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Tensile Strength of Clear Thin Wood Samples in Relation to the Slope of Grain*1

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ABSTRACT

The mechanical and physical properties of wood are strongly dependent upon the slope of grain. Specially, tensile strength is more severely affected by the slope of grain. Therefore, tension tests were performed on small thin wood samples made from *Pinus radiata* with varying the slope of grain. Determining the tensile strength for clear thin wood samples the other variabilities associated with material, size, drying, defects, etc were discarded. Slope of grain was measured by the slope of grain indicator and actual slope of grain was also determined by a protractor. Correlation coefficients between machine measured and actual slope of grain for 40 pieces of 2×20 mm, 300 mm long *Pinus radiata* were 0.84 for wide face measurement. Results also showed that tensile strength and MOE from stress wave tests decreased with increasing the slope of grain. This study did not establish a relationships for tensile strength and MOE from stress wave with slope of grain. However, the trends of MOEs from stress wave test with both slope of grain are agreed well with Hankinson's equation. Predicted tension strength curve by Hankinson's equation was also agreed well with the experimental data over the range from 0 to 13 degrees for slope of grain.
Keywords: slope of grain, slope of grain indicator, tensile strength, and stress wave MOE

1. INTRODUCTION

The grain is the direction of the main elements of wood such as fibers or tracheids. The fibers or tracheids deviate from the true longitudinal axis due to the taper and the growth in a spiral formation of trees. This causes to affect the performance and reliability of lumber and other wood products produced from such trees in service. And excessive slope of grains are also undesirable in wood structures because of the problems associated with bowing of joists and trusses with changes in moisture contents(MC). Therefore, the slope of grain is an important characteristic in wood quality. However, the slope of grain in lumber is difficult to detect by optical measurement unlike the most other defects affecting the wood quality. As a result, lumbers with unacceptable slope of grain are often used into structure where strength and dimension stability are of importance.

Many researches have been suggested to provide the automatic measurement of the slope of grain. These processes are based on the use

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of stress wave (Armstrong etc., 1991), reflected light sources (Eastin and Johnson, 1993), and dielectric sensor (McLanchlan etc., 1973; Samson, 1988; Steele etc. 1991) based on the principle of rotating electrical field. Samson (1988) and Steele etc. (1991) showed that a electrical capacitance type device, called the slope of grain indicator (SOGI), was found to be a suitable alternative to visual assessment of the slope of grain in lumber. Although the slope of grain indicator could be valuable instrument for providing assistance in lumber grading as a means for controlling the slope of grain, its use for this application has not been thoroughly investigated.

Tensile strength has been found to be more severely affected by slope of the grain than bending and compressive strength. Consequently, it is essential that wood intended to withstand tensile forces should be selected so that the slope of grain is strictly limited. Therefore, the objective of this study was to determine the technical feasibility for using the slope of grain indicator to measure the slope of grain in a thin wood samples of *Pinus radiata*. This study also investigate the feasibility to predict the tensile strength and MOE from stress wave test of thin wood samples by the slope of grain measured from SOGI.

2. TESTS and MATERIALS

The test specimens were prepared for tension test from planks of *Pinus radiata*. Forty samples of kiln dried *Pinus radiata* measuring 35×90×650 mm were selected from wood technology laboratory stock room at Univ. of Canterbury. From selected lumber, each 650 mm long specimen was cut into 300 mm blocks perpendicular to the longitudinal axis. An attempt was made to eliminate some wood variables by increasing the uniformity for test specimens. Specially, cares for specimen were taken to discard any material that would have knots or other defects. Sliced thin veneer was obtained with a table saw from each blocks, then residual fibers were cleaned off the surface by sanding. The final cross section of test specimens was 2×20 mm and 300 mm long. Overall 40 specimens were prepared for tension test.

2.1. Stress Wave Test

Stress wave measurements were made from *Pinus radiata* of dimension with 2×20 mm in cross section and 300 mm long. Transit time measurements were taken at three different places for each specimen with a commercial stress wave device by SYLVATEST (Fig. 1). It is equipped with two test probes, of which the two probes consist of piezo-electric transducers, one generates the waves (sender), the other catches the transmitted wave (receivers). They worked on simple, direct contact with the wood. Wave propagation times were measured to a microsecond. The stress wave speed was computed as distance divided by stress wave propagation time. Using the stress wave velocity and density, the MOE was calculated from the following equation:

$$MOEs = \rho v^2/g$$

MOEs : modulus of elasticity predicted from stress wave test (kgf/cm^2)
v : velocity of stress wave (m/sec)
ρ : density of wood (gr/cm^3)
g : acceleration due to gravity (9.806 m/sec^2)

2.2. Slope of Grain Measurement

The slope of the grain measures the angle between fibers and the longitudinal axis of the

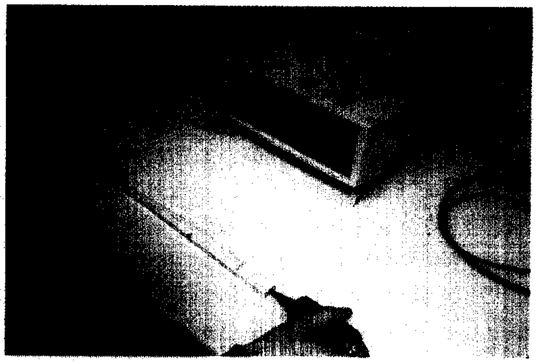

Fig. 1. Testing arrangement for stress wave test.

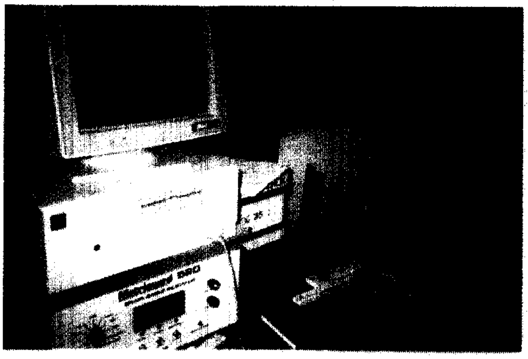

Fig. 2. Testing arrangement for slope of grain measurement by slope of grain indicator.

specimen. Model 520 slope of grain indicator (SOGI) was used to measure the slope of grain in specimen (Fig. 2). The SOGI is a noncontact device based on the dielectric constant of wood. For most woods, the dielectric constant of wood is about 50% greater along the grain than across the grain. Measurement of this difference by the SOGI provides an indication of slope of grain. The Model 520 SOGI used at the University of Canterbury, New Zealand consists of a sensor unit, a control unit and a personal computer. The specimens were scanned with a capacitance head position adjacent to the wood surface. Slope of grain measurements were taken along scan lines every 5 mm across the 20 mm. Therefore, 3 scan lines were required to completely scan the width of the each specimen. Measurements also at 5 mm intervals along this 15 cm specimen length without the grip areas resulted in 30 measured values. A sensed signal is processed to the personal computer through the control unit by an electrical cable to obtain the slope of grain.

2.3. Tension Test and Actual Slope of Grain Measurement

The tensile specimen attached to a specially designed frame that prevented vertical slippery movement. The fastener head was attached to a grip, which was connected to a load cell and movable head of machine. The fasteners were held by pneumatic pressure to prevent the grip failure. The testing machine was operated at a constant loading rate by a cross head movement of 2.5 mm/min. In all tests loads and displacements at testing were recorded continuously on an x-y recorder.

After tension test, the actual slope of grain was measured relative to the long axis of each specimen on the wide face. The slope of grain was determined by inspection of surface checks and break surface along the fractured surface by protractor and ruler. Then a small piece of wood was cut from unbroken parts of each specimen to determine MC and specific gravity (SG). SG and MC of each specimen were determined using standard testing methods (ASTM, 1995). Volume and weight were also measured from each specimen. The samples were dried at 104°C until constant weight was reached. Then the ovendry weight was measured to calculate SG and MC.

3. RESULTS and DISCUSSION

Summary data for actual and machine measured slope of grain for the 40 specimen are shown in Table 1. Actual slope of grains and

Table 1. Summary for actual and machine slope of grain measured at 40 specimens.

Method of measurement	Slope of grain(°)			
	Average	Standard deviation	Minimum	Maximum
Actual	6.97	2.42	3	13
Machine	6.61	2.05	3.5	11.9

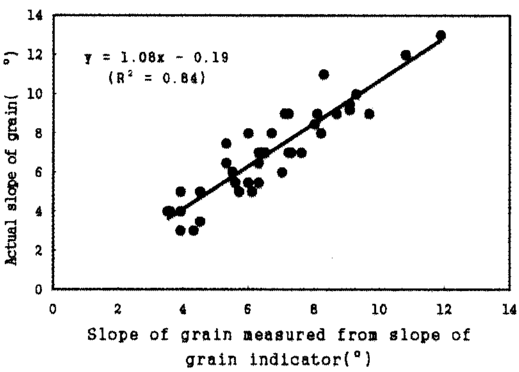

Fig. 3. Relationship between actual grain angle and grain angles from slope of grain indicator.

slope of grains measured from SOGI were spread over the range of 3 to 13 degrees and 3.5 to 11.9 degrees, respectively. Linear regression analyses also conducted on between slope of grain from SOGI and actual slope of grain. (Fig. 3) Regression equation and coefficient of determination (r^2) are also given in Fig. 3. The regression line in Fig. 3 do not correspond to the line of equality, thereby indicating that a little discrepancy exist between actual slope of grain and slope of grain from SOGI. However, the high precision of the machine is indicated visually at the tight clustering of the data around the regression line in Fig. 3. Clustering of data point around the regression line is extremely high, as revealed by the very high coefficient of determination (r^2) obtained within this range. According to the regression equation, the SOGI also tends to slightly underestimate the actual slope of grain. Since the accuracy of SOGI is about 1 degree, the instrument cannot reliably differentiate with the actual slope of grain. Therefore, the slope of grain indicator can be suitable for application in measurement of slope of grain for the thin wood samples.

Results of stress wave tests are given in Table 2. This study evaluated the relationship for predicting MOE from the stress wave test as a function of slope of grains. The relationship between many mechanical properties of wood and slope of grain can be expressed as a form of Hankinson's equation:

$$N(\theta) = \frac{PQ}{P \sin^{n}\theta + Q \cos^{n}\theta}$$

$N(\theta)$ = the property of the slope of grain, θ
P = the property parallel to the grain
Q = the property perpendicular to the grain.
n = the empirically determined exponent.

The usefulness of Hankinson's equation depends on the accurately determining the optional exponent of n for the mechanical properties. And the Wood Handbook (FPL, 1987) gives a range of values for n of 1.5 to 2.5 for mechanical properties with varying the

Table 2. Results from stress wave and tension tests

Wood characteristics		Stress wave MOE (10^3 kgf/cm^2)	Tensile strength (kgf/cm^2)	Failure		
MC (%)	SG			Along the grain	Grip	Others
11.6	0.42	104.3	737.3	10	3	27

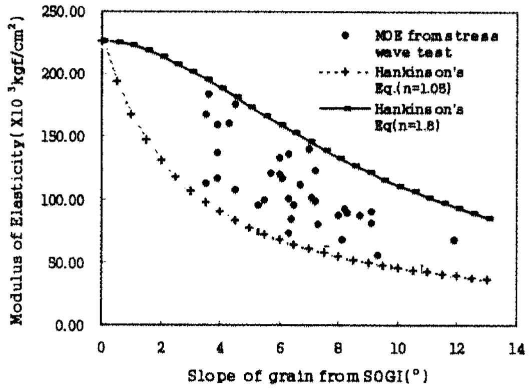

Fig. 4. MOEs from stress wave test as a function of slope of grain measured from grain angle indicators compared with the predicted values from the Hankinson's equation (n = 1.05 and 1.8).

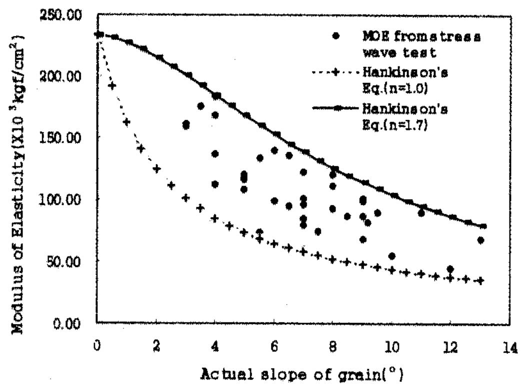

Fig. 5. MOEs from stress wave test as a function of actual slope of grain compared with the predicted values from the Hankinson's equation (n = 1.0 and 1.7).

Q/P ratio and properties. Therefore, the data for MOE from stress wave test was used to determine the optimal exponent for Hankinson's equation. Since MOE parallel to the grain are dependent variables in Hankinson's equation, regression technique for second order parabolic form was used to find the MOE parallel to the grain using the data for slope of grains between 3 to 13 degrees. The relative accuracy for Hankinson's equation cannot be determined by coefficient of determination (R^2) since Hankinson's equation is not statistically determined. Therefore, the exponent was increased by set increments through the range of values to find the optimal ranges of n for Hankinson's equation.

Fig. 4 shows Hankinson's equation (exponents of 1.05 and 1.8) plotted MOE with slope of grain from SOGI. Fig. 5 also Hankinson's equation (exponent of 1.0 and 1.7) plotted MOE with actual slope of grain. The general trend of Hankinson's equation is evident in the data, but the MOEs from stress wave test with slope of grain are underestimated by Hankinson's equation. The Wood Handbook (FPL, 1987) gives a value for n of 2.0 for MOE with varying slope of grain. The use of Hankinson's formula for predicting the MOE are required a large extent tests for thin wood specimen.

Forty specimens were tested in tension with actual slope of grain 3 to 13 degrees. The average SG and MC for specimens was also 0.42 and 11.6%, respectively (Table 2). A failure location frequency is also presented in Table 2. Only three of forty specimen produced grip failure, that is, the grip and specimen separated before the specimen failed. The average tensile strength are also shown in Table 2. Tensile strength data from specimen produced grip failure are discarded from the analyses. The data for tensile strength were also used to determine the optimal exponent for Hankinson's equation and compared with Wood Handbook equation by using the same procedure for MOE from stress wave test. There was a good agreement with the Hankinson's equation. Predicted tension strength curve by Hankinson's equation is agreed well with the experimental data over the range from 0 to 13 degrees for slope of grain. The tensile strength of thin wood samples decreased with increasing

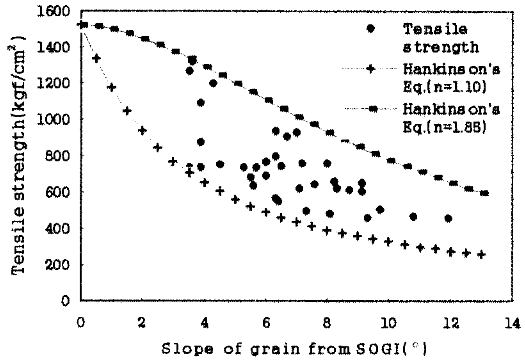

Fig. 6. Tensile strength as a function of slope of grain measured from grain angle indicators compared with the predicted values from the Hankinson's equation (n = 1.1 and 1.85).

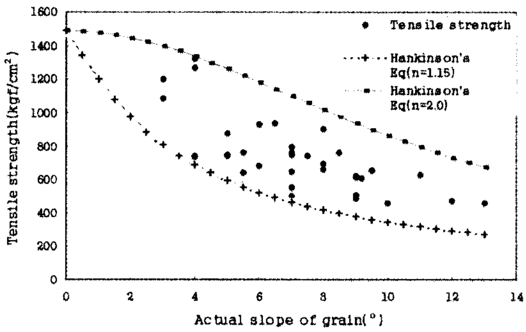

Fig. 7. Tensile strength as a function of actual slope of grain compared with the predicted values from the Hankinson's equation (n = 1.15 and 2.0).

the angle of specimen to the applied stress. Fig. 6 shows the Hankinson's equation (exponent of 1.10 and 1.85) plotted using the tensile strengths with slope of grain from SOGI. Fig. 7 also shows the Hankinson's equation (exponent of 1.15 and 2.0) plotted tensile strength with actual slope of grain. The Wood Handbook (FPL, 1987) gives a range of values for n from 1.5 to 2.0 for tensile strength with varying slope of grain. The general trend of tensile strength with the slope of grain shows a little discrepancy with Wood Handbook (FPL, 1987). The use of Hankinson's formula for predicting the tensile strength may be also required a more test for thin wood specimen.

4. CONCLUSIONS

On the basis of investigations conducted on thin wood samples from *Pinus radiata* the following conclusions are drawn:

1) Correlation coefficient between machine measured and actual slope of grain for 40 pieces of 2×20 mm, 300 mm long *Pinus radiata* was 0.84 for wide face measurement.

2) The general trend of the MOE from stress wave test with slope of grain was little underestimated by Hankinson's equation. However, there was a good agreement with the Hankinson's equation.

3) There is a little discrepancy in the range of n for Hankinson's equation to predict the tensile strength with varying slope of grain. However, Predicted tensile strength curve by Hankinson's equation agreed well with the experimental data over the range 0 to 13 degrees for slope of grain.

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