

# NDE of green material with stress waves: preliminary results using dimension lumber

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## Abstract

Longitudinal stress wave nondestructive evaluation techniques have proven to be an accurate means of evaluating the quality of wood-based products. Prior research has shown strong relationships between stress wave parameters and static mechanical properties of dry wood-based materials. This research provides some positive evidence that these techniques may be used to presort structural wood materials prior to drying. Literature dealing with stress wave and wood moisture content (MC) relationships has revealed that stress wave speed responds to changes in wood MC in a manner similar to that of other wood properties. This paper reports an experimental program designed to examine the relationship between stress wave characteristics and the static modulus of elasticity of green Douglas-fir dimension lumber. Strong correlative relationships exist between stress wave modulus of elasticity values and those obtained from static bending tests.

Longitudinal stress wave (LSW) nondestructive evaluation techniques are accepted methods of evaluating the quality of wood and structural wood products. These techniques are utilized in a variety of applications, from evaluating woodmembers in existing structures to sorting or process control work in composite material production quality-control programs (5,6),

Application of LSW techniques is presently limited to dry wood-based materials. In many applications, however, it would be beneficial to use LSW techniques at higher moisture content (MC) levels. As an example, consider laminated veneer lumber manufacturing facilities that utilize LSW techniques to categorize or sort incoming veneer into strength classes prior to processing into finished products. Veneers are assigned to strength categories, which are established through empirical relationships between stress wave velocity and strength, based on the velocity at which an induced

stress wave travels in them. At the present time, drying of allveneers is required before sorting. If an equivalent sorting process could be achieved with green material, considerable cost savings would be realized because unacceptable material would be identified and rejected before incurring drying costs.

Longitudinal stress wave techniques are not used with green materials because their effectiveness is questioned at high MC levels. Little information is available pertaining to stress wave behavior in wood at higher MC levels, and no published research addresses the correlative relationship between stress wave parameters and static mechanical properties at high MC levels. This pilot study was conducted to begin to address these deficiencies. We reviewed pertinent background information, and investigated whether a relationship exists between static modulus of elasticity (E) values and either speed of sound transmission or E values obtained from stress wave measurements on green Douglas-fir dimension lumber.

## Background information

Propagation of longitudinal stress waves in solids is influenced in a complex manner by the mechanical and physical properties of the medium. To describe the propagation for practical use, the complex expressions commonly are simplified to elementary, one-dimensional wave propagation theory as applied to an isotropic, homogeneous material. Using a specimen with lateral dimensions that are small compared with the wavelength of the propagating wave, this simplified theory yields the following equation, relating the dynamic stress wave modulus of elasticity,  $E_{sw}$ , to stress wave speed,  $C$  (in./sec.), and mass density,  $p$ .

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$$E_{sw} = C^2 p \quad [1]$$

The effect wood MC has on  $C$  has been investigated by several researchers. James (4) evaluated its effect within the hygroscopic range of wood and found that  $C$  decreased as MC increased, which would be expected from the known effect MC has on other mechanical properties of wood. Gerhards (2) investigated MC effects on  $C$ ,  $E_{sw}$ , and static bending modulus of elasticity,  $E_s$ , of several sweetgum specimens at MC levels ranging from 13 to 150 percent. His results (Fig. 1) revealed that both  $C$  and  $E_{sw}$  responded to wood MC increases below the intersection moisture content (IMC) level (the MC level at which mechanical properties begin to change when drying from the green condition) in a manner similar to that of  $E_s$ . At MC levels above the IMC level,  $C$  and  $E_s$  remained nearly constant, while in this range  $E_{sw}$  increased with MC levels. Such behavior would be expected because  $C$  remains nearly constant, and density increases in direct proportion to the amount of additional moisture in the wood. Based on these results, Gerhards concluded that  $E_{sw}$  is dependent upon MC levels over the range studied and that it can be higher than  $E_s$ . He made no inferences as to whether a relationship still would exist between  $E_{sw}$  and  $E_s$ . Both  $E_{sw}$  and  $C$  are strongly correlated to  $E_s$  for dry materials, and we believed that similar correlative relationships might exist with materials having higher MC values. Consequently, we conducted the experiment outlined in the following section.

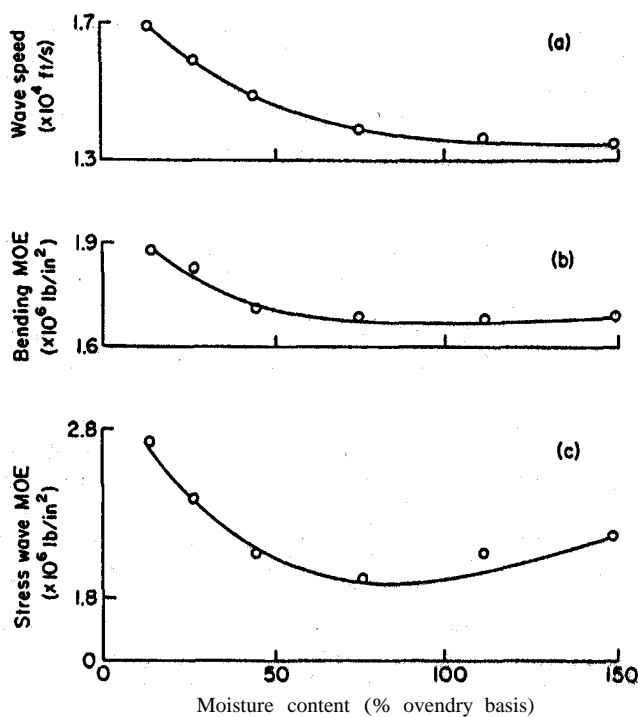


Figure 1. - Property and MC relationship for (a) stress wave speed ( $C$ ), (b) bending modulus of elasticity ( $E_s$ ), and (c) stress wave modulus of elasticity ( $E_{sw}$ ) (2).

## Materials and methods

We obtained 113 green Douglas-fir mill run dimension lumber specimens (12 ft. by 2 in. by 4 in.) from a local lumbermill. Upon arrival at Washington State University's Wood Engineering Laboratory, the weight, length, width, and thickness of each specimen were measured. Flatwise  $E_s$  was determined for the specimens using a center-point loading setup. A span of 140 inches was employed. Stress wave travel times were then measured over a gauge length of 143 inches using a commercially available stress wave timer and were used to compute  $C$ . The average MC of each specimen was estimated from the MC samples cut from them. Stress wave MOE ( $E_{sw}$ ) was calculated using  $C$ , green density, and Equation [1]. Linear regression analyses were then performed to examine relationships between stress wave parameters and  $E_s$ .

## Results and discussion

MC values varied significantly among specimens, ranging from 16.8 to 159.1 percent. As shown in Figure 2, almost 95 percent of the specimens tested were at or above the published Douglas-fir IMC value of 24 percent, and almost 20 percent had MC values greater than 45 percent (1).

Results of the regression analyses are summarized in Table 1. A comparison of  $E_s$  and  $C$  (Fig. 3) and results of the regression analyses revealed a useful relationship between  $C$  and  $E_s$ . The correlation coefficient ( $r = 0.78$ ) indicated that approximately 60 percent of observed behavior was accounted for by the regression model.

A comparison of  $E_s$  and  $E_{sw}$  is shown in Figure 4. Results of the regression analyses verified a strong relationship ( $r = 0.95$ ). This indicated that when using  $E_{sw}$  to predict  $E_s$ , 90 percent of observed behavior was accounted for by the regression model. This is some-

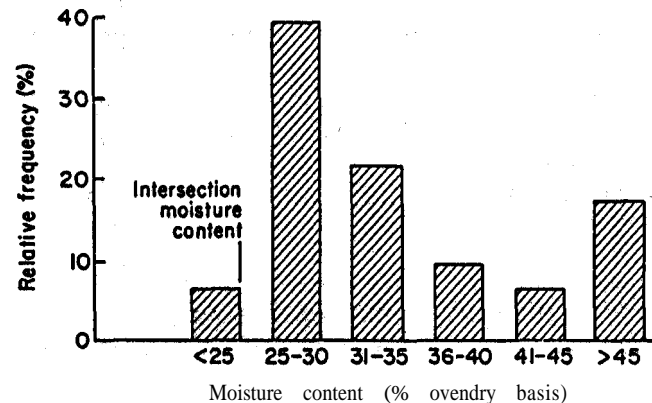


Figure 2. - Relative frequency and MC relationship.

TABLE 1. - Results of regression analyses, relating stress wave speed ( $C$ ) and stress wave modulus of elasticity ( $E_{sw}$ ) to flexural modulus of elasticity ( $E_s$ ).<sup>a</sup>

Stress wave parameter	Slope $m$ of regression line	$y$ intercept $b$	Correlation coefficient ( $r$ )
$C$ (ft./sec.)	$0.95 \times 10^3$	$0.29 \times 10^6$	0.78
$E_{sw}$ (psi)	1.01	-0.14	0.95

<sup>a</sup> General form of the regression equation  $E_s = m(s) + b$ .

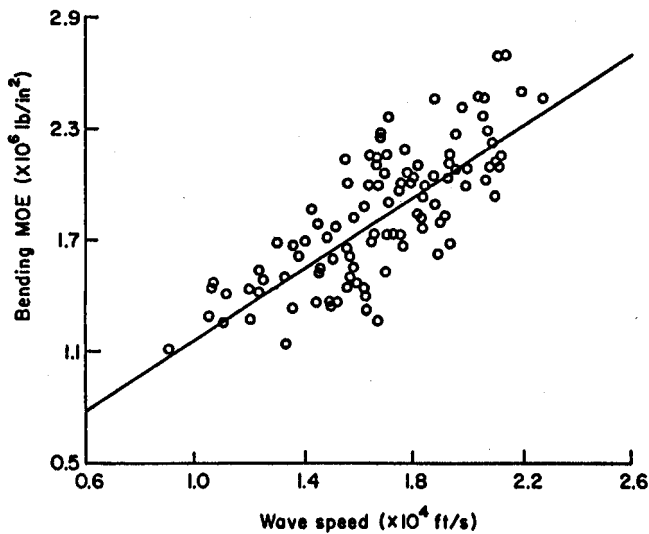


Figure 3. – A comparison of bending modulus of elasticity ( $E_s$ ) and stress wave speed ( $C$ ) of the specimens.

what lower than would be observed for dry materials and may be attributed to the wide range of MC values observed. Higher MC values would tend to introduce additional variability, which would result in a lower correlation coefficient. An examination of values for the slope and y intercept of the regression equation revealed that both were in the range of those reported in the literature for dry materials (3). Values of 1.01 and -0.14 were found for the slope and y intercept, respectively. Reported slope values ranged from 0.83 to 1.02, while those for they intercept ranged from -0.04 to -0.28.

#### Concluding remarks

Based on the results of our pilot study, we conclude that longitudinal stress wave nondestructive evaluation techniques may be useful in assessing the modulus of elasticity of green material. Also, further analyses of our preliminary results are being conducted to examine possible MC stratification effects on the correlative relationship between stress wave and static E values. Future experimentation will examine the use of green stress wave parameters to predict dry static E values.

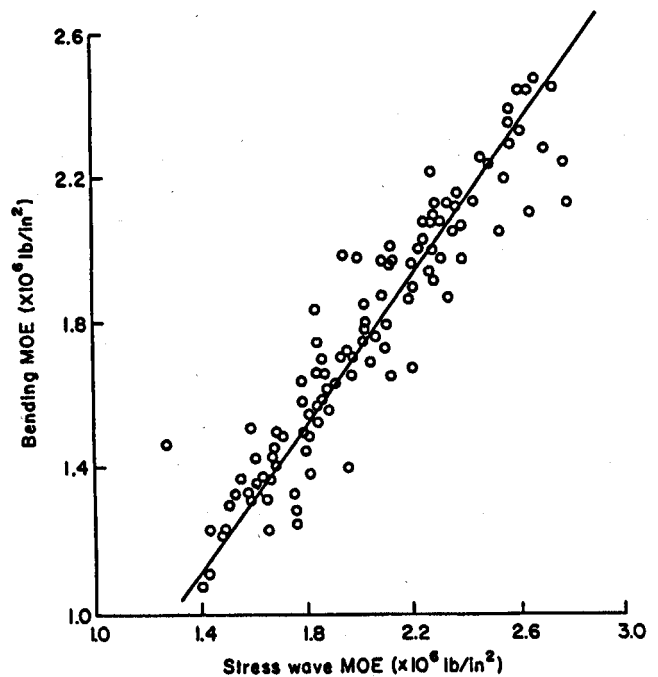


Figure 4. – A comparison of bending modulus of elasticity ( $E_s$ ) and stress wave modulus of elasticity ( $E_{sw}$ ) of the specimens.

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