STRESS WAVE VELOCITY AND DYNAMIC MODULUS OF ELASTICITY OF YELLOW-POPLAR RANGING FROM 100 TO 10 PERCENT MOISTURE CONTENT

Jody D. Gray, Shawn T. Grushecky, and James P. Armstrong[1]

Abstract.—Moisture content has a significant impact on mechanical properties of wood. In recent years, stress wave velocity has been used as an in situ and non-destructive method for determining the stiffness of wooden elements. The objective of this study was to determine what effect moisture content has on stress wave velocity and dynamic modulus of elasticity. Results indicated significant relationships between moisture content and average wave time. This study suggests that increasing moisture content reduces stress wave velocity and needs to be considered when performing non-destructive evaluations using stress wave velocity.

INTRODUCTION

Research concerning the mechanical properties of solid wood indicated that modulus of elasticity (MOE) in bending and compressive strength, both parallel and perpendicular to the grain, increase linearly with drying below fiber saturation point (Green and Kretschmann 1994). However, some research indicates that mechanical properties do not always increase with decreasing moisture content. Kretschmann and Green (1996) found that ultimate tensile strength increases as moisture content decreases, reaching its maximum at about 10-12 percent. However, they also note that the ultimate tensile strength then decreases with additional drying below 10 percent.

Exactly what effect does moisture content have on stress wave propagation? The Forest Products Laboratory (1999) noted that the speed of sound propagating through wood decreases with increasing moisture content. It was also noticed that the decrease is proportional to the influence that moisture content has on the modulus of elasticity and density. Halabe and others (1995) observed that wave velocity and bending MOE are significantly higher for dry wood than for green wood. Gerhards (1975) also noted that in solid sweetgum (*Liquidambar styraciflua*), stress wave time increases as the moisture content decreases during five intermediate stages of drying in the range of 150 to 15 percent. Wu (1999) stated that stress wave velocity is affected by approximately 1 percent per 1 percent change in moisture content of the composite panel. Brashaw and others (1997) examined the relationship between moisture content, preservative treatment, and the dynamic MOE. Their results showed a definite relationship between the green and dry dynamic MOE, although they noted that separate regression analysis was required for each species tested.

[1]Research Associate (JDG), Assistant Director Appalachian Hardwood Center (STG), and Associate Professor (JPA), Division of Forestry, West Virginia University, 322 Percival Hall, Morgantown, WV 26501. JDG is corresponding author: to contact, email at Jody.Gray@mail.wvu.edu.

Dynamic modulus of elasticity (ED) may be calculated from the stress wave velocity using the following formula:

$$E_D = v^2 \rho$$

Where:
E_D = dynamic modulus of elasticity (Pa)
v = velocity (m/s)
r = density (kg/m^3)

The effect of moisture content on stress wave velocity, and its resultant E_D, has not been adequately addressed. If stress wave velocity is to be used as a tool for performing in situ evaluations of the stiffness for wooden members, then we should consider the effect that moisture content might have on wave velocity. Therefore we initiated this research project to evaluate the extent to which moisture content affected the stress wave velocity in yellow-poplar in a moisture content range of 100 to 10 percent.

MATERIALS AND METHODS

The 100 yellow-poplar (*Liriodendron tulipifera*) specimens used in this study were cut to target dimensions of 0.0508 x 0.0508 x 0.762 meters. Specimens were chosen to be free of any defects, such as sloping grain and knots, and any other form of irregularity that may occur. Specimens were cut from lumber obtained from a sawmill, so it is not certain how many logs were used or how many specimens came from each log. At the start of the study, specimens were at a green moisture content of approximately 100 percent. The specimens were stored in a conditioning chamber in which the temperature and relative humidity were set to provide equilibrium moisture content conditions of 10 percent (22.2 °C and 55 percent relative humidity).

Five stress waves were sent through each specimen over a distance of 0.635 meters and the average wave velocity was used for comparisons. Measurements were performed daily for average dimensions, mass, and stress wave velocity as the specimens air-dried. Once the specimens dried down to approximately 10 percent moisture content, the study was concluded.

At the conclusion of the study the specimens were oven dried to determine the oven dry mass for use in moisture content calculations. Using the measurements, we could track the density, average wave time, and dynamic MOE moisture content dropped.

RESULTS

Ten random samples were taken, without replacement, at each of 10 moisture contents from 100 to 10 percent. The dataset turned out to be not approximately normal, so to meet normality requirements we used the box-cox transformation method. Box-cox transformation is defined as:

$$T(Y)=(Y^l-1)/l$$

Where Y is the response variable and l is the transformation parameter. We then could develop the model:

$$\text{Wave time X} = 38.348126 + 0.3232955\text{MC}$$

Where MC= moisture content in percent.

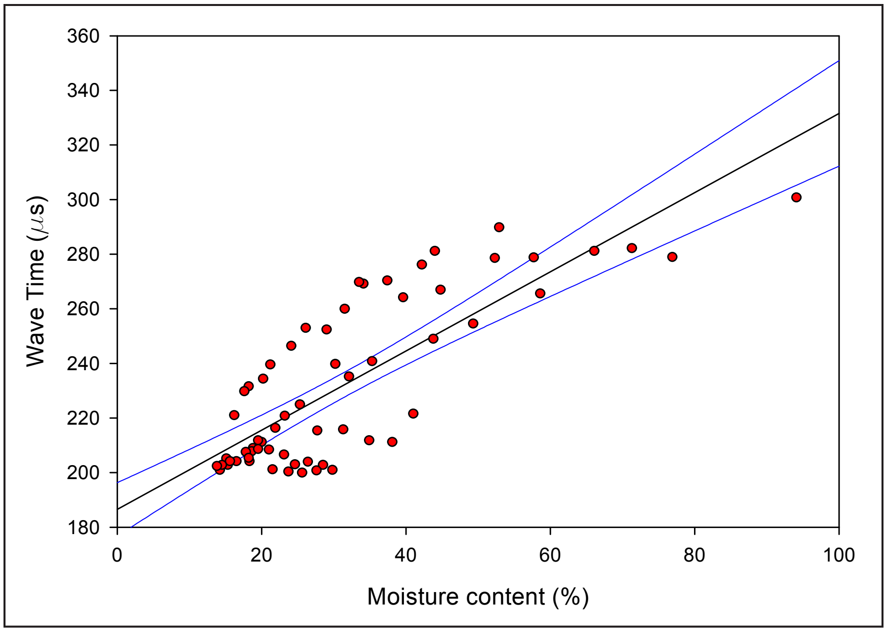

Figure 1.—Regression analysis of moisture content vs. stress wave time $r^2 = 0.68$, with 95 percent confidence bands.

We derived wave time X through the transformation process using:

$$\text{Wave time X} = (\text{wave time}^2 - 1)/(2*111.1329^2 - 1)$$

Where 111.1329 is the geometric mean.

Figure 1 is a plot of the wave time by moisture content. From this we can see that an approximately linear relationship, $r^2 = 0.68$, exists between the moisture content of the specimen and its wave time in microseconds.

DISCUSSION

This study indicated that moisture content directly affects the results obtained from the nondestructive testing method being investigated. Moisture content (MC) appears to affect stress wave velocity and the calculated dynamic modulus of elasticity in the same manner that it affects the true modulus of elasticity, determined through static testing. This study was approached from an applied angle to test for an effect of moisture on wave velocity. The model presented in the results section was developed to determine if there was a general relationship present. After 50 percent MC the data appear to be leveling off perhaps because the moisture, rather than the wood, is the dominate influence on wave velocity rather than the wood. Within few data points above the 50 percent moisture content range, the extent of leveling is not conclusive. However, within the typical range of conditions of 10 to 30 percent MC, though, there is a stronger adherence to a linear relationship. Additional data and more extensive investigations on this topic would be required to establish a model that could be used in a predictive manner.

CONCLUSIONS

From this research we conclude that the presence of moisture in wood affects the wave velocity. Therefore, when performing the in situ, nondestructive evaluation described in this research, investigators must take into account the moisture content of the wooden element in question. Failure to do so could contribute to false evaluations.

LITERATURE CITED

Brashaw, B.; Ross, R.; Pellerin, R. 1997. **Stress wave nondestructive evaluation of green veneer: southern yellow pine and Douglas fir.** International Society for Optical Engineering. 2944: 296-306.

Forest Products Laboratory. 1999. **Wood Handbook: wood as an engineering material.** Gen. Tech. Rep. FPL-113. Madison, WI: USDA Forest Service, Forest Products Laboratory. 463 p.

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

Green, D.; Kretschmann, D. 1994. **Moisture content and the properties of clear southern pine.** Res. Pap. FPL-531. Madison, WI: USDA Forest Service, Forest Products Laboratory.

Halabe, U; Bidigalu, G.; Hota, G.; Ross, R. 1995. **Nondestructive evaluation of green wood using stress wave and transverse vibration techniques.** Materials Evaluation. 55(9): 1013-1018.

Kretschmann, D.; Green, D. 1996. **Modeling moisture content-mechanical property relationships for clear southern pine.** Wood and Fiber Science. 28(3): 320-337.

Wu, Q. 1999. **Influence of moisture on stress-wave properties of wood-based panels.** In: Proceedings, 11th International symposium on nondestructive testing of wood; 1998 September 9-11; Madison, WI. Madison, WI: Forest Products Society: 19-25.