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Damping Capacity of Finger-Jointed Lumber*1

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손가락 결합부재의 감쇠거동*1

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要 約

본 연구는 침엽수재를 사용한 손가락결합부재의 강도 및 감쇠특성을 측정함으로서 문창틀재로의 사용가능성을 시험하기 위하여 수행하였다. 손가락결합부 시험편의 형태는 손가락부분의 길이와 경사도에 따라서 다섯가지로 제작하였다. 하중은 4개의 하중단계를 갖는 양방향휨으로 가하였으며 각각의 하중단계는 3개의 하중주기로 구성되었다. 손가락결합부의 파괴특성을 분석하기 위하여 감쇠시험 과정에 AE신호를 측정하였다.

MOE는 시험편의 형태와 뚜렷한 관련을 갖고 있지 않으나, MOR은 손가락부분의 경사도가 증가될수록 감소되는 뚜렷한 관계를 나타내었다. 감쇠비는 하중단계가 증가될수록 감소되었으나 파괴직전의 단계에서는 증가되는 경향을 나타내었다. 하중방향에 대하여 수직한 방향의 손가락결합부재가 수평방향부재보다 더 높은 강도를 나타내었다. 60dB 이상의 AE신호는 목재 또는 접착층의 파괴에 의하여 발생되는 것으로 분석되었다. 완전한 파괴가 발생하는 경우에는 100dB 이상의 AE신호가 발생하였다.

Keywords : Finger joint, Damping, Damping ratio, MOE, MOR, AE

1. INTRODUCTION

World population is drastically increasing in the 20th century, which again causes increased demand for raw materials. Demand for wood materials is also increasing rapidly. Recently, this increased demand for wood is compounded with environmental problems. Therefore, recent trends in wood industry is changing to the complete utilization of small pieces of wood and reducing waste.

To accomplish this goal, the technology of producing large useful members from small pieces of wood is important. Finger joints have been developed for this purpose and can make rigid connection between wood pieces. Finger jointing can produce members as strong as solid wood. Furthermore, members produced by finger jointing have better dimensional stability than solid wood. Therefore, finger joint is widely used in many fields of wood utilization such as wood construction and furniture manufacturing.

Even though finger joints are commonly used, many characteristics of finger joints have not been well known. Especially, creep

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and fatigue behavior should be studied throughly for better utilization of finger joints. Up to present, most of researches on finger joints have been limited to static behavior(Jokerst, 1981 ; Moody, 1970 ; Troughton & Chow, 1977).

Materials show increased deformation under repeated loads, which is called fatigue. Under fatigue loads, large deformation is developed during the initial stage(Jang et. al., 1993) and the fatigue behavior is largely affected by the behavior in the initial stage. Long-term behaviors such as creep and fatigue are mutually related to some extent(Jang et. al. 1993 a, b). Therefore, it is thought that the behavior under some initial steps of repeated loads, which can also be described as damping characteristics, can be related to the long-term behavior of finger-jointed lumber. This study was carried out as a preliminary of creep and fatigue tests of finger-jointed lumber.

Damping is the ability of material to absorb and dissipate energy when transferring vibration or repeated loads(Atherton, et. al., 1980). In semi-rigidly jointed structures, joints are regarded as main sources of overall damping of vibration forces(Atherton et. al., 1980; Chou & Polensek, 1985 ; Polensek, 1976 ; Polensek, 1984). Nailed joints showed 10% to 40% damping compared to material damping of 0.35%(Polensek & Bastendorff, 1985). Damping ratio of whole nailed wood systems was about 10%(Polensek, 1975). It is expected that the rigid connections like finger joints do not have so large damping capacity as nailed joints. However, damping behavior of finger joints has not been clearly inve- stigated up to present.

Under repeated loading conditions, finger-jointed lumber may show different behavior from solid wood. To reveal what happened inside the finger joints under loads, acoustic emission(AE) technique was used. Recently, AE is being used widely in the various field of wood utilization, such as finding internal decay(Marcia, et. al., 1988 ; Noguchi & Nishimoto, 1985), dimensional stability(Rice & Kabir, 1992), wood drying(Skaar et. al., 1980), wood machining(Murase et. al., 1988), etc. AE is thought to be developed when change is happened in the micro-structure of material. Even in elastic range of wood, AE is developed. The behavior of wood can be estimated more precisely by recording and analyzing AE signals developed under loads. In this study, AE technique was applied to estimate the fracture chacteristics of finger joints during repeated loading.

2. DAMPING RATIO

Under one cycle of bidirectional loading and unloading, finger joints show deformation and recovery curve as shown in Fig. 1.

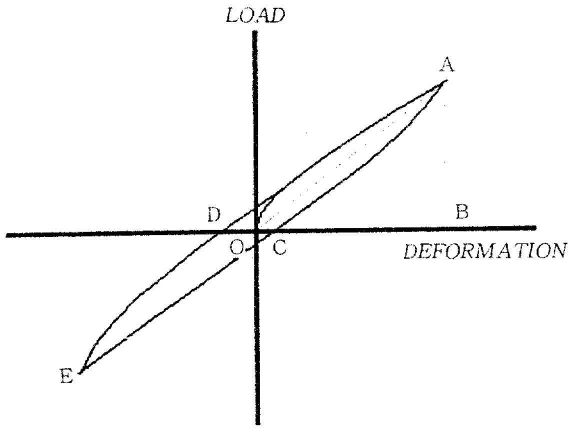

Fig. 1. Typical load-deformation curve un- der one cycle of bidirectional bending loads.

In Fig. 1, damping ratio can be expressed by the ratio of the dissipated energy to the total available potential energy as follows (Ray, 1975):

$$\lambda = \frac{C}{C_C} = \frac{A_D}{4\pi\ A_S} \quad \text{......} \quad (1)$$

where

λ = damping ratio

C = damping coefficient

C_C = critical damping coefficient

A_D = dissipated energy (area of ACEDA in Fig. 1)

A_S = total available potential energy (area of OABO in Fig. 1)

In Fig. 1, area ACEDA is almost equally divided into two parts by x-axis. Therefore, damping ratio can be obtained from the curves above x-axis as follows(Polensek, 1984 : Polensek & Bastendorff, 1985):

$$\lambda = \frac{E_D}{2\pi E_S} \quad (2)$$

where

E_D = dissipated energy (area of ACDA in Fig. 1)

E_S = total available potential energy (area of OABO in Fig. 1)

In this study, dissipated energy was assumed to be the area of triangle ACD because the loading and unloading curves were almost linear and for the simplicity of analysis. The average of daming ratios obtained from curves above and below of x-axis was taken as the value for the given specimen and load level.

3. EXPERIMENT

To make specimens, Douglas-fir was used. Some logs were purchased from log importing company, and sawn and dried to target moisture content of 10%. Physical and mechanical properties of the specimen used in this study are summarized in Table 1.

For the damping tests, ramp loading and unloading as shown in Fig. 2 has been employed. Load levels L1, L2, L3 and L4 were varied depending on the types of specimen as given in Table 2.

5 types of fingers given in Table 2 were manufactured and poly-vinyl acetate emulsion adhesive was used to assemble finger joints. The number of test replications for each joint type was 10.

Testing arrangement employed in damping tests is given in Fig. 3. Specimen size was 4cm × 4cm × 68cm and loading span was 60cm. Loads were applied as bidirectional bending by a universal testing machine with loading speed of 10mm/min. Specimens that was not failed by cyclic loads were tested to failure by applying static ramp loads with the same loading speed.

AE tests were also performed at the same

Table 1. Physical and mechanical properties of testing material.

Moisture content(%)	Specific gravity	Bending*a		Compression parallel to grain*a		Shear parallel to grain*a	
		MOE	MOR	σ_{pl}*b	S_{max}*c	Radial	Tangential
8.4	0.41	10423	87.9	11.3	17.0	8.33	9.31

*a Unit is MPa. *b Stress at proportional limit. *c Maximum strength.

Table 2. Specimen types and load levels employed in damping tests.

Specimen type		Load level (N(kgf))			
Symbol	Specification*a	L1	L2	L3	L4
C	Control	490(50)	980(100)	1470(150)	1960(200)
F720V	6-20-1, Vertical	490(50)	980(100)	1470(150)	1960(200)
F715V	6-15-1, Vertical	294(30)	588(60)	882(90)	1176(120)
F710V	6-10-1, Vertical	196(20)	392(40)	588(60)	784(80)
F510V	4-10-1, Vertical	490(50)	980(100)	1470(150)	1960(200)
F510P	4-10-1, Parallel	245(25)	490(50)	735(75)	980(100)

*a Figer height-length-tip (mm), direction of finger to loads.

time with damping tests by attaching sensor to the specimen 10cm away from the loading point. LOCAN 320 system was used to collect and analyze AE data. Frequency range of the sensor was 0 to 1000 KHz. Gains of 40 dB in preamplifier and 20 dB in main amplifier were employed to collect AE signals. In the range of threshold under 30 dB, a lot of noise were detected. Therefore, threshold level was selected as 30 dB.

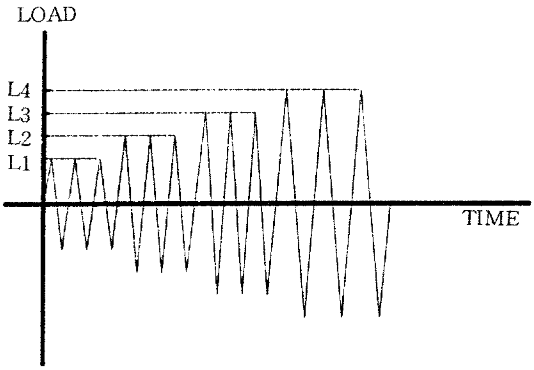

Fig. 2. Load function for damping tests.

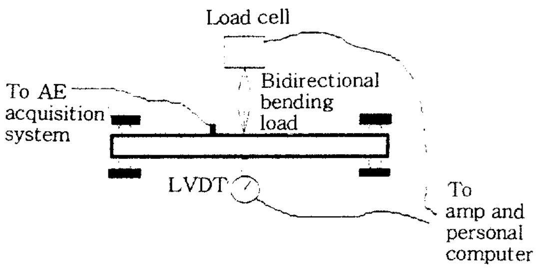

Fig. 3. Arrangement for damping tests.

4. RESULTS AND DISCUSSION

4. 1 Deflection and slope of load-displacement curves

In this study, three loading cycles were employed for each load level. Among these three, the second cycle was selected for data analysis because the first and third were somewhat related to the previous and next loading steps (Atherton et. al., 1980; Polensek, 1984; Polensek & Bastendorff, 1985). For each specimen, maximum deflection at each load level and slopes of load-deflection curves were calculated and are given in Table 3.

As shown in Table 3, deflection increased almost linearly with load levels. On the contrary, the slope of load-deflection curves decreased as load level increased. Maximum strength was highest for control specimen (no

Table 3. Maximum deflection and slopes of load-deflection curves.

Specimen	Slope of finger(°)	Properties	Loading step				Maximum strength (N)
C		Deflection*a	1.2	2.5	3.9	5.3	3775
		Slope*b	408.2	375.3	365.5	358.7	
F720V	7.1	Deflection	1.4	2.9	4.5	6.3	2140
		Slope	350.8	327.3	314.6	273.4	
F715V	8.5	Deflection	0.9	1.8	2.9	4.0	1242
		Slope	342.0	306.7	282.2	257.7	
F710V	14.0	Deflection	0.5	1.1	1.8	- -*c	686
		Slope	362.6	338.1	301.8	- -	
F510V	8.5	Deflection	1.3	2.8	4.4	- -	1979
		Slope	368.5	326.3	304.8	- -	
F510V	8.5	Deflection	0.6	1.3	2.0	- -	889
		Slope	400.8	377.3	335.2	- -	

*a Unit of deflection is mm, *b Unit of slope of load-deflection curves is kN/m,
*c Some of specimens were failed in this loading step.

finger joint) and decreased as the slope of finger increased. Among vertically oriented finger joint specimens, F720V showed the highest value, F510V was the second highest, and the lowest was F710V.

Vertically oriented finger joint was more than twice stronger than parallel orientation. The stiffness and strength of finger joints were strongly related to the slope of finger rather than the height or length of finger.

4. 2 MOE and MOR

MOE and MOR were calculated for the first load level and for the maximum load before failure. The change of MOE and MOR depending on specimen types are given in Fig. 4. MOE was not clearly related to the shape of finger. MOE was similar in all specimen types. However, MOR showed close relations with the slope and orientation of finger. MOR decreased as the slope of finger increased, and vertical orientation showed higher MOR than parallel orientation.

4. 3 Damping ratio

Damping ratios obtained from tests are given in Figure 5. Damping ratio was expected to increase as load level increase. However, damping ratios decreased as load level increased in this study, which was considered to be caused by the effect of previous loading history. In control specimens, damping ratio decreased almost linearly from 0.0062 (0.62%) for the first loading step to 0.0026 (0.26%) for the fourth loading step.

Finger jointed specimen showed decrease of damping ratio with increase of loading steps, however, it increased in the loading step just prior to failure. It is thought that finger joint experience partial failure first in the glue line before complete fracture, which causes slight relative movement in the joint and increases energy dissipation.

Damping ratio increased as the slope of finger increased. Vertical finger orientation showed smaller damping ratio than parallel orientation.

4. 4 Failure and acoustic emission characteristics

Finger joint specimens that have low slope of fingers, such as F720V and F510V, showed higher percentage of wood failure than those for high slope finger joint specimens. In F720V, which has the longest finger among the specimens used in this study, some finger were broken when failure occurred. Finger joint specimens with high slope and short length of finger, such as F710V, were failed entirely by glue line failure and showed slight wood failure in the glue line.

Typical amplitude-time relations of AE signals for specimens are given in Figure 6. AE signals developed under initial loading steps (low load levels) were mostly between 30 dB and 60 dB. AE signals having higher amplitude than 60 dB were thought to be associated with wood or glue line failure. During the final loading step or when failure occurred, number and amplitude of AE signals

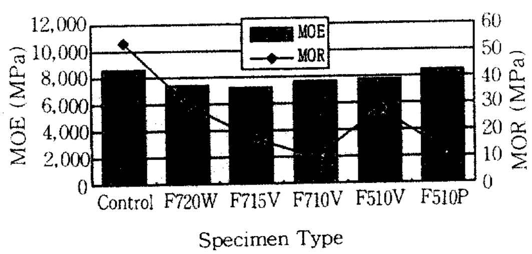

Fig. 4. Change of MOE and MOR depending on specimen types.

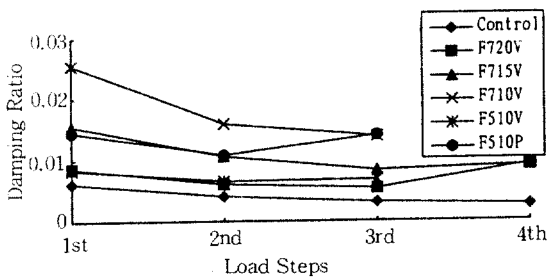

Fig. 5. Damping ratio of finger jointed specimens.

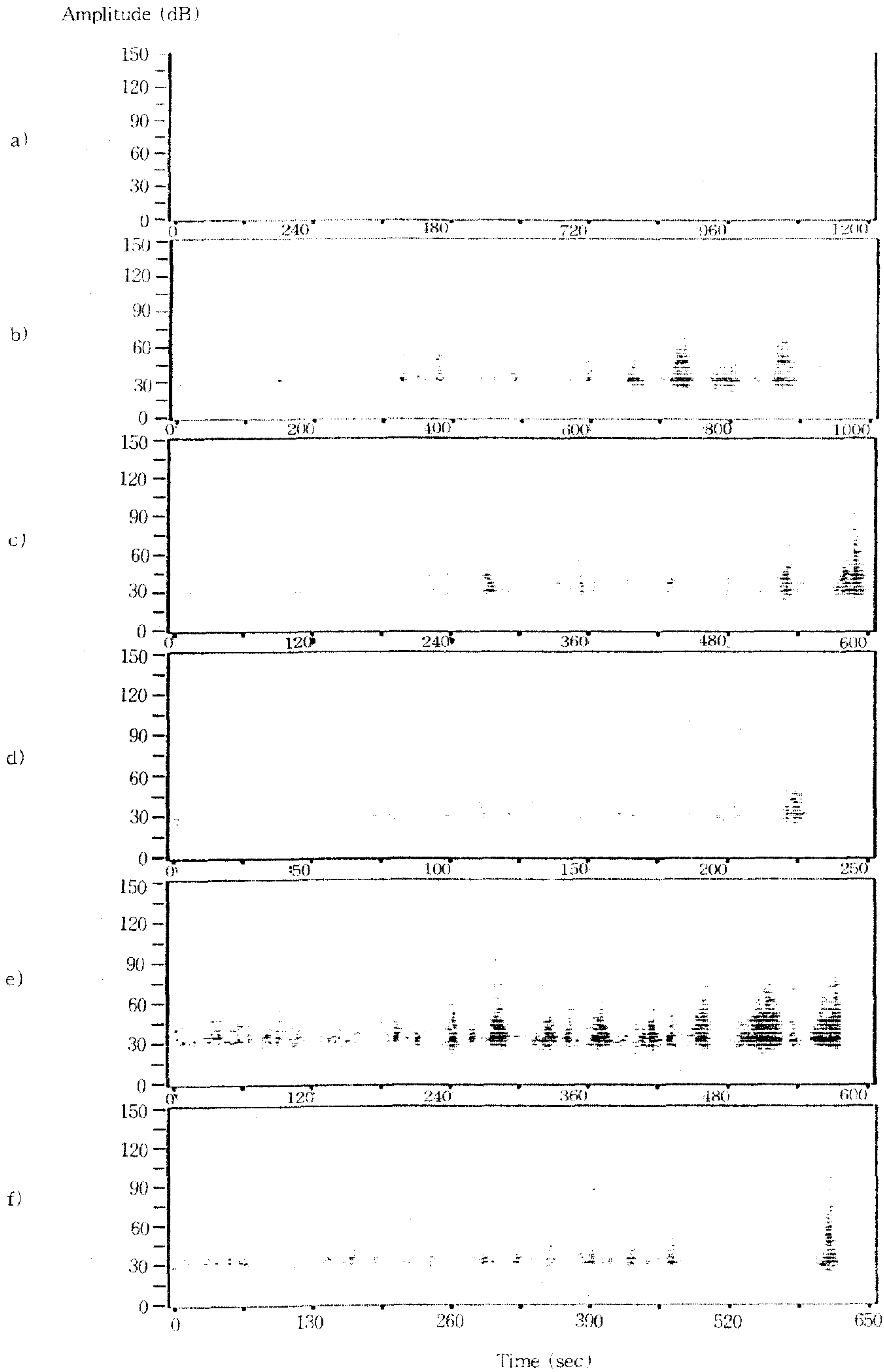

Fig. 6. Typical amplitude-time relations for AE signals developed in control (a), F720V (b), F715V (c), F710V (d), F510V (e) and F510P (f) specimens.

increased rapidly, and amplitude of AE signals reached around 100 dB when complete fracture of specimen happened.

F720V and F510V specimens produced many AE signals ranged between 30 dB and 60 dB during the initial loading cycles. However, F715V, F710V and F510P specimens produced less AE signals at first and showed abrupt increase in the number and amplitude of AE signals just before complete fracture. In F720V and F510V specimens, it is thought that AE signals were produced by micro-fracture or movement of wood fibers in fingers, which eventually caused much wood failure in glue line and fingers. In F715V, F710V and F510P specimens, failure occurred mostly in the glue line. It is thought that adhesive experience less deformation or structural movement before failure than wood, which caused less AE signal development before fracture of specimens.

5. CONCLUSIONS

From the tests on damping of finger joints, the following conclusions were obtained:

1. In all specimens, deflection increased almost linearly as loading steps increased.
2. MOE was not clearly related to specimen types and MOR decreased as the slope of finger increased.
3. Damping ratio decreased as loading step increased but increased in the loading step just prior to complete fracture.
4. Damping ratio increased as the slope of finger increased.
5. Vertical finger direction to loading showed higher strength and smaller damping ratio than parallel finger direction.
6. Finger joint specimens having low slope of finger showed higher percentage of wood failure and larger number of AE signals compared to high slope finger joints.
7. AE signals having amplitude higher than 60 dB was thought to be associated with permanent wood or glue line failure, and AE signals having amplitude around 100 dB were developed when complete fracture of specimens occurred.

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