J. Korean Wood Sci. Technol. 2020, 48(3): 345~363

pISSN: 1017-0715 eISSN: 2233-7180
https://doi.org/10.5658/WOOD.2020.48.3.345

Original Article

Effect of Kerfing and Incising Pretreatments on High-Temperature Drying Characteristics of Cedar and Larch Boxed-Heart Timbers with Less than 150 mm in Cross Section Size[1]

Chang-Jin LEE[2,†]

ABSTRACT

This study was conducted to identify the effect of kerfing and incising pretreatments on high-temperature drying characteristics of cedar and larch boxed-heart timbers with a cross section of less than 150 mm. The result showed that the pretreatments have made a significant difference regarding surface check and shrinkage. Although the kerfing was suitable as a pretreatment to reduce the occurrence of surface check, the incising was not suitable as a pretreatment since the knives of timber joined together, causing the conversion to the surface checks. The shrinkage showed a significant result that the final moisture content was reduced in the order of incising, kerfing, and kerfing-incising after the drying process based on the pretreatment condition. Twist was more affected by the grain angle than the anisotropy of the juvenile wood, and there was no effect of pretreatments.

Keywords: small-diameter log, thinning-out tree, boxed-heart timber, longitudinal kerfing, knife incising, drying pretreatment, wood drying

1. INTRODUCTION

Since timbers that have a smaller diameter such as thinning logs have a poor yield as boards or square lumbers, boxed-heart timbers can be considered to use as an efficient method. However, since a boxed-heart timber includes juvenile wood that largely forms growth stress, there is a problem that drying defects such as checks, splits, and warps are easily produced. In order to solve this issue, studies have been conducted to find a method of drying timbers after mechanically processing them such as longitudinal kerfing and incising.

The longitudinal kerfing was proposed to prevent drying defects which often occur when drying logs with pith, such as V-type cracks (Hsu and Tang, 1974). This is known to be effective in preventing the occurrence of surface check in the early stage of drying process by inducing the concentration of stress in the groove formed in a cross section (Jung *et al.*, 1997). In addition, although the longitudinal kerfing does not affect the drying rate much, it can influence

[1] Date Received January 9, 2020, Date Accepted April 28, 2020
[2] Department of Wood Science & Technology, Jeonbuk National University, Jeonju 54896, Republic of Korea
† Corresponding author: Chang-Jin LEE (e-mail: ycj1114@nate.com, ORCID: 0000-0002-8208-9082)

the distribution of the final moisture content after the drying process. It can also be treated with the incising (Lee *et al*., 2016a; Lee *et al*., 2017).

The incising treatment is a method to create an artificial knife on timbers for the purpose of facilitating chemical injection to refractory wood species. It was reported that the treatment can be processed even prior to the drying process and help not only in the chemical injectability but also in reducing the duration of the drying process (Islam *et al*., 2009). Moreover, the knife processed on the wood surface could suppress the occurrence of the surface check by evenly dispersing the tensile stress of the surface layer at the initial phase of the drying process (Lee *et al*., 2017). However, the knife processed on the surface reduces several mechanical characteristics of wood (Winandy and Morrel, 2007; Park *et al*., 2008). In particular, since the increase in the incising density leads to the decrease in the physical characteristics, the incising density should be low when it is used as a pretreatment for the drying process (Lee *et al*., 2016a; Suzuki *et al*., 1996).

The effects of these pretreatments on the drying defects in coniferous boxed-heart timber are varied depending on the factors such as tree species, size, etc., and the bigger the size of the cross section, the more the effect tends to increase. Although several studies (150 mm thick pine, 150 mm and 180 mm thick hemlock and radiata pine) said that the longitudinal kerfing reduces the twist of the boxed-heart timber (Lee *et al*., 2016b; Lee *et al*., 2016c), other studies (200 mm thick pine, 210 mm and 220 mm thick nut pine) reported that it does not affect the reduction of the twist (Lee *et al*., 2013; Lee *et al*., 2014). In addition, it was described that the incising can make the knife of a boxed-heart timber of 200 mm thick pine evenly disperse the tensile stress of the surface layer (Lee *et al*., 2017), but it was said that the knives joined together resulting in the conversion to the surface check in a boxed-heart timber of 250 mm and 300 mm thick douglas-fir (Lee *et al*., 2016a).

The drying defects are an important factor of processing yield after the drying process, and the surface check deteriorates the quality of the dried woods. Furthermore, the twist affects the processing yield greater than the surface check does. Thus, a study needs to be conducted on the effects of the kerfing and incising pretreatments on major drying defects which occur during the drying process of cedar and larch boxed-heart timbers. Accordingly, this study aims to identify the effects of the kerfing and incising pretreatments on the high-temperature drying characteristics of cedar and larch boxed-heart timbers processed to a cross section of less than 150 mm.

2. MATERIALS and METHODS

2.1. Preparation of test materials

Cedar (*Cryptomeria japonica*, L.F. D.Don) and larch (*Larix Kaempferi* C.) were selected as published tree species. The trees were processed into square and round timbers with the length of 2,400 mm, thicknesses and diameters of 90 (9), 120 (12), and 150 (15) mm. The species were prepared that contain each of the five square timbers and six round timbers, according to the tree species, sizes of cross section, and pretreatment conditions.

2.2. Pretreatment processing

The test materials were classified into control (C), incising (I), kerfing (K), and combination of kerfing and incising (KI), based on pretreatment conditions. The incising pretreatment processed with a blade thickness of 2 mm, depth of 10 mm, and incising density of approximately 2,400/m^2 (Fig. 1(a)), and the kerfing pretreatment processed to a width of 3 mm and depth of 1/3 of the size of cross sectionusing a circular saw (Fig. 1(b)).

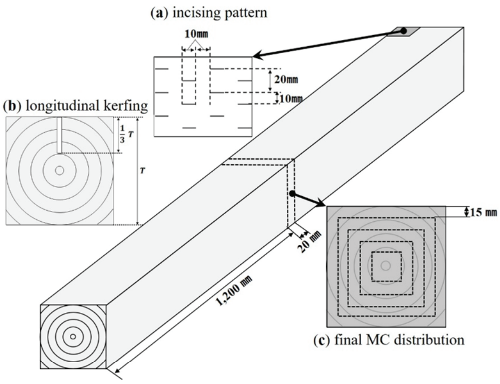

Fig. 1. Processing diagram of the specimens ((a) incising, (b) longitudinal kerfing, (c) final MC distribution).

Table 1. Drying schedule

Stage	Time (Hours)	Dry-bulb (℃)	Wet-bulb (℃)
1	12	95	95
2	36	120	90
3	96	90	70
Cooling	24	25	-
Total time	168		

2.3. Drying test

The drying test was performed between April and May by a 40 m^3 commercial hot air drying machine. The drying schedule was set as shown in Table 1, based on the results of studies by Lee *et al*. (2013), Lee *et al*. (2014), Lee *et al*. (2016b; 2016c), and Lee *et al*. (2017), as well as considering the sizes of the test speciesused in this study.

2.4. Moisture Content (MC) examination

The weights of all test materials were examined prior to the drying process. The heaviest one in each pretreatment condition was selected as a representative test material and used for the moisture content examination after the drying process. The final MC was analyzed by collecting test pieces of 20 mm thickness at the spot of 1,200 mm from the cross section and using an oven-drying method. The final moisture content distribution was investigated by dividing the collected test pieces by 15 mm intervals from the surface (Fig. 1(c)). The initial MC was calculated from the changes in weight and the final moisture content of the test materials before and after the drying process.

2.5. Surface check examination

For the surface check, the width and length of the check that has the width of at least 2 mm were examined in all test materials after the drying process. Since the maximum width of the investigated surface check was 5 mm, the average surface check length based on the pretreatment conditions was calculated by the following equation:

$$\text{Average surface check length} = \frac{\sum_1^n lw_2 + \sum_1^n lw_3 + \sum_1^n lw_4 + \sum_1^n lw_5}{N} \quad (1)$$

where, *lw* length of each surface check with width 2-5 mm, *N* number of species.

2.6. Twist examination

The twist was tested only in the square timbers, and it was measured four times each in both cross sections per test material and eight times in total after the drying process.

2.7. Shrinkage and kerf widening rate examination

The shrinkage and kerf widening rate were examined to find the width of the kerf and to measure the changes in thickness and diameters at the spot of 1,200 mm from the cross section before and after the drying process using a Vernier caliper.

$$\text{Kerf widening rate (\%)} = \frac{(W_s - W_k)}{W_s} \times 100 \qquad (2)$$

W_s: width of a circular saw,
W_k: width of the kerf after drying

3. RESULTS and DISCUSSION

Table 2 shows the result of regression analysis between various factors of woods and the drying characteristics of larch and cedar boxed-heart timbers. The analysis result indicated factors that have made significant differences as follows: 1) tree species, shapes, sizes of cross sections, and the initial moisture content in the final moisture content; 2) sizes of cross sections, and pretreatments in the surface check; 3) shapes, sizes of cross sections, pretreatments, and the initial moisture content in the shrinkage; and 4) tree species in the twist.

The pretreatments had largely affected the surface check, and showed a significant difference in the shrinkage. In the surface check, the kerfing process was the major factor indicating a significant difference. Regarding the shrinkage, it was determined that each pretreatment affected the final moisture content distribution, which led to a significant difference.

3.1. Final moisture content and distribution

The final moisture content and distribution showed significant differences based on the tree species, sizes of cross sections, shapes, and the pretreatment conditions (Figs. 2~3, Table 3). The moisture content of

Table 2. Regression analysis result using SPSS

Model		*B*	SE	β	*t*	*p*	*F*	*R*	R^2	ΔR^2
Final MC	Species	-4.264	.827	-.405	-5.157	.000***	23.994	.861	.741	.710
	Type	-5.180	.955	-.492	-5.426	.000***				
	Size	5.259	.781	.816	6.731	.000***				
	Pretreatment	-.682	.381	-.145	-1.79	.081				
	Initial MC	-.097	.041	-.309	-2.358	.023*				
Surface check	Species	49.056	30.771	.160	1.594	.118	11.509	.760	.578	.528
	Type	4.756	35.534	.015	.134	.894				
	Size	119.181	29.078	.634	4.099	.000***				
	Pretreatment	-61.639	14.171	-.449	-4.35	.000***				
	Initial MC	-.694	1.529	-.076	-.454	.652				
Shrink	Species	.173	.174	.115	.998	.324	6.747	.667	.445	.379
	Type	.643	.200	.426	3.21	.003**				
	Size	-.697	.164	-.753	-4.248	.000***				
	Pretreatment	.191	.080	.282	2.387	.022*				
	Initial MC	.024	.009	.536	2.801	.008**				
Twist	Species	10.162	1.223	.873	8.31	.000***	17.887	.889	.790	.746
	Type	-	-	-	-	-				
	Size	-.944	1.525	-.133	-.619	.543				
	Pretreatment	.201	.565	.039	.356	.726				
	Initial MC	-.012	.076	-.034	-.160	.875				

*** $p < .001$. ** $p < .01$. * $p < .05$.
B: regression coefficient, SE: standard error, β: standardized regression coefficient, *t*: *t*-value, *p*: *p*-value, *F*: *F*-value, *R*: correlation coefficient, R^2: coefficient of determination, ΔR^2: Adjusted-R^2.

Table 3. Initial MC and Final MC according to species, type, size, and pretreatment condition

Specimens		Cedar				Larch			
		Square timber		Round timber		Square timber		Round timber	
		Initial MC (%)	Final MC (%)	*Initial MC* (%)	Final MC (%)	*Initial MC* (%)	Final MC (%)	*Initial MC* (%)	Final MC (%)
9 cm	C	*27.9*	12.8	*17.2*	10.2	*33.7*	8.9	*25.6*	7.8
	I	*32.5*	17.1	*32.2*	7.9	*33.3*	8.9	*20.2*	8.6
	K	*34.4*	10.9	*18.7*	8.3	*28.5*	8.5	*28.7*	8.2
	KI	*35.2*	9.7	*23.8*	10.3	*32.4*	8.3	*22.6*	7.3
12 cm	C	*52.6*	20.5	*29.0*	15.5	*37.8*	13.4	*37.2*	10.0
	I	*49.7*	13.3	*26.7*	11.1	*41.8*	12.3	*28.7*	11.5
	K	*47.3*	20.6	*29.7*	13.7	*48.5*	11.8	*43.5*	7.2
	KI	*41.9*	19.6	*85.4*	9.9	*44.7*	11.1	*41.5*	8.6
15 cm	C	*57.3*	29.9	*53.9*	12.4	*66.7*	15.6	*50.2*	13.5
	I	*49.1*	29.1	*37.9*	23.8	*70.4*	17.9	*54.0*	13.2
	K	*87.7*	17.6	*46.0*	15.1	*57.5*	21.2	*41.5*	11.1
	KI	*63.2*	16.5	*43.6*	15.7	*87.1*	13.6	*44.4*	10.9

C: control, I: incising, K: kerfing, KI: a combination of incising and kerfing.

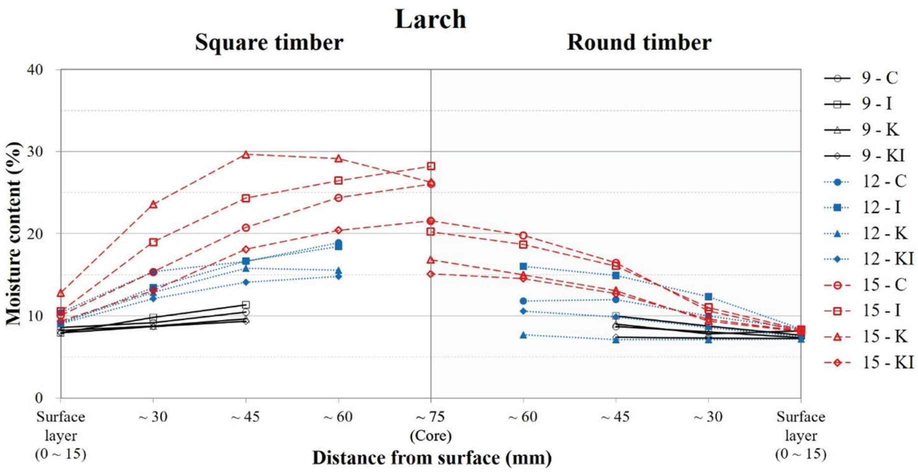

Fig. 2. Final moisture content distribution of larch according to the distance from surface layer. 9: 90 mm-thick (or diameter), 12: 120 mm-thick (or diameter), 15: 150 mm-thick (or diameter), C: control, I: incising, K: kerfing, KI: a combination of incising and kerfing.

the square timbers was higher than that of the round timbers, and the increase in the size of the cross section led to the increase of the moisture content after the drying process. Although the pretreatment conditions were not significant as a result of the regression analysis, it showed a tendency of decreasing the moisture content in the order of I – K – KI.

Permeability was affected by the factors, such as specific gravity, extractives, and late wood percentage, and varied depending on the tree species (Hur and

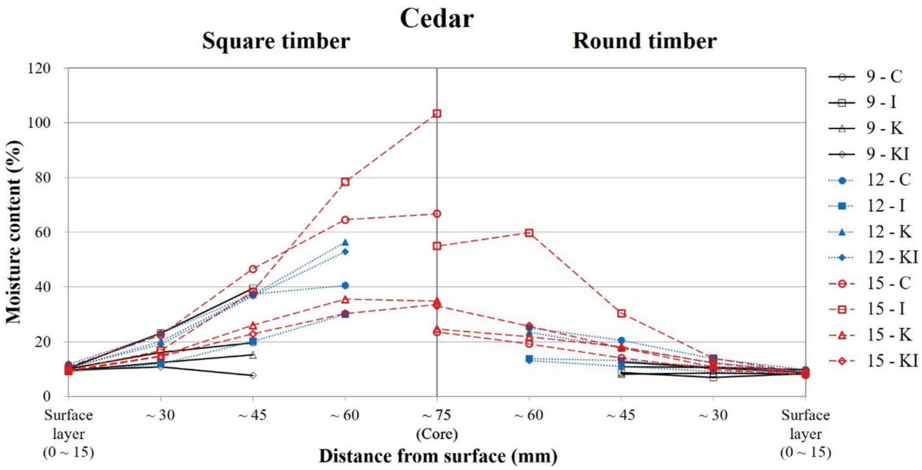

Fig. 3. Final moisture content distribution of cedar according to the distance from surface layer.
9: 90 mm-thick (or diameter), 12: 120 mm-thick (or diameter), 15: 150 mm-thick (or diameter), C: control, I: incising, K: kerfing, KI: a combination of incising and kerfing.

Kang, 1997; Jee and Kim, 1996). Moreover, the moving distance of moisture from the center of the woods to the evaporation surfaces was affected by the factors, such as the shape of the woods, sizes of cross sections, and the pretreatment condition (Lee *et al*., 2013; Lee *et al*., 2016a; 2016c). In particular, the heartwood area of cedar is known to be the most difficult to dry since it has a high initial moisture content with poor permeability (Hermawan *et al*., 2012). It is also shown to have high moisture content after the drying process in this study. Hence, it is considered that the moisture content results investigated in this study were based on the final moisture content and distribution affected by the following: 1) tree species, sizes of cross sections, shapes, and pretreatments and 2) drying schedule which was uniformly applied regardless of tree species, shapes, and sizes.

Meanwhile, the study found that several test materials have higher values of moisture content despite having low initial moisture contents. This tendency was noticeable in cedar trees that have the initial moisture content in the range of 30 ~ 50%, and similar tendencies were shown in 150 mm thick larch square timbers. In general, given the same time for the drying process, the wood with high initial moisture content shows higher moisture content after the drying process. However, bordered pit aspiration which occurs when the wood is dried reduces the permeability of the wood after the drying process to the level between 1/10 and 3/10 (Erickson and Crawford, 1959). The incidence of the bordered pit aspiration is also varied due to the drying conditions (Fujii *et al*., 1997). Furthermore, regarding a commercial-scale drying test, the test material is exposed to the outdoor air for a longer time during preparation of the test than in industrial site and small-scale tests. Therefore, the moisture content of the surface layer may be reduced prior to the initiation of the drying test, and the bordered pit aspiration may be emerged during the process. Accordingly, the several test materials showed relatively higher moisture content after the drying process despite their lower initial moisture content. This was presumed to be because the factors, such as moisture content of the surface layer and border pit aspiration, were affected while the test materials were exposed to the outdoor air before the drying process, which in turn affected the final moisture content and distribution after the drying process.

3.2 Surface check

The average length of surface check based on the width of the investigated checks after the drying process is shown in Fig. 4 and 5, and it displayed differences depending on the sizes of the cross section and pretreatment conditions.

As the thickness of the wood increases, the large moisture profiles are formed. As a result, the surface layer is placed under a higher tensile condition. Moreover, since a longer time is required until the moisture inside is removed, the conversion of the

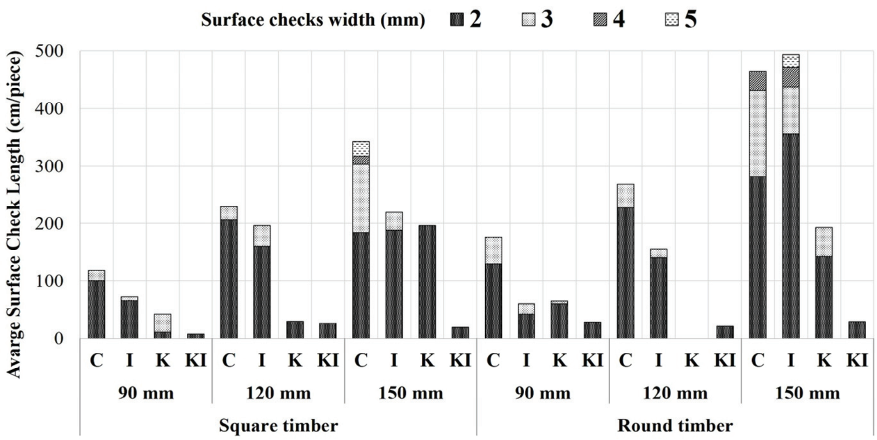

Fig. 4. Average surface check length of larch according to surface checks width. C: control, I: incising, K: kerfing, KI: a combination of incising and kerfing.

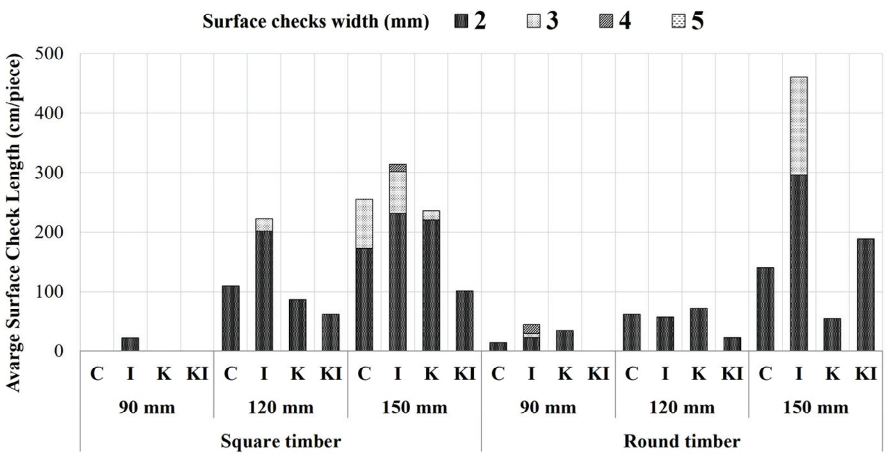

Fig. 5. Average surface check length of cedar according to surface checks width. C: control, I: incising, K: kerfing, KI: a combination of incising and kerfing.

tensile stress formed on the surface layer to compressive stress is delayed. Thus, the difference in the surface check based on the size of the cross section is caused because a large tensile stress is formed on the surface layer as the thickness increases, and the stress reversal is delayed, which makes the surface check to occur more easily.

The effects of kerfing and incising pretreatments on the occurrence of surface check were comprehensively reviewed along with previous studies (Lee *et al*., 2013; Lee *et al*., 2014; Lee *et al*., 2016a; 2016b; 2016c; Lee *et al*., 2017). As a result of the review, the kerfing was proved to be suitable as a pretreatment for reducing the surface check. However, the kerf widening rate indicated that it had no correlation to the surface check (Table 4). This is because even if the kerf is expanded in the early stage of the drying process, the kerf widening rate is affected by the shrink behavior and creep effect based on the decrease in moisture content in the inner layers after the middle stage of the drying process. On the other hands, the incising was determined to be not suitable as a pretreatment since it caused the conversion into the surface check as each knife joined together. However, it is considered that the incising can be used as a pretreatment

Table 4. Kerf widening rate according to species, timber type, size, and pretreatment condition

Specimens		Kerf widening rate (%)			
		Cedar		Larch	
		Square	Round	Square	Round
9 cm	K	-30.7	-65.3	82.7	72.7
	KI	-100.0	-27.0	45.0	99.0
12 cm	K	125.3	24.0	-22.7	-100.0
	KI	102.0	-38.0	120.7	43.3
15 cm	K	-12.3	-16.0	32.0	193.0
	KI	8.7	142.3	114.7	97.7

K: kerfing, KI: a combination of incising and kerfing.

method for boxed-heart timbers, if the size and gap of the incising are adjusted to the extent that it can prevent each knife joining together.

Meanwhile, in the condition above the fiber saturation point, the drying is proceeded rapidly as the initial moisture content increases (Han *et al.*, 2019a). Furthermore, the equilibrium moisture content in the period when the wood is exposed to the outdoor air (April~May) before the drying process was 9.6 ~ 11.7%, which was the period when natural drying was easily performed (Han *et al*., 2019b). Since the surface of the boxed-heart timber is configured with a tangential section, not only the moisture is quickly evaporated, but also the bordered pit aspiration and surface check occurred in this process cause a negative impact on the permeability and drying defects of the wood (Amer *et al*., 2019; Lee *et al*., 2014).

In addition, regarding thick woods such as the boxed-heart timber, even if the moisture content at its core is indicated to be above the fiber saturation point, the movement of free water during the drying process cannot be removed as quickly as it was on the surface layer (Kim *et al*., 2017; Park *et al*., 2020). Furthermore, since the pressure inside the timber increases with the increase in temperature during the drying process, the boiling point of water increases, so that most of the free water at the core cannot be evaporated in the form of steam, but remains as liquid. Therefore, the movement of the free water located at the core of the test material is interfered. Particularly, since this problem is occurred more severely with a poor permeability, it leads to more severe moisture profiles on the surface and inner layers. In addition, as the time of maintaining the moisture profiles on the surface and inner layers is prolonged, it is affected by creep, which leads to its impact on the shrinkage. Thus, it causes a negative impact on the occurrence of the closed checks after the middle stage of the drying process.

Therefore, the followings are significant factors causing the occurrence of the surface check in addition to the sizes of the cross section and pretreatments shown in the results of the regression analysis: 1) differences in inner moisture content due to a poor permeability of the cedar boxed-heart timber; 2) effects of creep; 3) changes in moisture content on the surface layer by exposure to the outdoor air before the drying process.

3.3 Shrinkage

The shrinkages of the cedar and larch boxed-heart timbers are shown in Figs. 6~7. The shrinkage of the timber appears with the changes in moisture content, and the kerfing and incising pretreatments cause differences in moisture moving distance from the core of the timber to the evaporation surface. This may also affect the stress behavior which occurs inside the

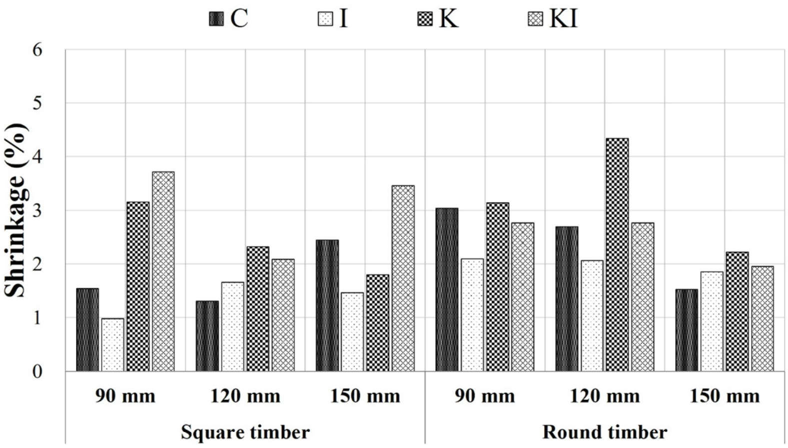

Fig. 6. Shrinkage of larch according to species, type, size, and pretreatment condition. C: control, I: incising, K: kerfing, KI: a combination of incising and kerfing.

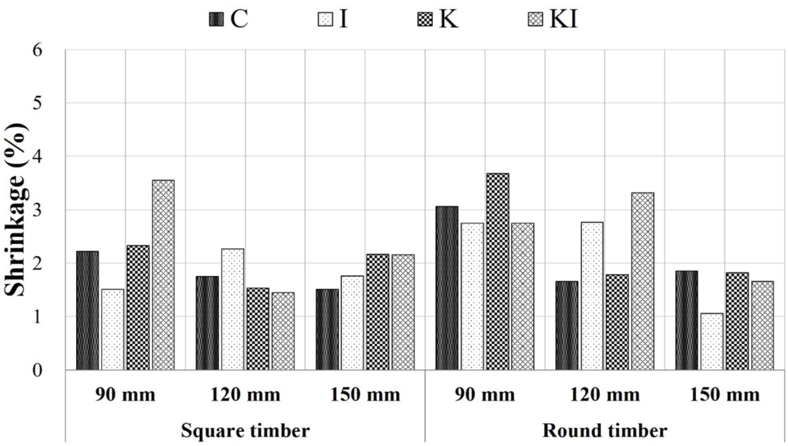

Fig. 7. Shrinkage of cedar according to species, type, size, and pretreatment condition. C: control, I: incising, K: kerfing, KI: a combination of incising and kerfing.

timber during the drying process (Lee *et al*., 2016a). Moreover, creep and tension set which occur inside the timber during the drying process show differences based on the tree species, sizes of cross section, and the ratio of sapwood-heartwood. As the size of the cross section increases, the shrinkage decreases due to the effects of creep and tension set (Hwang and Park, 2009; Lee *et al*., 2016c; Yamashita *et al*., 2014). This shrinking behavior indicates differences depending on the degree of moisture profiles formed inside the timber and time of its maintenance, and it plays a role as a significant cause of the drying defects. In addition, as previously mentioned, a commercial-scale drying test is exposed to the outdoor air for a relatively longer time during its preparation. Therefore, the shrinkage of the boxed-heart timber is caused by following factors affecting the stress behavior inside the timber: 1) anisotropy of juvenile wood; 2) moisture removed during the exposure to the outdoor air; 3) difference in moisture of surface and inner layers (the degree of moisture profiles); 4) differences in permeability based on the tree species; and 5) drying time and creep effect based on the sizes of the cross section. It is also considered that the stress behavior inside the timber affected the occurrence of surface check and twist.

3.4 Twist

The twist of cedar and larch square timbers is shown in Fig. 8, and it showed that a more severe twist occurred in larch than cedar. Although juvenile wood has a severe anisotropy, the twist of timber is related to the distance from the pith and grain angle. In particular, the grain angle is the most significant factor of the twist occurrence (Frühwald 2006; 2007; Nilsson *et al*., 2007; Kubojima *et al*., 2013; Straže *et al*., 2011). Thus, the cause of the difference in twist between two tree species is the grain angle, and the difference in twist based on the thickness in each tree species is due to the anisotropy of the juvenile wood. Furthermore, since the twist was more severely occurred on larch than cedar, it was considered that the twist of boxed-heart timbers was affected by the grain angle more than by the anisotropy of the juvenile wood.

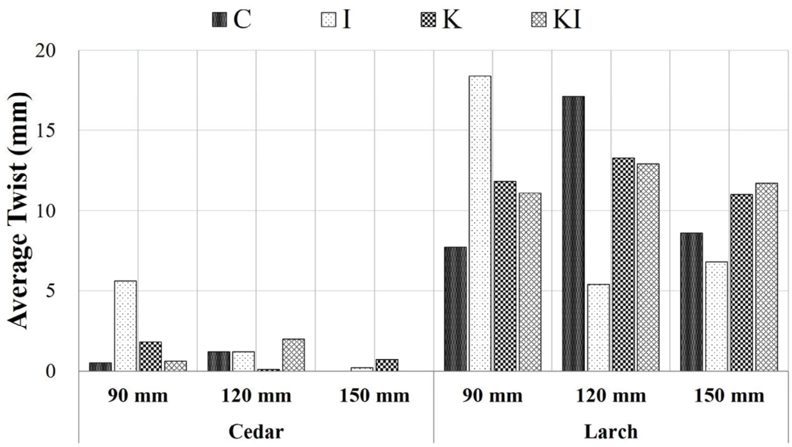

Fig. 8. Average twist of square timber according to species, size, and pretreatment condition.
C: control, I: incising, K: kerfing, KI: a combination of incising and kerfing.

3.5 Evaluation on commercial-scale drying test

Since a commercial-scale drying test consumes a tremendous amount of time for its preparation, there is a problem that test materials are exposed to the outdoor air for a longer time in the industrial site. In order to derive a result which can be applied to the industrial site, this study prepared a total of 264 cedar and larch boxed-heart timbers without using dummy boards by filling a commercial drying machine with the size of 40 m^3 to perform the drying test between April and May (spring). Nevertheless, this study was able to observe the differences of the shape of test material, size of cross section, initial moisture content, and kerfing and incising pretreatments in high-temperature drying characteristics of cedar and larch boxed-heart timbers. Thus, the drying schedule used in this study maybe applied to the industrial sites if it is improved based on tree species, shapes, and sizes. Since the industrial sites have a shorter time for the exposure to the outdoor air than in this study, it is also considered that the effects of the outdoor air can be reduced.

Meanwhile, the study was able to identify that the moisture content inside the test materials shown in Fig. 2 and 3 had a significant difference from the final moisture content shown in Table 3. As reported by Lee *et al*. (2016a), this is because the ratio of volume possessed by each surface layer and inner layer with respect to the entire volume of the timber, or the solid volume, displayed a large difference. Given the 150 mm thick square timber used in this study as an example, the ratios that each layer possessed based on the distance from surfaces are as follows: 0~15 mm - 36%, ~30 mm - 28%, ~45 mm - 20%, ~60 mm - 12%, and ~75 mm - 4%. Therefore, even though the moisture content at the core and areas adjoined with the core showed high values, it has a small impact on the final moisture content. Thus, if the drying time is excessively applied based on the moisture content at the core of timber at the industrial sites, an unnecessary energy waste and additional defects may occur due to the excessive drying process. Regarding thick timbers such as the boxed-heart timbers, it will be important to evaluate the moisture content suitable for the purpose of products based on “one-fourth to one-fifth thickness rule (ASTM 1968)”.

The reality is that the industrial sites require information which can be immediately applied to manufacture and processing of products. In order to provide study results that conform with the needs from the site, a commercial-scale study needs to be conducted. However, timbers show differences by tree species, population within the species, and areas within the population. Therefore, for the timber specimens, there is no other option than preparing different conditions including ages of hardwood, areas processed within population (large end diameter and upper end diameter), configuration ratio of cross section (heart timber ratio and summerwood ratio), etc. Furthermore, since it takes a tremendous amount of time for sawing, pretreatment processing, and basic data research prior to the drying process compared to a research center-scale test, it is highly difficult to control the environment where test materials are exposed to the outdoor air during the preparation of testing.

However, this does not mean that controlling such problems is impossible. The first method is to proceed with the test in winter. In winter, moisture evaporation takes the longest time during the test preparation. Thus, it is the period when the problems caused by the exposure to the outdoor air before the drying process can be minimized. The second method is to reduce the time required for sawing, pretreatment processing, and basic data research prior to the drying process by minimizing the quantity of timber species. Finally, it can be considered to come up with the third method to filling vacant spaces inside the drying room with dummy, etc. Through these methods, the problems occurred in a commercial-scale study can be minimized. However, the drying process is not only proceeded in winter at the industrial sites, and if the quantity of timber species is reduced, the test results may be indicated differently due to timbers which belong to dummies filling the vacant spaces inside the drying room. Hence, the first method can be the most effective when proceeding with a commercial-scale drying test, and properly combining the second and third methods may be an alternative depending on the situations.

4. CONCLUSION

This study was performed to identify the effects of kerfing and incising pretreatments on high-temperature drying characteristics of cedar and larch boxed-heart timbers with the size of the cross section less than 150 mm. The study results displayed significant differences of the pretreatments only in the surface check and shrinkage. Significant differences were shown in each drying characteristic based on the following factors: 1) final moisture content – tree species, shapes, sizes of cross section, and initial moisture content; 2) surface check – sizes of cross section and pretreatments; 3) shrinkage – shapes, sizes of cross section, pretreatments, and initial moisture content; and 4) twist – tree species. For the surface check, the kerfing treatment was the major factor which showed a significant difference, whereas for the shrinkage, the pretreatment condition showed a significant difference as it reduces the final moisture content after the drying process in the order of I – K – KI.

Although the kerfing was suitable as a pretreatment for reducing the surface check, the incising was not suitable as a pretreatment since each knife joined together to cause a conversion to the surface check.

For the twist, the grain angle affected more than the anisotropy of the juvenile wood, and there were no effects of pretreatments.

ACKNOWLEDGMENT

This work (No. S2075092) was supported by Business for Start-up Growth Technology Development funded Korea Small and Medium Business Administration in 2012.

REFERENCES

Amer, M., Kabouchi, B., El Alami, S., Azize, B., Rahouti, M., Famiri, A., Fidah, A. 2019. Water Sorption/Desorption Kinetics and Convective Drying of Eucalyptus globulus Wood. Journal of the Korean Wood Science and Technology 47(5): 557-566.

American Society for Testing and Materials. 1968. Methods of measuring moisture content of wood (ASTM Standard D 2016). Philadelphia, United States.

Erickson, H.D., Crawford, R.J. 1959. The effects of several seasoning methods on the permeability of wood to liquids. In American Wood Preservers' Association. Proceedings, 55: 210-219.

Frühwald, E. 2006. Improvement of shape stability by high-temperature treatment of Norway spruce Effects of drying at 120°C with and without restraint on twist. Holz als Roh-und Werkstoff 64(1): 24-29.

Frühwald, E. 2007. Effects of high drying temperatures and restraint on twist of larch (Larix). Wood Material Science and Engineering 2(2): 55-65.

Fujii, T., Suzuki, Y., Kuroda, N. 1997. Bordered pit aspiration in the wood of Cryptomeria japonica in relation to air permeability. International Association of Wood Anatomists Journal 18(1): 69-76.

Han, Y., Chang, Y.S., Eom, C.D., Lee, S.M. 2019a. Moisture Content Change of Korean Red Pine Logs During Air Drying: II. Prediction of Moisture Content Change of Korean Red Pine Logs under Different Air Drying Conditions. Journal of the Korean Wood Science and Technology 47(6): 732-750.

Han, Y., Eom, C.D., Lee, S.M., Park, Y. 2019b. Moisture content change of Korean red pine logs during air drying: I. Effective air drying days in major regions in Korea. Journal of the Korean Wood Science and Technology 47(6): 721-731.

Hermawan, A., Fujimoto, N., Sakagami, H. 2012. Effects of high-temperature and low-humidity pretreatment on the drying properties of sugi boxed-heart timber with black-colored heartwood. Drying Technology 30(7): 780-786.

Hsu, N., Tang, R. 1974. Internal stresses in wood logs due to anisotropic shrinkage. Wood Science and Technology 7(1): 43-51.

Hur, J.Y., Kang, H.Y. 1997. Measurement of longitudinal liquid permeability using pressure bomb method. Journal of the Korean Wood Science and Technology 25(3): 66-74.

Hwang, K.H., Park, B.S. 2009. Effect of cross-sectional dimension on the shrinkage property of Korean red-pine wood. Journal of the Korean Wood Science and Technology 37(3): 231-238.

Islam, M.N., Ando, K., Yamauchi, H., Hattori, N. 2009. Effects of species and moisture content on penetration of liquid in laser incised lumber by the passive impregnation method. European Journal of Wood and Wood Products 67(2): 129-133.

Jee, W.K., Kim, G.H. 1996. Air Permeability of Softwoods Imported from the Russian Far East. Journal of the Korean Wood Science and Technology 24(4): 22-31.

Jung, H.S., Lee, N.H., Park, J.H. 1997. The characteristics of vacuum drying heated by hot plates for the thinned logs and pillars of korean pine. Journal of the Korean Wood Science and Technology 25(4): 51-60.

Kim, H., Han, Y., Park, Y., Yang, S.Y., Chung, H., Eom, C.D., Yeo, H. 2017. Finite Difference Evaluation of Moisture Profile in Boxed-heart Large-cross-section Square Timber of Pinus densiflora during High Temperature Drying. Journal of the Korean Wood Science and Technology 45(6): 762-771.

Kubojima, Y., Kobayashi, I., Yoshida, T., Matsumoto, H., Suzuki, Y., Tonosaki, M. 2013. Twisting force during drying of wood. European Journal of Wood and Wood Products 71(6): 689-695.

Lee, C.J., Lee, N.H., Oh, S.W. 2016a. Effects of the knife-incising andkerfing pretreatment on moisture content and surface check occurrence of douglas-fir heavy timber. Journal of the Korean Wood Science and Technology 44(3): 302-314.

Lee, C.J., Lee, N.H., Oh, S.W. 2016b. Effects of the Knife-Incising and Longitudinal Kerfing Treatment on High-Temperature Drying Characteristics of Red Pine Square Timber. Journal of the Korean Wood Science and Technology 44(5): 677-684.

Lee, C.J., Lee, N.H., Oh, S.W. 2016c. Studies on the High-Temperature Drying Characteristics of Douglas-fir, Hemlock and Radiata Pine Square Timber. Journal of the Korean Wood Science and Technology 44(5): 726-735.

Lee, C.J., Oh, S.W., Lee, N.H., Kang, C.W. 2017. Effect of the knife-incising pretreatment on the surface checks occurrence of red pine heavy timberafter drying. European Journal of Wood and Wood Products 75(1): 143-145.

Lee, C.J., Lee, N.H., Eom, C.D., Shin, I.H., Park, M.J., Park, J.S. 2013. Effect of end-coating around pith of heavy timbers of red pine and korean pine on high-temperature and low-humidity drying characteristics. Journal of the Korean Wood Science and

Technology 41(3): 221-233.

Lee, C.J., Lee, N.H., Park, M.J., Park, J.S., Eom, C.D. 2014. Effect of reserve air-drying of korean pine heavy timbers on high-temperature and low-humidity drying characteristics. Journal of the Korean Wood Science and Technology 42(1): 49-57.

Nilsson, B., Sjödén, T., Nordebo, S., Säll, H. 2007. A method for under-bark detection of the wood grain angle radial dependence. Wood Material Science and Engineering 2(3-4): 118-129.

Park, J.C., Kim, S.W., Ryu, J.Y., Hong, S.I. 2008. Strength Property of the incised larix (*Larix kaempferi* Carr.) round posts treated with CCA. Journal of the Korean Wood Science and Technology 36(3): 85-92.

Park, Y., Chung, H., Kim, H., Yeo, H. 2020. Applicability of Continuous Process Using Saturated and Superheated Steam for Boxed Heart Square Timber Drying. Journal of the Korean Wood Science and Technology 48(2): 121-135.

Straže, A., Kliger, R., Johansson, M., Gorišek, Ž. 2011. The influence of material properties on the amount of twist of spruce wood during kiln drying. European Journal of Wood and Wood Products 69(2): 239-246.

Suzuki K, Teduka Y, Ando K, Hattori N, Kitayawa S, Kato H, Nagao H, TanakaT. 1996. Laser incising of wood, the effect of incising density on bending strength of sugi square lumber (in Japanese). Proceedings of the 46th Annual Meeting of the Japanese Wood Research Society. Japan Wood Research Society, Kumamoto, Japan. pp.130.

Winandy, J.E., Morrell, J.J. 2007. Effects of incising on lumber strength and stiffness: relationships between incision density and depth, species, and MSR grade. Wood and Fiber Science 30(2): 185-197.

Yamashita, K., Hirakawa, Y., Saito, S., Nakatani, H., Ikeda, M., Ohta, M. 2014. Effect of cross-sectional dimensions on bow and surface checking of sugi (*Cryptomeria japonica*) boxed-heart square timber dried by conventional kiln drying. Journal of Wood Science 60(1): 1-11.

APPENDIX

(Korean Version)

배할 및 인사이징 전처리가 횡단면 크기 150 mm 이하 삼나무와 낙엽송 수심재의 고온건조특성에 미치는 영향

초록 : 본 연구는 배할 및 인사이징 전처리가 횡단면 크기 150 mm 이하 삼나무와 낙엽송 수심재의 고온건조 특성에 미치는 영향을 확인하기 위해 수행되었다. 그 결과, 전처리는 표면할렬과 수축률에 대하여 유의한 차이를 나타내었다. 배할처리는 표면할렬 발생을 줄이기 위한 전처리로서 적합하였으나, 인사이징은 재면의 자상이 서로 연결됨으로써 표면할렬로 전환되는 현상을 야기하기 때문에 전처리로서 적합하지 않았다. 수축률은 전처리 조건에 따라 건조 후 최종함수율이 인사이징, 배할, 배할-인사이징 순으로 감소되는 경향을 나타냄으로써 유의한 결과를 나타내었다. 뒤틀림은 미성숙재의 수축이방성보다 목리각도가 더 크게 영향을 주었으며, 전처리의 영향은 없었다.

1. 서 론

간벌재와 같이 직경이 작은 원목은 판재 또는 각재로의 가공 수율이 불량하기 때문에 효율적인 활용방법으로 수심재(boxed-heart timber)로의 활용이 고려될 수 있다. 하지만 수심재는 생장응력(growth stress)이 크게 형성되는 미성숙재(juvenile wood)를 포함하고 있기 때문에 할렬(checks), 갈라짐(splisp), 틀어짐(warp)과 같은 건조결함(drying defect)이 쉽게 발생되는 문제가 있다. 이러한 문제를 해결하기 위해 배할(longitudinal kerfing) 및 인사이징(incising)과 같이 목재를 기계적으로 가공한 후 건조하는 방법이 연구되고 있다.

배할은 V형 크랙과 같이 수를 포함하는 통나무를 건조할 때 흔히 발생되는 건조결함을 예방하기 위해 제안되었으며(Hsu and Tang, 1974), 한 단면에 생성된 홈으로 응력(stress)의 집중을 유도하여 건조 초기 표면할렬(surface check) 발생을 예방하는데 효과적인 것으로 알려져 있다(Jung *et al.*, 1997). 또한 배할은 건조속도(drying rate)에 큰 영향을 미치지는 않으나 건조 후 최종함수율 분포에 영향을 미칠 수 있으며, 인사이징과도 함께 처리될 수 있다(Lee *et al.*, 2016a; Lee *et al.*, 2017).

인사이징 처리는 난주입성 수종들의 약제주입을 용이하게 할 목적으로 재면에 인위적인 자상(knife)을 내는 방법으로, 건조 전에도 가공이 가능하고 약제주입성뿐만 아니라 건조시간의 단축에도 도움이 된다고 보고되었다(Islam *et al.*, 2009). 또한 목재표면에 가공된 자상은 건조 초기 표층의 인장응력(tensile stress)을 고르게 분산시킴으로써 표면할렬의 발생을 억제하는 것이 가능하다(Lee *et al.*, 2017). 하지만 표면에 처리된 자상(knife)은 목재의 몇몇 기계적 특성을 감소시킨다(Winandy and Morrell, 2007; Park *et al.*, 2008). 특히 인사이징 밀도가 증가함에 따라 물리적 특성이 감소되기 때문에, 건조전처리로서 사용될때에는 인사이징 밀도가 낮게 처리되어야 한다(Lee *et al.*, 2016a; Suzuki *et al.*, 1996).

이러한 전처리 방법들이 침엽수 수심재의 건조결함발생에 미치는 영향은 수종, 크기 등과 같은 요인들에 따라 차이를 보이며, 단면의 크기가 커질수록 그 영향이 커지는 경향을 나타낸다. 배할은 일부 연구(두께 150 mm 소나무, 두께 150, 180 mm 햄록과 라디아타소나무)에서 수심재의 뒤틀림(twist)을 감소시킨다고 하였지만(Lee *et al.*, 2016b; 2016c), 다른 연구(두께 200 mm 소나무, 두께 210 mm와 220 mm 잣나무)에서는 영향을 주지 않는다고 보고되었다(Lee *et al.*, 2013; Lee *et al.*, 2014). 또한 인사이징은 두께 200 mm 소나무 수심재에서 자상이 표층의 인장응력을 고르게 분산시킬 수 있다고 하였지만(Lee *et al.*, 2017), 두께 250 mm와 300 mm douglas-fir 수심재에서는 자상이 서로 연결됨으로써 표면할렬로 전환되는 현상을 야기한다고 보고되었다(Lee *et al.*, 2016a).

건조결함은 건조 후 가공수율에 중요한 요인이며, 표면할렬은 건조재의 품질을 저하시킨다. 또한, 표면할렬보다 뒤틀림이 가공수율에 더 크게 영향한다. 따라서 배할 및 인사이징 전처리가 삼나무와 낙엽송 수심재 건조 중 발생되는 주요 건조결함들에 미치는 영향에 대한 연구가 필요하다. 이에 본 연구에서는 횡단면 크기가 150 mm 이하로 가공된 삼나무와 낙엽송 수심재의 고온건조특성에 배할 및 인사이징 전처리가 미치는 영향을 확인하고자 한다.

2. 재료 및 방법

2.1. 시험재 준비

공시수종으로 삼나무(Cedar: *Cryptomeria japonica* (L.f.) D.Don)와 낙엽송(Larch: *Larix Kaempferi* C.)을 선정하였으며, 길이 2,400 mm, 두께 및 직경 90 (9), 120 (12), 그리고 150 (15) mm의 정각재와 원주재로 가공 하였다. 시편의 수량은 수종, 단면의 크기, 그리고 전처리 조건에 따라 정각재는 각 5개, 원주재는 각 6개씩을 준비하였다.

2.2. 전처리(pretretment) 가공

시험재는 전처리조건에 따라 대조군(C: control), 인사이징(I: incising), 배할(K: kerfing), 그리고 배할-인사이징(KI: combination of kerfing and incising)으로 분류하였다. 인사이징처리는 칼날 두께 2 mm, 깊이 10 mm, 인사이징 밀도 약 2,400개/m^{2}로 가공하였으며(Fig. 1(a)), 배할처리는 둥근톱을 사용하여 폭 3 mm, 횡단면 크기의 1/3 깊이로 가공하였다(Fig. 1(b)).

2.3. 건조 시험

건조시험은 40 m^3 규모의 상업용 열기건조기를 사용하여 4~5월에 수행되었다. 건조스케줄은 Lee *et al.* (2013), Lee *et al.* (2014), Lee *et al.* (2016b; 2016c), 그리고 Lee *et al.* (2017)의 연구결과와 함께 본 연구에 사용된 시험재의 크기를 고려하여 Table 1과 같이 작성되었다.

2.4. 함수율(MC, moisture content) 조사

건조 전 모든 시험재의 중량을 조사하고 각 전처리 조건에서 가장 무거운 것을 대표시험재로 선정하여 건조 후 함수율 조사에 사용하였다. 최종 함수율(final MC)은 횡단면으로부터 1,200 mm 위치에서 20 mm 두께의 시험편을 채취하여 전건법으로 조사하였으며, 최종 함수율 분포는 채취한 시험편을 표면으로부터 15 mm 간격으로 층을 구분하여 조사하였다(Fig. 1(c)). 초기함수율(initial MC)은 건조 전·후 시험재의 중량변화와 최종함수율로부터 계산되었다.

2.5. 표면할렬(surface check) 조사

표면할렬은 건조 후 모든 시험재에서 폭 2 mm 이상인 할렬의 폭과 길이를 조사하였다. 조사된 표면할렬의 최대 폭이 5 mm 였기 때문에 전처리 조건에 따른 평균 표면할렬 길이는 다음의 식으로 산출하였다.

$$\text{Average surface check length} = \frac{\sum_1^n lw_2 + \sum_1^n lw_3 + \sum_1^n lw_4 + \sum_1^n lw_5}{N}$$

where, *lw* length of each surface check with width 2-5 mm, *N* number of specimens.

2.6. 뒤틀림(twist) 조사

뒤틀림은 정각재에서만 조사하였으며, 건조 후 시험재당 양쪽 횡단면에서 각각 4회씩 총 8회씩 측정하였다.

2.7. 수축률(shrinkage) 및 배할 홈 확장률(kerf widening rate) 조사

수축률과 배할홈 확장률은 건조 전·후 횡단면으로부터 1,200 mm 위치에서 두께 및 직경 변화와 배할 홈을 버니어켈리퍼스를 이용하여 조사하였다.

$$\text{Kerf widening rate (\%)} = \frac{(W_s - W_k)}{W_S} \times 100$$

W_s: width of a circular saw, W_k: width of the kerf after drying

3. 결과 및 고찰

목재가 가지는 다양한 요인들과 낙엽송 및 삼나무 수심재의 건조 특성 사이의 회귀분석(regression analysis) 결과를 Table 2에 나타내었다. 그 결과 1)최종함수율은 수종, 형상, 단면의 크기 및 초기함수율이, 2)표면할렬은 단면의 크기와 전처리가, 3)수축률은 형상, 단면의 크기, 전처리 및 초기함수율이, 그리고 4)뒤틀림은 수종에 대하여 유의한 차이를 나타내었다.

전처리는 표면할렬에 크게 영향을 주었으며, 수축률에서도 유의한 차이를 나타내었다. 표면할렬의 경우 배할처리가 유의한

차이를 나타낼 수 있었던 주요한 요인이었으며, 수축률의 경우 각 전처리가 최종함수율 분포에 영향을 미침으로써 유의한 차이를 나타낼 수 있었던 것으로 판단된다.

3.1. 최종 함수율 및 분포

최종 함수율 및 분포는 수종, 단면의 크기, 형상, 그리고 전처리 조건에 따라 차이를 나타내었다(Figs. 2~3, Table 3). 정각재의 함수율은 원주재보다 높았으며, 단면의 크기가 증가함에 따라 건조 후 더 높은 함수율을 나타내었다. 전처리 조건의 경우 회귀분석 결과 유의하지는 않았으나 건조 후 함수율은 I - K - KI의 순으로 감소되는 경향을 나타내었다.

투과성(permeability)은 비중(specific gravity), 추출물(extractives), 그리고 만재율(late wood percentage)과 같은 요인에 의해 영향을 받으며, 수종에 따라 차이가 나타난다(Hur and Kang, 1997; Jee and Kim, 1996). 또한, 목재의 중심으로부터 증발표면(evaporation surface)까지 수분의 이동거리는 목재의 형상, 단면의 크기, 그리고 전처리 조건과 같은 요인들에 의해 영향을 받게 된다(Lee *et al.*, 2013; Lee *et al.*, 2016a; 2016c). 특히 삼나무 심재(heartwood)부위는 초기함수율이 높고 투과성이 불량하여 건조하기 가장 어려운 것으로 알려져 있으며(Hermawan *et al.*, 2012), 본 연구에서도 건조 후 높은 함수율을 나타내고 있었다. 따라서 본 연구에서 조사된 함수율 결과는 1)수종, 단면의 크기, 형상, 그리고 전처리의 영향과 2)수종, 형상, 크기에 관계없이 동일하게 적용된 건조스케줄이 건조 후 최종함수율 및 분포에 영향을 주었기 때문인 것으로 판단된다.

한편, 일부 시험재에서 초기함수율이 낮았음에도 불구하고 건조 후 함수율이 더 높은 값을 나타내는 현상이 발견되었다. 이러한 경향은 30 ~ 50% 범위의 초기함수율을 가지는 삼나무에서 현저 하였으며, 두께 150 mm 낙엽송 정각재에서도 유사한 경향을 나타내었다. 건조시간이 동일할 때 초기함수율이 높은 목재가 건조 후 더 높은 함수율을 나타내는 것이 일반적이다. 하지만 목재가 건조 될 때 발생하는 벽공폐색(bordered pit aspiration)은 건조 후 목재의 투과성을 1/10 에서 3/10 사이의 수준으로 감소시키며(Erickson and Crawford, 1959), 건조 조건에 의해서 또한 벽공폐색의 발생 정도에 차이를 나타낸다(Fujii *et al.*, 1997). 더욱이 상업용 규모로 진행되는 건조 시험의 경우, 시험을 준비하는 동안 시험재는 산업현장 및 소규모로 진행되는 시험에서 보다 더 긴 시간 동안 외기에 노출되기 때문에, 건조 시험이 시작되기 이전에 표층의 함수율이 감소되고 그 과정에서 벽공폐색이 발생될 수 있다. 따라서 일부 시험재의 초기함수율이 낮았음에도 불구하고 건조 후 상대적으로 높은 함수율을 나타내었던 것은 건조 전 외기에 노출되는 동안 표층의 함수율 및 벽공폐색과 같은 요인들이 영향을 받음으로써 건조 후 최종함수율 및 분포에 영향을 주었기 때문인 것으로 추측된다.

3.2. 표면할렬

건조 후 조사된 할렬 폭에 따른 평균 표면할렬 길이는 Figs. 4~5에 나타내었으며, 단면 크기와 전처리 조건에 따라 차이를 나타내었다.

목재는 두께가 증가함에 따라 수분경사가 크게 형성되고, 그로인해 표층은 더 큰 인장 상태에 놓이게 된다. 또한 내부의 수분이 제거되기 까지 더 긴 시간이 필요하기 때문에 표층에 형성된 인장응력(tensile stress)이 압축응력(compressive strees)으로의 전환이 지연된다. 따라서 단면의 크기에 따른 표면할렬의 차이는 두께가 증가함에 따라 표층의 인장응력이 크게 형성되고 응력 역전이 지연됨으로써 표면할렬이 더 쉽게 발생되기 때문이다.

배할과 인사이징 전처리가 표면할렬 발생에 미치는 영향과 그 효과는 이전의 보고들과 함께 종합하여 검토하였다(Lee *et al.*, 2013; Lee *et al.*, 2014; Lee *et al.*, 2016a; 2016b; 2016c; Lee *et al.*, 2017). 그 결과 배할은 표면할렬을 감소시키기 위한 전처리로서 적합하였다. 하지만 배할홈 확장률은 표면할렬의 발생과 서로 관계가 없는 것으로 조사되었으며(Table 4), 이는 건조 초기에 배할홈이 확장된다고 하더라도 건조 중기 이후에는 표층과 인접한 내층의 함수율 감소에 따른 수축거동 및 크리프 효과에 배할 홈 확장률이 영향을 받기 때문이다. 반면 인사이징은 각각의 자상이 서로 연결됨으로써 표면할렬로 전환되는 현상을 야기하기 때문에 전처리로서 적합하지 않다고 판단되었다. 하지만 자상이 서로 연결되는 것을 방지할 수 있는 수준으로 인사이징의 크기와 간격을 조절한다면 수심재의 전처리 방법으로 사용이 가능할 수 있을 것으로 사료된다.

한편 섬유포화점 이상에서는 초기함수율이 증가함에 따라 빠르게 건조가 진행되며(Han *et al.*, 2019a), 건조 전 목재가 외기에 노출된 시기(4~5월)의 평형함수율은 9.6 ~ 11.7% 로 천연건조가용이한 시기였다(Han *et al.*, 2019b). 수심재의 재면은 접선단면으로 구성되기 때문에 수분이 빠르게 증발될 뿐만 아니라 그 과정에서 발생된 벽공폐색과 표면할렬은 목재의 투과성과 건조결함에 부정적인 영향을 미치게 된다 (Amer *et al.* 2019; Lee *et al.*, 2014).

또한 수심재와 같이 두꺼운 목재는 중심부의 함수율이 섬유포화점 이상을 나타내고 있다고 하더라도 건조 중 자유수의 이동은 표층에서와 같이 빠르게 제거될 수 없다(Kim *et al.*, 2017; Park *et al.*, 2020). 더욱이 건조 중 목재는 온도의 증가와

함께 내부의 압력이 증가하기 때문에 물의 끓는점이 증가되어 중심부에 존재하는 대부분의 자유수는 수증기의 형태로 기화하지 못하고 액상으로 존재하게 된다. 이로 인해 시험재의 중심에 존재하고 있는 자유수의 이동이 곤란해지게 된다. 특히 이러한 문제는 투과성이 불량 할수록 더 심해지기 때문에 표층과 내층의 수분경사가 더 심하게 형성된다. 또한 표층과 내층의 수분경사가 유지되는 시간이 장기화 됨에 따라 크리프의 영향을 받게 되어 수축에도 영향을 주기 때문에 건조 중기 이후 닫힌 할렬의 발생에 부정적인 영향을 미치게 된다.

따라서 회귀분석 결과에서 나타난 단면의 크기와 전처리 이외에도, 1) 삼나무 심재의 불량한 투과성으로 인한 내부함수율 차이, 2) 크리프(creep)의 영향, 3) 건조 전 외기 노출에 의한 표층의 함수율 변화와 같은 요인들 또한 표면할렬 발생에 영향을 미치는 중요한 요인이라고 판단된다.

3.3. 수축률

삼나무와 낙엽송 수심재들의 수축률은 Figs. 6~7에 나타내었다. 목재의 수축은 함수율변화에 따라 시작되며, 배할과 인사이징 전처리는 처리조건에 따라 목재의 중심으로부터 증발표면까지의 수분이동거리에 차이를 야기하고, 건조 중 목재내부에서 발생되는 응력 거동(stress behavior)에도 영향을 미칠 수 있다(Lee *et al.*, 2016a). 또한 건조 중 목재내에서 발생되는 크리프(creep)와 인장세트(tension set)는 수종, 단면의 크기, 심변재 비율에 따라 차이를 나타내며, 단면의 크기가 증가함에 따라 크리프(creep)와 인장세트(tension set)의 영향으로 인해 수축이 감소되는 경향을 나타낸다(Hwang and Park, 2009; Lee *et al.*, 2016c; Yamashita *et al.*, 2014). 이러한 수축 거동은 목재 내 형성된 수분경사의 정도 및 지속시간에 따라 차이를 나타내며, 건조결함 발생에 주요한 원인으로 작용하게 된다. 또한 앞서 언급한 바와 같이 상업용 규모의 건조 시험은 시험을 준비하는 동안 상대적으로 더 오랜 시간 동안 외기 조건에 노출되게 된다. 따라서 수심재의 수축은 1)미성숙재의 수축이방성(anisotropy), 2)외기에 노출되는 동안 제거된 수분, 3)표층과 내층의 함수율 차이(수분경사의 정도), 4)수종에 따른 투과성 차이, 5)그리고 단면의 크기에 따른 건조 시간 및 크리프의 영향과 같은 다양한 요인들이 목재 내부의 응력 거동에 영향을 주었기 때문인 것으로 판단되며, 이러한 목재 내 응력 거동이 표면할렬 및 뒤틀림 발생에도 영향을 주었을 것으로 사료된다.

3.4. 뒤틀림

삼나무 및 낙엽송 정각재의 뒤틀림은 Fig. 8에 나타내었으며, 삼나무보다 낙엽송의 뒤틀림이 더 심하게 발생되었다. 미성숙재는 수축이방성이 심하지만, 목재의 뒤틀림은 수(pith)로부터의 거리 및 목리 각도(grain angle)와 관련이 있으며, 특히 목리 각도가 뒤틀림 발생에 가장 중요한 요인이다(Frühwald, 2006; 2007; Nilsson *et al.*, 2007; Kubojima *et al.*, 2013; Straže *et al.*, 2011). 따라서 두 수종 사이의 뒤틀림 차이는 목리 각도가 원인이며, 각각의 수종에서 두께에 따른 뒤틀림 차이는 미성숙재의 수축이방성이 원인인 것으로 판단된다. 또한 삼나무보다 낙엽송의 뒤틀림이 더 심하게 발생되었기 때문에 수심재의 뒤틀림은 미성숙재의 수축이방성보다 목리각도가 더 크게 영향을 미치는 것으로 판단된다.

3.5. 상업용 규모의 건조 시험에 대한 평가

상업용 규모의 건조 시험은 시험의 준비에 상당한 시간이 소요되기 때문에 시험재가 산업현장에서보다 더 긴 시간 동안 외기에 노출되는 문제가 있다. 본 연구에서는 산업현장에 적용이가능한 결과를 도출하기 위해 더미(dummy board)를 사용하지 않고, 총 264개의 삼나무와 낙엽송 수심재를 준비하여 40 m³ 규모의 상업용 건조기를 채우는 방법으로 4~5월(봄)에 건조시험을 수행하였다. 그럼에도 불구하고 삼나무와 낙엽송 수심재의 고온건조 특성에 시험재의 형상, 단면의 크기, 초기함수율, 배할 및 인사이징 전처리에 따른 차이를 확인할 수 있었다. 따라서 본 연구에 사용된 건조스케줄은 수종, 형상, 크기에 따라 스케줄을 개량한다면 산업현장에 적용이 가능한 시간스케줄을 제공할 수 있을 것으로 판단되며, 산업현장에서는 본 연구에서보다 외기에 노출되는 시간이 더 짧기 때문에 외기에 의한 영향도 감소될 수 있을 것으로 사료된다.

한편, Figs. 2~3에 나타낸 시험재의 내부의 함수율이 Table 3에 나타낸 최종함수율과 상당한 차이를 나타내고 있는 것을 확인할 수 있다. 이는 Lee *et al.* (2016a)이 보고한 바와 같이 목재 전체 부피에 대한 표층과 내층이 각각 차지하고 있는 부피의 비율, 즉 실질률(solid volume)에서 큰 차이를 가지기 때문이다. 본 연구에 사용된 두께 150 mm 정각재를 예로 들면, 표면으로부터 거리에 따라 각 층이 차지하고 있는 비율은 0~15 mm - 36%, ~30 mm - 28%, ~45 mm - 20%, ~60 mm - 12%, ~75 mm - 4%이기 때문에, 중심부 및 중심부와 인접한 부위의 함수율이 높은 값을 나타내고 있다고 하더라도 최종함수율에 미치는 영향은 미미하다. 그러므로 산업현장에서 목재 중심부의 함수율을 기준으로 무리하게 건조시간을 적용할 경우, 과건조로 인한 불필요한 에너지 낭비와 추가적인 결함이 발생될 수 있기 때문에, 수심재와 같이 두께가 두꺼운 목재에 대해서는 “one-fourth to one-fifth thickness rule (ASTM 1968)”에 기초하여 제품의 용도에 적합한 함수율을 평가하는 것이 중요할 것으로 판단된다.

산업현장에서는 제품의 생산 및 가공에 즉시 적용이 가능한 정보를 요구하고 있는 것이 현실이며, 이러한 현장의 요구에 상응하는 연구결과를 제공하기 위해서는 상업용 규모에서의 연구가 필요하다. 하지만 목재는 수종에 따라, 수종내에서도 개체에 따라, 개체에서도 부위에 따라 차이를 나타내는 재료이기 때문에 시험에 사용되는 목재 시편들도 원목의 수령, 개체내 가공된 부위(원구 및 말구), 횡단면의 구성비율(심재율 및 만재율) 등과 같은 조건이 다르게 준비될 수 밖에 없다. 더욱이 일반적으로 연구실 규모에서 진행되는 시험보다 제재, 전처리 가공, 건조 전 기초자료 조사 등에 상당한 시간이 소요되기 때문에, 시험을 준비하는 동안 시험재가 외기에 노출되는 환경을 통제한다는 것은 매우 어려운 일이다.

그렇다고 하여 이러한 문제들을 통제할 수 없는 것은 아니다. 첫번째 방법은 겨울에 시험을 진행하는 것이다. 겨울은 시험을 준비하는 동안 수분증발이 가장 느리게 일어나는 시기이기 때문에, 건조 전 외기에 노출됨으로써 발생되는 문제들을 최소화 할 수 있는 시기이다. 두번째 방법은 목재 시편의 수량을 적게 함으로써 제재, 전처리 가공, 건조 전 기초자료 조사 등에 소요되는 시간을 단축하는 것이다. 그리고 세번째는 건조실 내 빈 공간을 더미로 채우는 등의 방법들이 고려될 수 있다. 이러한 방법들을 통해 상업용 규모의 연구에서 발생되는 문제들이 최소화될 수 있다. 하지만 산업현장에서는 겨울에만 건조가 진행되지 않으며, 목재 시편의 수량을 적게 할 경우 건조실 내 빈 공간을 채우고 있는 더미로 들어가는 재목에 의해 시험결과가 다르게 나타날 수 있는 문제가 있다. 따라서 상업용 규모의 건조 시험을 진행할 때에는 첫번째 방법이 가장 효과적일 수 있으며, 상황에 따라 두번째와 세번째 방법을 적절히 조합하는 방법이 대안이 될 수 있을 것으로 판단된다.

4. 결 론

본 연구는 횡단면의 크기 150 mm 이하인 삼나무와 낙엽송 수심재의 고온건조특성에 배할 및 인사이징 전처리가 미치는 영향을 확인하기 위해 수행되었다. 그 결과 전처리는 표면할렬과 수축률에서만 유의한 차이를 나타내었으며, 각각의 건조특성에 대해서는 다음과 같은 요인들에 의해서 유의한 차이를 나타내었다; 1)최종함수율 - 수종, 형상, 단면의 크기, 그리고 초기함수율, 2)표면할렬 - 단면의 크기 및 전처리, 3)수축률 - 형상, 단면의 크기, 전처리, 그리고 초기함수율, 4)뒤틀림 – 수종.

표면할렬의 경우 배할처리가 유의한 차이를 나타낼 수 있었던 주요 요인이었으며, 수축률의 경우 전처리 조건에 따라 건조 후 최종함수율이 I - K - KI의 순으로 감소되는 경향을 야기함으로써 유의한 차이를 나타내었다.

배할은 표면할렬을 감소시키기 위한 전처리로서 적합하였으나, 인사이징은 각각의 자상이 서로 연결됨으로써 표면할렬로 전환되는 현상을 야기하기 때문에 전처리로서 적합하지 않았다.

뒤틀림은 미성숙재의 수축이방성보다 목리 각도가 더 크게 영향을 주었으며, 전처리의 영향은 없었다.