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Effects of Transducer Position in Ultrasonics Nondestructive Tests of Finger-Jointed Lumber*1

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손가락결합부재에 대한 초음파 비파괴시험에서 센서 위치의 영향 *1

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요 약

손가락결합부재에 대한 정적휨시험 및 초음파 비파괴시험을 실시하였다. 발신 및 수신 변환기의 상대 위치와 두 변환기 사이의 거리에 따른 음전달속도의 변화를 분석하였으며 정적 휨시험으로 부터 구한 MOE 및 MOR과 비교하였다. MOR과 음전달속도는 손가락의 경사가 증가할수록 감소하였다. MOR은 음전달속도와 매우 밀접한 상관관계를 보였으나 MOE는 손가락의 경사도나 음전달속도에 큰 영향을 받지 않는 것으로 나타났다. 음전달속도는 섬유방향이 방사방향이나 접선방향에 비하여 더 높은 값을 나타내었다. 발신 및 수신 변환기를 동일면에 부착한 경우에 직각면 또는 반대면에 부착한 경우보다 더 높은 음전달속도를 나타내었다. 변환기 사이의 거리가 증가할수록 음전달속도는 양끝면에 변환기를 부착한 경우의 속도에 수렴하는 경향을 나타내었다.

Keywords : Ultrasonics, finger joint, nondestructive test (NDT), velocity of ultrasonic wave, MOE, MOR

1. INTRODUCTION

Finger-joints have been quickly spread to many fields of wood utilization since the first commercial use in the late 1950s, and became one of the most frequently used jointing methods to produce long products by using short pieces of lumber. Many applications of finger joints include structural members such as glulam. Therefore, it is important to produce reliable finger-joints in structural point of view. A lot of methods have been proposed to improve the quality control of finger joints, which include proof-loading (Eby, 1981) and application of non-destructive testing (NDT) techniques.

Various NDT techniques have been developed and applied to wood products. Among those, MSR and MSE techniques applied to lumber production have been most successful. So far, stress wave has also been successful in evaluation of wood decay (Ross & Ward, 1992) and effect of grain orientation on strength properties (Armstrong & Patterson, 1991). Many other NDT techniques and application has been well summarized by Ross (1992) and Ross *et al.* (1991, 1994)

Among many NDT techniques, Beall (1987,

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1989) demonstrated that parameters of acousto-ultrasonic(AU) wave showed close correlation with the cure state of epoxy bonds. Recently, many researchers have applied AU to evaluate wood products in terms of degree of decay(Patton-Mallory *et al.*, 1988; Patton-Mallory & DeGroot, 1990) and drying defects(Fuller *et al.*, 1994; Verkasalo *et al.*, 1993). AU has also been successfully applied to grading and sorting of wooden pallet parts(Schmoldt, 1994). These researches demonstrated that AU can be used as an index indicating strength properties of wood products including finger joints.

AU tests were conducted by dos Reis *et al.* (1990) on finger-jointed specimens manufactured with various defects in the gluelines to provide wide variety of joint strength. The results showed good correlation between AU parameters and tensile strength of finger joints. Anthony and Phillips(1994) studied the feasibility of AU application to prediction of tensile strength of finger joints and proposed some improvements in test equipment and procedure.

Quality assurance of finger joints is essential for structural uses of many wood products containing finger joints. In this point of view, ultrasonics application to finger joints is promising to detect low-strength joints in the manufacturing process. However, a lot of basic aspects about the relation between ultrasonics parameters and finger joint configurations should be studied more thoroughly before ultrasonics can be successfully applied to the manufacturing processes of finger joints.

This research is aimed at studying the relations between velocity of ultrasonics propagation and bending strength of finger-jointed lumber with variables such as position of transmitting and receiving transducers, distance between two transducers, and slope and relative direction of fingers to applied loads.

2. METHOD & MATERIALS

Douglas-fir lumber was used to make finger joint specimens. Average moisture content and specific gravity of lumber were 8.4% and 0.41, respectively. Five different finger types given in Table 1 were manufactured with isocyanate adhesive obtained from glulam manufacturing company located in Incheon, Korea. Size of specimen was 4cm × 4cm × 64cm. Number of specimen was 15 for each finger joint type and control, and total was 90.

Table 1. Types of finger joint specimens.

Symbol	Specification		
	Finger size[a]	Direction[b]	Finger slope (°)
Control	-	-	-
F 720V	6-20-1	Vertical	7.1
F 715V	6-15-1	Vertical	8.5
F 710V	6-10-1	Vertical	14.0
F 510V	4-10-1	Vertical	8.5
F 710P	6-10-1	Parallel	14.0

Notes; [a] Finger height-length-tip (mm),
[b] Relative direction of finger to applied load.

Time of ultrasonics propagation was measured by PUNDIT manufactured by C.N.S. Electronics Ltd with 37KHz transducers. Transducers were attached to specimen by applying petroleum jelly to ensure contact between specimen and transducer. To estimate the effect of position of transmitting and receiving transducers and distance between them on velocity of ultrasonics propagation, various positions and distances were selected as given in Table 2.

In Table 2, position ① means attachment of transmitting and receiving transducers to both ends of specimen, and ② and ③ mean attachment of transducers right on the joint - flat sides in ② and finger sides in ③.

Position ④ to ⑨ were again subdivided into three types such as (a), (b) and (c) depending on relative position of transmitting and receiving transducers, which are illustrated in Fig. 1.

In all specimens, fingers were carved so that finger tips were perpendicular to annual rings in

Table 2. Position of transmitting and receiving transducers and distance between them.

Symbol	Position of transducer[a]		Distance[b] (cm)
	Transmitting	Receiving	
①	End (C)	End (C)	64
②	Joint (R)	Joint (R)	4
③	Joint (T)	Joint (T)	4
④	5cm from joint (R)	5cm from joint (R,T)	10
⑤	10cm from joint (R)	10cm from joint (R,T)	20
⑥	15cm from joint (R)	15cm from joint (R,T)	30
⑦	5cm from joint (T)	5cm from joint (R,T)	10
⑧	10cm from joint (T)	10cm from joint (R,T)	20
⑨	15cm from joint (T)	15cm from joint (R,T)	30

Notes; [a] C : cross section; R : radial section; T : tangential section,
[b] Horizontal distance between transmitting(T) and receiving(R) transducers.

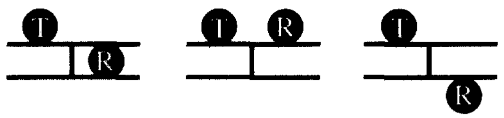

Fig. 1. Position of transmitting (T) and receiving (R) transducers.

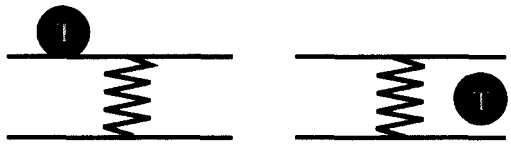

Fig. 2. Position of transmitting transducer (T).

cross section. As shown in Fig. 2, transmitting transducers were placed on the flat side in specimens ②, ④, ⑤ and ⑥ types, which was radial surface, and on the finger side in specimens ③, ⑦, ⑧ and ⑨ types, which was tangential surface.

Therefore, total 21 different positions of transducers in one specimen were selected to measure the effect of position of transducers and distance between them on the velocity of ultrasonics propagation. After nondestructive tests were complete, the same specimens were tested destructively under static bending loads. And the velocity of ultrasonics transmission was compared to MOE and MOR of the specimens.

3. RESULTS & DISCUSSION

Velocity of ultrasonics propagation at various measuring positions, and MOE and MOR obtained by static bending tests are summarized in Table 3. From Table 3, changes of MOE and MOR depending on finger type were redrawn as Fig. 3.

As shown in Table 3 and Fig. 3, MOE of finger-jointed lumber was not affected by finger types. However, MOR showed very close relation with finger slope, so that MOR decreased as finger slope increased. F510V specimen has similar finger slope as F715V specimen, and both showed similar MOR values.

From Table 3, it is evident that higher ultrasonics velocity corresponds to higher bending strength (MOR). Control (solid wood) specimen showed the highest velocity in general, and velocity decreased as finger slope increased. By comparing measurement of the velocity of ultrasonics propagation at positions ①, ② and ③ in Table 3, it is shown that the velocity was highest in longitudinal direction and was slightly higher in

Table 3. Ultrasonics velocity at various measuring positions, and MOE and MOR of specimens.

Specimen	Ultrasonics velocity at various transducer positions (m/sec)									Bending (Mpa)	
	①	②	③	④c[a]	⑤c	⑥c	⑦c	⑧c	⑨c	MOE	MOR
Control	5599	1914	2223	3937	5051	5343	4190	5296	5550	11213	732
F720V	5597	1882	2131	3917	5020	5336	4108	5168	5374	10254	512
F715V	5578	1935	2229	3929	4990	5247	4122	5101	5315	9149	347
F710V	5526	1993	2184	3893	4943	5183	4073	5106	5325	10803	272
F510V	5573	2007	2221	3996	5059	5298	4135	5194	5404	9311	331
F710P	5537	2125	1997	3852	4934	5255	3909	5132	5387	9155	197

Note; [a] c in position symbol means opposite attachment of transducers as shown in Fig. 1.

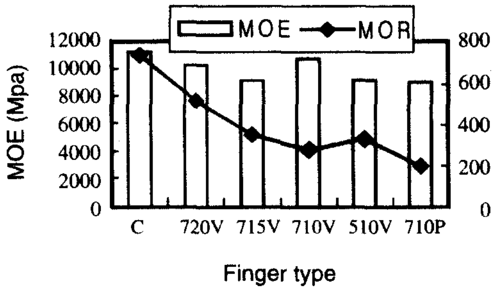

Fig. 3. MOE and MOR of specimens.

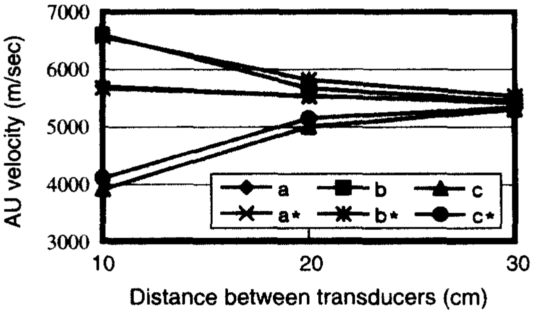

Fig. 4. Ultrasonics velocity of F720V specimens depending on positions of transducers: Transmitting transducer was attached to flat side in a, b and c, and to finger side in a*, b* and c*; a and a* = orthogonal, b and b* = parallel, and c and c* = opposite attachment of transducers.

radial direction when compared to that in tangential direction.

Comparing measurements at positions from ④ to ⑨ to each other showed that ultrasonics velocity was higher when transmitting transducer was attached to tangential surface(finger side) than it was attached to radial surface(flat side). However, the difference was negligible.

Changes of ultrasonics velocity depending on position of transducers are given in Fig. 4 and 5 for F720V and control specimens as examples, respectively. Other specimen types also showed similar changes of ultrasonics velocity depending on position of transducers as Fig. 4 and 5.

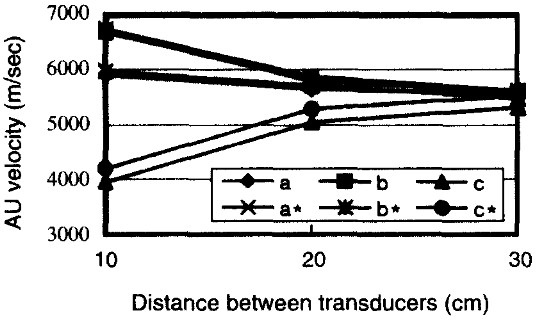

Fig. 5. Ultrasonics velocity of control specimens depending on positions of transducers: a, b, c, a*, b*, and c* = same as Fig. 4.

As the distance between transmitting and receiving transducers increased, ultrasonics velocity approached to steady state, that was defined as the velocity in longitudinal direction and was measurement at position (in this study. As it is shown in Fig. 4 and 5, b and b* position that was parallel attachment of transducers showed very high velocity when distance between transducers was short, and the velocity decreased to steady

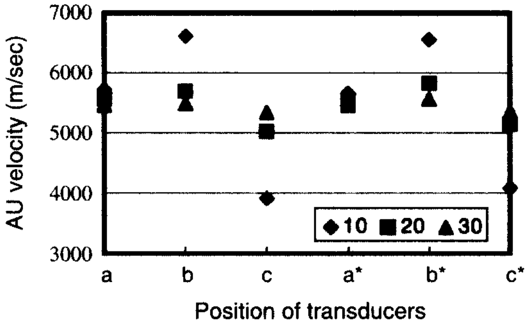

Fig. 6. Changes in ultrasonics velocity of F720V specimen depending on relative position of transducers: 10, 20 and 30 in legend mean distances between transducers in the unit of cm; a, b, c, a*, b*, and c* = same as Fig. 4.

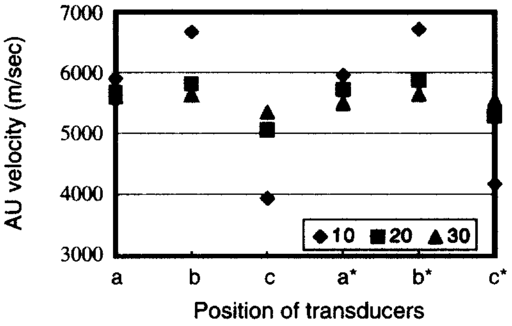

Fig. 7. Changes in ultrasonics velocity of control specimen depending on relative position of transducers: 10, 20 and 30 in legend mean distances between transducers in the unit of cm; a, b, c, a*, b*, and c* = same as Fig. 4.

state as distance between transducers increased.

It is also shown that ultrasonics velocity was very slow at c and c* position, that was opposite attachment of transducers, when distance between transducers was short, and approached to steady state as distance between transducers increased. Positions a and a* that were orthogonal attachment of transducers showed intermediate values and did not show great variation when distance between transducers changed.

When distance between transducers was equal, relative position of transmitting and receiving transducers had effect on measurement of ultrasonics velocity as shown in Fig. 6 and 7 for F720V and control specimens. Other specimen types also showed similar trends to Fig. 6 and 7.

As shown in Fig. 6 and 7, b and b* position in which transducers were attached on the same surface (parallel attachment) showed the highest ultrasonics velocity. The second highest velocity was measured at a and a* positions that were orthogonal attachment of transducers. Opposite attachment of transducers, that is illustrated as positions c and c* in Fig. 6 and 7, showed the lowest ultrasonics velocity. This was considered to be caused by the difference of grain direction through which ultrasonic wave was transmitted between transducers.

4. CONCLUSION

From tests of finger-jointed lumber by application of ultrasonic wave and static bending loads, following conclusions were obtained:

1. MOR decreased as finger slope increased but MOE did not show specific relation with finger slope.
2. Velocity of ultrasonics propagation decreased as finger slope increased.
3. Velocity of ultrasonics propagation was higher in longitudinal grain direction when compared to those in tangential and radial directions.
4. When transducers were attached to radial or tangential surfaces, velocity of ultrasonics propagation approached to steady state that was the velocity in longitudinal direction as distance between transducers increased.
5. Attaching transmitting and receiving transducers to the same surface showed the highest velocity of ultrasonics propagation when compared to orthogonal and opposite attachments.

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