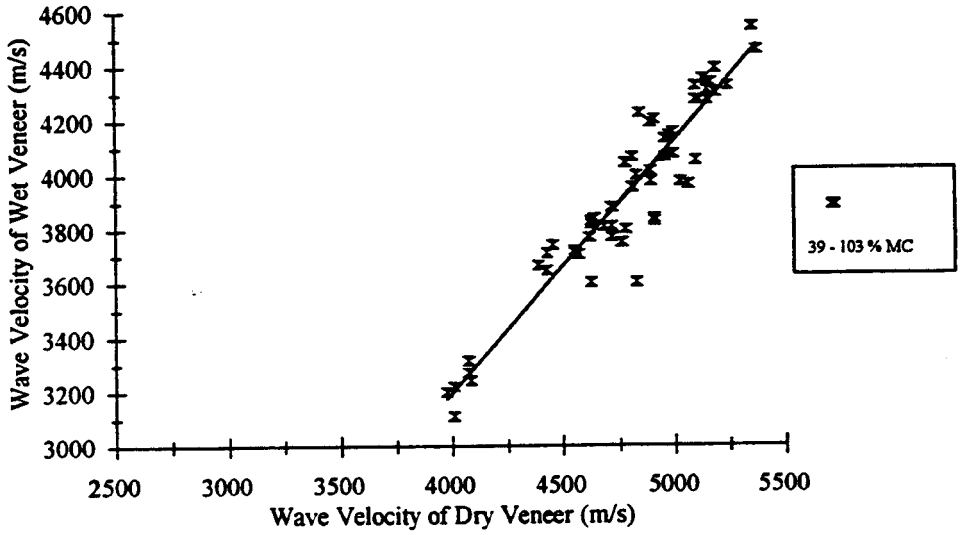

Figure 8. A comparison of the longitudinal stress wave velocities at several moisture content ranges to the velocity of@ untreated Douglas fir veneer as measured using an oscilloscope.

Table 3. Results of regression analyses between stress wave velocities of southern yellow pine and Douglas fir veneer in the green and dry conditions as measured using an oscilloscope (general form of the regression equation: Dry $C = m(x) + b$).

Dry versus Green					
Southern Yellow Pine Group	Moisture Content Range (%)	Slope	Y-intercept	Correlation Coefficient (r)	Coefficient of Determination (r^2)
Untreated	33 - 106	0.96	40.2	0.93	0.86
CCA treated	41 - 128	0.99	47.8	0.93	0.86
Borate treated	82 - 154	0.83	75.3	0.91	0.83
Douglas Fir Group					
Untreated	39 - 103	0.66	97.5	0.92	0.96
Dry versus Intermediate # 1					
Southern Yellow Pine Group	Moisture Content Range (%)	Slope	Y-intercept	Correlation Coefficient (r)	Coefficient of Determination (r^2)
Untreated	21 - 75	0.96	31.3	0.93	0.86
Borate treated	52 - 106	0.76	81.3	0.90	0.81
Dry versus Intermediate #2					
Southern Yellow Pine Group	Moisture Content Range (%)	Slope	Y-intercept	Correlation Coefficient (r)	Coefficient of Determination (r^2)
Untreated	17 - 27	1.02	10.0	0.98	0.96
CCA treated	19 - 24	1.03	13.5	0.99	0.98
Borate treated	22 - 27	0.95	28.4	0.99	0.98

5. CONCLUSIONS

The conclusions made from this study were limited to the work accomplished at the time this paper was written. These conclusions were

- *Stress* wave velocities of green (wet) and dry southern yellow pine and Douglas fir veneer are strongly correlated. Stress wave NDE provides an accurate method for grading green veneer.
- Successful stress wave NDE can be conducted using both the digital oscilloscope and commercial grading devices.
- Preservative treatment did not appear to affect the longitudinal stress wave velocity or the ability to measure transit time through veneer.

Further analyses of the influence of MC on MOE_{sw} will be conducted. The veneer from both species will be used to manufacture LVL to verify the use of green stress graded veneer on final product performance.

6. ACKNOWLEDGMENTS

Funding for this project was provided by the Unites States Department of Agriculture through their Competitive Grants Research Initiative Program The authors wish to thank Trus Joist MacMillan Corporation and Tecton Laminates Corporation for donating the veneer used during the project.

7. BIBLIOGRAPHY

1. R.H Kunesh, "Using ultrasonic energy to grade veneer". *Proceedings, Fourth Symposium on the Nondestructive Testing of Wood*, pp. 275-278, Washington State University, Pullman, WA.1978

2. J.D. Logan, "Continuous ultrasonic veneer testing: sorting veneer for structural applications," Sawmill Clinic, Portland, OR, 1987.

3. D.L. Sharp, "Nondestructive testing techniques for manufacturing LVL and predicting performance," *Proceedings, Fifth Symposium on the Nondestructive Testing of Wood*, pp. 99-108, Washington State University, Pullman, WA, 1985.

4 C.F. Edwardson and K.D. Roos, "Preliminary evaluation of parallel laminated veneer lumber made from preservative treated veneers", *NRRI Technical Report NRRI/TR-90/14*, University of Minnesota, Natural Resources Research Institute, Duluth, Minnesota, 1990.

5 W.L. James, "Effect of temperature and moisture content on internal friction and speed of sound of Douglas fir," Forest Products Journal 11(9):383-390, 1961.

6 A. Burmester, "Relationship between sound velocity and morphological, physical, and mechanical properties of wood., Holz als Roh und Werkstoff, 23(6):227-236, 1965.

7 C.C. Gerhards, "Stress wave speed and MOE of sweetgum ranging from 150 to 15 percent MC," Forest Products Journal 25(4):51-57, 1975.

8 R.J. Ross, and R.F. Pellerin. "NDE of green material with stress waves: preliminary results using dimension lumber," Forest Products Journal 41(6):57-59, 1991.

9. R.J. Ross, D.W. Green, K.A. McDonald, and K.C. Schad, "NDE of logs with longitudinal stress waves," *Proceedings, 10th Internatinal Symposium on Nondestructive Testing of Wood*, pp. 117-123, Presses Polytechniques et Universitaires Romandes, Lausanne, Switzerland, 1996.

PROCEEDINGS

SPIE—The International Society for Optical Engineering

Nondestructive Evaluation of Materials and Composites

Steve Doctor
Carol A. Lebowitz
George Y. Baaklini
Chairs/Editors

3–5 December 1996
Scottsdale, Arizona

Sponsored by
SPIE—The International Society for Optical Engineering

Cosponsored by
Federal Highway Administration
Nondestructive Testing Information Analysis Center
Air Force Wright Laboratory
Pressure Vessel Research Council
The Materials Properties Council, Inc.

Cooperating Organizations
U.S. Department of Energy
DARPA
National Institute of Standards and Technology
Lawrence Livermore National Laboratory
Society for Experimental Mechanics
American Society of Mechanical Engineers
Federal Aviation Administration
American Society for Testing and Materials
CalTrans
Electric Power Research Institute
Battelle Pacific Northwest National Laboratory

Volume 2944

Published by
SPIE—The International Society for Optical Engineering

SPIE is an international technical society dedicated to advancing engineering and scientific applications of optical, photonic, imaging, electronic, and optoelectronic technologies.

The papers appearing in this book comprise the proceedings of the meeting mentioned on the cover and title page. They reflect the authors' opinions and are published as presented and without change, in the interests of timely dissemination. Their inclusion in this publication does not necessarily constitute endorsement by the editors or by SPIE.

Please use the following format to cite material from this book
Author(s), "Title of paper," in *Nondestructive Evaluation of Materials and Composites*, Steve Doctor, Carol A. Lebowitz, George Y. Baaklini, Editors, Proc. SPIE 2944, page numbers (1996).

Library of Congress Catalog Card No. 96-70121
ISBN 0-8194-2348-3

Published by
SPIE—The International Society for Optical Engineering
P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone 360/676-3290 (Pacific Time) • Fax 360/647-1445

Copyright ©1996, The Society of Photo-Optical Instrumentation Engineers.

Copying of material in this book for internal or personal use, or for the internal or personal use of specific clients, beyond the fair use provisions granted by the U.S. Copyright Law is authorized by SPIE subject to payment of copying fees. The Transactional Reporting Service base fee for this volume is $6.00 per article (or portion thereof), which should be paid directly to the Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923. Payment may also be made electronically through CCC Online at http://www.directory.net/copyright/. Other copying for republication, resale, advertising or promotion, or any form of systematic or multiple reproduction of any material in this book is prohibited except with permission in writing from the publisher. The CCC fee code is 0-8194-2348-3/96/$6.00.

Printed in the United States of America.