Assessing stiffness on finger-jointed timber with different non-destructive testing techniques

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Abstract

Non-destructive testing (NDT) is a common method to determine the stiffness of timber before its utilisation for construction purposes. In this project a total of 188 pieces of 2" x 4" black spruce unjointed and finger-jointed timber (38 x 89 x 2438mm) were tested with different NDT techniques. Testing was applied on three main specimen groups: 1.) unjointed timber, 2.) finger-jointed timber with 2-3 joints and 3.) finger-jointed timber with 5-7 joints. Three NDT techniques were chosen. These were stress wave propagation, transverse vibration and bending as applied by a grading machine. The stress wave technique was applied via a commercial machine (Timber Grader MTG) which is a hand-held device. Transverse vibration was applied by using a spectrum analyser, an accelerometer and an instrumented hammer. The main objective of this study was to evaluate the application of present NDT techniques to finger-jointed timber. The modulus predicted on unjointed sawn timber and timber with different number of finger joints were correlated with three-point bending test results, which are used as a reference for the "real" stiffness. The results showed that modulus values measured using the three NDT methods correlate well with three-point bending modulus for both unjointed and finger-jointed timber. The regression coefficient between NDT modulus and three-point bending modulus (R^2) ranged from 0.80 to as high as 0.97. The grading machine provided the lowest R^2 values than stress wave and transverse vibration. Similar R^2 values were observed for both unjointed and finger-jointed timber, indicating that these NDT techniques can be used for grading finger-jointed timber with the same degree of accuracy as solid sawn timber. Furthermore, results show that modulus decreases with any increase in number of finger joints.

1 Introduction

Non-destructive testing (NDT) techniques are commonly used by the wood industry and wood research community to evaluate quality and strength properties of timber. For residential constructions finger-jointed timber is often utilized. Literature provides a wide range of NDT testing on unjointed timber of

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different tree species all over the world (Auty & Achim 2008; Carter *et al*. 2006; Mišeikyte *et al*. 2008; Sandoz 1989) whereas non destructive measurements on finger-jointed timber are less found in literature.

In the present study different NDT techniques for stiffness measurement were selected using stress wave propagation and transverse vibration. Furthermore the test specimens were Centre point loaded as well as run through an MSR machine.

Based on the intention of this study to examine and analyse mechanical properties on unjointed and finger-jointed timber the following main research questions were formulated.

- Can NDT techniques be applied on finger-jointed timber for stiffness measurement?
- Is accuracy influenced by the finger-joints?
- Is the stiffness of unjointed and finger-jointed wood comparable?
- Is there an effect of number of finger-joints on stiffness of timber?

2 Material and Method

Stiffness and strength was measured on 2 by 4” studs (38x89x2438mm). These studs were sawn from Black spruce (*Picea mariana*) trees, grown in the Northern Parts of Quebec. Testing was applied on three main specimen groups: 1.) unjointed timber (n=40), 2.) finger-jointed timber with 2-3 joints (n=47) and 3.) finger-jointed timber with 5-7 joints (n=101). For density calculation the exact dimensions and weight of the specimens was taken. Before the stiffness and strength measurements the moisture content (MC) was measured with a moisture meter. The average MC was calculated from three measurement points on the unjointed wood specimens and from each finger-jointed piece of the finger-jointed timber. The experimental Modulus of Elasticity testing contained four non-destructive methods using a Stress wave timer, Transverse Vibration, Centre Point Loading and a MSR machine. These NDT techniques are used in the industry and wood science for assessing stiffness on timber.

2.1 NDT techniques used for stiffness measurement

Stress wave propagation

The stress wave timer used in this study is called Timber Grader MTG, which is a handheld strength grading device for sawn wood developed by Brookhuis Micro-Electronics and TNO (Netherlands). The measurement principle of the Timber Grader MTG is based on stress wave propagation in the wood. It measures the natural frequency of timber. After that the software calculates the strength and static modulus of elasticity (Rozema 2007).

Transverse vibration

The vibration of the beam is recorded by an accelerometer. The hammer impact and vibration signals were transferred to a spectrum analyzer and then converted into the modal frequencies. The test method is based on the measurement of the first and second natural frequencies of a wooden beam under free vibration. The first natural frequency (f1) was determined based on the modal shape. MOE (Ed) was calculated using Equation 1 (Warburton 1976)

$$MOE = \frac{12\rho}{d^2}\left(\frac{2\pi f_1 l^2}{22.37}\right)^2$$ Equation 1

where *MOE* = Modulus of Elasticity, *ƒ*1 = first natural Frequency, *ƒ*1 = first natural Frequency, p = density, l = span of beam, d = depth of the beam

MSR Machine

For the MSR grading a Cook-Bolinder grading machine was used. By passing through the timber the machine measures the force required to deflect the timber by 6 mm over a 900 mm span at intervals of 100 mm. Then the timber was flipped and ran through the machine a second time to measure the other side using the same approach. The measured forces for each side were then averaged to determine MOE at each interval. The MOE values for each interval were average to determine the average MOE for each piece of timber. Equation 2, given below, was used to calculate the MOE.

$$MOE = \left(\frac{P}{\Delta}\right)\left(\frac{L^3}{4bh^3}\right)$$ Equation 2

where MOE = Modulus of Elasticity; P = force; L = span of beam; b = width of beam; h = depth of beam; Δ = slope

Centre- Point loading

All specimens were manually loaded flat wise with 10.34 kg (101.44 N) weight at the mid point of the specimen and deflection (mm) was measured with a sensor, positioned under the specimen at middle length. After preloading the specimen with 2 kg the sensor was put to zero. Then weight to a total of 10.34 kg was applied and deflection recorded. For stiffness calculation the following Equation 3 for MOE calculation of Centre-Point loading was applied, which can be found in ASTM D198.

$$MOE = \left(\frac{P}{\Delta}\right)\left(\frac{L^3}{4bh^3}\right)$$ Equation 3

where MOE = Modulus of Elasticity; P = force; L = span of beam; b = width of beam; h = depth of beam; Δ = deflection at mid span

3 Results and Discussion

3.1 Density and Moisture Content

Before stiffness measurement the Moisture Content (MC) was measured with a moisture meter. To assure homogeneous data material the MC has to be kept homogeneous because of its effect on stiffness measurement especially when stiffness is measured with stress wave propagation (Sandoz 1993). Average MC and Coefficient of variation (CV) is shown in Table 1.

Table 1: Data of Moisture content and Density

Specimen group		MC (%)	Density (kg/m³)
A (2-3 FJ)	Avg.	11.5	484
	CV (%)	6.1	3.8
B (5-7 FJ)	Avg.	12.0	479
	CV (%)	7.5	2.9
C (unjointed)	Avg.	11.6	487
	CV (%)	9.5	7.3

3.2 MOE

In the Table 2, the descriptive statistic of the MOE from four different NDT methods is shown.

Table 2: Data of MOE for different NDT techniques

Specimen group	MOE	Stress wave (Mpa)	Transverse Vibration (Mpa)	MSR Eavg., (Mpa)	Centre-Point loading (Mpa)
A (2-3 FJ)	Avg.	9990	9689	8843	9437
	CV (%)	14.2	14.8	13.3	14.1
B (5-7 FJ)	Avg.	9457	9213	8650	9044
	CV (%)	13.8	14.8	13.2	14.6
C (unjointed)	Avg.	10447	10285	9769	10129
	CV (%)	14.8	16.6	12.2	14.1

The unjointed test specimens have a higher average MOE than the finger-jointed test specimens. Also the average MOE decreases with any increase in the number of finger-joints. Figure 1 illustrates this using the results from the stress wave groups. The highest average MOE values are measured with Stress wave than transverse vibration and MSR machine. Similar levels of CV between the three specimen groups occur for all measurement techniques ranging from 12.2 % to 14.8 %, hence it can be stated that the amount of finger joints in timber doesn't produce larger stiffness variation inside one group.

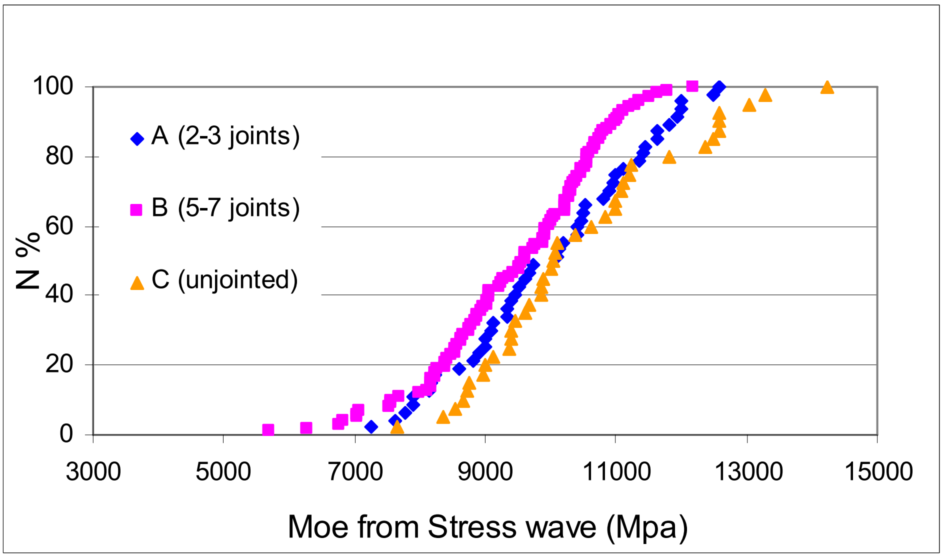

Figure 1: Cumulative distribution of MOE from Stress wave measurement for the different specimen groups

In Table 3 the Coefficient of determination (R^2) of the regression analysis between the NDT techniques are presented. The R^2 values range from 0.80 to as high as 0.97. Examining the R^2 values it can be seen that machine grading (MSR) reaches lower R^2 values than Stress wave and Transverse vibration.

Table 3: Coefficient of determination (R^2) of MOE measurement

Specimen group	MOE	Stress wave	MSR	Transverse vibration
A (2-3 FJ)	Centre point loading	$R^2 = 0.91$	$R^2 = 0.88$	$R^2 = 0.93$
B (5-7 FJ)	Centre point loading	$R^2 = 0.90$	$R^2 = 0.80$	$R^2 = 0.97$
C (unjointed)	Centre point loading	$R^2 = 0.93$	$R^2 = 0.90$	$R^2 = 0.97$

In this study Centre point loading is used as a reference for “real” stiffness. All three NDT techniques correlate very well with Centre point loading, indicated by high R^2 values. Similar R^2 values were observed for both unjointed and finger-jointed timber, indicating that these NDT techniques can be used for grading finger-jointed timber with the same degree of accuracy as unjointed timber.

4 Conclusions

The results presented in this paper show that different NDT techniques available at the market not only show their reliability and accuracy on unjointed timber but also on finger-jointed timber. The regression coefficient between NDT modulus and three-point bending modulus (R^2) ranged from 0.80 to 0.97. The highest R^2 is from transverse vibration, than stress wave than grading machine. Measuring timber with different number of finger joints, the results show that the MOE decreases with any increase in number of finger joints. While all NDT methods show high accuracy for stiffness measurement the operator has to choose which device best fits his purpose. Comparing the devices the Stress wave grading device Timber Grader MTG can be recommended if fast stiffness measurement is required.

5 Acknowledgements

Thanks to Peter Rozema from Brookhuis Micro-Electronics for providing stress wave device Timber Grader MTG; Also thanks to WSTC staff for helping with data acquisition.

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