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...
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 percent units in fiber moisture. For an additional increase of 125 percent 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 modulus of elasticity (MOE) of 2 by 4 (51 by 102 mm) sweet gum (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 dynamic 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 (Pseudotsuga 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 separate 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.

<table>
<thead>
<tr>
<th>Species</th>
<th>Range Mean</th>
<th>Range Mean</th>
<th>Range Mean</th>
<th>Range Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southern pine</td>
<td>33 to 106 60.1</td>
<td>21 to 75 39.8</td>
<td>17 to 27 21.4</td>
<td>9 to 13 10.3</td>
</tr>
<tr>
<td>Douglas-fir</td>
<td>39 to 103 53.8</td>
<td>-- --</td>
<td>-- --</td>
<td>3 to 10 8.0</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Species</th>
<th>SWV of green veneer</th>
<th>a</th>
<th>b</th>
<th>r</th>
<th>r²</th>
<th>Sₓₓ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southern pine</td>
<td>1515.0</td>
<td>0.8794</td>
<td>0.905</td>
<td>0.819</td>
<td>207.48</td>
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<tr>
<td>Douglas-fir</td>
<td>1826.7</td>
<td>0.7826</td>
<td>0.907</td>
<td>0.823</td>
<td>167.89</td>
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</table>

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

<table>
<thead>
<tr>
<th>Species</th>
<th>SWV of green veneer</th>
<th>a</th>
<th>b</th>
<th>r</th>
<th>r²</th>
<th>Sₓₓ</th>
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<tbody>
<tr>
<td>Southern pine</td>
<td>1021.5</td>
<td>0.9553</td>
<td>0.933</td>
<td>0.871</td>
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<td>Douglas-fir</td>
<td>983.3</td>
<td>0.9685</td>
<td>0.948</td>
<td>0.899</td>
<td>112.32</td>
<td></td>
</tr>
</tbody>
</table>

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

The stress wave velocity of veneer increased continuously as veneer MC decreased from the green to dry condition. 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.

Literature cited


