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R&R study of using a stress wave timer to measure the elastic modulus of structural dimension lumber

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ABSTRACT

The repeatability and reproducibility (R&R) analysis is of great importance in measurement of a material property in science and engineering. Stress Wave Timer is a portable and efficient instrument, which has been widely applied to measure the modulus of elasticity (MOE) of lumber. The study was aimed at analyzing the R&R of using Metriguard 239A Stress Wave Timer to measure the MOE of the structural dimension lumber of lodgepole pine (*Pinus contorta* var. *latifolia*), and providing a scientific measurement, i.e. a measurement plus an uncertainty, for any accredited testing laboratory and quality control department in a manufacturer. It was found that the R&R of using Metriguard 239A Stress Wave Timer to measure the MOE of lumber was very reliable when the standard operation procedure was strictly applied. The uncertainty of an MOE measurement was 335 MPa at a confidence level of 95%. The average MOE measured was 12,098 MPa.

1. Introduction

The non-destructive evaluation techniques have been widely used for evaluating the mechanical properties of wood and wood-based composite products, which mainly include vibration [1–3], static bending [4–6] and stress wave methods [5,7,8]. The stress wave technique done via a stress wave timer is preferred by researchers to some degree due to its accuracy and efficiency, the principle of which is to measure the velocity of stress wave travelling in a sample wood product and therefore figure out the modulus of elasticity (MOE).

Smulski [5] investigated the relationship of MOE values measured using the stress wave and static bending methods with four northern hardwoods. It was observed that the MOE values, obtained by the stress wave timer of the four species were on average up to 32% higher than those measured by the static bending test. Pu and Tang [7] studied the elastic properties of southern yellow pine (*Pinus* spp.) laminated veneer lumber (LVL) by using the stress wave and transverse vibration tests. The effects of veneer grade and surrounding relative humidity (RH) were taken into account. They found that the MOE determined from the stress wave test was, regardless of RH, consistently higher than that obtained by transverse vibration test. Lee and Kim [9] estimated the localized MOE and long-span MOE of structural glued laminated timber (glulam) made of Japanese larch (*Larix leptolepis*) using stress wave test, static bending and machine stress rating methods, respectively. They discovered that the results determined by the stress wave method are significantly correlated to those by the other two methods. Passialis and Kirrazakos [10] measured the MOE of seven wood specimens of straight grain and free of visible defects of juvenile and mature wood of naturally-grown fir trees (*Abies cephalonica* × *A. alba*, *populous hybridogenous*), using stress wave test. They discovered that the average MOE of juvenile wood was 10,774 MPa, which was about 7% lower than that (11,591 MPa) of the mature wood. Ericson et al. [11] assessed the potential of using red maple (*Acer rubrum*) sawlogs to manufacture laminated veneer lumber. They grouped the specimens in terms of the MOE values obtained by an ultrasonic veneer grader, which were verified using a stress wave timer. They found that the MOE values of the veneer were normally distributed with moderate variation (i.e. mean = 12.4 MPa, standard deviation = 2.3 MPa).

On the other hand, the repeatability and reproducibility (R&R) of a method is extremely important in measurement of a material property in science and engineering [12]. The repeatability is defined as the measurement variability of using a specific gauge to repeatedly measure a property by the same operator, which can also be called "equipment variation". The reproducibility is the additional measurement variability of using the same gauge

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to measure a property by different operators, which is often called "appraiser variation" [13]. The R&R study is considerably important to obtain a material property in engineering design. At a given confident level such as 95%, a property measured using a method should be scientifically reported its value associated with its range such as standard error. Phillips et al. [14] used the R&R study to evaluate the tear strength of fiberglass shingles using the so-called Elmendorf tear test method. By ignoring the within-sample variability, they did a two phases of research, i.e. they found that the within-sample variability took up about 91% and 95% of the total R&R variability in each study. Besides, the standard errors of the two phases were 8.7 and 36.8 g, respectively. Eperjesi et al. [15] studied the R&R of the OcuSense TearLad™ osmometer by recruiting 29 participants whose ages ranged from 19 to 49 years. They concluded that the mean coefficient of variation among the four readings of the 29 participants was 2.9%, which was well in agreement with the value reported by the manufacturer, suggesting very good R&R of using the OcuSense TearLad™ osmometer.

Although the studies respectively on R&R of gauges or methods and with a stress wave timer were not a few, almost no studies were found, up to date, to relate to the R&R of using a stress wave timer to measure MOE of structural dimension lumber. This study was aimed at filling up this gap and providing some reliable indication for the researchers who may use this instrument to measure MOE in their research.

2. Experimental

2.1. Materials

The species of lumber was identified to be lodgepole pine (*Pinus contorta* var. *latifolia*). The dimensions of each lumber piece were about 1100 mm in length, 89 mm in width and 38 mm in thickness. Eleven (11) pieces of lumber were randomly selected from a bundle (104 lumber pieces) of 2 × 4 spruce-pine-fire (SPF) lumber of the grade "#2 and better", which were placed in a condition chamber at the Wood Science and Technology Centre (WSTC), the University of New Brunswick, Canada. The temperature and relative humidity (RH) of the chamber were set at 20 °C and 65%. The average moisture content of these lumber pieces was 13.4% at test.

2.2. Method

2.2.1. Preparation prior to experiment

The actual dimensions and weight of each lumber piece were measured first, which was used to determine density and speed of stress wave, and then to calculate MOE after testing.

Metriguard 239A Stress Wave Timer is a commercial portable instrument that records the propagation time of longitudinal stress wave at a given length of a specimen, on which to be based an operator can calculate the speed of the wave and furthermore MOE. This instrument includes a power switch, a LCD screen for displaying the propagation time, two sensitivity adjusting gain transducer channels and two connectors for connecting the start and stop accelerometers with the instrument, Fig. 1. Such an instrument was used to perform the study.

Two cables were tightly fixed on the connectors for connecting the stress wave timer instrument and two laboratory clamps. One of the clamps with start accelerometer was configured with a pendulum ball. Two laboratory clamps were placed on the horizontal ground based on two pre-drawn lines for marking the span of about 1000 mm between two accelerometers. Power switch was turned on and both of the gain transducer channels were fixed at gauge "1". The settings were pre-tested in advance for the optimum channels. The stress wave timer was placed on the operating desk for reading the display easily. Each sample was set flatwise with the mark on the top along the same orientation and fastened at both ends with the two clamps (Fig. 2). The three appraisers (namely A, B and C) were invited to conduct the tests strictly following the standard operation procedure (SOP) developed by the authors.

Fig. 1. Metriguard 239A Stress Wave Timer.

2.2.2. Standard operation procedure (SOP)

At the beginning of each test, the actual span of each sample between the start and stop accelerometers was precisely measured by each appraiser with a measuring tape. Then, the pendulum ball-hammer was raised to the fixed level and free fallen to hit the clamp only once impacting the sample to generate the stress wave. Meanwhile, the propagation time of the stress wave along the span was automatically recorded and displayed on the LCD screen. Each appraiser read the propagation time and wrote down the reading. Subsequently, the finished sample was taken off the setup and set up a new sample for testing. After one trial of testing all 11 samples was completed, the appraiser repeated the test twice. The experiment was fully completed after three appraisers finished their assigned tasks. The three trials by an appraiser were called Trial 1, Trial 2 and Trial 3. Each trial individually contained 11 measurements named from Part 1 to Part 11 [12].

The MOE of a lumber piece can be computed as:

$$MOE = \rho v^2 \tag{1}$$

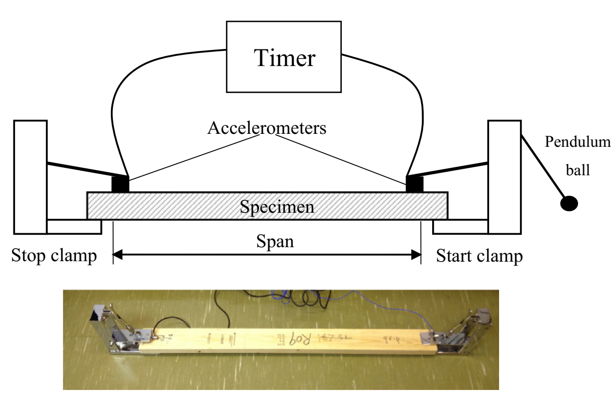

Fig. 2. Experimental setup of using the stress wave timer: (top – sketch showing the principle; bottom – picture showing an on-going test).