Evaluation of the Strength Characteristics of *Cunninghamia lanceolata* Timber Using Continuous Mechanical Stress Rating Equipment

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Before timber is used for engineering and structural purposes, it is necessary to grade the strength of the timber. In order to obtain the static modulus of elasticity value of timber quickly and accurately, this study used ultrasonic waves and continuous mechanical stress rating equipment and two non-destructive test methods to analyze the correlation between the non-destructive test measured value and the static modulus of elasticity value. It also evaluated the influence of the feeding orientation of the boards, the forward and reverse feed directions, feeding speed, and break area ratio. The analysis results indicated that the modulus of elasticity value determined through continuous mechanical stress rating equipment had the highest correlation with the static modulus of elasticity value. Moreover, according to the results, the feeding orientation of the boards, the forward and reverse feed directions, and the feeding speed did not influence the prediction of the continuous mechanical stress rating equipment modulus of elasticity value. Meanwhile, to ensure the accuracy and uniformity of the continuous mechanical stress rating equipment modulus of elasticity detection value, it is necessary to avoid an excessively high break area ratio in *Cunninghamia lanceolata* timber during the preparation process.

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INTRODUCTION

In recent years, forest plantation tending and the reforestation of slope land have shown fruitful results. Proper thinning operations help stand density management and tree growth as well as enhance stumpage values (Pirard *et al*. 2016; McEwan *et al*. 2020). It should be noted that plantation forests in Taiwan are more suited to growth at mid-high altitude zones, where coniferous species, *e.g.*, Chinese fir (*Cunninghamia lanceolata*), Japanese cedar (*Cryptomeria japonica*), and Taiwan fir (*Taiwania cryptomerioides*), are particularly abundant. Thus, using these thinning timbers for architectural and structural applications could increase the value of thinned wood and promote the effective use of forest resources (Chen *et al*. 2005; Cao *et al*. 2019). However, domestic thinned wood is mostly composed of small-medium diameter timbers, with a high proportion of juvenile wood and knots, which often causes the quality and strength of the timber to decrease.

Therefore, before thinned timbers are used as structural materials, they must be subjected to strength analysis in order to meet the requirements of structural timbers.

Additionally, Firmanti *et al*. (2005) and França *et al*. (2021) stated that the strength and stiffness of wood are primarily determined by specific gravity, fiber and tissue characteristics, and defects or flaws of wood, *e.g.*, density, knots (number, size, and position of knots on the board), slope of the grain, and interlocked grain. Moreover, there can be great differences between different tree species or even among the same tree species. Therefore, in order to ensure the safety of wood structure materials, nondestructive testing (NDT) methods, *e.g.*, visual grading, and mechanical grading or a combination of the two grading methods are used to detect the internal flaws and external shortcomings of the wood.

Some studies have analyzed the structure compositions and properties of materials based on the above methods and used their findings as the basis for quality identification (Wang *et al*. 2008; Brashaw *et al*. 2009; Kovryga *et al*. 2020). Based on simplification and cost considerations, timbers with similar mechanical properties are placed in the same category of stress level (Ross 2015). Moreover, the strength properties of timber are mostly linearly proportional to the modulus of elasticity (MOE). Thus, NDT is used for determining the MOE value of timber as the basis for estimating its strength properties (Firmanti *et al*. 2005; Ross 2015). Generally, in addition to the measurement and classification of the actual MOE value of wood materials using a universal strength testing machine, ultrasonic wave and tap-tone sound measuring methods are also used to analyze the dynamic moduli of elasticity (DMOE) of wood materials (Wang *et al.* 2008; Kovryga *et al*. 2019; 2020).

Mechanical stress rating (MSR) is currently the most important method for grading the strength of wood materials. However, although a universal strength testing machine can measure the static MOE value of timbers, due to its slow operation speed, this kind of machine is only suitable for use in laboratory analysis of the various strength properties of materials. The ultrasonic wave and tap-tone sound measuring methods can readily detect the DMOE value of timber, and through correlation analysis with the actual MOE, the stress level between each material can be indirectly determined. However, there are big differences between the DMOE values of various tree species and the static MOE (Ross 2015).

In view of this, this study uses a three-point load method to measure the actual MOE value of timber and is equipped with a mechanical stress grading device with a roller design that can accommodate the speed of production line load cells and the continuous mechanical stress rating equipment (CMSR) of rapid analysis computer technology. The test content includes analysis of the MOE_{CMSR} and static MOE_{static} value, the ultrasonic measurement of the DMOE correlation, and evaluation of the CMSR analysis methods, *e.g.*, feeding direction and board surface characteristics. Furthermore, the proposed method evaluates the analysis method of the CMSR, *e.g.*, the feeding direction and board surface characteristics, and the influence of whether the bark side is up or down on the bending properties. This includes bending tests that are static and continuous, analysis methods related to the ultrasonic measurement of the DMOE, *e.g.*, feed direction and board surface characteristics, and a comparison of the influence of the bark facing upwards or downwards against the bending properties.

EXPERIMENTAL

Materials

The 25- to 30-year-old China fir (*Cunninghamia lanceolata*) samples were collected from the Neimaopu tract in the Experimental Forest of the National Taiwan University in Nan-Tou County, Taiwan in October of 2018. All the China fir trees were cut into 3.6 m × 8.9 cm × 3.5 cm (length × width × thickness) sized samples; 40 specimens (n = 40) were dried to less than 15% by kiln drying and were tested for each condition.

Methods

Relationship between the various bending elastic modulus analysis methods

The following relationships were analyzed in this study: (1) the relationship between the modulus of elasticity (MOE_{static}) and the ultrasonic-wave velocity (V_u) speed of transmission, as well as the dynamic modulus of elasticity ($DMOE_u$); (2) the relationship between the MOE of the continuous mechanical stress rating machine (MOE_{CMSR}) and the V_u speed of transmission, as well as the $DMOE_u$; and (3) the relationship between the MOE_{static} and the MOE_{CMSR}.

Feeding rate of the continuous mechanical stress rating equipment (CMSR)

Three different speeds were analyzed to determine the differences between feeding speeds of the continuous mechanical stress rating machine (CMSR): 40 m/min (22.95 Hz), 60 m/min (34.44 Hz), and 80 m/min (45.90 Hz).

Feeding plate surface direction and feeding method

The CMSR had a roller-shaped three-point bending design. The material surface of the feed was the tensile side of the bending test. Therefore, the bark side of the specimen was placed bark up and down (as shown in Fig. 1) and the difference between the forward and reverse feed directions was evaluated.

Fig. 1. Schematic diagram of the bark side and pith side of the specimen

Characteristics of different break areas

The term "break area (BA)" means drilling failure area. It is mainly to simulate the cross-sectional area loss in the vertical wood direction caused by knots or wormholes. It was reduced by 13%, 27%, and 40%, and holes were made in the laminae artificially. The recorded data point of the maximum value of the MOE_{CMSR} decline was measured *via* the CMSR. As shown in Table 1, since the CMSR uses roller mechanisms for feeding, reducing the feeding speed can lead to a higher data point frequency, which can provide a more accurate distribution of data.

Table 1. Drilling Position of the Laminae and the Data Volume of the Mechanical Stress Rating (MSR)

Lumber Position (mm)	CMSR Data Account (No.)	MOE_{CMSR} Ratio Decrease (%)		
		BA-13%	BA-27%	BA-40%
1430	154	2.82	5.63	8.45
1800	221	4.73	6.77	8.89
2170	291	2.70	6.76	9.46

Static bending test

The centralized load tests of this investigation were conducted using a universal strength testing machine (AG-IC 250 kN, Shimadzu, Kyoto, Japan). The upper limit load and lower limit load, along with the corresponding deflection difference within the proportional limit, were recorded. Bending strength analysis was carried out according to CNS standard 2215 (2017), which involved the following procedures. The constant temperature and humidity chamber should be adjusted to a temperature of 20 °C at a relative humidity of 65% for two weeks. The length of each dimension was measured, and the test material thickness was set as 20 times the load of a 600 mm unit test sample, with a load speed of 10 mm/min. The modulus of elasticity (MOE_{static}) was calculated according to the Eq. 1,

$$MOE_{static}(MPa) = \frac{\Delta P L^3}{4\delta b h^3} \tag{1}$$

where L is the span (mm), b is the width (mm), h is the depth (mm), ΔP is the difference between the upper limit load and the lower limit load within the proportional limit (N), and δ is the bending deformation of the center of the span relative to ΔP.

In addition, the mechanical grades of the laminae were distinguished according to the cross laminated timber outlined in CNS standard 11031 (2014) and the Japanese Agricultural Standard standards (JAS) 1152 (2007) (as shown in Table 2).

Table 2. CNS Standard 11031 (2014) Mechanical Stress Rating (MSR) Grading Level of the Structural Glulam for Laminae

CNS Grade	MOE (GPa)	JAS CLT Grade
L200	20.0	M120 A
L180	18.0	
L160	16.0	
L140	14.0	
L125	12.5	
L110	11.0	M90
L100	10.0	
L90	9.0	
L80	8.0	M60
L70	7.0	
L60	6.0	
L50	5.0	M30
L40	4.0	
L30	3.0	

Continuous mechanical stress rating

This experiment utilized an SSR-7001 continuous mechanical stress rating machine (CMSR) from Advanced Technology Associates Co. (Westlake, OH) (as shown in Fig. 2). The machine is divided into three sets of rollers, at the front, central, and end, starting from the feeding direction. The machines spans a total of 1200 mm from the front to end sections. It has a load detection mechanism for recording the upward MOE. Table 3 shows the CMSR efficiency. The feeding speed is between 40 and 80 m/min over spans between 1200 and 1207 mm, with a maximum load of 500 kgF. The system uses laser detection to record the load resistance data once the sample has passed the mid-section rollers.

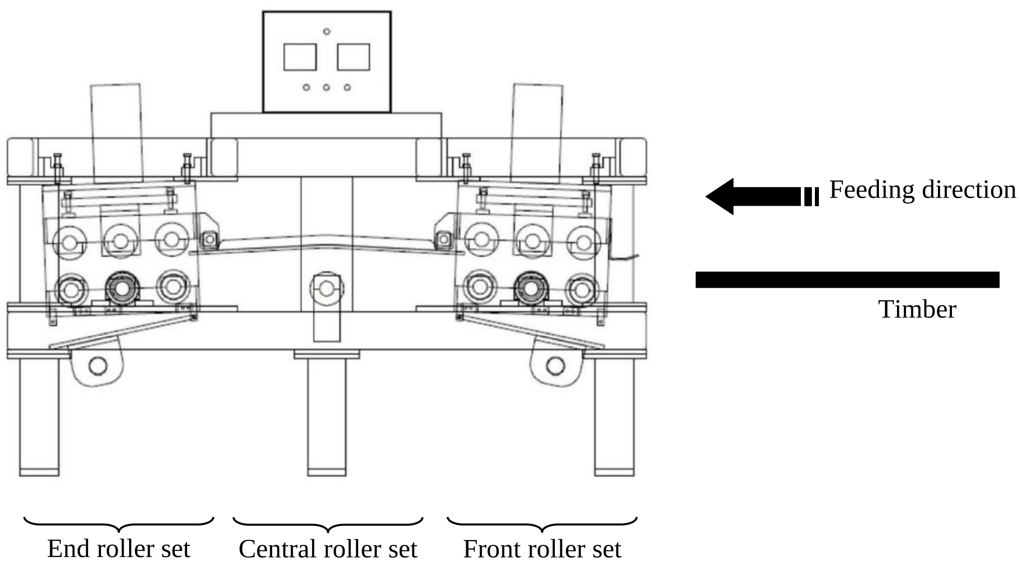

Fig. 2. Continuous mechanical stress rating equipment

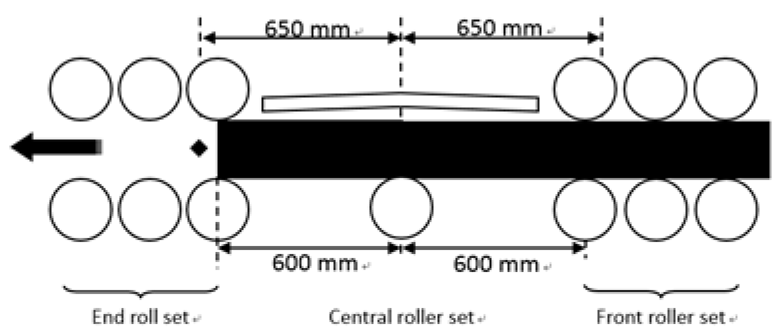

Fig. 3. Measuring range of the continuous mechanical stress grading equipment

Figure 3 shows the relative location between the specimens and the test machine with the laser detector at 1300 mm, which covers 1250 mm of the specimens. The system begins to collate the MOE_{CMSR} values and calculate its mean, maximum, and minimum values according to the CNS standard 11031 (2014) to establish the grading system *via* spray-painting a particular color. The color standards were outlined according to the guidelines of JAS 1152 (2007) for laminated timber. The four colors, *i.e.*, M30, M60, M90, and M120, are distinguished by the MOE value.

Table 3. Efficacy of the Continuous Mechanical Stress Rating Equipment (CMSR)

Project		Performance
Machine	Feeding speed	40 to 80 (m/min)
	Pivot spacing	1200 to 1207 (mm)
	Load range	0.0 to 500.0 (kgF)
	Accuracy	0.1 (kgF)
Timber	Length	2500 to 6000 (mm)
	Width	80 to 250 (mm)
	Thickness	18 to 45 (mm)

Ultrasonic wave settings

Non-destructive evaluation techniques were conducted to evaluate the ultrasonic-wave velocity (V_u), as shown in Eq. 2,

$$V_u = \frac{L}{t} \tag{2}$$

where V_u is the ultrasonic transmission speed (m/s), L is the length of the test material (m), and t is the transmission time (s), and the dynamic modulus of elasticity ($DMOE_u$), as shown in Eq. 3,

$$DMOE_u = \rho V_u^2 \tag{3}$$

where ρ is the mass density (kg/m^3), by using a portable ultrasonic non-destructive testing device (Sylvatest Duo, Saint Sulpice, Switzerland) at a frequency of 22 kHz. The specimens were placed between the transmitting and receiving transducers (n = 40), and the travel times of the ultrasonic waves (transmission time) were recorded.

Statistical analysis

This study used SPSS analysis software (Statistics v20, IBM, Armonk, NY) to diagnose the analysis of variance (ANOVA) using Scheffe's Method and Tukey's Test. The difference between each set of data revealed a 95% confidence interval (CI). The regression analysis of each test was carried out using Microsoft Office 2007 Excel to test the significance of each regression.

RESULTS AND DISCUSSION

Relationship between Various Measurements of Modulus of Elasticity (MOE)

Relationship between the modulus of elasticity (MOE_{static}), ultrasonic velocity (V_u), and dynamic modulus of elasticity ($DMOE_u$)

Figures 4 and 5 present the linear regression analysis between the MOE_{static} and V_u and the MOE_{static} and $DMOE_u$, respectively. The linear regression graph shows that the MOE_{static} increased as the V_u and $DMOE_u$ increased. The results of Figs. 4 and 5 also indicate that the slopes of the two linear regression equations were all positive and both the V_u and $DMOE_u$ were positively correlated with the MOE_{static}. From the coefficient of determination (R^2) results, it can be seen that the two linear regression equations were able to effectively explain the correlation between the MOE_{static} and the two independent variables, *i.e.*, V_u, and $DMOE_u$.

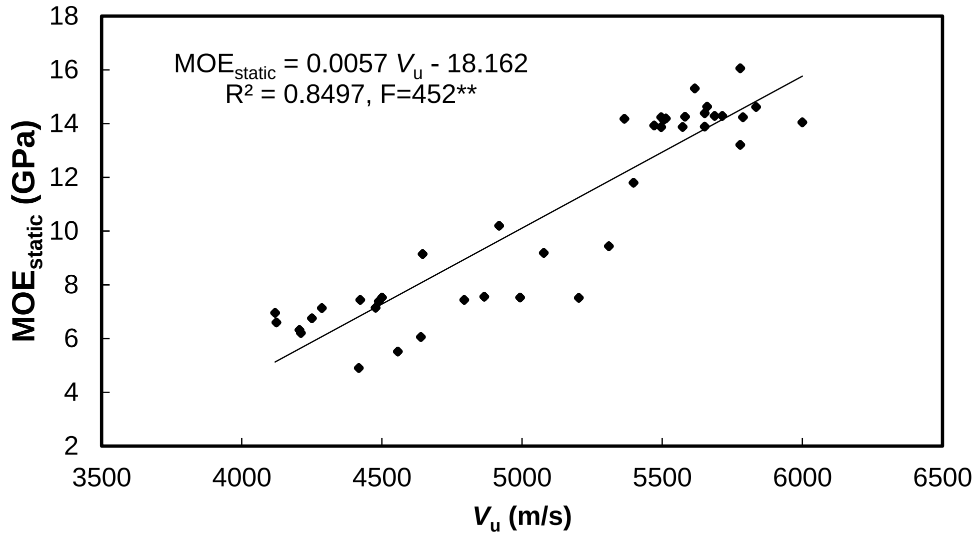

Fig. 4. Correlation between the MOE_{static} and the ultrasonic velocity (V_u) of *C. lanceolata*

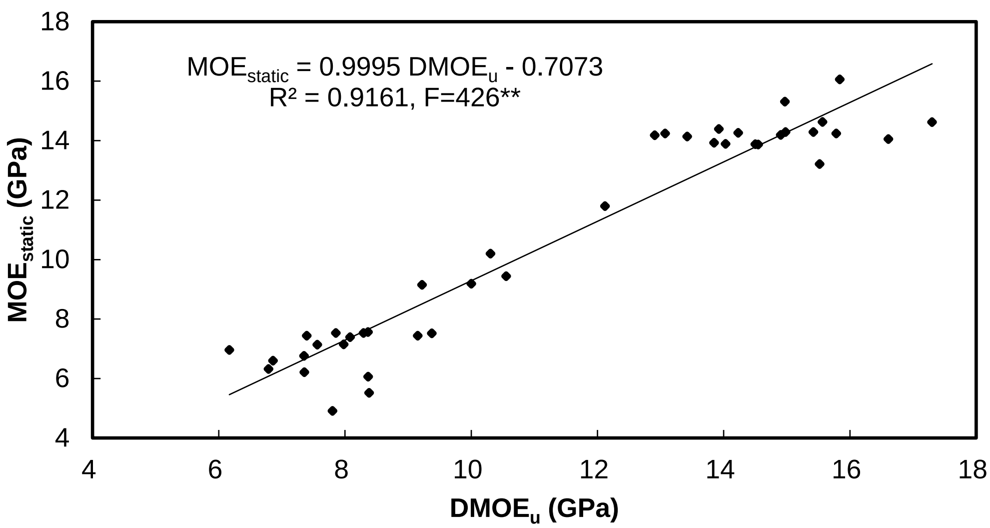

Fig. 5. Correlation between the MOE_{static} and the $DMOE_u$ of *C. lanceolata*

The p-values of the two sets of regression formulas were all less than 0.01, which indicated that this regression formula was significant and had predictive potential. However, from the comparison results of the coefficient of determination values of the regression formula, it can be found that the value of the $DMOE_u$ (0.9161) was higher than the R^2 V_u (0.8497), which indicated that compared to the MOE_{static}, using the $DMOE_u$ for testing is more apt. Ilic (2001) also used ultrasonic detection to predict the MOE of *Eucalyptus delegatensis*. The results indicated that both the vertical $DMOE_u$ and V_u held a significant positive correlation with the MOE value. The R^2 value of the vertical $DMOE_u$ and MOE was 0.95, while the R^2 value of the V_u and MOE was 0.78. Besides, Wang *et al.* (2008) indicated that the DMOE was slightly higher than MOE value, and there were good relationships between the DMOE and MOE of the four softwood lumber. Chung and Wang (2018) and Lee *et al.* (2021) also revealed that when using ultrasound to measure oriented *Phyllostachys makinoi* and *P. pubescens* scrimber boards, their V_u and $DMOE_u$

had a high correlation with the MOE value. As can be known from the above related studies, these results may have been influenced by the tree species, factors such as preparation conditions, or the testing environment, which showed a different pattern compared to the results of this study. However, these experiments showed that the $DMOE_u$ can be used to accurately predict the MOE value.

Relationship between the modulus of elasticity of the continuous mechanical stress rating machine (MOE_{CMSR}), ultrasonic velocity (V_u), and dynamic modulus of elasticity ($DMOE_u$)

Figures 6 and 7 show the relationships between the average values of the MOE_{CMSR} and the V_u with $DMOE_u$, respectively.

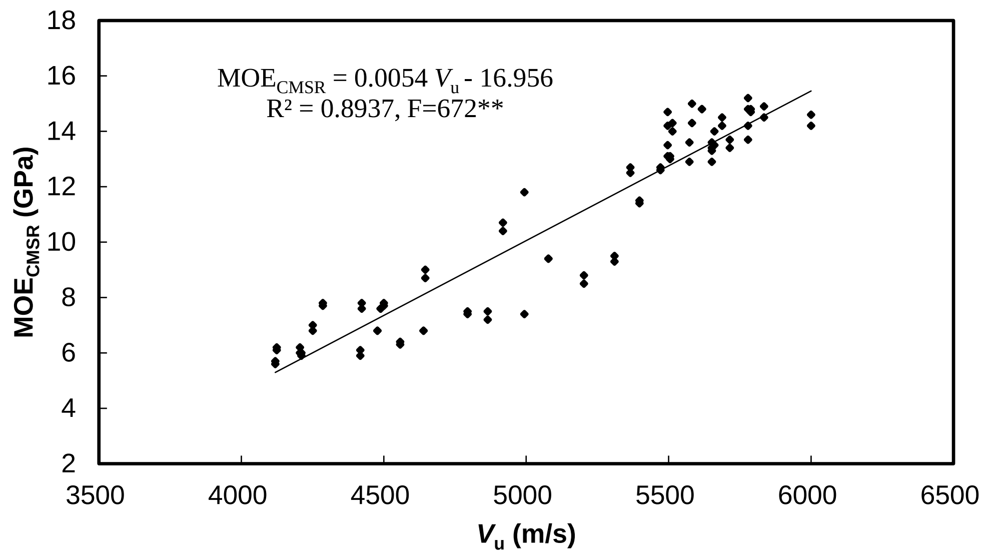

Fig. 6. Correlation between the V_u and MOE_{CMSR} of *C. lanceolata*

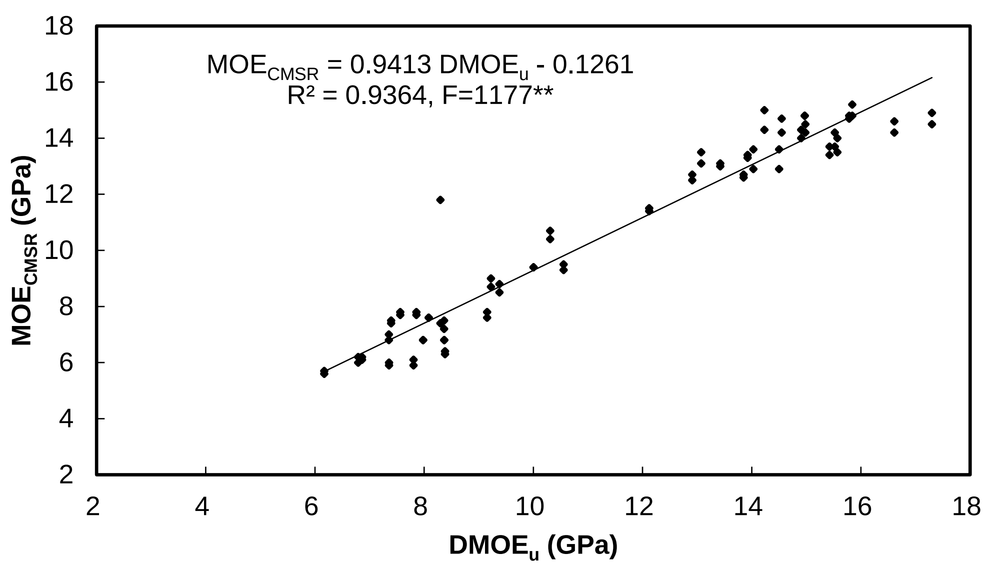

Fig. 7. Correlation between the $DMOE_u$ and MOE_{CMSR} of *C. lanceolata*

The slopes of the two sets of linear regression equations were all positive, which indicated that the $DMOE_u$ and V_u were positively correlated with the MOE_{CMSR}. The p-value being less than 0.01 indicated that the two sets of regression held evident significance with each other; this further indicated that the V_u and $DMOE_u$ can be used to further predict the MOE_{CMSR} value with high reliability. Comparing the R^2 values indicated that the regression formula established with the $DMOE_u$ as the independent variable had a higher explanatory power; this points to the same statistical trend as in the two above-mentioned sets of regression formulas for predicting the MOE_{static}.

Relationship between the modulus of elasticity (MOE_{static}) and the modulus of elasticity of the continuous mechanical stress rating machine (MOE_{CMSR})

The relationships of the MOE_{static} and MOE_{CMSR} are shown in Figs. 8 and 9. From the slope of linear regression shown in Fig. 8, it can be seen that the average MOE_{CMSR} value and the central location of the specimen at 900 mm (as shown in Fig. 9) were both positively correlated to the MOE_{static} value. Additionally, the p-values of both sets of regression equations were found to be than 0.01, which indicated that the regression equations were significant and had predictive value. The resulting positive correlation aligns with the research of Kretschmann and Hernandez (2006), who achieved the same correlational outcomes *via* MSR for *Pinus ponderosa* timber. The R^2 value reached 0.98, which indicated an exceptional predictive ability and the CMSR grading achieved high accuracy as a method for predicting the profile of the static bending elastic modulus. By comparing the R^2 values in Figs. 4 and 5 with the R^2 values in Figs. 8 and 9, it can be seen that using the MOE_{CMSR} as an independent variable to predict the regression of the MOE_{static} gave a higher explanatory power. In particular, the MOE_{CMSR} in the middle of the specimen had a high explanatory power, which assists with deducing its relationship with the static bending modulus. Among the three detection methods, the detection method using CMSR achieved the highest correlation.

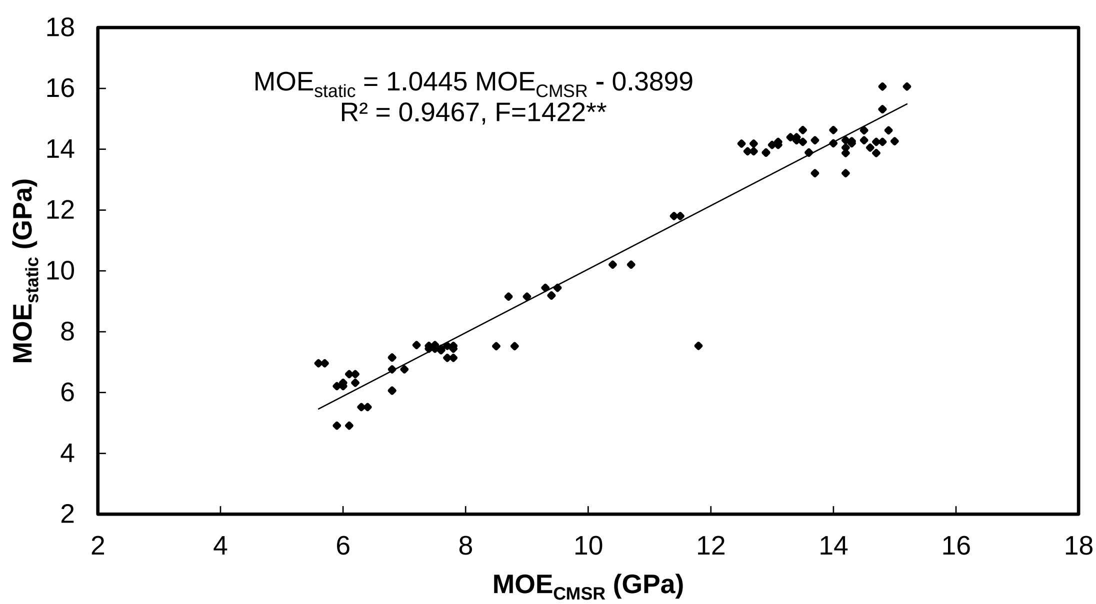

Fig. 8. Correlation between the MOE_{CMSR} and MOE_{static} of *C. lanceolata*

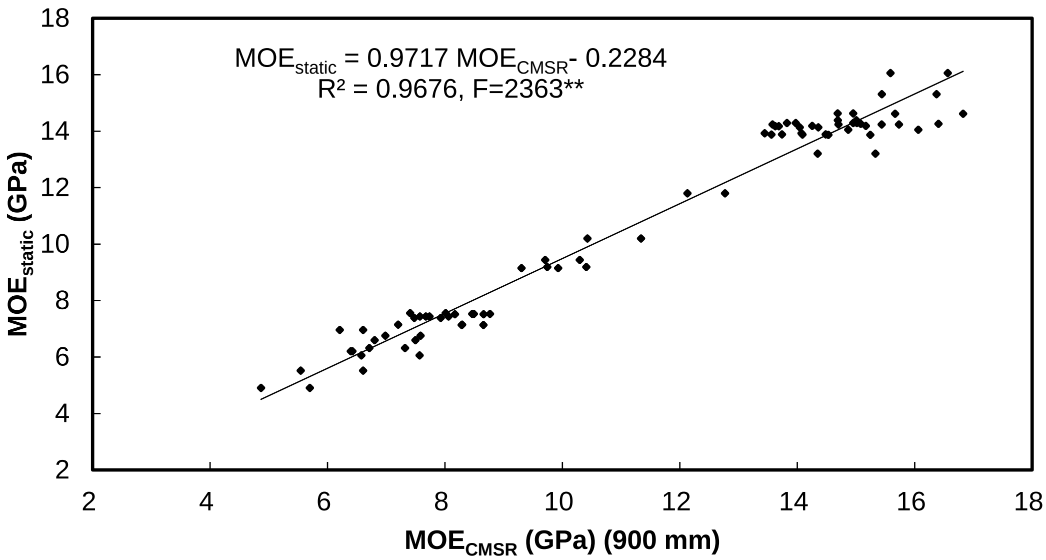

Fig. 9. Correlation between the MOE$_{CMSR}$ at the middle position (900 mm) and MOE$_{static}$ of *C. lanceolata*

The Grading Characteristics of Continuous Mechanical Stress Rating Equipment (CMSR)

Difference between the feeding orientation and feeding method

In general, the bending strength is better when the bark side of the timber is extended. Therefore, when a timber sample has the bark side facing up, the lower grain angle achieves higher lamina strength (Olsson *et al*. 2013; Anderson *et al*. 2020). The CMSR equipment used in this research operates by bending the specimens upwards to obtain the MOE value. Therefore, the authors evaluated both side orientations in order to further understand the different impacts of both the feeding orientation and feeding method on CMSR analysis.

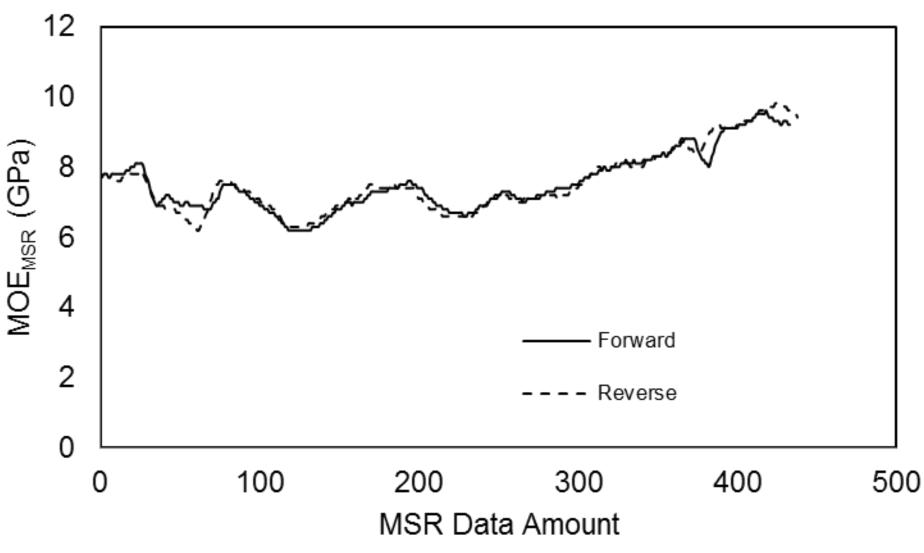

Fig. 10. Curve data of the forward and reverse MOE$_{CMSR}$ progress of the *C. lanceolata*

Table 4. Correlation Between the Direction of Bark Side and the Modulus of Elasticity of the Continuous Mechanical Stress Rating Machine (MOE_{CMSR}) of *C. lanceolata*

Grade (n)	D (kg/m^3)	*V* (m/s)	$DMOE_u$ (GPa)	MOE_{static} (GPa)	MOE_{CMSR} (GPa)				Percentage Difference Between the MOE_{CMSR} in Both Sides (%)
					Bark side up		Bark side down		
					Average*	900 mm**	Average*	900 mm**	
M30 (3)	393 (6.7) [a]	4249 (3.6) [a]	7.1 (11.9) [a]	6.0 (17.2) [a]	5.9 (4.5) [a]	6.2 (7.7) [a]	5.8 (2.0) [a]	5.8 (14.3) [a]	-1.0 ± 4.16 [a]
M60 (14)	393 (9.1) [a]	4533 (6.4) [a]	8.1 (10.3) [a]	7.1 (12.1) [a]	7.3 (12.1) [b]	7.9 (10.6) [a]	7.3 (11.1) [a]	7.6 (12.7) [b]	-1.8 ± 7.68 [a]
M90 (4)	401 (6.0) [a]	5176 (4.2) [b]	10.7 (8.8) [b]	10.2 (11.6) [b]	10.3 (9.8) [c]	11.2 (10.2) [b]	10.1 (9.7) [b]	10.5 (10.8) [c]	-0.1 ± 1.85 [a]
M120 (19)	465 (4.2) [b]	5640 (2.7) [c]	14.8 (7.9) [c]	14.3 (4.1) [c]	14.0 (5.0) [d]	14.8 (7.1) [c]	13.8 (6.2) [c]	14.9 (5.1) [d]	0.8 ± 3.13 [a]

Note: *: Data detected from full length of the sample; **: Data detected from central distance (900 mm) of the sample; and a, b, and c values in parentheses are coefficient of variation; Different letters in a given row indicate significant differences at the 0.05 level by Scheffe test

Table 5. Difference Ratio in the Modulus of Elasticity of the Continuous Mechanical Stress Rating Machine (MOE_{CMSR}) Compared to Feeding Speed of 40 m/min

Grade	60 m/min		80 m/min	
	Bark side up	Bark side down	Bark side up	Bark side down
M30	-0.12 ± 5.00	-2.41 ± 5.10	-2.85 ± 2.93	-2.88 ± 2.18
M60	-0.37 ± 3.63	0.36 ± 6.67	-1.95 ± 2.09	-0.41 ± 3.98
M90	-0.81 ± 3.51	-0.53 ± 3.30	-2.42 ± 2.11	-1.16 ± 1.91
M120	0.08 ± 3.23	-0.10 ± 5.26	-1.43 ± 1.76	-1.46 ± 2.67

Note: results are mean underestimate% ± S.D.

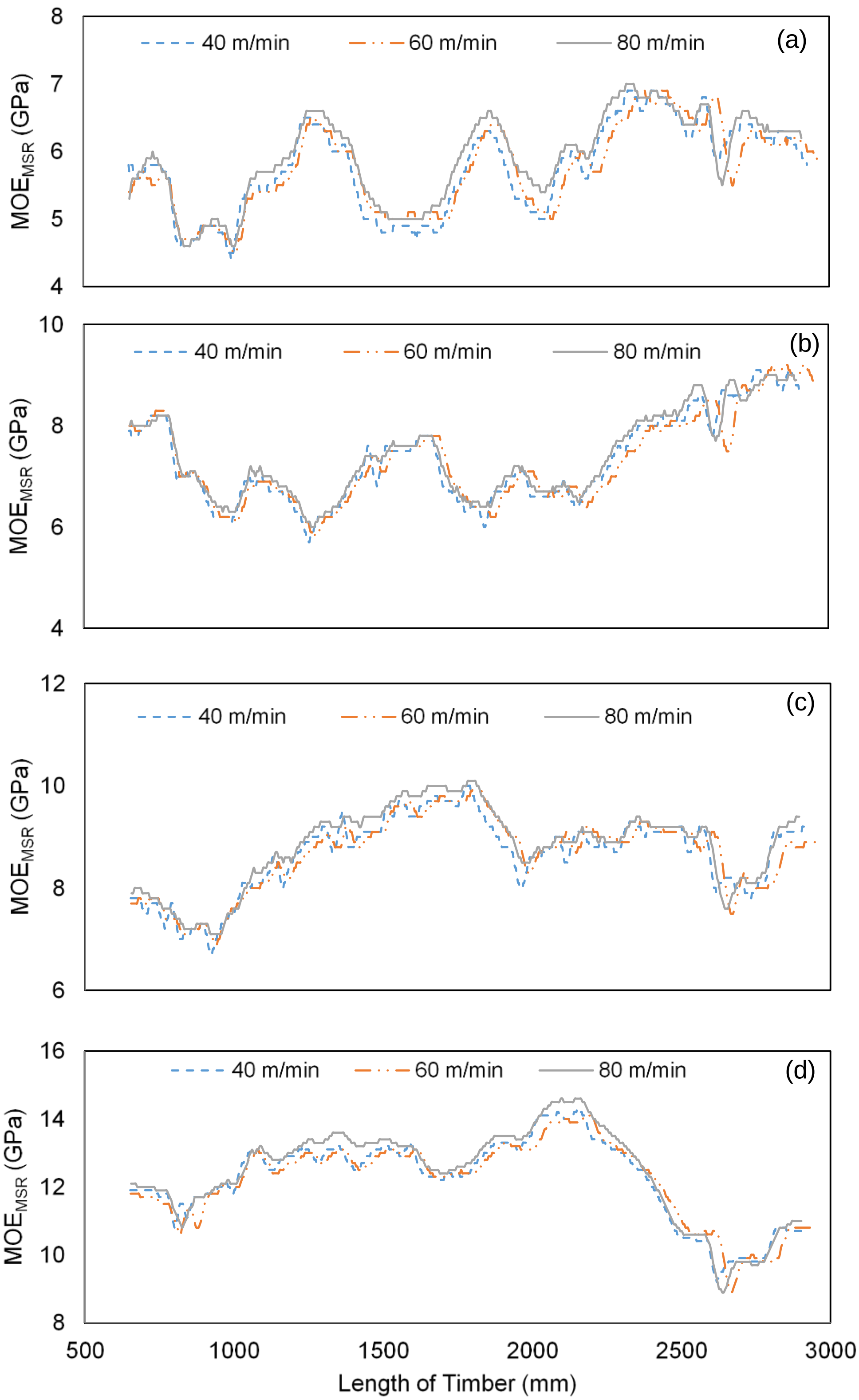

Fig. 11. Results of the MOE$_{CMSR}$ in M30 (a); M60 (b); M90 (c); and M120 (d) with different feeding speeds

As shown in Table 4, the average difference in the lateral direction of the bark side of each grading was 1.8%. However, the maximum standard deviation was 7.68%, which indicated that there was no significant difference in the side orientation of the bark. However, it is still better to proceed with the bark side down when conducting CMSR testing. In addition, in order to evaluate whether the feeding direction of the specimens were different from the MOE_{CMSR} analysis, this study also explored the difference between the curve data of the forward and reverse progress of the specimen. Figure 10 shows that the data of the forward or reverse progress had similar analysis results. It can be seen that the MOE_{CMSR} has a high degree of reproducibility, which shows that the front and back feeding directions of the specimen did not affect the analysis results.

Analytical characteristics of the continuous mechanical stress rating equipment (CMSR) with different feeding rates

In this test, laminae of different strength levels were tested at speeds of 40, 60, and 80 m/min. The MOE_{CMSR} at the same position was calculated from the test distance of each speed in the test, and the effects of different speeds on the MOE_{CMSR} were compared. Frist, taking 40 m/min as the test standard, the difference ratios of the MOE_{CMSR} obtained with different feeding speeds were calculated. Table 5 shows that as the feeding speed increased, the difference ratio of the MOE_{CMSR} of different grades of lamina trended downwards. From this result, it can be seen that increasing the feeding speed increased the MOE_{CMSR} detection difference. As shown in Fig.11a through 11d, it can be seen that the MOE_{CMSR} detection value at a feeding speed of 80 m/min was higher than the MOE_{CMSR} detection value of the other two feeding speeds during the rating process.

However, feeding speeds of 40 and 60 m/min produced alternating MOE_{CMSR} values. Although the 80 m/min feeding speed was the fastest of all three, the results of all three feeding speeds showed no significant difference. Samson (1987) derived the MOE_{CMSR} from boards made from various tree species and showed that feeding speeds that fall within the range of 0 to 350 m/min did not lead to significant differences in the MOE values. This shows that the feeding speed has no significant effect on the MOE test results, which matches the trend shown in the results of this study. Therefore, based on the accuracy of the strength analysis and the consideration of grading efficiency, the authors recommend using 80 m/min as the primary production speed to obtain more accurate MOE_{CMSR} measurements.

Analyzed characteristics of difference break areas

When the break area (BA) was decreased by 13%, 27%, and 40%, the effects of the various reductions in the BA on the MOE_{CMSR} are shown in Table 6. The cross-sectional area was reduced by 13% when a hole was drilled to a diameter of 12 mm. As a result, the MOE_{CMSR} value was significantly reduced, from between 2.70% to 4.73%. When the hole was drilled to 36 mm, the cross-sectional area was reduced by 40%, and the MOE_{CMSR} was reduced to between 8.45% and 9.46%. This result showed that the rate of decrease of the MOE_{CMSR} value increased as BA decreased. Gaff *et al*. (2017) conducted a bending test on lamina made from hard wood. The results showed that the MOE increased due to the increased thickness of the test material. The results of the bending test on different sized boards conducted by McNatt (1984) shows that as the size of the board decreased, the MOE coefficient of variation of the specimen tended to increase, *i.e.*, the uniformity of the bending properties of the specimen were affected by the reduction in dimensions. Therefore, to ensure the accuracy and uniformity of the detection value of the MOE_{CMSR}, it is necessary to prevent the specimen from losing too much cross-sectional area ratio during and before the preparation process. Otherwise, it is necessary to produce a sufficient cross-sectional area size prior to preparation.

Table 6. Effect of Reduction in Break Area on the Modulus of Elasticity of the Continuous Mechanical Stress Rating Machine (MOE_{CMSR}) Decrease Ratio

Reduction Rate of BA	Measuring Point MOE (GPa)	Decline Rate of Measuring Point MOE (%)	Average MOE (GPa)
BA-0%	12.2	-	10.89
BA-13%	11.8	3.27	10.75
BA-27%	11.6	4.91	10.67
BA-40%	11.3	7.37	10.61

CONCLUSIONS

1. The test results showed that the MOE_{static} was positively correlated with the MOE_{CMSR}, V_u, and $DMOE_U$. Among them, the correlation between the MOE_{static} and $DMOE_U$ was higher than the correlation with the V_u. The R^2 values showed that the MOE_{CMSR} was more suitable as a detection method for predicting the MOE_{static} than other methods, *e.g.*, the V_u or $DMOE_u$.
2. Results of the feeding orientation of the boards and whether the bark side direction was up or down did not have a significant influence on predicting the MOE value. Although the data from the forward and reverse feed directions were offset, the overlapped data had a high degree of repetition, which indicated that the feeding direction did not affect the detection results.
3. The feeding speed will affect the measured distance and the number of records, but there was no significant difference between the average MOE values obtained from the three feeding speeds.
4. To ensure the accuracy and uniformity of the MOE_{CMSR} detection value, it is necessary to avoid an excessively high break area ratio in the experimental material during the preparation process or to reserve enough break area size before preparation.

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