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Structural Performance of Finger-Jointed Lumber with Different Joint Configurations*1

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ABSTRACT

Three different finger-jointed lumbers which have different geometric features and adhesives were manufactured and studied in this study. Larch and pitch pine lumbers with and without preservative treatment were used. Bending MOE was measured as the preliminary investigation for grouping the specimen. After the finger, bending MOE of two wood species without preservative treatment shows over 97% property of the control group. The tensile modulus also shows almost same property after the finger joint. And it is found out that the preservative treatment induce little effect on bending and tensile MOE. Based on this result, high performance of examined finger-jointed lumber can be found out. However, tensile strength decreased around 20% which would be induced by the crack along the root of the finger which is formed near the edge during manufacturing stage. And finger-jointed lumber with preservative treatment even shows higher decrement of the tensile strength with higher wooden part failure mode.

Keywords : finger-jointed lumber, preservative treatment, MOE, tensile modulus, tensile strength

1. INTRODUCTION

There are several methodologies for connecting laminar along the longitudinal direction. And the finger joint has been widely applied because of its high workability and efficiency with the high production yield (Byeon *et al.*, 1997; Ryu *et al.*, 2004). It has been widely used as the structural and non-structural applications for increasing the length of the member and avoiding unwanted defects which induce the value-added product. Additionally, recent rising concern about the large span wooden structure would make more needs on the finger joint method.

Many researches have been conducted to find out the optimum geometry of the finger joint (Hong *et al.*, 2000; Byeon *et al.*, 2001; Ryu *et al.*, 2003), effect of the applied adhesives (Shaler *et al.*, 1988; Lawrence and Jerrold, 1989; So and Chai, 2005), changes in mechanical properties due to the finger joint (Eby, 1981; Kim and Lee, 2000; Ozcifci and Yapici, 2008), evaluation and prediction on structural perfor-

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Table 1. Specification of the tested specimen

		Larch	Pitch Pine	CuAz-3 Pitch Pine
Number of specimens	(EA)	80	60	56
	(EA/group)	20	15	14
Average MOE (MPa)	Control	10,854	8,589	8,873
	Group A	10,863	8,576	8,843
	Group B	10,862	8,516	8,815
	Group C	10,869	8,598	8,836
	Average	10,862	8,570	8,842

mance of the glulam which have finger-jointed lumber (Park and Hong, 2001; So, 2007) and so on. Many of these findings offer the effective production of finger-jointed lumber and glulam. Therefore, it is expected that many manufacturers applied these findings to make commercially produced finger-jointed lumber. However, many researches limited to find out the specific factors affecting the performance of the finger- jointed lumber. Even except the above-mentioned factors, the overall research which can analyze the performance of the finger-jointed lumber should be performed including the species of wood, whether or not the lumber treated with preservatives, finger at wide and narrow face, and so on.

In this study, the structural performance of the commercially manufactured finger joint was examined. Structural performance based on the bending and tensile property was investigated as the finger-jointed lumber can be used for the structural use. Finger geometry in terms of the adhesion area and differences in width of top and root were considered. Additionally, effect of preservative treatment on the structural performance of the lumber was investigated.

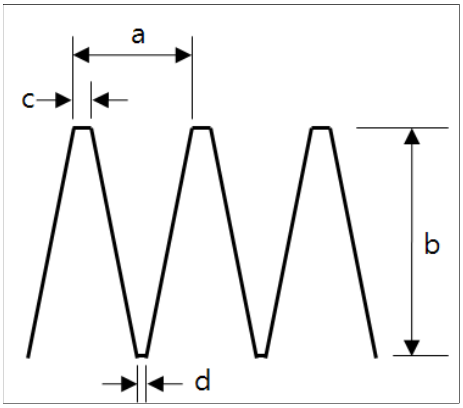


Fig. 1. Measured size of the finger.

2. MATERIALS and METHODS

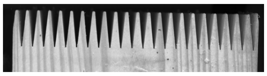
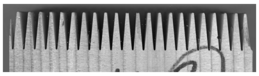
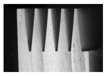
2.1. Materials

2 by 6 (35 mm × 138 mm × 3,600 mm) lumbers with two wood species (Larch, pitch pine and pitch pine treated with *CuAz-3* - named as CuAz-3 pitch pine) were prepared. Specimens were targeted to kiln-dried to reach 15% moisture content. In the case of the CuAz-3 pitch pine, specimens were treated with the preservative due to hazard class of H3 (*Korea Forest Research Institute notification 2009-07*). And bending MOE was measured as the preliminary investigation of this study (*see also chap. 2.3*), and then lumbers were grouped (four groups - control and three groups which will be finger-jointed at different three manufacturers) to have almost same average MOE (Table 1). Total number of each group of specimens were 80, 60 and 56 for larch, pitch pine and CuAz-3 pitch pine respectively.

2.2. Manufacture of the Finger Joint

Finger joint was manufactured from three different Korean manufacturers. Finger joint was made at the middle part of the lumber

Table 2. Manufacturing condition of the finger joint with three different types

Manufacturer		A	B	C
Manufactured face		Wide face	Wide face	Narrow face
Number of the finger		22	22	4
Size (mm)	Pitch, a	6.24	6.23	6.49
	Length, b	19.75	19.46	23.64
	Tip width, c	1.39	1.36	1.17
	Root width, d	0.61	0.95	1.17
Adhesive area (cm^2)		310.73	306.64	262.04
Adhesive		*Resorcinol-phenol*	*Polyvinyl acetate*	*Resorcinol-phenol*
Photograph				

without visible knots and other defects. Manufactured size such as pitch, length and tip and root width was measured and geometry which includes the adhesive area were measured (Table 2). *Resorcinol-phenol* was used for group A and C while *polyvinyl acetate* was used for group B.

2.3. Measurement of the Edgewise Bending MOE

Continuous MOE measuring equipment (5 kN; Dryingeng Co. Ltd., Gwangju, Korea) was used for measuring the edgewise bending MOE. The equipment was designed to meet the requirements of Korean standard (*KS F 3021-2005*). A center-point load was applied with 3 m of simple span of the specimen and the cross-head speed was 10 mm/min. Induced load was measured by imposing a midspan deflection of 5 mm. The MOE results from two opposite faces were averaged.

2.4. Measurement of the Tensile Properties

Tensile properties including tensile modulus and strength were measured with the tension testing machine (1 MN; Kyoung Sung Testing Machine Co. Ltd., Ansan, Korea) with 600-mm-long grips and 2 mm/min cross-head speed. The 3600-mm-long specimens were centered in the testing machine so that the middle 1 m could be subjected to uniform tensile stress. The displacement was measured by two LVDTs at 40-kN tensile load for measuring the tensile modulus. The LVDT were centered on the opposite wide faces at midspan. Tensile modulus was determined from the average displacement measured by the two LVDTs at a target load level. The tensile load was applied till the failure of the specimen for determining the tensile strength. And the failure mode was checked with naked eye.

3. RESULTS and DISCUSSION

3.1. MOE

Measured MOE is described at Table 3. Average MOEs of control specimens show 10,320 MPa, 8,110 MPa and 8,540 MPa for larch, pitch pine and CuAz-3 pitch pine

Table 3. Average MOE of the control and manufactured groups for larch, pitch pine and CuAz-3 pitch pine

	Larch		*Pitch pine*		*CuAz-3 pitch pine*	
	MOE (MPa)	Ratio (%)	MOE (MPa)	Ratio (%)	MOE (MPa)	Ratio (%)
Control	10,320	100	8,110	100	8,540	100
Group A	10,050	97	8,140*	100	8,160	96
Group B	9,790	95	7,670	95	8,060	94
Group C	10,130**	98	8,130	100	8,130	95
Average of Group A, B and C	9,990	97	7,980	98	8,110	95

* Failure occurred by mis-operation of test machine for one specimen.
** Glue line failure due to inadequate production for four specimens.
※ Failed specimens were excluded for calculation the average MOE.

respectively. The MOE difference around 5% of control specimens in Table 1 and 3 seemed to induced by the change of moisture content after drying. Unfortunately, the moisture content just after drying process was not checked, and it was deduced that the specimen had been over-dried (lower MC at Table 1). For finding out the exact effect of before and after the finger joint, average MOEs of each group were compared with that of the control group.

Average MOEs of the group B which uses the *polyvinyl acetate* show about 5～6% reduction compared with that of the control group. However, it is not significant decrement compared with previous reports (Byeon *et al.*, 2001; Ryu *et al.*, 2003). Around 2～3% percent of MOE was decreased after the finger. And four specimens which have the glue line failure at the manufacturing process for larch of the group C were excluded and this would be due to zero value of the tolerance (‘c’ - ‘d’ of Table 2). Excepting these specimens, high adhesion performance was found out even the adhesive area is about 85% of other two groups.

It is also confirmed that the preservative treatment with CuAz-3 induces almost same MOE. MOEs of pitch pine with and without preservative treatment show 8,110 MPa and 8,540 MPa respectively. Around 5% of MOE decreased after the finger joint for the CuAz-3 pitch pine and is slightly higher decrement compared with the non-treated pitch pine (2%).

3.2. Tensile Properties

Tensile modulus and tensile strength of finger joint lumbers were measured (Table 4). Same as the bending MOE, decrement ratio was calculated to consider the effect of finger joint based on the property of the control group. Tensile modulus of three control groups show 14.05 GPa, 11.53 GPa and 11.90 GPa for larch, pitch pine and CuAz-3 pitch pine respectively. Tensile modulus of three groups show almost same and/or even increased value compared with that of the control group. The increment of the tensile modulus would be induced by the adhesive layer which have relatively higher stiffness.

Specimens with preservative treatment also shows almost same tensile modulus after the finger (101% of the control group for pitch pine with and without the preservative treatment). This indicates that the bending and tensile

Table 4. Tensile roperties of the control and manufactured groups for larch, pitch pine and CuAz-3 pitch pine

	Tensile modulus (GPa)			Tensile strength (MPa)		
	Larch (Ratio (%))	Pitch pine (Ratio (%))	CuAz-3 pitch pine (Ratio (%))	Larch (Ratio (%))	Pitch pine (Ratio (%))	CuAz-3 pitch pine (Ratio (%))
Control	14.05 (100)	11.53 (100)	11.90 (100)	25.9 (100)	24.2 (100)	25.8 (100)
Group A	14.77 (105)	11.75 (102)	11.58 (97)	20.6 (80)	20.7 (86)	19.5 (76)
Group B	14.00 (100)	11.17 (97)	12.15 (102)	22.1 (85)	19.0 (79)	19.3 (75)
Group C	14.67 (104)	11.88 (103)	12.00 (101)	20.1 (78)	20.4 (84)	17.1 (66)
Average of Group A, B and C	14.48 (103)	11.60 (101)	11.91 (101)	20.9 (81)	20.0 (83)	18.6 (72)

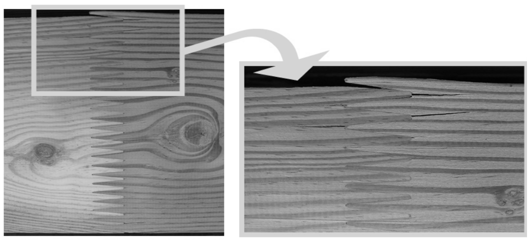


Fig. 2. Cracks along the root of the finger joint.

modulus would not seriously affected by preservative treatment throughout proper treat process.

Tensile strength of control groups show 25.9 MPa, 24.2 MPa and 25.8 MPa for larch, pitch pine and CuAz-3 pitch pine respectively. Comparing with the MOE and tensile modulus, tensile strength drops down dramatically from 14 to 34% for each group. This significant strength reduction would be induced because of the crack along the root of the finger which is formed near edge during the manufacturing process (Fig. 2).

The failure mode which differentiates the tensile failure at the wooden part or the finger-jointed part was checked with naked eye and around 41, 48 and 60% of test specimen for larch, pitch pine and CuAz-3 pitch pine shows failure at the wooden part. Table 5 shows the tensile strength of finger-jointed lumber divided by the failure mode. The tensile strength decreased about 15 and 9% for the lumbers which failed at the jointed part while about 25 and 27% were decreased for the lumbers which failed at the wooden part. The above-mentioned crack would induce the failure at the wooden part which makes overall strength loss around 20%. Therefore, it is considered that the failure at the wooden part which would be induced by the crack cause even serious strength reduction while finger joint itself makes less than 15% of tensile strength reduction.

The average strength decrement of the finger-jointed lumber with preservative treatment (CuAz-3 pitch pine) shows much lower value of 72%. Especially, the strength of the specimens which failed at the wooden part (60% of failure

Table 5. The tensile strength due to the failure mode for larch, pitch pine and CuAz-3 pitch pine

	Larch		*Pitch pine*		*CuAz-3 pitch pine*	
	Tensile strength (MP)	Ratio (%)	Tensile strength (MP)	Ratio (%)	Tensile strength (MP)	Ratio (%)
Control	25.9	100	24.2	100	25.8	100
Failure at finger joint	21.9	85	22.1	91	21.7	84
Failure at wooden part	19.3	75	17.7	73	16.4	64
Average	20.9	81	20.0	83	18.6	72

mode for CuAz-3 pitch pine) shows serious decrement (64%) and this also would be occurred by the above-mentioned crack. So, it seems that the preservative treatment would raise up the frequency of the presence of the crack which induce the failure at the wooden part even with the well-known pre-hardening effect of preservatives. Therefore, the performance of the finger-jointed lumber especially the preservative treated lumber should be carefully considered at the manufacturing stage.

4. CONCLUSIONS

Mechanical properties of commercially manufactured three type of finger-jointed lumber were investigated. Bending and tensile modulus show almost same value after the finger joint. In the case of the bending MOE, 5～6% of reductions in property occurred which uses *polyvinyl acetate* as the adhesive. And high performance was found out for the finger-jointed lumber at the narrow face even the adhesive area is about 85% of other groups. In the case of the tensile modulus, there is little differences by the species, whether or not the lumber treated with the preservative. Differ from the bending and tensile modulus, tensile strength shows around 20% reduction after the finger. Failure at the wooden part due to the crack along the root of the finger would be the reason for strength reduction. The manufacturing process need to be more carefully considered about the cracks along the root of the finger especially for the preservative treated lumber.

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