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국산 소경재를 이용한 집성재 개발을 위한 응력파 연구(I)

- Glulam 부재의 응력파에 대한 함수율 영향 -

차 재 경[*2]

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

- Effect of MC on Stress Wave in Glulam Member -

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요 약

두께가 20mm 와 30mm이고, 폭이 40mm 와 60mm인 600mm 길이의 낙엽송 제재목에 응력파 시험을 실시하였다. 모든 시험편은 생재 상태로 구입 후 함수율 27%, 22%, 17%,과 12%조건으로 조습 처리하였다. 함수율 변화에 따른 응력파 속도와 영계수를 구하기 위한 응력파 시험을 4종류의 함수율 조건에서 실시하였다. 응력파 속도와 응력파 시험으로부터 구한 영계수는 시편의 함수율, 치수, 그리고 시험편의 옹이와 옹이 주변 목리의 상호작용에 의해 영향을 받았다. 모든 함수율 및 각 함수율 조건에서 응력파 속도는 응력파에 의해 구한 영계수와 양호한 상관관계를 나타냈다. 응력파 속도와 응력파 시험으로 구한 영계수는 함수율이 증가할 때 비선형적으로 감소하였으나, 함수율 25% 이상에서는 응력파에 의해 구한 영계수의 변화가 거의 없었다.

Keywords : Stress wave test, stress wave speed, stress wave MOE, larch

I. INTRODUCTION

When the span becomes longer or the load becomes larger, the use of wood as a structural member 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 lumber. Each piece of lumber is graded, and then end jointed to produce the length required. The strength of single piece 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

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of great efficiency.

The focus of many researches(Burmester, 1965; Gerhards, 1975; James, 1961) 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.

Many mechanical properties are affected by changes in moisture content(MC) below the fiber saturation point(FSP). Very little research has been reported on the effect of MC on stress wave characteristics in wood. Stress wave speed has been shown to decrease as MC of wood increased. James(1961) evaluated its effect within the hygroscopic range(from 0% to about 30%) on the speed of longitudinal stress wave for clear lumber. Burmester(1965) reported on speed of stress waves in clear specimen of pine in relation to MC in the range of from the water-soaked condition to FSP. Below the FSP, Burmester and James agree very closely, with respective reductions in stress wave speed of 15% for 27 percentage units increase in fiber MC and 13% for 25 percentage units increase in fiber MC. A curvilinear relationship between stress wave speed and MC outside the hygroscopic range found by Gerhards(1975) in a study on 8-foot clear sweetgum sapwood 2 by 4's. Stress wave speed and static flexural stiffness were measured on specimen containing initial MC of about 150% and after several steps of drying down to 15%. Stress wave speed increased curvilinearly but at different rates as MC decreased. Modulus of elasticity(MOE) calculated from stress wave formula(stress wave MOE: MOEs) was strongly dependent on MC; however, MOEs did not change much at MC above 50%. The ratio of MOEs to static MOE decreased curvilinearly from 1.63 to 1.16 as lumber dried from 150 to 15% MC. James(1961) dealt with both MC and temperature effect on stress wave propagation. Stress wave speed and MOEs have been shown to decrease with increasing temperature and MC of wood.

Researches(Burmester, 1965; James, 1961) have been shown strong relationships between stress wave parameters and static mechanical properties of veneer and clear lumber. However, stress wave techniques may be overestimate the static MOE of incompletely dried lumber containing detel. Therefore, the main objective in this investigation was to evaluate the effect of MC on stress wave speed and MOEs of number containing knot. Another objective of this study was to assess the influence of specimen geometry(different thickness and width of lumber containing knot) upon the stress wave propagation.

2. MATERIALS & METHODS

Stress wave measurements were made using Japanese larch of nominal dimension 20×40, 20×60, 30×40, and 20×60mm in cross section and 600mm long. All samples were selected green from a local sawmill and then conditioned to MC levels of about 27, 22, 17, and 12%. The wide faces of specimen were marked "F" for face and "B" for back, respectively. Measurements of the width and thickness of each specimen were then taken near both ends and at midlength using calipers, the average values being used in subsequent calculations. In the case of specimen containing knot, the size and location of knot were measured, and then recorded. The properties that were determined from each sample include MC, specific gravity at 12% MC(SG_{12}), ring width(RW) and density are shown in Tables 1 and 2. Each specimen was then tested to determine stress wave speed and MOEs.

Transit time measurements were taken with a commercial impact stress wave device. Transducers were clamped to each specimen's tangential surface at a constant pressure. The stress wave measurements were made in a short time in order to prevent the moisture loss from

Table 1. Description of average physical properties of specimen types*.

Specimen type	Sample size	Dimention Depth (mm)	Width (mm)	Ring Width (cm)	SG_{12}
A	27	20.01	39.14	0.43	0.47
		(0.16)	(0.393)	(0.08)	(0.04)
B	29	29.78	59.52	0.51	0.47
		(0.43)	(0.434)	(0.09)	(0.03)
C	26	29.95	39.09	0.47	0.47
		(0.22)	(0.335)	(0.05)	(0.02)
D	22	19.83	59.75	0.48	0.47
		(0.26)	(0.426)	(0.08)	(0.02)

* Values in parenthesis are standard deviation.

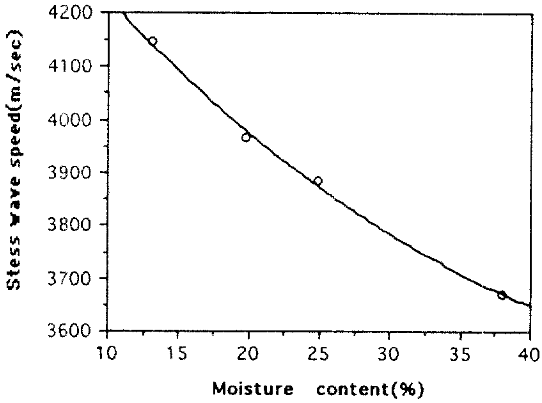

Fig. 1. Stress wave speed and MC in larch lumber.

the specimen during test. The dimension, weight of each specimen at each MC levels were measured and recorded. Wave propagation time was measured to a microsecond. The stress wave speed was computed as distance divided by stress wave propagation time. The MOEs can be also calculated from the following:

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

MOEs : modulus of elasticity predicted from stress wave test(kg/cm^2).

υ : velocity of stress wave (m/sec).

ρ : density of material(gr/cm^3).

g : acceleration due to gravity (9.806m/sec^2).

At the completion of all the test, moisture samples were cut from the end of each specimen for estimating the ovendry weight of each sample. This estimated ovendry weights were used to calculate specimen' s MCs at the end of each conditioning stage.

3. RESULTS & DISCUSSION

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

3.1 Stress wave speed

Table 2 lists the means and standard deviation(SD) of the stress wave speed measured at face and back of lumber having different geometry and MC. Maximum and minimum speed were obtained from the fastest and slowest point of the stress wave propagation, respectively. Minimum values for specimen containing knot were measured by the stress wave passing through the knot. F-test was conducted to determine if the stress wave speed was affected by specimen geometry at each MC level. There were no significant differences($\alpha = 0.05$) in maximum, minimum, and average stress wave speed among specimen types. Table 2 and Figure 1 show how stress wave speed was affected by MC. Stress wave speed decreased curvilinearly with increasing MC. These results are relatively consistent with those reported in the literatures(Burmester, 1965; Gerhards, 1975; James, 1961).

Table 3 shows the means and SD of stress wave speed measured at face and back of lumber by width and thickness of specimen. T-test was conducted to determine if stress wave speeds were affected by thickness and width. There was considerable difference in stress wave speed between widths and to some extent between thicknesses. The average stress wave speed was the higher in the narrow specimen in

Table 2. Stress wave speeds for all types of specimen.

Specimen type		MC (%)	Density (gr/cm³)	Stress wave speed(m/sec) Face			Back		
				Maximum	Minimum	Average	Maximum	Minimum	Average
A	1	39.45	0.65	3745.89*	3666.24	3706.06	3724.65	3678.57	3701.61
(27)		(10.09)	(0.05)	(278.03**)	(235.65)	(254.77)	(228.99)	(233.72)	(230.00)
	2	25.12	0.60	3969.23	3907.04	3938.14	3968.98	3914.04	3941.50
		(1.32)	(0.05)	(279.83)	(265.03)	(271.14)	(270.63)	(276.48)	(272.55)
	3	19.72	0.59	4117.22	4042.66	4079.94	4097.84	4049.06	4073.44
		(0.84)	(0.05)	(286.93)	(263.63)	(273.14)	(279.81)	(285.20)	(281.54)
	4	12.96	0.57	4287.32	4218.22	4252.77	4283.05	4235.48	4259.27
		(0.43)	(0.05)	(279.56)	(273.64)	(274.85)	(289.38)	(287.44)	(287.68)
B	1	37.29	0.65	3706.77	3600.95	3653.87	3696.92	3599.12	3648.01
(29)		(5.53)	(0.04)	(248.86)	(238.69)	(239.88)	(268.51)	(261.54)	(261.68)
	2	24.53	0.60	3894.36	3771.99	3833.19	8903.12	3789.45	3846.28
		(1.33)	(0.04)	(243.12)	(236.65)	(236.84)	(270.41)	(264.34)	(263.83)
	3	19.42	0.59	3988.74	3879.66	3934.19	3997.07	3892.38	3944.73
		(0.78)	(0.04)	(247.23)	(251.98)	(247.41)	(273.79)	(266.05)	(265.35)
	4	13.06	0.58	4120.18	4021.59	4070.89	4142.17	4044.97	4093.58
		(0.62)	(0.04)	(256.59)	(257.74)	(253.25)	(283.49)	(263.61)	(269.55)
C	1	34.62	0.63	3710.20	3675.88	3693.04	3716.10	3959.22	3687.66
(26)		(4.97)	(0.04)	(253.02)	(270.15)	(260.10)	(263.04)	(263.39)	(261.31)
	2	24.47	0.60	3893.73	3858.37	3876.06	3916.55	3868.59	3892.57
		(1.21)	(0.03)	(220.65)	(223.27)	(221.19)	(219.22)	(221.10)	(218.80)
	3	20.13	0.59	3990.03	3948.97	3969.51	4010.72	3965.04	3987.87
		(0.78)	(0.03)	(233.73)	(229.86)	(231.27)	(224.69)	(247.47)	(234.68)
	4	13.39	0.57	4157.54	4119.17	4138.35	4167.28	4130.78	4149.02
		(0.65)	(0.03)	(247.35)	(252.91)	(249.27)	(227.59)	(229.33)	(226.70)
D	1	41.18	0.66	3669.43	3555.15	3612.29	3705.25	3582.45	3643.86
(22)		(6.28)	(0.05)	(163.49)	(181.74)	(167.66)	(144.54)	(164.20)	(150.39)
	2	25.66	0.60	3840.10	3734.04	3787.07	3849.49	3736.96	3793.21
		(1.05)	(0.04)	(175.98)	(184.65)	(173.68)	(175.80)	(166.26)	(167.00)
	3	19.76	0.59	3985.45	3899.58	3942.52	3988.44	3888.14	3938.28
		(0.76)	(0.03)	(155.91)	(174.97)	(162.67)	(160.67)	(172.23)	(164.01)
	4	12.99	0.57	4140.32	4052.88	4096.60	4144.06	4052.59	4098.31
		(0.56)	(0.03)	(169.24)	(181.07)	(171.48)	(158.41)	(159.85)	(154.99)
Gross	1	38.01	0.65	3709.89	3626.94	3668.41	3710.68	3631.25	3670.96
average		(7.33)	(0.05)	(240.89	(237.18)	(235.45)	(232.40)	(237.28)	(231.89)
(104)	2	24.91	0.60	3902.16	3820.62	3861.40	3912.23	3830.47	3871.35
		(1.31)	(0.04)	(236.65)	(237.88)	(234.17)	(240.92)	(245.62)	(240.55)
	3	19.75	0.59	4021.72	3943.52	3982.62	4024.82	3950.32	3987.57
		(0.82)	(0.04)	(242.58)	(240.86)	(239.54)	(244.14)	(255.08)	(246.92)
	4	13.10	0.57	4177.17	4103.65	4140.41	4185.42	4117.49	4151.46
		(0.59)	(0.04)	(250.60)	(255.18)	(250.33)	(253.27)	(252.58)	(250.22)

* Means.

** Standard deviation.

Table 3. Sress wave speed by specimen width and thickness.

Specimen type			Stress wave speed(m/sec)					
			Face			Back		
			Maximum	Minimum	Average	Maximum	Minimum	Average
Width	40mm	1	3728.38*	3670.97	3699.67	3720.46	3669.07	3694.77
			(264.11**)	(250.75)	(254.99)	(243.93)	(246.50)	(243.57)
		2	3932.19	3883.17	3907.69	3943.26	3891.74	3917.50
			(253.00)	(244.31)	(247.51)	(245.81)	(249.50)	(246.51)
		3	4054.83	3996.70	4025.77	4055.10	4007.83	4031.46
			(267.49)	(249.77)	(257.14)	(255.64)	(268.16)	(260.72)
		4	4223.65	4169.63	4196.64	4226.26	4184.12	4205.19
			(269.78)	(265.88)	(266.42)	(264.92)	(263.41)	(263.03)
	60mm	1	3690.67	3581.19	3635.93	3700.51	3591.94	3646.22
	(51)		(215.07)	(215.18)	(210.86)	(221.74)	(222.93)	(218.74)
		2	3870.95	3755.62	3813.29	3879.98	3766.80	3823.38
			(216.44)	(214.57)	(211.22)	(233.77)	(226.78)	(226.71)
		3	3987.32	3888.25	3937.78	3993.35	3890.55	3941.95
			(210.81)	(220.26)	(213.09)	(229.87)	(228.26)	(225.25)
		4	4128.87	4035.09	4081.98	4142.98	4048.26	4095.62
			(221.37)	(226.31)	(220.07)	(235.68)	(222.85)	(225.35)
Thickness	20mm	1	3711.56	3616.36	3663.96	3715.94	3635.42	3675.68
	(49)		(234.61)	(218.28)	(222.88)	(194.01)	(209.08)	(198.47)
		2	3911..25	3829.37	3870.31	3915.33	3834.53	3874.92
			(245.31)	(246.01)	(242.45)	(238.33)	(247.83)	(240.81)
		3	4058.06	3978.42	4018.24	4048.72	3976.81	4012.76
			(244.16)	(237.09)	(238.24)	(238.17)	(252.14)	(243.55)
		4	4221.32	4143.99	4182.66	4220.64	4153.37	4187 00
			(245.61)	(248.61)	(244.83)	(247.42)	(253.73)	(248.76)
	30mm	1	3708.39	3636.37	3672.38	3705.99	3627.53	3666.76
	(55)		(248.50)	(254.47)	(248.09)	(263.65)	(261.73)	(259.84)
		2	3894.06	3812.83	3853.45	3909.47	3826.86	3868.16
			(230.63)	(232.40)	(228.48)	(245.38)	(245.87)	(242.48)
		3	3989.35	3912.43	3950.89	4003.52	3926.72	3965.12
			(238.72)	(242.08)	(238.36)	(249.58)	(257.67)	(249.96)
		4	4137.84	4067.72	4102.78	4154.04	4085.53	4119.79
			(250.64)	(257.83)	(251.35)	(256.54)	(249.50)	(249.49)

* Mean.

** Standard deviation.

width than in wide specimen. The stress wave speed through the wider specimen in width might be reduced by the effect on readily undetectable defects. It is also interest to note in Table 3 that the difference in stress wave speed between specimens of 40mm and 60mm width is increased with decreasing MC.

Table 4 shows the means and SDs of stress wave speed measured at face and back of specimen containing knot. Stress wave speed was reduced by knot. Average stress wave speed in the clear area was about 3644.96 to 4126.40m/sec. Average speed through the knot area was about 3537.95 to 4038.14m/sec. Knot consis-

Table 4. Summary of average stress wave speed for clear area and knot area of specimen.

Specimen type		Stress wave speed(m/sec)			
		Maximum*	Minimum**	Corrected	Averge
Knot (83)	1	3644.96 (210.90)	3537.95 (207.25)	3572.42 (211.94)	3591.45 (204.71)
	2	3857.74 (219.32)	3752.51 (214.30)	3789.89 (215.61)	3805.12 (212.73)
	3	3970.67 (220.77)	3876.66 (215.15)	3914.56 (218.07)	3923.66 (214.92)
	4	4126.40 (221.77)	4038.14 (212.63)	4077.41 (216.33)	4082.27 (213.64)
Knot-free (125)	1	3753.65 (242.69)	3689.62 (236.31)	-	3721.63 (237.00)
	2	3940.04 (245.44)	3874.05 (246.67)	-	3907.04 (244.02)
	3	4058.20 (251.16)	3993.57 (257.19)	-	4025.88 (252.13)
	4	4217.75 (263.81)	4158.67 (267.25)	-	4188.21 (263.46)

* Values obtained from clear area of specimen.

** Values for knotty specimen obtained through knot area.

tantly caused the abnormal wave front that leads in the grain direction and lags through knot as stress wave passed through it. This, of course, would be expected because wave travels faster in the grain direction than across grain, as it does when it passes through the distorted grain around knot. Corrected speed through the knot area was calculated from using the distance around the knot area instead of the distance across the knot. Corrected speed through the knot area was 3572.42 to 4077.41m/sec. From the above results, the most noticeable features of the stress wave speed were probably impeded by the knot and grain deviation around knot. This fact may limit the amount of the information available from stress wave tests. Table 4 also shows means and SDs of stress wave speed measured from knotty and knot-free specimen. Stress wave speeds from knot-free specimen show higher than those from specimen containing knot.

3.2 Stress wave MOE

Table 5 lists the means and SDs of the MOEs for all specimens. F-test was also conducted to determine if MOEs was affected by geometry at each MC levels. There were no significant differences in maximum, minimum, average of MOEs among specimen types at 5% significance

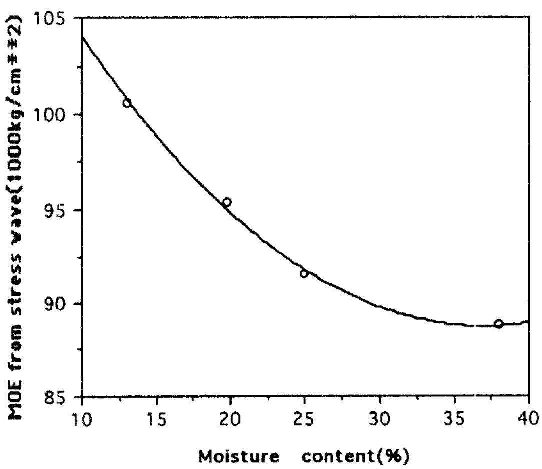

Fig. 2. MOE predicted from stress wave and MC in larch lumber.

Table 5. Stress wave MOE for all types of specimen.

Specimen type		MOE predicted from stress wave(10^3kg/cm^2)					
		Face			Back		
		Maximum	Minimum	Average	Maximum	Minimum	Average
A	1	93.05*	88.99	91.00	91.78	89.60	90.68
(27)		(14.36**)	(11.59)	(12.84)	(11.11	(11.56)	(11.28)
	2	95.87	92.86	94.35	95.78	93.16	94.46
		(12.77)	(11.91)	(12.27)	(11.90)	(11.93)	(11.860)
	3	101.20	97.53	99.35	100.15	97.79	98.96
		(13.25)	(12.10)	(12.56)	(12.13)	(12.21)	(12.11)
	4	106.91	103.41	105.14	106.58	104.20	105.38
		(13.35)	(12.38)	(12.85)	(12.69)	(12.29)	(12.45)
B	1	90.88	85.69	88.26	90.48	85.62	88.02
(29)		(14.54)	(13.04)	(13.61)	(15.34)	(13.56)	(14.26)
	2	93.33	87.54	90.40	93.82	88.37	91.06
		(14.52)	(13.63)	(13.95)	(15.66)	(14.31)	(14.81)
	3	96.15	90.97	93.54	96.59	91.49	94.01
		(14.88)	(14.40)	(14.54)	(15.73)	(13.99)	(14.64)
	4	100.15	95.34	97.72	101.21	96.36	98.75
		(15.72)	(14.49)	(14.93)	(16.14)	(13.90)	(14.82)
C	1	88.44	86.82	87.62	88.71	86.01	87.35
(26)		(11.43)	(11.85)	(11.56)	(11.56)	(11.38)	(11.37)
	2	92.49	90.63	91.65	93.58	91.31	92.44
		(11.56)	(11.50)	(11.49)	(11.74)	(11.60)	(11.61)
	3	95.67	93.70	94.68	96.65	94.52	95.58
		(12.32)	(11.98)	(12.13)	(12.15)	(12.99)	(12.51)
	4	101.24	99.41	100.32	101.70	99.95	100.82
		(13.03)	(13.28)	(13.12)	(12.56)	(12.74)	(12.58)
D	1	90.83	85.16	87.96	92.55	86.50	89.49
(22)		(9.61)	(8.40)	(8.75)	(8.62)	(8.43)	(8.35)
	2	90.90	85.84	88.34	91.21	85.93	88.54
		(9.93)	(8.56)	(8.93)	(8.51)	(7.67)	(7.91)
	3	95.23	91.13	93.16	95.33	90.61	92.95
		(8.11)	(7.84)	(7.82)	(7.62)	(7.87)	(7.63)
	4	100.18	95.96	98.05	100.31	95.91	98.09
		(9.02)	(8.57)	(8.61)	(8.04)	(7.62)	(7.64)
Gross	1	90.82	86.72	88.75	90.81	86.94	88.86
average		(12.76)	(11.43)	(11.91)	(12.03)	(11.50)	(11.61)
(104)	2	93.26	89.38	91.30	93.72	89.83	91.76
		(12.41)	(11.86)	(11.99)	(12.37)	(11.98)	(12.04)
	3	97.12	93.39	95.25	97.26	93.70	95.46
		(12.67)	(12.16)	(12.32)	(12.46)	(12.34)	(12.26
	4	102.18	98.59	100.37	102.53	99.20	100.85
		(13.39)	(12.81)	(12.97)	(13.00)	(12.38)	(12.55)

* Means.

** Standard Deviation.

Table 6. Stress wave MOEs by specimen width and thickness.

Specimen type			MOE predicted from stress wave(10^3kg/cm^2)					
			Face			Back		
			Maximum	Minimum	Average	Maximum	Minimum	Average
Width	40mm	1	90.79*	87.92	89.34	90.27	87.84	89.05
	(53)		(13.09**)	(11.66)	(12.23)	(11.33)	(11.51)	(11.34)
		2	94.21	91.86	93.03	94.70	92.25	93.47
			(12.19)	(11.65)	(11.86)	(11.76)	(11.69)	(11.67)
		3	98.49	95.65	97.06	98.44	96.19	97.30
			(12.98)	(12.08)	(12.45)	(12.15)	(12.58)	(12.31)
		4	104.13	101.45	102.78	104.18	102.12	103.14
			(13.47)	(12.86)	(13.09)	(12.74)	(12.58)	(12.60)
	60mm	1	90.86	85.47	88.13	91.37	86.00	88.66
	(51)		(12.53)	(11.17)	(11.66)	(12.81)	(11.53)	(11.99)
		2	92.28	86.81	89.51	92.70	87.32	89.98
			(12.69)	(11.64)	(11.98)	(13.02)	(11.87)	(12.27)
		3	95.75	91.04	93.38	96.05	91.11	93.55
			(12.32)	(11.91)	(12.01)	(12.78)	(11.65)	(12.03)
		4	100.17	95.61	97.86	100.82	96.16	98.47
			(13.14)	(12.18)	(12.49)	(13.16)	(11.51)	(12.15)
Thickness	20mm	1	92.05	87.27	89.64	92.13	88.21	90.15
	(49)		(12.38)	(10.36)	(11.19)	(9.98)	(10.29)	(9.99)
		2	93.64	89.71	91.65	93.73	89.91	91.80
			(11.73)	(11.02)	(11.21)	(10.66)	(10.77)	(10.60)
		3	98.52	94.66	96.57	97.98	94.56	96.26
			(11.52)	(10.79)	(11.04)	(10.53)	(10.99)	(10.68)
		4	103.89	100.06	101.96	103.76	100.48	102.11
			(12.09)	(11.36)	(11.60)	(11.20)	(11.16)	(11.09)
	30mm	1	89.73	86.22	87.96	89.64	85.81	87.70
	(55)		(13.08)	(12.39)	(12.57)	(13.59)	(12.46)	(12.86)
		2	92.93	89.09	91.00	93.71	89.76	91.71
			(13.09)	(12.66)	(12.75)	(13.82)	(13.07)	(13.29)
		3	95.93	92.26	94.08	96.62	92.921	94.75
			(13.61)	(13.26)	(13.34)	(14.02)	(13.489)	(13.57)
		4	100.67	97.27	98.95	101.44	98.055	99.73
			(14.39)	(13.95)	(14.04)	(14.42)	(13.363)	(13.72)

* Means.

** Standard deviations.

level. Table 5 and Figure 2 show how MOEs was affected by MC. Results are relatively consistent with those reported in the literatures (Burmester, 1965; James, 1961). MOEs decreased curvilinearly until MC increased to around 25% MC, and then almost remained constant.

Table 6 shows the MOEs by width and thickness of specimen. T-test was conducted to determine if MOEs was affected by the thickness and width. There was considerable difference in MOEs between widths and to some extent between thicknesses. As expected, the average MOEs was higher in the narrower thickness and width of specimen. This decrease in MOEs for

Table 7. Average stress wave MOE from clear area and knot area of specimen.

Specimen type		MOE predicted from stress wave(10^3kg/cm^2)			
		Maximum*	Minimum**	Correct	Average
Knot	1	90.29	84.98	86.66	87.61
(83)		(12.72)	(11.29)	(11.66)	(11.80)
	2	93.31	88.24	90.02	90.75
		(12.16)	(11.13)	(11.45)	(11.45)
	3	96.80	92.24	94.07	94.50
		(12.41)	(11.55)	(11.97)	(11.83)
	4	101.87	97.47	99.40	99.65
		(12.69)	(11.24)	(11.72)	(11.80)
Knot-free	1	91.17	88.05	-	89.60
(125)		(12.17)	(11.42)		(11.66)
	2	93.61	90.51	-	92.05
		(12.55)	(12.34)		(12.35)
	3	97.47	94.40	-	95.93
		(12.67)	(12.63)		(12.55)
	4	102.69	99.83	-	101.25
		(13.51)	(13.34)		(13.33)

* Values obtained from clear area of speciemen.

** Values for knotty specimen obtained through knot area.

30mm-thick specimen was related to the small defects which might not be easily observed.

Table 7 shows the means and SDs of MOEs using the stress wave speed of specimen containing knots. As expected, MOEs was consistently reduced by the presence of knot. The MOEs from knot-free specimen is somewhat higher than MOEs from specimen containing knot. Average MOEs in the clear area was 90.29 to 101.87 × 10^3kg/cm^2. Average values of MOEs in the knot area was 84.98 to 97.47 × 10^3kg/cm^2. Average corrected MOEs through the knot area was about 86.66 to 99.40 × 10^3kg/cm^2. These values were very close to the average MOEs of knot-free specimen.

3.3 Relationships between stress wave speed and stress wave MOE

Linear regression analyses were used to identify the best predictor of stress wave speed and MOEs from physical properties of wood. Density, MC, RW and SG have not shown to be a

Table 8. Regression coefficients for predicting MOEs by stress wave speed at different MC levels.

MC level	Regression equation		R
	Constant	Slope	
1	-67.229	43	0.844
2	-77.136	44	0.860
3	-78.174	44	0.860
4	-80.896	44	0.857
All	-50.359	36	0.848

good predictors of stress wave speed and MOEs of specimen. Maximum, minimum, corrected, and average of MOEs were relatively well correlated with those of stress wave speed. The best single predictor of stress wave speed was average values of MOEs. However, it would be difficult to visually compare stress wave speed with MOEs due to multitude of data, only regression coefficients were presented, these values give a general picture of how the two types of data correlated on the 60cm span basis. Results of the regression analyses between stress wave speed and MOEs are summarized in Tables 8 and 9. Table 8 shows that stress wave speed is a good predictor of MOEs at each MC levels. Results of the regression analyses veri-

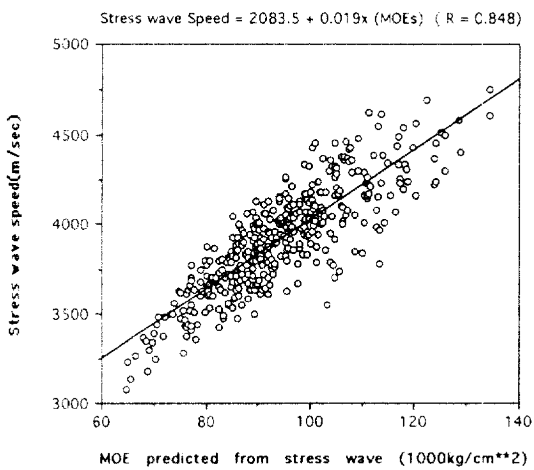

Fig. 3. Relationship of stress wave speed and MOE predicted from stress wave.

Table 9. Regression coefficients for predicting MOEs by stress wave speed at different MC levels by differnt specimen geometry.

Specimen type		MC level	Regression equation		R
			Constant	Slope	
Width	40mm	1	-56,926	40	0.837
	(53)	2	-67,152	41	0.861
		3	-68,596	41	0.862
		4	-70,971	41	0.854
		All	-47,164	36	0.863
	60mm	1	-85,262	48	0.864
	(51)	2	-92,739	48	0.857
		3	-92,569	47	0.855
		4	-95,780	47	0.853
		All	-54,728	38	0.825
Thickness	20mm	1	-48,711	38	0.752
	(49)	2	-49,793	37	0.813
		3	-49,600	36	0.810
		4	-52,372	37	0.805
		All	-29,314	32	0.810
	30mm	1	-78,713	45	0.905
	(55)	2	-102,561	50	0.904
		3	-103,515	50	0.902
		4	-106,370	50	0.899
		All	-69,676	42	0.883

fied a good relationship(r = 0.844, 0.860, 0.860 and 0.857, respectively). This indicated that when using stress wave speed to predict MOEs, above 71.2% of the observed behavior was accounted for by the regression models. Figure 3 and Table 8 show the relations between stress wave speed and MOEs. When the all MC combined, the correlation coefficient was 0.848.

Table 9 shows the regression coefficients for specimen having different geometry to predict the MOEs by stress wave speed at each MC levels. It would be also difficult to visually compare MOEs with stress wave speed due to multitude of data, only regression coefficients were presented, these values gave a general picture of how the MOEs correlated with stress wave speed. Regression coefficients at each MC levels between stress wave speed and MOEs for each width also show good relationships. When all MCs were combined for each width, the correlation coefficients (r = 0.863 and 0.825, respectively) indicated that approximately 68.1% of the observed behavior was accounted for by the regression model. Regression coefficients at each MC levels between stress wave speed and MOEs for each thickness also show a good relationship. When all MCs were combined, the correlation coefficients between MOEs and stress wave speed were 0.810 and 0.883 for 20mm and 30mm thick lumber, respectively. The correlation values for the latter was slightly higher than those for the former. From the above results, the stress wave method can be useful for predicting MOEs in situation where it is not feasible to test in bending destructively.

4. CONCLUSION

This research provides some positive evidences that stress wave techniques may be used to predict MOEs and presort structural wood material prior to drying. The major conclusions which could be drawn are as :

1. The speed of stress wave and MOEs were influenced by presence of knots and specimen geometry. The stress wave speed and MOEs were higher in the narrow specimen in thickness and width than those in the wide specimen. and were also influenced by interaction between knot and grain deviation around knot.
2. Good relationships between stress wave speed and MOEs of wood were found, regardless of MC levels and specimen geometry.
3. Stress wave speed and MOEs decreased curvilinearly with increasing MC, but MOEs remained almost constant above 25% MC.

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