Relationship between stress wave velocities of green and dry veneer

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Abstract

This paper evaluates the relationship between the stress wave velocities of green and dry southern pine and Douglas-fir veneers. A commercial stress wave timer and a laboratory signal analysis system were used to measure the transit time required for an induced stress wave to travel the longitudinal length of each veneer. Stress wave transit times were measured in the veneers in the wet condition and at a dry equilibrated moisture content of approximately 10 percent. A strong linear relationship was found between green and dry stress wave velocity for both southern pine and Douglas-fir veneers. The strength of the relationship was improved significantly when the signal analysis system was used.

Stress wave nondestructive evaluation (NDE) methods have been intensively investigated for use with wood and wood-based composite materials and are currently used for mechanical property evaluations in veneer grading programs. Strong correlations have been found between stress wave parameters, such as stress wave velocity and wave attenuation, and the mechanical properties of laminated veneer lumber (LVL), particleboard, and medium density fiberboard (Ross and Vogt 1985, Ross and Pellerin 1988, Brashaw 1991).

The present application of longitudinal stress wave methods to sort 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., stiffness and strength) into structural LVL material possessing low variability and predictable strength properties (Kunesh 1978). After the veneer is dried, a commercial veneer grader ultrasonically transmits stress waves longitudinally through the wood (Logan 1987). The average wave velocity is calculated for each veneer, and the veneer is then categorized into predetermined strength and stiffness classes that correspond to the wave velocity of each piece. Initially, strength classes were determined by empirical relationships between wave velocity and stiffness of the veneer and final LVL mechanical properties (Sharp 1985).

By the time the veneer is sorted into stress grades, significant drying costs have been incurred. If a similar sorting procedure could be developed for green veneer, it might be possible to dry materials with similar strength and stiffness together in customized drying schedules. These customized drying schedules, based on veneer strength and stiffness, may lead to increased efficiency, energy savings, and lower costs by reducing or eliminating veneer redrying. The first step towards developing a sorting procedure for green veneers is to determine if a relationship exists between green and dry stress wave velocities.

The primary objectives of this study were to investigate the effect of moisture content (MC) on stress wave velocity of

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veneer and to examine the relationship between green and dry stress wave velocities in southern pine and Douglas-fir veneers.

Background

Longitudinal stress wave NDE is a dynamic analysis of material properties. In the process, a stress wave is induced to the material and the transit time of the longitudinal stress wave is measured over a specified gauge length. These values are then used to calculate the stress wave velocity. The propagation of longitudinal stress waves in wood is influenced by both the material property and MC.

The effect of high MC on stress wave grading of wood has been investigated by a number of researchers. James (1961) evaluated stress wave velocity in Douglas-fir lumber at 0 to 27 percent MC and found that stress wave velocity decreased as MC increased. Burmester (1965) developed data on the effect of MC on wave velocity in European pine within the hygroscopic range and in the water-soaked condition. Below the fiber saturation point (FSP), the results of Burmester and James agree very closely, with respective reductions in wave velocity of 15 percent for an increase of 27 percentage units in fiber moisture. For an additional increase of 125 percentage units, Burmester observed 14 percent more reduction in wave velocity. One limitation of these studies was the lack of data between the FSP and water-soaked conditions.

Gerhards (1975) studied the effect of MC on wave velocity and dynamic and static modulus of elasticity (MOE) of 2 by 4 (51 by 102 mm) sweetgum (*Liquidambar styraciflua*) lumber. The MC of the lumber specimens ranged from 15 to 150 percent (ovendry basis). The results showed a decrease in wave velocity and dynamic MOE of lumber as wood MC increased to a level of about 50 percent. Above this MC level, wave velocity and static MOE remained relatively unchanged; dynamic MOE, however, increased significantly with an increase in MC. The dynamic MOE increase was expected because density increases in direct proportion to the amount of free water in the specimen. Gerhards (1975) concluded that dynamic MOE was dependent on wood MC across the whole moisture range studied.

Ross and Pellerin (1991) investigated the hypothesis that a relationship should exist between dynamic MOE and static MOE of green Douglas-fir lumber. Because both dynamic MOE and stress wave velocity are strongly correlated to static MOE of dry wood materials, these researchers believed that a similar correlation might exist for wood materials with MC above the FSP. They measured both dynamic and static MOE of 113 green Douglas-fir lumber specimens (nominal 2 in. by 4 in. by 12 ft., standard 38 mm by 89 mm by 7 m). Linear regression analysis revealed a useful relationship between stress wave velocity and static MOE. A strong relationship (r = 0.95) was also evident between dynamic and static MOE.

Recent studies at the USDA Forest Service, Forest Products Laboratory, have focused on NDE of green wood materials (Ross et al. 1996; Wang et al. 2001, 2002a, 2002b; Pellerin and Ross 2002). Useful correlations between green NDE parameters and final properties have been shown to exist in trees, logs, veneer peeler cores, and railroad switch ties.

Materials and methods

One-hundred southern pine (*Pinus* spp.) and 30 Douglas-fir (*Psuedotsuga menziesii*) green veneer specimens were obtained from 2 veneer mills in Georgia and eastern Oregon. The dimensions of each veneer sheet were 1/8 inch by 52 inches by 100 inches (3 mm by 132 cm by 254 cm). These veneers were rotary peeled from average candidate logs in terms of size, age, and MC. Specimens were randomly selected from all grades and shipped in green (wet) form to the Natural Resources Research Institute, University of Minnesota, in Duluth, Minnesota.

Each veneer piece was cut in half lengthwise, resulting in 200 southern pine and 60 Douglas-fir specimens, each measuring 1/8 inch by 25 inches by 100 inches (3 mm by 66 cm by 254 cm). In this study, we used 50 southern pine specimens and all 60 Douglas-fir specimens. The selected southern pine veneers included all four visual grades (i.e., A, B, C, and D) to ensure a wide range of material properties. The remainder of the southern pine veneer specimens were used for additional study of the effect of preservative treatment on stress wave velocity (Brashaw et al. 1996).

Each veneer specimen was evaluated in green and dry (specimens equilibrated to approximately 10% MC) conditions. Stress wave measurements were taken along the grain at three places on each specimen to obtain a mean transit time for calculating stress wave velocity. For southern pine specimens, stress wave measurements were also taken at two intermediate moisture conditions during drying.

Two accelerometers were clamped on the specimen over a gauge length of 96 inches (244 cm). A stress wave was induced into the specimen via a pendulum impactor. The transit time was first measured using a commercially available stress wave timer. The highest stop gain setting was selected to maximize sensitivity to the received wave signal. The wave signals from two accelerometers were also captured by a computer data-acquisition system and then analyzed to determine the transit time. Stress wave velocity was computed by dividing the gauge length by measured transit time.

Results and discussion

The MC of the green veneer specimens ranged from 33 to 106 percent for southern pine and from 39 to 103 percent for Douglas-fir. This wide MC range was due to the moisture differences in heartwood and sapwood of both species. According to the *Wood Handbook* (FPL 1999), the MC of heartwood is 31 to 41 percent for southern pine and about 37 percent for Douglas-fir. The MC of sapwood is 106 to 120 percent for southern pine and 115 percent for Douglas-fir. Consequently, the MC of veneer peeled from the outer part of logs is much higher than that of veneer peeled from the inner part of logs. Because the purpose of this study was to evaluate the potential of using stress wave methods to sort veneers, we did not attempt to pre-separate veneer specimens into heartwood, sapwood, or mixed veneer groups.

For southern pine, the MC of dry veneer specimens was 9 to 13 percent, with a mean of approximately 10 percent. For Douglas-fir dry veneer, MC was 3 to 10 percent, with a mean of 8 percent. The slightly lower MC of Douglas-fir specimens could be caused by environmental changes during material handling and stress wave testing.

For southern pine veneer specimens, stress wave velocity was also determined at two intermediate MC conditions during drying to examine moisture

Table 1. — MC of southern pine and Douglas-fir veneer at time of stress wave testing.

	MC of veneer at time of stress wave testing							
	Green condition		Intermediate condition #1		Intermediate condition #2		Dry condition	
Species	Range	Mean	Range	Mean	Range	Mean	Range	Mean
	(%)							
Southern pine	33 to 106	60.1	21 to 75	39.8	17 to 27	21.4	9 to 13	10.3
Douglas-fir	39 to 103	53.8	--	--	--	--	3 to 10	8.0

Table 2. — Correlation of green and dry veneer stress wave velocities as measured by a stress wave timer.[a]

	y: SWV of dry veneer				
x: SWV of green veneer	*a*	*b*	*r*	r^2	S_{yx}
	(m/sec.)				
Southern pine	1515.0	0.8794	0.905	0.819	207.48
Douglas-fir	1826.7	0.7826	0.907	0.823	167.89

[a]Linear regression model: $y = a + bx$; SWV = stress wave velocity of veneer; r = correlation coefficient; r^2 = coefficient of determination; S_{yx} = standard error of estimate.

Table 3. — Correlation of green and dry veneer stress wave velocities as measured by a signal analysis system.[a]

	y: SWV of dry veneer				
x: SWV of green veneer	*a*	*b*	*r*	r^2	S_{yx}
	(m/sec,)				
Southern pine	1021.5	0.9553	0.933	0.871	148.55
Douglas-fir	983.3	0.9685	0.948	0.899	112.32

[a] Linear regression model $y = a + bx$; SWV = stress wave velocity of veneer; r = correlation coefficient; r^2 = coefficient of determination; S_{yx} = standard error of estimate.

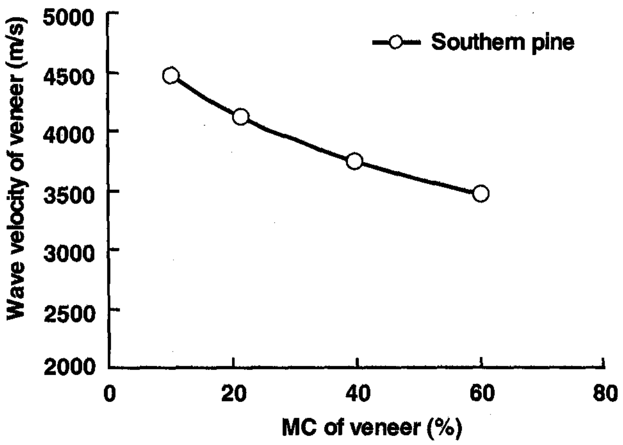

Figure 1. — Effect of MC on stress wave velocity of southern pine veneer.

effect **(Table 1).** MC was 21 to 75 percent at the first intermediate condition and 17 to 27 percent at the second intermediate condition. **Figure 1** shows the relationship between the mean wave velocity and average MC of southern pine veneer specimens. Note that wave velocity increased at different rates but continuously, as veneer MC decreased from the green to dry condition. This observation is in agreement with the results obtained from tests on lumber and small clear wood materials (James 1961, Burmester 1965, Gerhards 1975, Ross and Pellerin 1991).

Figure 2 shows stress wave velocity for southern pine and Douglas-fir veneer as determined using a stress wave timer. Wave velocity measured in the green condition was plotted against wave velocity measured in the dry condition. Results of the regression analysis of stress wave velocity are shown in **Table 2. A** strong correlation apparently exists between green and dry veneer stress wave velocity values. The relationship shows a correlation coefficient of 0.91, indicating that the linear regression model ($y = a + bx$) accounted for 82 percent of observed behavior of both southern pine and Douglas-fir veneer. Although a good relationship was found, the scatter around the regression line is fairly large. The standard error of estimate is 207.48 m/sec. for southern pine veneer and 167.89 m/sec. for Douglas-fir veneer. During stress wave testing, we observed that the wave signals of the wettest specimens were highly damped, which could have caused inaccurate readings on the stress wave timer.

Figure 3 shows the relationship between green and dry stress wave velocities as determined using the signal analysis system. Results of the regression analysis are shown in **Table 3.** We noted that the correlations between green and dry veneer wave velocity were improved when the signal analysis system was used instead of the stress wave timer. For example, the correlation coefficient for Douglas-fir veneer was 0.95 for the signal analysis system, compared with 0.91 for the stress wave timer. More importantly, the standard error of estimate was reduced significantly when the signal analysis system was used. This improvement could have contributed to the capability of the signal analysis system to analyze the highly damped stress wave signals that occur in wet conditions.

Conclusions

The stress wave velocity of veneer increased continuously as veneer MC decreased from the green to dry condition. A strong linear relationship was found between stress wave velocities of green and dry veneer for both southern pine and Douglas-fir. The strength of the relationship was improved when a signal

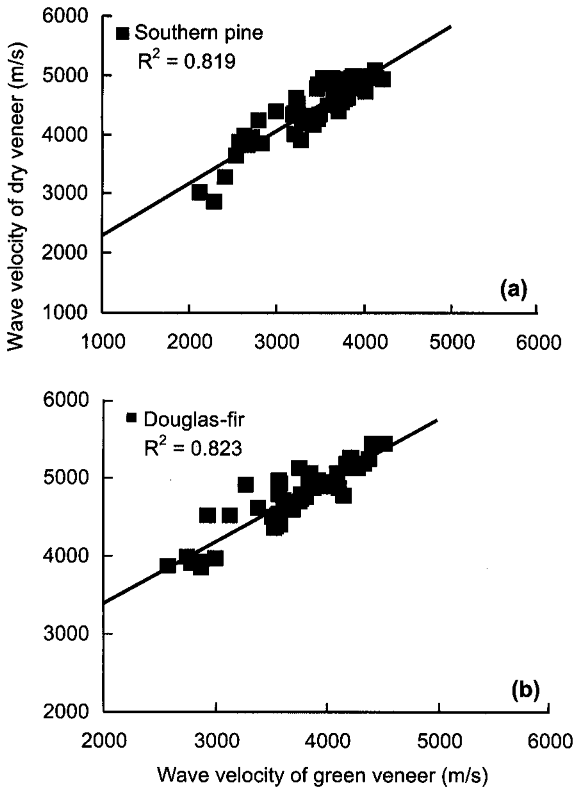

Figure 2. — Relationship between stress wave velocities of green and dry veneers as measured by a stress wave timer; (a) southern pine, (b) Douglas-fir.

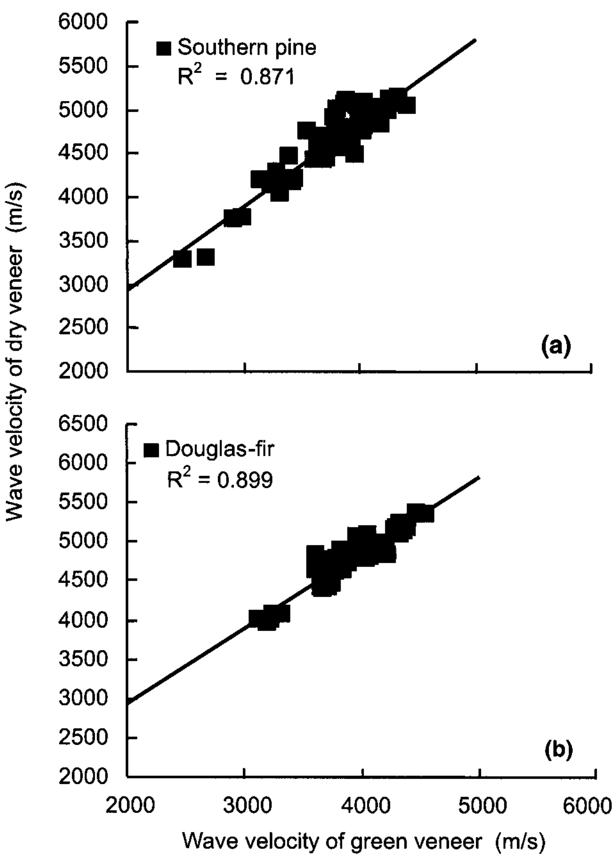

Figure 3. — Relationship between stress wave velocities of green and dry veneers as measured by a signal analysis system; (a) southern pine, (b) Douglas-fir.

analysis system was used instead of a stress wave timer. The results of this laboratory study illustrate the potential of using stress wave nondestructive evaluation methods to sort green veneer into stress grades before drying. We recommend that a broader database on stress wave properties of green veneer be further developed and tested on an industrial application scale.

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