Mokchae Konghak 28(4) : 61~71, 2000

Dimensional Stability and Bending Properties of Small Diameter Log Treated by Sap-displacement Method*1

Jun-Jae Lee*2, Ja-Il Koo*2, and Su-Kyoung Chun*3

ABSTRACT

The effect of the treatment with CCFZ, FR-4, and PEG400 from butt end on the dimensional stability and bending properties was examined. Three softwood species such as red pine, Korean white pine and Japanese larch and three hardwood species such as poplar, alder and oak were investigated in this research. Shrinkage of red pine, Korean white pine, poplar, and alder treated with PEG400 decreased. However, there was no significant decrease of shrinkage in Japanese larch and oak. The decrease of shrinkage when moisture content changed from about 20% to 10% was larger than that at any other phase. In regard to the effect of treatment on bending properties, bending MOE and MOR of all specimens treated with PEG400 decreased significantly. Especially in the case of red pine, poplar, and alder treated with PEG400, bending MOR reduced 9%, 14%, and 12%, respectively. Reductions of MOR of the hardwood was also much larger than that of the softwood. However, in all species, treatment with CCFZ and FR-4 did not affect the change of bending MOE and MOR significantly. Comparing the large specimen which also included heartwood with the small specimen which included only treated sapwood, there was a difference in the change of bending MOE and MOR between them. The large specimens of Korean white pine, alder and Poplar, which had a relatively low proportion of sapwood(18~22%), showed the decrease of MOR by 11~13% more than that of small specimens, while red pine, Japanese larch and oak, which had a relatively high proportion of sapwood(35~40%), showed little decrease. It means that bending MOE and MOR of structural wood treated from butt end should be considered in terms of sapwood proprotion as well as effect of treated chemicals.

Keywords : Dimensional stability, bending properties, small diameter log, sap-displacement method

1. INTRODUCTION

These days it seems that people have a preference for both wooden framed buildings and playground equipments. Also, it seems, they have a desire to create a comfortable domestic living space by wood. Wooden buildings are popular in leisure and sports spaces. Thus, the demand of wood as a structural material is increasing rapidly. Unfortunately, the wood used in all

*1 Received on June 10, 2000, accepted on November 23, 2000
This study was financially supported by Agricultural R&D Promotion Center.
*2 College of Agriculture & Life Sciences, Seoul National University, Suwon 441-744, Korea
*3 College of Forest Science, Kangwon National University, Chunchon 200-701, Korea

these structures is imported from North America and New Zealand. Even though there is little necessity for using imported wood in playground equipment and similar small size outdoor structures, domestic wood is still eschewed by builders. It is obvious that our country is not making efficient use of its forest resources, especially small diameter logs and low-quality hardwood correspond to nearly 70% of forest resources. It is necessary to increase the consumption of domestic wood, especially in small diameter logs, which should be treated well before they are used.

On the other hand, though all the wood in the case of using domestic wood as a structural material should be treated with preservative and other chemicals in accordance with ASTM F 1487, this process is insufficient and has problems. It is necessary to correct the defects of low dimensional stability, rapid decay using a simple treatment like sap-displacement method for adding value to domestic small diameter log. The benefits to the national economy and structural safety will be ensured throuth the extended durability of structures by this treatment. Thus, it is essential to analyze dimensional stability and mechanical properties of domestic small diameter log treated by sap-displacement method.

Many studies have been conducted on mechanical properties of treated wood (Gerhards, 1970; Resch and Parker, 1982; Lee, 1985; Soltis and Winandy, 1989; Manbeck *et al.*, 1995). However, very few studies have been conducted on the bending properties of domestic wood simply treated by sap-displacement method.

Accordingly, the object of this study was the evaluation of the bending properties and dimensional stability of small diameter log treated by sap-displacement method.

2. MATERIALS and METHODS

2.1 Materials

The small diameter logs of Japanese red pine (*Pinus densiflora*), Korean white pine (*Pinus koraiensis*), Japanese larch (*Larix leptolepis*), Poplar (*Populus tomentiglandulosa*), Alder (*Alnus japonica*), Oak (*Quercus variabilis*) were treated by sap-displacement method using a 5%

Table 1. Radial penetration depth and retention of various chemicals into the wood.

Species	Chemicals	Ave. penetration depth (mm)	Ave. retention (kg/cm^2)
Red pine	CCFZ	29.3	17.1
	FR-4	42.1	22.1
	PEG-400	33.5	18.7
Korean white pine	CCFZ	21.1	16.5
	FR-4	27.2	18.3
	PEG-400	25.7	16.8
Japanese larch	FR-4	15.9	5.5
	PEG-400	14.8	5.0
Poplar	CCFZ	21.9	14.2
	FR-4	22.7	15.1
	PEG-400	22.4	16.0
Alder	CCFZ	20.8	14.9
	FR-4	46.9	25.0
	PEG-400	34.7	19.1
Oak	FR-4	18.3	7.9
	PEG-400	17.6	7.0

CCFZ (preservative), 10% FR-4 (fire-retardant chemical) or 50% PEG-400 (dimensional stabilizer) solution. The diameter of the small logs ranged from 10 to 20 cm with a length of 150 cm. Following treatment, two 1 cm-thick discs were cut at mid-length and about 30 cm from the ends of each log; one for penetration measurement and another for analysis of chemical retention. Chemical penetration and retention were measured by an appropriate method for both species and chemicals (Table 1). Average retentions of Japanese larch and oak were relatively low but those of other species were similar. And except for Japanese larch and oak treated with CCFZ, sapwood was fully penetrated regardless of species and chemicals, although the patterns of penetration were somewhat different as shown in Figure 1.

For evaluating effects of treatment on dimensional stability and bending properties, the small specimens, 22 cm in cross section and 30 cm long, were cut from the sapwood zone because chemical penetration was limited to this zone(Figure 2). The large specimens were also prepared including pith for evaluating effects of the inclusion of treated sapwood in a sample on bending properties(Figure 2). Both shrinkage and bending test were conducted by ten specimens for each species-chemicals combination.

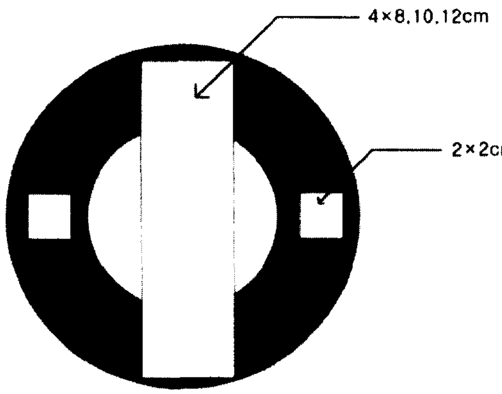

Fig. 1. Specimen preparation.

Fig. 2. Patterns of penetration.

2.2 Measurement of moisture content and specific gravity

Two types of specimens which were in green and air-dried condition were used in this study. The following equation was used to measure moisture content in each test (KS F 2202, 1989).

$$\text{Moisture Content (\%)} = \left(\frac{W_g - W_o}{W_o}\right) \times 100 \cdots\cdots (1)$$

where, W_g = weight of green wood
W_o = weight of oven-dried wood

To confirm the increase of specific gravity by treatment, basic specific gravity was also measured according to KS F 2202 (1989).

$$\text{Basic Specific Gravity} = \left(\frac{W / V}{D}\right) \cdots\cdots (2)$$

where, W = weight of oven-dried wood (g)
V = volume of green wood (cm^3)
D = density of water (1 g/cm^3)

2.3 Measurement of shrinkage and dimensional change

To evaluate the effect of treatment on dimensional stability, total shrinkage, and linear swelling and shrinkage were measured in accordance with KS F 2203 (1989) from the small specimens. The small specimens were cut from the sapwood. Shrinkages of specimens from green to oven-dried and from air-dried to oven-dried were calculated from the following equation. Dimensional change was also evaluated in terms of treatment when moisture content was changed from the fiber saturation point to oven-dried. Dimensional change was chosen instead of anti-shrinkage efficiency because control and treated specimen were selected from separate logs. The initial dimensions of air-dried specimens were used as a basis for calculating dimensional change when moisture content was changed.

Shrinkage and dimensional change (%) =

$$\left(\frac{ID - FD}{ID}\right) \times 100 \quad \cdots\cdots (3)$$

where, ID = Initial Dimension
FD = Final Dimension

The dimensional change for each 1 percent moisture content change was calculated in each step of moisture content change according to the following equation. In order to change moisture content, specimens put into the temperature and humid chamber and then water is sprayed.

Dimensional change for each 1 percent MC

$$\text{change}(\%) = \frac{\left(\frac{ID - FD}{ID}\right)}{(IMC - FMC)} \times 100 \quad \cdots\cdots (4)$$

where, IMC = Initial MC
FMC = Final MC

2.4 Static bending test

The static bending test was conducted on a small green specimen and both a small and large air-dried specimens by a Universal Testing Machine (UTM). The bending test was followed by ASTM D 143 (1995) for the small specimen and ASTM D 198 (1995) for the large specimen. The span was 28 cm and 120 cm, respectively. The load was applied continuously at a rate of motion of the movable crosshead of 1 mm/min to the small specimens. For the large specimens, the rate of loading was 5 mm/min to achieve maximum load in 6 to 20 min. The slope of initial linear portion of the load-deformation curve, maximum load, and deflection was recorded on computer recorder.

3. RESULTS and DISCUSSION

3.1 Moisture content and specific gravity

Moisture content and specific gravity measured from each specimen was listed in Tables 2 and 3.

Because all the specimen was in a green condition at the beginning of treatment, moisture content was significantly high and there were large differences in the values for each species and treatments. In softwood, Korean white pine was higher than the other softwoods in regards to moisture content. In hardwood, poplar had a large variation of moisture content. And moisture content of alder and oak was relatively uniform. It is considered that the time elapsed for moving specimen cause to the differences of moisture contents between treated woods and controls.

As expected, treated specimens showed increased specific gravities. But there was a difference in the relative amount of specific gravity changes for each chemicals and species. Specific gravities of PEG400 treated specimens, except for Japanese larch and oak, increased more than

Table 2. Moisture content and specific gravity of softwoods.

Species	Treatment	Moisture content (%)			Specific gravity		
		Green	Air-dried		Green	Air-dried	
Red pine	CCFZ	68.2*1	15.0*1	14.9*2	0.45*1	0.48*1	0.49*2
	FR-4	71.3	14.8	14.9	0.49	0.48	0.48
	PEG400	71.9	14.3	14.7	0.48	0.50	0.47
	Control	78.9	13.6	14.3	0.44	0.47	0.46
Korean white pine	CCFZ	129.4	16.0	15.2	0.39	0.39	0.41
	FR-4	109.5	14.0	15.3	0.41	0.41	0.40
	PEG400	99.5	13.6	14.8	0.46	0.41	0.42
	Control	125.4	13.4	14.3	0.35	0.37	0.39
Japanese larch	FR-4	34.4	14.6	15.1	0.47	0.46	0.46
	PEG400	31.2	14.7	14.7	0.45	0.47	0.46
	Control	36.3	14.8	14.7	0.46	0.46	0.46

*1 The values of the small specimen.
*2 The values of the large specimen.

Table 3. Moisture content and specific gravity of hardwoods.

Species	Treatment	Moisture content (%)			Specific gravity		
		Green	Air-dried		Green	Air-dried	
Poplar	CCFZ	98.7*1	15.2*1	15.2*2	0.38*1	0.40*1	0.42*2
	FR-4	66.5	14.8	14.9	0.37	0.40	0.39
	PEG400	60.3	14.4	15.0	0.41	0.41	0.41
	Control	58.7	13.1	14.7	0.35	0.38	0.38
Alder	CCFZ	68.0	15.4	15.3	0.45	0.49	0.48
	FR-4	60.1	15.1	15.2	0.47	0.49	0.49
	PEG400	55.7	13.4	14.8	0.51	0.50	0.49
	Control	67.6	12.8	14.4	0.44	0.47	0.46
Oak	FR-4	49.0	16.0	17.1	0.75	0.75	0.75
	PEG400	46.8	15.6	16.8	0.74	0.74	0.75
	Control	46.8	14.0	16.4	0.74	0.74	0.74

*1 The values of the small specimen.
*2 The values of the large specimen.

those of CCFZ treated and FR-4 treated specimens.

3.2 Comparison of shrinkage

The values of shrinkage of the small specimens treated with PEG400 were listed in Table 4. With regard to the normal conditions of woods, which were air-dried and then used, shrinkages of the air-dried small treated specimens were compared with the controls.

In softwood, the PEG400 treated red pine decreased 20% in tangential direction and 19% in radial direction than the control in regards to shrinkage. And the ratio of T/R was similar to that of the control. The shrinkage of Korean white pine decreased 36% in tangential direction and 40% in radial direction than that of the control. The ratio of T/R increased a little more than

Table 4. Shrinkage of softwoods and hardwoods.

Species	Treatment	Shrinkage (%) From green to oven-dried			Shrinkage (%) From air-dried to oven-dried		
		Tangential	Radial	T/R	Tangential	Radial	T/R
Red pine	PEG400	6.10*1	4.09*1	1.49	3.59*1	2.78*1	1.30
	Control	7.40	4.78	1.54	4.47	3.43	1.30
Korean white pine	PEG400	3.98	1.94	2.05	2.49	1.38	1.80
	Control	6.44	3.59	1.79	3.92	2.32	1.69
Japanese larch	PEG400	7.55	4.46	1.69	4.04	3.02	1.33
	Control	7.46	4.52	1.65	4.08	3.30	1.23
Poplar	PEG400	6.31	3.23	1.95	2.97	2.03	1.46
	Control	7.86	4.22	1.86	3.70	2.39	1.54
Alder	PEG400	4.16	2.88	1.44	2.35	1.24	1.89
	Control	7.64	4.50	1.69	3.91	2.46	1.58
Oak	PEG400	9.18	5.07	1.81	4.67	3.12	1.49
	Control	9.23	5.13	1.79	4.74	3.15	1.50

*1 The values of the small specimen.

that of the control. However, there was no significant difference in Japanese larch due to the low PEG400 retention.

For hardwood, shrinkage of poplar decreased 20% in tangential direction and 15% in radial direction than that of the control. The ratio of T/R was similar to that of the control. In case of alder, there was a decrease of 40% in tangential direction and 50% in radial direction. The ratio of T/R showed a small increase. There was no significant difference in oak like Japanese larch, which showed the low PEG400 retention.

This study showed that there was a 15 to 50% decrease in shrinkage when wood was treated with PEG400 which has low molecular weight. It was considered that PEG remains in the cell walls when the wood is dried because of the low vapor pressure of PEG. This bulking action prevented the wood from shrinking. As water evaporated and increased the concentration of PEG in the solution, the rate of diffusion into the cell wall increased (Rowell, 1984).

The shrinkage in tangential and radial direction of PEG400 treated specimen decreased but the ratio of T/R was similar or little increased. It was considered that nonuniform shrinkage in tangential and radial direction occurred because of the small cross-section of the specimen.

3.3 Comparison of dimensional change when moisture content changed

In order to evaluate the effect of treatment on dimensional stability, dimensional change was calculated when moisture content was in the process of changing from fiber saturation point to oven-dried condition.

In normal conditions, woods are air-dried and then used. So it is necessary to check the dimensional change from air-dried to wet condition and from wet condition to air-dried condition. Therefore, dimension of initial air-dried condition was used for calculating the dimensional change. The values of dimensional change were shown in Figures. 3, 4, 5, 6, 7, and 8. The results of dimensional change for each 1 percent moisture content change when moisture content is changed from about fiber-saturation point to

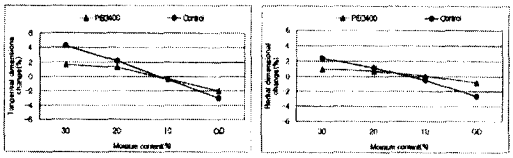

Fig. 3. Tangential and radial dimensional change of air-dried red pine when moisture content chandged.

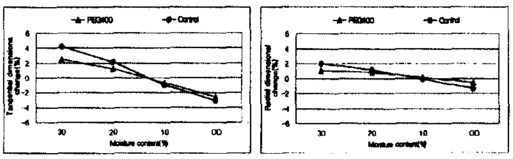

Fig. 4.Tangential and radial dimensional change of air-dried korean white pine when moisture content changed.

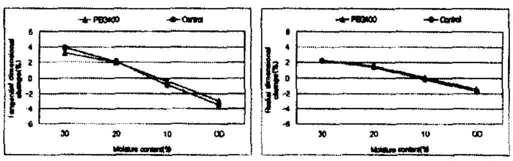

Fig. 5. Tangential and radial dimensional change of air-dried Japanese larch when moisture content changed.

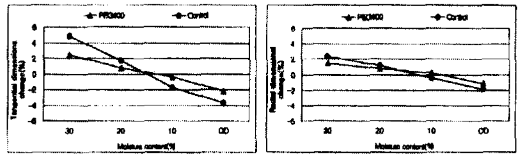

Fig. 6. Tangential and radial dimensional change of air-dried polar when moisture content changed.

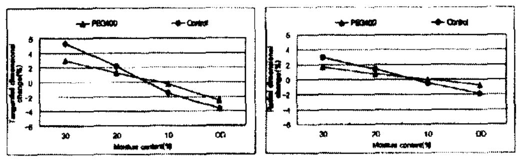

Fig. 7. Tangential and radial dimensional change of air-dried alder when moisture content changed.

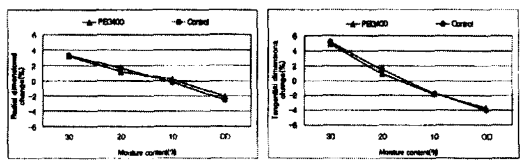

Fig. 8. Tangential and radial dimensional change of air-dried oak when moisture content changed.

oven-dried are listed in Table 5 and 6. They are evaluated for checking which phase of moisture content change largely affects to shrinkage of the treated wood.

The range of dimensional change of all the specimens treated with PEG400, except for the specimen of Japanese larch and oak, was generally narrower than that of the control. Moreover, the difference between the PEG400 treated specimen and the control, when moisture content changed from about 20% to 10%, was larger than that at other phases. Therefore, it is considered that the phase changing from about 20% to 10% in moisture content is important in the real condition.

In softwood, red pine was larger than other species in regards to the difference of dimensional change of the PEG400 treated specimen and control when moisture content changed from about 30% to 0%. There was little difference in Japanese larch. In the case of red pine and Korean white pine, the dimensional change of the PEG400 treated specimen decreased by about 38% when moisture content changed from

Table 5. Dimensional change of air-dried softwood for each 1 percent MC change when moisture content changed.

Species	Treatment	From about 30% to 20% T	R	T/R	From about 20% to 10% T	R	T/R	From about 10% to 0% T	R	T/R
Red pine	PEG400	-0.04*1	-0.03	1.33	-0.16	-0.06	2.67	-0.16	-0.09	1.78
	Control	-0.21	-0.13	1.62	-0.26	-0.16	1.63	-0.25	-0.21	1.19
Korean white pine	PEG400	-0.12	-0.03	4.00	-0.19	-0.07	2.71	-0.20	-0.08	2.50
	Control	-0.21	-0.08	2.63	-0.31	-0.10	3.10	-0.21	-0.13	1.62
Japanese larch	PEG400	-0.12	-0.07	1.71	-0.35	-0.16	2.19	-0.15	-0.15	1.00
	Control	-0.18	-0.08	2.25	-0.30	-0.16	1.88	-0.26	-0.08	3.25

Dimensional change for each 1 percent moisture content change (%)

*1 - means shrinkage.

Table 6. Dimensional change of air-dried hardwood for each 1 percent MC change when moisture content changed.

Species	Treatment	From about 30% to 20% T	R	T/R	From about 20% to 10% T	R	T/R	From about 10% to 0% T	R	T/R
Poplar	PEG400	-0.17*1	-0.07	2.43	-0.12	-0.06	2.00	-0.18	-0.14	1.29
	Control	-0.32	-0.12	2.67	-0.34	-0.17	2.00	-0.19	-0.14	1.36
Alder	PEG400	-0.18	-0.10	1.18	-0.15	-0.08	1.88	-0.22	-0.18	1.22
	Control	-0.31	-0.16	1.93	-0.37	-0.29	1.28	-0.22	-0.14	1.57
Oak	PEG400	-0.40	-0.21	1.90	-0.27	-0.10	2.70	-0.22	-0.21	1.05
	Control	-0.36	-0.17	2.12	-0.32	-0.18	1.78	-0.23	-0.23	1.00

Dimensional change for each 1 percent moisture content change (%)

*1 - means shrinkage.

about 20% to 10%.

With regard to hardwood, there was a significant difference in dimensional change of PEG400 treated specimen and the control in poplar and alder when moisture content changed from about 30% to 0%. The trend of dimensional change of PEG400 treated oak was similar to that of the control. In the case of poplar and alder, when moisture content changed from about 20% to 10%, the dimensional change of the PEG400 treated specimen decreased by about 60% and 65%, respectively.

Dimensional changes of the PEG400 treated specimens in hardwood were less than those of the specimens in softwood when moisture content changed. And there was no specific effect of PEG400 treatment in Japanese larch and oak because of the low retention. Additional research is needed with regard to these species and treatments.

3.4 Comparison of MOE and MOR

The static bending test was conducted to the small and large specimens. The small specimens cut from sapwood of small diameter log were used for evaluating the effect of the treatment on its bending properties. To evaluate the effect of sapwood proportion on the bending properties,

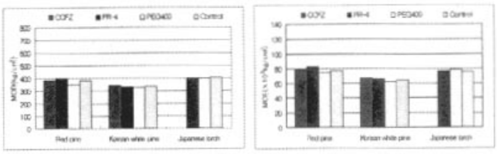

Fig. 9. MOE and MOR of small size specimens in softwoods.

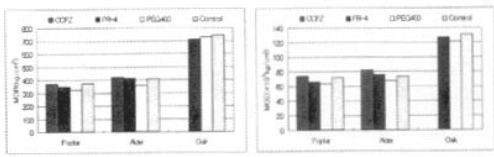

Fig. 10. MOE and MOR of small size specimens in hardwoods.

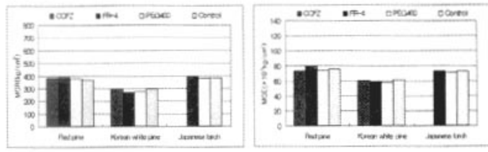

Fig. 11.MOE and MOR of structural size specimens in softwoods.

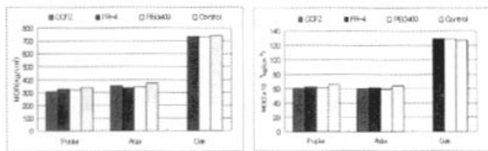

Fig. 12.MOE and MOR of structural size specimens in hardwoods.

the large specimen was used. The test results are shown in Figure 9, 10, 11, and 12. The two-tailed test is used to check the significance. The MOE and MOR of the PEG-400 treated specimen of both softwood and hardwood, except for Japanese larch and oak, were significantly reduced in comparison to other combinations. It is considered that shrinkage of the cell wall was restrained and the amount of lignin per unit area decreased when wood is treated with PEG-400 and is dried(Rowell, 1984).

With regards to the small specimen, when the green and air-dried wood were compared, it was obvious that there was a significant increase in the MOE and MOR of air-dried wood. However, there was no significant difference in the green wood because the variation of moisture content was great.

In the case of softwood, the MOE and MOR of PEG400 treated specimen in red pine were reduced by 9% and 13%, respectively. Differences between other chemical treated specimen and the control were not significant. There was little reduction in the MOE and MOR of all the specimen treated with chemicals in Korean white pine. There was no difference in the MOE and MOR of all the treated specimen in Japanese larch.

The MORs of FR-4 treated and PEG400 treated specimens in poplar in regards to hardwood were reduced by 7% and 15%, respectively. There was no reduction in the CCFZ treated specimen. The MOR of PEG400 treated specimen in alder was reduced by 12%. Any specific differences were not shown in the tests of the other chemicals. There was no difference in regards to MOE and MOR for all the treated specimen in oak.

The PEG400 treated specimens of red pine, poplar, and alder have a 12 to 15% reduction in MOR. A reduction of MOR was much larger in hardwood than in softwood.

Comparing the large specimen with the small specimen, the large specimens of Korean white pine had an average sapwood proportion of about 18%. The MOR of the large specimen of

Korean white pine was reduced 13% more than that of the small specimen. In alder, a sapwood proportion was about 22% and its MOR reduction was 11%. Poplar was similar to alder. There was little reduction of MOR in red pine, Japanese larch, and oak in which the sapwood proportion hovered between 35 to 40%. It is considered to be the reason why these species have a relative high sapwood proportion.

For domestic small diameter log, PEG-400, dimensional stabilizer reduced the strength of the wood. However, there was little reduction of the strength of the wood when FR-4, fire retardant was applied.

4. CONCLUSION

The following conclusions could be drawn from this study on evaluating the dimensional stability and mechanical properties of small diameter log treated by sap-displacement method.

1. Shrinkage of red pine, Korean white pine, poplar, and alder treated with PEG400 decreased. There was no significant decrease of shrinkage in Japanese larch and oak. The decrease of shrinkage was larger when moisture content changed from about 20% to 10% than at any other phases.
2. The values of MOR of the small specimen in the case of PEG400 treated with Korean white pine, poplar, and alder were reduced by 9%, 14%, and 12%, respectively. Reduction of MOR of the hardwood was also much larger than that of MOR of the softwood.
3. Comparing the large specimen with the small specimen, the large specimens of Korean white pine had an average sapwood proportion of 18%. The MOR of the large specimen of Korean white pine was reduced 13% more than that of the small specimen. In alder, a sapwood proportion was about 22% and its MOR reduction was 11%. Poplar was similar to alder. There was little reduction of MOR in red pine, Japanese larch, and oak in which the sapwood proportion hovered between 35 to 40%.

From the above results, it can be deduced that shrinkage of wood treated with PEG400 was effectively reduced. However, this treatment also reduced MOR of wood. For the CCFZ and FR-4 treated woods, no significant difference could be spotted. And it is thought that more research is needed to determine the effect of the treatment on the bending properties of wood according to the change of the moisture content.

ACKNOWLEDGEMENT

This study was financially supported by Agricultural R&D Promotion Center.

REFERENCES

1. American Society for Testing and Materials. 1995. Methods of Testing Small Clear Specimens of Timber. ASTM Designation: D 143-94, Section 4, Volume 04.09: Wood. ASTM, Philadelphia, Pa. pp. 23-53.
2. American Society for Testing and Materials. 1995. Methods of static tests of timbers in structural sizes. ASTM Designation: D 198-94, Section 4, Volume 04.09: Wood. ASTM, Philadelphia, Pa. pp. 57-75.
3. Gerhards, C. C. 1970. Effect of fire-retardant treatment on bending strength of wood. Res. Pap. FPL 145. U. S. Department of Agriculture, Forest Service, Forest Products Laboratory. Madison, WI:
4. Lee, A. W. C. 1985. Effect of CCA-treating and air-drying on the properties of southern pine lumber and plywood. Wood and Fiber Science.

17(2): 209-213.
5. Manbeck, H. B., K. R. Shaffer., J. J. Janowiak., P. R. Blankenhorn., P. Labosky., R. T. Baileys., and D. A. Webb. 1995. Creosote treatment effect on hardwood glulam beam properties. Wood and Fiber Science. 27(3): 239-249.
6. Resch, H. and R. Parker. 1982. Strength and stiffness of preservative-treated marine piles Wood and Fiber Science. 14(4): 310-319.
7. Rowell, R. 1984. The Chemistry of Solid Wood. American Chemical Society, Washington, D. C. pp. 257-260.
8. Soltis, L. A. and J. E. Winandy. 1989. Long-term strength of CCA-treated lumber. Forest Prod. J. 39(5): 64-68.
9. Korean Satndards Association. 1989. Tests for average spacing of annual ring, moisture content and specific gravity of wood. KS F 2202.
10. Korean Standards Association. 1989. Tests for shrinkage of wood. KS F 2203.