목재공학 24(4) : 7～14
Mokchae Konghak 24(4) : 7～14, 1996

Study on Stress Waves for Development of Glulam from Domestic Small Diameter Log (Ⅱ)[*1]

- Static Bending Properties of Glulam Member -

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국산 소경재를 이용한 집성재 개발을 위한 응력파 연구(Ⅱ)[*1]

- Glulam 부재의 휨강도 특성 -

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요 약

두께가 20㎜와 30㎜이고, 폭이 40㎜와 60㎜인 길이 600㎜의 낙엽송 제재목에 응력파 시험과 휨강도 시험을 실시하였다. 모든 시험편은 생재 상태로 구입 후 함수율 약 13%로 조습 처리하여 응력파 시험과 휨강도 시험을 시행하였다. 휨 영계수와 휨강도는 두께가 큰 것이 작게 나타났다. 최상의 상관관계는 휨 영계수와 양 표면에서 구한 값의 평균값을 사용한 응력파 속도 및 영계수 사이에 나타났다. 휨 영계수와 관계에서 응력파 영계수는 응력파 속도 보다 더 확연한 옹이의 영향을 보였다.

Keyword : Stress wave test, bending test, stress wave speed, stress wave MOE, static MOE, MOR

1. INTRODUCTION

When the span becomes longer or the load becomes larger, the use of wood as a structural material may become impractical. Under this circumstances structural glue-laminated timber (Glulam) can be used. Glulam is an engineered wood product using stress rated, seasoned and selected lumbers. Each piece of lumber is graded, and end- jointed to produce the length required. Glulam is fabricated using lumber of different sizes and grades and is used for a wide variety of structural members. The strength of single pieces of lumber is as strong as its weakest point, which is usually the largest knot. In laminating, the weakest point of lumber is bonded to the higher strength of adjoining pieces, thus forming a homogeneous structural component of great efficiency.

The focus of many researches(Burmester,

[*1] 접수 1996년 8월 7일 Received August 7, 1996
본 논문은 1995학년도 학술진흥재단의 공모과제 연구비에 의해 연구되었음.
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1965; Dean & Kaiserlic, 1984; Smulski, 1991) has been towards realizing the potential of stress wave techniques as a rapid, nondestructive means of stress grading of lumber. While a lumber grading system has not yet to be commercialized, a better understanding of how stress waves propagate and interact with inherent characteristics in lumber should enhance the commercial use of stress wave techniques for lumber grading. Smulsky(1991) studied the stress wave characteristics on small clear straight-grained beams of four U.S. northeastern hardwoods. Characteristic impedance and stress wave MOE(MOEs) were correlated well with MOR, apparently because of their mutual relationship with specific gravity(SG). The potential of nondestructive testing technique for screening hardwood specialty blanks were evaluated by Dean and Kaiserlik(1984). Linear regression analysis was used to identify the best nondestructive predictions of modulus of rupture(MOR) in static, rapid and impact bending. Stress wave MOE has been shown to be a good indicator of bending strength of clear wood. Jung(1979) showed that stress wave speed was highly affected by the angle. Speed of stress waves decreased as grain angle increased. The width of veneer also affected the stress wave speeds. The results also indicated that the narrower the veneer pieces, the better the stress wave estimate of veneer quality. The results for the strip of veneer with knots showed a significant increases in wave transit times.

From the above results, longitudinal stress wave techniques have proven to be an accurate means of evaluating the quality of veneer and clear lumber. Researches have been shown strong relationships between stress wave parameters and mechanical properties of wood materials. Therefore, this study was undertaken to evaluate whether the bending strength properties of specimen containing knot are related to stress wave speed and MOEs. In addition, the relationships were needed to assess the influences of specimen geometry containing knots upon the effectiveness of bending strength properties.

2. MATERIALS & METHODS

Stress wave measurements and subsequent static bending test were performed using Japanese larch of nominal dimensions 20×40, 20×60, 30×40 and 30×60㎜ in cross section and 600㎜ long. Before stress wave measurement, all samples conditioned at 110 degree F and 70% RH to a MC of about 12% were obtained from companion study to this paper(Cha, 1996). The properties that were determined from each sample include MC, SG(volume at about 13% MC and ovendry weight basis), and ring width(RW). The specimen preparation and stress wave measuremnts used in this study are described in the companion paper to this study. The physical properties of specimen are shown in Table 1.

After stress wave measurements, static bending test was conducted on all specimens. A static bending test was made to determine the static MOE of each specimen for later comparison with MOEs. Bending test procedures was followed by American Society for Testing and Materials Standards D-245(1986). All specimens for 12% MC level were tested in static bending by centerpoint loading. Forces were applied by Instron using the crosshead movement of 5mm/min until failure, resulting in failure times from 1 to 2 minutes. The load and displacement was continuously recorded on the personal computer. The data were used to compute static MOE and MOR by personal computer using the load and displacement data, and specimen' s dimension.

At the end of the bending test, moisture samples were cut from the end of each specimen for estimating the ovendry weight of the samples to determine the SG and MC.

Table 1. Description of physical properties of specimen types.

Specimen type	Sample size	Dimension Depth (mm)	Width (mm)	Ring Density (cm)	SG[1]	MC (%)
A	27	20.01 (0.16)	39.14 (0.39)	0.43 (0.08)	0.47 (0.04)	12.96 (0.43)
B	29	29.78 (0.43)	59.52 (0.43)	0.51 (0.09)	0.47 (0.03)	13.06 (0.62)
C	26	29.95 (0.22)	39.09 (0.34)	0.47 (0.05)	0.47 (0.02)	13.39 (0.65)
D	22	19.83 (0.26)	59.75 (0.43)	0.48 (0.08)	0.47 (0.03)	12.99 (0.56)
Gross average	104[2]			0.48 (0.08)	0.47 (0.04)	13.10 (0.59)

*1 Based on ovendry weight and volume at about 13% MC.

*2 Total specimens.

3. RESULTS & DISCUSSION

The Statistical Analysis System(SAS) programming package was used for most of the statistical analyses.

3.1 Bending properties

The results of the mechanical properties are summarized as property average and SD in Table 2. Average MC in static bending test was approximately 13% for all specimens. Table 3 shows the bending properties by widths and thicknesses. T-test was conducted to determine if static MOE and MOR were affected by the width and thickness of specimen. There was no considerable difference between widths in static MOE and MOR. However, there was considerable differences between thicknesses in static MOE and to some extent in MOR. This reduction is probably related to small defects which may not easily seen. The larger the volume of material in a wood member, the more likely it is that it will contain a more severe defect, or combination of defects, than a member of small volume. It is interest to note in Table 3 that the static MOE for 20㎜ thicness is about 17.0% higher than that for 30mm thickness, but MOR for 30㎜ thickness is about 6.4% less than MOR for 20㎜ thickness. However, the companion study to this research(Cha, 1996) shows that MOEs for thickness effect on between 20㎜- and 30㎜- thickness of specimen was 4.6%.

Table 2. Bending properties by specimen types.

Specimen Types	MOE (10^3kg/cm^2)	MOR (kg/cm^2)
A	91.93[1] (15.53[2])	755.45 (158.13)
B	76.85 (12.12)	740.26 (119.36)
C	75.98 (10.42)	682.04 (94.08)
D	86.36 (9.59)	762.70 (92.56)

*1 Means.

*2 Standard deviations

Table 3. Bending properties by different width and thickness.

Specimen types		MOE (10^3kg/cm^2)	MOR (kg/cm^2)
Width	40㎜	84.10[*1]	719.44
		(15.41[*2])	(134.65)
	60㎜	80.95	749.94
		(11.98)	(108.18)
Thickness	20㎜	89.43	758.70
		(13.36)	(131.55)
	30㎜	76.44	712.74
		(11.25)	(111.11)

*1 Means.
*2 Standard deviations.

3.2 Relationships between stress wave properties and bending properties

Linear regression analysis was used to identify the best nondestructive prediction of MOR and static MOE. Density, RW and SG have not shown to be good predictors of bending properties of lumber. Maximum, minimum, corrected, and average of stress wave speed and MOEs were correlated with static MOE and MOR. The stress wave speed and MOEs, measured at same MC as bending test, were obtained from companion study to this research. The best single predictor of static MOE and MOR was average values of stress wave speed and MOEs.

Results of the regression analyses revealed a

Table 4. Regression coefficients for predicting static MOE and MOR by stress wave speed.

Dependant variable	Independant variable			Regression equation		R
				Constant	Slope	
MOR	Speed at Face	All		120.96	0.148	0.302
		Thickness[*1]	A	146.81	0.142	0.265
			B	168.50	0.133	0.300
		Width[*2]	A	-100.28	0.195	0.386
			B	200.07	0.135	0.274
	Speed at Back	All		143.57	0.142	0.290
		Thickness	A	290.05	0.112	0.212
			B	93.506	0.150	0.338
		Width	A	- 37.385	0.180	0.352
			B	173.83	0.141	0.293
Static MOE	Speed at Face	All		- 95.843	43	0.778
		Thickness	A	- 99.219	45	0.826
			B	- 69.602	36	0.795
		Width	A	-102.110	44	0.767
			B	- 95.933	43	0.796
	Speed at Back	All		- 87.340	41	0.739
		Thickness	A	- 73.043	39	0.722
			B	- 78.029	37	0.831
		Width	A	- 97.617	43	0.738
			B	- 79.506	39	0.737
	Average speed	Thickness	A	- 93.145	44	0.789
			B	- 80.113	38	0.831
		Width	A	-107.270	46	0.767
			B	- 95.586	43	0.784

*1 Thickneess A : 20㎜, B : 30㎜
*2 Width A : 40㎜, B : 60㎜.

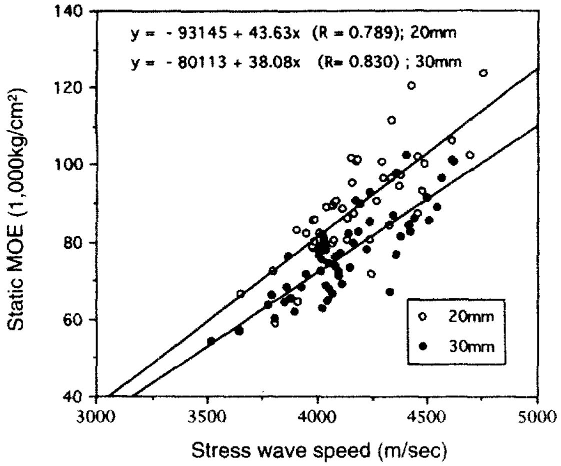

Fig 1. Relationships between stress wave speed and static MOE by different thicknesses.

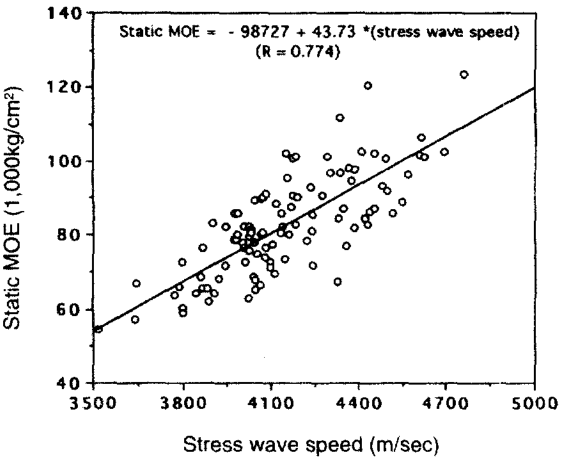

Fig 2. Relationship between stress wave speed and static MOE.

useful relationship between stress wave speed, and static MOE and MOR(Table 4). Stress wave speed measured from face and back of specimen are poorly correlated with MOR. However, stress wave speeds measured from face and back of specimen are shown to be a good indicator of static MOE. The correlation coefficients (r=0.778 and 0.739, respectively) indicated that approximately 54.6% of the observed behavior was accounted for by the regression models. The correlation coefficients between stress wave speed and static MOE were 0.789 and 0.831 for 20mm and 30mm thick lumber, respectively(Fig. 1). Figure 1 also shows the thickness effect on static MOE. Static MOE measured from 30mm thick specimen indicated the lower regression line than that from 20mm thick specimen. When the two thickness were combined, the correlation coefficient was 0.774 (Fig. 2). There was no discernible effect on sta-

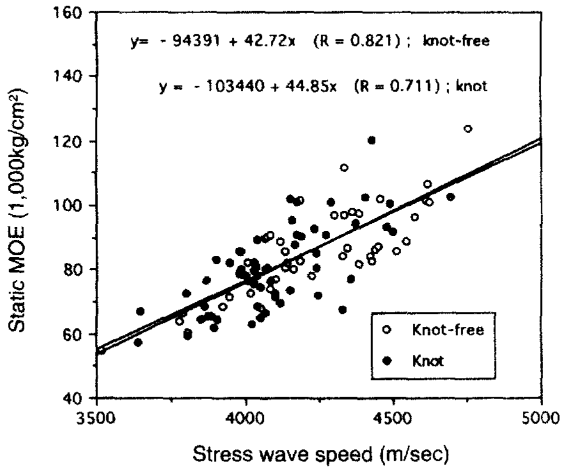

Fig 3. Relationships between stress wave speed and static MOE for knot-free and knotty specimen.

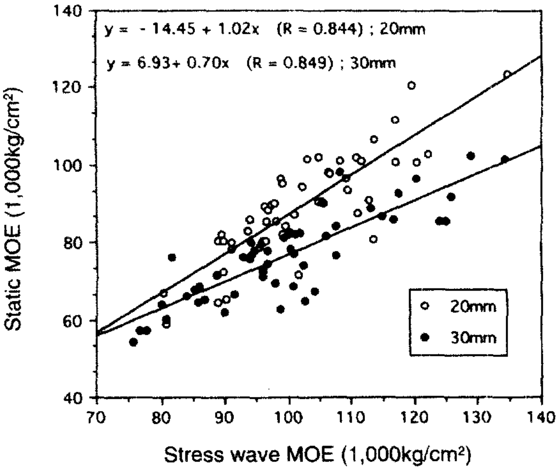

Fig 4. Relationship between stress wave speed and static MOE and static MOE by thickness.

Table 5. Regression coefficients for predicting static MOE and MOR by stress wave MOE.

Dependant variable	Independant variable			Regression equation		R
				Constant	Slope	
MOR	MOEs at Face	All		416.30	$3.169(10^{-3})$	0.335
		Thickness[*1]	A	478.95	$2.744(10^{-3})$	0.242
			B	399.97	$3.161(10^{-3})$	0.399
		Width[*2]	A	314.57	$3.939(10^{-3})$	0.383
			B	451.97	$3.045(10^{-3})$	0.352
	MOEs at Back	All		398.00	$3.330(10^{-3})$	0.340
		Thickness	A	509.86	$2.437(10^{-3})$	0.205
			B	352.03	$3.617(10^{-3})$	0.447
		Width	A	322.00	$3.853(10^{-3})$	0.361
			B	405.04	$3.503(10^{-3})$	0.394
	Static-MOE	All		302.48	$5.232(10^{-3})$	0.591
		Thickness	A	303.53	$5.090(10^{-3})$	0.517
			B	216.50	$6.492(10^{-3})$	0.657
		Width	A	230.85	$5.809(10^{-3})$	0.665
			B	363.49	$4.774(10^{-3})$	0.529
Static MOE	MOEs at Face	All		-0.181	0.824	0.772
		Thickness	A	-10.800	0.983	0.854
			B	12.024	0.651	0.812
		Width	A	-8.651	0.902	0.766
			B	7.561	0.750	0.782
	MOEs at Back	All		-2.417	0.840	0.760
		Thickness	A	-8.268	0.957	0.794
			B	6.084	0.705	0.860
		Width	A	-11.236	0.924	0.756
			B	6.288	0.758	0.769
	Average MOEs	Thickness	A	-14.451	1.018	0.844
			B	6.929	0.700	0.849
		Width	A	-13.889	0.952	0.777
			B	4.203	0.782	0.790

[*1] Thickneess A : 20mm, B : 30mm.

[*2] Width A : 40mm, B : 60mm.

tic MOE measured from specimen containing knot (Fig. 3). It should be emphasized that stress wave speed was taken for each specimen's face and back, then averaged. This causes that stress wave speed is less affected by knots than static MOE.

It would be difficult to visually compare MOEs with MOR due to multitude of data, so only regression coefficients, will be presented. these values gives a general picture of how MOEs and static MOE correlated with MOR. Results of the regression analyses are summarized in Table 5. The capability of various models to predict MOR was very poorer than those used to predict static MOE. Table 5 also shows that static MOE was a better predictor of MOR than by MOEs. MOEs measured from face and back of specimen was also shown to be a good indicator of static MOE. Results of the regression analyses verified a good relationship (R=

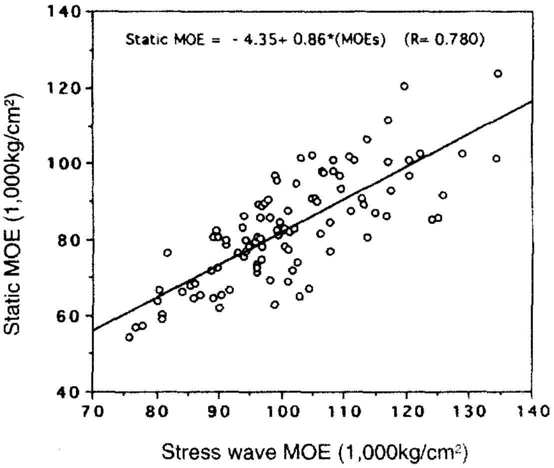

Fig 5. Relationship between static-MOE and stress wave MOE.

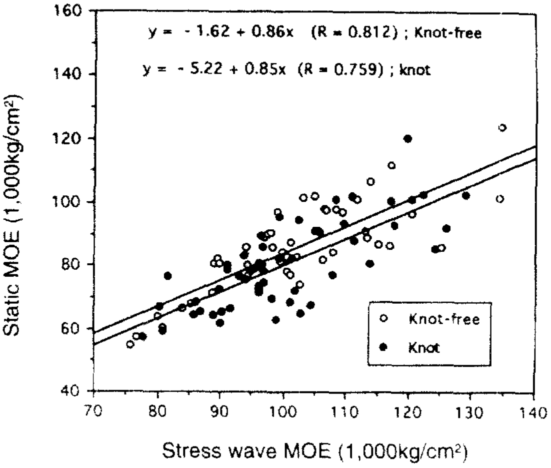

Fig 6. Relationships between static MOE and stress wave MOE for knot-free and knotty specimens.

0.772 and 0.760, respectively). This indicated that when using MOEs to predict static MOE, about 57.8% of the observed behavior was accounted for by the regression model. The highest correlation coefficients, were derived from regression analysis between all the average values of MOEs and static MOE, were 0.844 and 0.849 for 20mm and 30mm thick lumber, respectively(Fig. 4). It is interesting to note that MOE measured from back of lumber of 30 mm thickness showed better correlation with static MOE than that of 20mm-thick(Table 5). Fig. 5 shows the relations between MOEs and static MOE, when combined thickness. When the two thickness combined, the correlation coefficient was 0.780. The MOEs was taken for each specimen's face and back, then averaged. Fig. 6 shows the relationship between static MOE and stress wave MOE for knot-free and knotty specimen. The regression line between stress wave MOE and static MOE measured from knotty specimen shows a lower than that from knot-free specimen. Comparing to Fig. 3, stress wave MOE is more affected by knots than stress wave speed.

4. CONCLUSION

Although bending test is generally recognized as a more desirable method of determining MOR, the stress wave method could be useful for predicting MOE in situation where it is not feasible to conduct destructive test. This research provides some positive evidences that these techniques may be used to presort structural wood material. The major conclusions which could be drawn are as :

1. Static MOE and MOR decreased with increasing the lumber thickness. Static MOE for 20mm thickness is about 17% higher than that for 30mm thickness, but MOR for 30mm is about 6.4% less than MOR for 20mm thickness.
2. Good correlation was obtained between static MOE, and stress wave speed and MOEs obtained from specimen's face and back average values.
3. There was better discernible knot effect on stress wave MOE than that on stress wave speed comparing the relation between static MOE and stress wave MOE with static MOE and stress wave speed.

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