Effects of Knife-incising and Longitudinal Kerfing Pretreatments on High-temperature Drying of Red Pine and Pitch Pine Timbers

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Effects of knife-incising and longitudinal kerfing pretreatments were analyzed relative to the high-temperature drying of red pine and pitch pine timbers with cross-sections less than 15 cm. Specimens were prepared as round and square timbers with thicknesses of 9, 12, and 15 cm. They were divided into four groups: control, longitudinal kerf, knife-incised, and a combination of knife-incised and longitudinal kerf. Some results from this study, such as commercial availability and application methods of drying schedules, have immense commercial importance. The incising and kerfing treatment can be used not only to improve drying quality but also as a tool for deriving an optimal drying schedule. The kerfing treatment noticeably reduced the surface checks in square timber. However, the incising treatment caused a phenomenon in which the incisions connect to each other and develop into surface checks. The wood characteristics, such as species, type, thickness, and initial MC, had more influence on determining the drying defects than the pretreatments. For the commercial use of the drying schedule used in this study, it can be useful to determine the appropriate drying time in the third step according to the species, thickness, and shape.

Keywords: Timber drying; Drying defects; Knife-incising; Longitudinal kerfing; High-temperature drying

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INTRODUCTION

Small-diameter logs, such as those obtained from thinning-out trees, provide a poor yield when processed for planks or lumber. However, they can be efficiently used for rafters, park benches, and fences, among other structures. The limitation is the relatively large cross-section of the logs. The moisture movement distance from the core to the evaporation surface is long; and therefore, the deviation in moisture content between the surface layer and the inner layer is high. Therefore, drying the logs to achieve internal moisture content below 19% is difficult and time-consuming. Moreover, these logs comprise juvenile wood with significant growth stress. Hence, drying defects, such as surface checks and warping, can occur easily. To solve these problems, high-temperature and low-humidity treatment and pretreatment methods, such as longitudinal kerfing and knife-incising, have been explored in several studies (Jung *et al*. 1997; Yoshida *et al*. 2000; Lee *et al*. 2016a, 2017).

High-temperature and low-humidity treatment is effective in preventing surface checks in boxed-heart timber in the initial stage of drying (Yoshida *et al*. 2000; Hermawan *et al*. 2012). Pretreatment reduces the time taken to complete a high-temperature drying cycle, and it allows a drying set to occur more quickly between the surface layer and the internal layer.

At this time, in the surface layer, a compressive stress corresponding to the tensile stress before the drying set is induced after the drying set, thereby contributing to the reduction of surface checking (Lee *et al*. 2013).

Longitudinal kerfing has been found to prevent the end checks and splits that commonly occur when drying pith-containing logs (Hsu and Tang 1974). According to the anisotropic shrinkage stress distribution model, the depth of longitudinal kerfing should be one-third of the total thickness of the log (Jung *et al*. 1997). The longitudinal kerfing does not affect the drying rate of lumber but it is an effective method to prevent surface checks caused by the concentration of stress generated in the surface (Lee *et al*. 2013, 2014, 2016a-c, 2017).

Knife-incising combined with longitudinal kerfing is a common pretreatment used for increasing the penetration of preservatives, but it can also be applied on timbers as a pretreatment for drying. This pretreatment can be applied before drying because it does not affect the permeation of preservatives after drying (Islam *et al*. 2009; Lee *et al*. 2017). Moreover, it can prevent surface checks by facilitating the dispersion of stress in the surface layer (Lee *et al*. 2017). However, because the mechanical properties decrease with increasing density of incising, the incising treatment should only be applied at low density (Suzuki *et al*. 1996; Park *et al*. 2008; Lee *et al*. 2016a).

Despite numerous studies on knife-incising and longitudinal kerfing pretreatments, knowledge of their effects on the occurrence of drying defects remains incomplete. While some studies have reported longitudinal kerfing to reduce the twisting of boxed-heart timber (Lee *et al*. 2016b,c), other studies reported no such effect (Lee *et al*. 2013, 2014). Studies have reported prevention of surface checks by knife-incising treatment (Lee *et al*. 2017). Conversely, the incising can also become connected to each other and thus develop into surface checks (Lee *et al*. 2016a).

This study was conducted using a commercial dryer to confirm the effects of the incising and kerfing treatment on the occurrence of drying defects in round and square boxed-heart timber with cross-sections measuring 9 cm, 12 cm, and 15 cm.

EXPERIMENTAL

Material Preparation

Specimens from red pine (*Pinus densiflora* S. *et*. Z) and pitch pine (*Pinus rigida* Mill.) were used in this study (Gangwon-Do, Republic of Korea). Each specimen was processed to form either a square or a round timber with a length of 240 cm and thickness of one of these three values: 9 cm, 12 cm, or 15 cm. Specimens were then divided into four groups according to the applied pretreatment, namely: control (C), knife-incising (I), longitudinal kerfing (K), and a combination of knife-incising and longitudinal kerfing (IK). There were only four incising-treated 15-cm-thick red pine square specimens as against six specimens of all other categories. This was a result of uncontrolled processing during the pretreatment (Table 1).

The incising treatment was processed with an incising density of approximately 2,400 piece/m^2 using a knife with 2 mm width and 10 mm depth (Fig. 1a). Next, longitudinal kerfs were cut on non-incised and incised specimens using a circular saw at one-third depth from the surface along the cross-section on one side of the specimens (Fig. 1b).

Table 1. Quantity of the Test Specimens According to Species, Type, Size, and Pretreatment Condition

Size	Treatment			Number (Pieces)			
				Red Pine		Pitch Pine	
				Square	Round	Square	Round
9 cm	Non-kerfed	Control	C	6	6	6	6
		Incising	I	6	6	6	6
	Kerfed	Control	K	6	6	6	6
		Incising	KI	6	6	6	6
12 cm	Non-kerfed	Control	C	6	6	6	6
		Incising	I	6	6	6	6
	Kerfed	Control	K	6	6	6	6
		Incising	KI	6	6	6	6
15 cm	Non-kerfed	Control	C	6	6	6	6
		Incising	I	**4**	6	6	6
	Kerfed	Control	K	6	6	6	6
		Incising	KI	6	6	6	6
Total Quantity				**70**	**72**	**72**	**72**

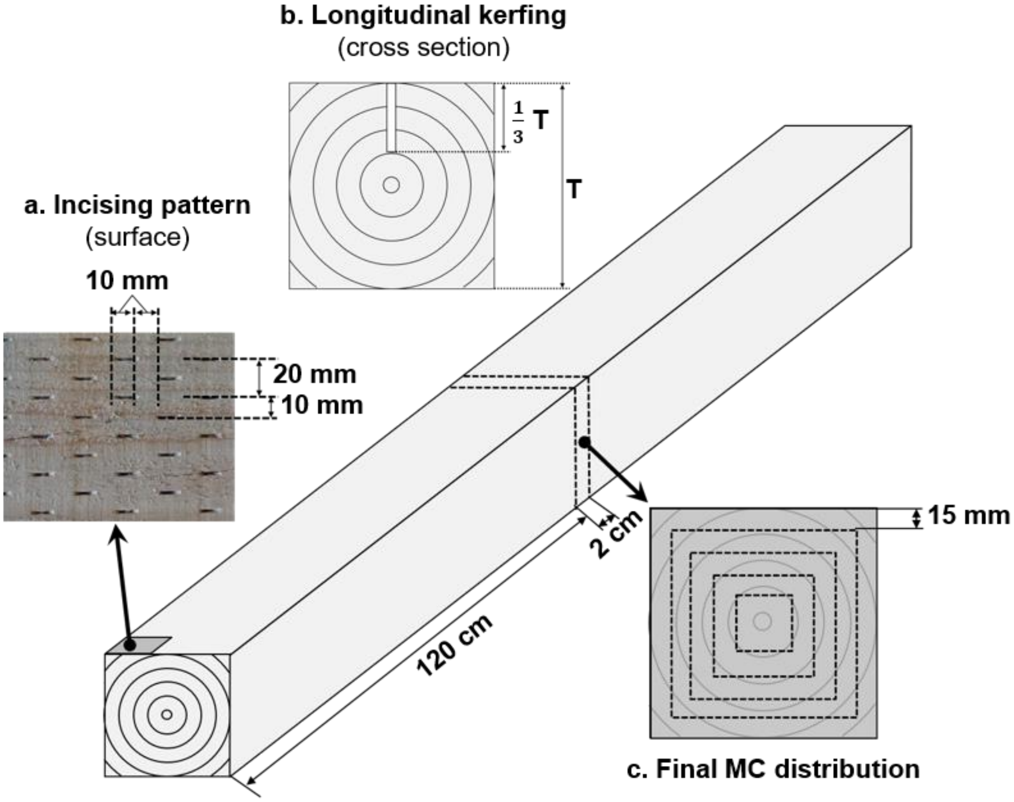

Fig. 1. Processing diagram of the specimens (**a**: incising pattern, **b**: longitudinal kerfing, **c**; final MC distribution)

Drying Test

The drying test was performed using a commercial dryer (SKD-90HPT, Shinshiba and Co., Asahikawa, Japan) with a volume capacity of approximately 40 m^3. Specimens were stacked in an open pile using wood stickers of dimensions 3 cm × 3 cm × 100 cm. The drying schedule is shown in Table 2. Two concrete slabs of dimensions 180 cm × 180 cm × 20 cm, each weighing approximately 1,600 kg, were used for top loading.

Table 2. Drying Schedule

Step	**Time (h)**	**Dry-bulb (°C)**	**Wet-bulb (°C)**
1	12	95	95
2	36	120	90
3	96	90	70
4 (Cooling)	24	-	-
Total Time (h)	**168**		

Moisture Content and Drying Defects

All specimens were weighed before and after drying. The heaviest specimen according to each condition before drying was selected for shrinkage and moisture content (MC) investigation after drying (Lee *et al*. 2013, 2014, 2016a-c, 2017). Shrinkage of the four long surfaces and the kerf widening rate were measured at a distance of 120 cm from the cross-sectional end (Lee *et al*. 2013, 2014, 2016a-c, 2017). Next, samples, approximately 2 cm thick, were taken from the same site where previous measurements on shrinkage and kerf widening were recorded. These samples were taken at depths of 1.5 cm intervals from the surface (Fig. 1-c) (Lee *et al*. 2016a-c, 2017). The final MC and its distribution were investigated in these samples by the oven-dry method (ISO 3130, 1975). The initial MC was calculated from the final MC of the excised samples and the change in weight of the entire specimens before and after drying (Lee *et al*. 2016b,c, 2017).

Drying defects were investigated in all specimens after the drying test (Lee *et al*. 2013, 2014, 2016a-c, 2017). The length and width of surface checks were measured for all checks of widths greater than 2 mm. The average number and length of the surface checks were determined based on the width of the surface checks. Twist was measured on all four surfaces of the specimens.

$$\text{Average surface check number and length} = \frac{\sum_1^n w}{N} \qquad (1)$$

where w is the surface check number and length of according to the surface check width, and N is the number of specimens.

RESULTS AND DISCUSSION

Final MC and MC Distribution

The final MC and MC distribution showed variations according to species, size, shape, and pre-treatment conditions (Fig. 2, Tables 3 and 4). The MC after drying was higher in square timber than that in round timber. Although increasing thickness led to an increase in the MC and a steep moisture gradient after drying, pretreatment tended to decrease the MC after drying.

Table 3. Initial MC, Final MC, Shrinkage, and Kerf Widening Rate of Red Pine According to Type, Size, and Pretreatment Condition

Specimens		**Red Pine**							
		Square				**Round**			
		Initial MC (%)	**Final MC (%)**	**Shrinkage (%)**	**Kerf Widening Rate (%)**	**Initial MC (%)**	**Final MC (%)**	**Shrinkage (%)**	**Kerf Widening Rate (%)**
9 cm	**C**	60.4	10.5	4.2	**-**	80.4	8.8	4.7	-
	I	102	10.1	4.4	**-**	69.2	9.1	4.2	-
	K	80.3	9.9	4.8	23.0	79.4	9.3	4.2	5.3
	KI	63.6	10.3	3.8	50.3	72.7	9.2	4.5	13.7
12 cm	**C**	159.5	11.5	3.5	-	153.4	9.8	3.7	-
	I	128.8	11.1	3.7	-	97.5	10.2	3.5	-
	K	105.2	11	3.5	72.3	148.1	10.7	3.8	*-23.7*
	KI	117.8	10.8	2.5	169.7	143.6	9.6	4.2	*-11.3*
15 cm	**C**	157.8	13.3	3.1	-	179	11.2	3.1	-
	I	139.4	14.9	2.8	-	176.1	11.5	3.5	-
	K	170	13.2	2.4	113.7	175	12.7	3.4	38.7
	KI	197	12.8	2.5	256.7	178.4	10.7	3.3	11.3

Table 4. Initial MC, Final MC, Shrinkage, and Kerf Widening Rate of Pitch Pine According to Type, Size, and Pretreatment Condition

Specimens		**Pitch Pine**							
		Square				**Round**			
		Initial MC (%)	**Final MC (%)**	**Shrinkage (%)**	**Kerf Widening Rate (%)**	**Initial MC (%)**	**Final MC (%)**	**Shrinkage (%)**	**Kerf Widening Rate (%)**
9 cm	**C**	108.5	7.9	4.0	-	71.1	8.7	3.3	-
	I	123.7	8.1	3.7	-	88.3	9.1	3.2	-
	K	96.4	7.1	2.8	2.7	86.4	8.8	3.8	-27.0
	KI	98.2	8.5	4.3	-0.7	75.8	8.9	4.1	-62.0
12 cm	**C**	131.7	13.6	2.8	-	161.7	9.1	3.4	-
	I	171.7	11.5	4.1	-	129.5	11.1	3.7	-
	K	119	10.6	3.3	86.3	151.3	9	3.4	-100.0
	KI	118.4	10.7	3.0	249.0	113.5	9.6	4.7	-100.0
15 cm	**C**	162.9	18.5	1.6	-	182.2	12.8	2.6	-
	I	124.6	23.8	0.9	-	198.2	12.2	3.0	-
	K	186	15.6	2.3	232.3	170.2	11.5	3.8	-100.0
	KI	185.8	15.2	2.6	125.7	229.4	12.6	2.4	47.0

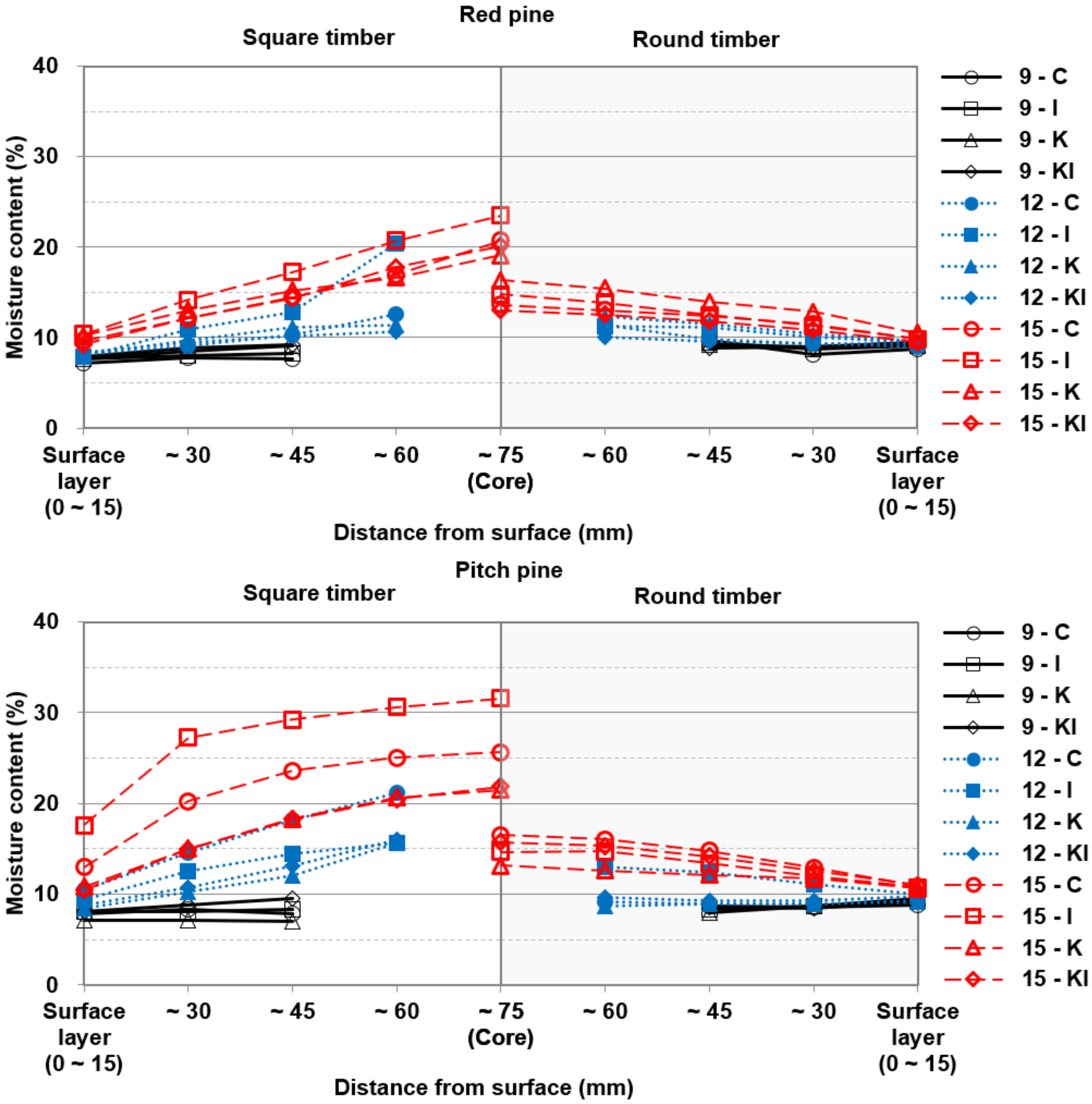

Fig. 2. Moisture content distribution according to the distance from surface layer

Permeability of wood varies among species because this property is influenced by factors such as specific gravity, extractive content, latewood percentage, and wood microstructure (particularly in the types with bordered pits) (Jee and Kim 1996; Hur and Kang 1997). Moreover, the distance from the core to the evaporation surface depends on factors such as shape, thickness, and pretreatment conditions. The incising and kerfing treatment affects the distribution of MC (Lee *et al*. 2013, 2016a,c). Therefore, because the same drying schedule as in the studies by Lee *et al*. (2013, 2016a,c) was used in the present study, the observed differences in the final MC and MC distribution after drying were attributed to the variations in species, shape and thickness of specimens, and pretreatment.

For the commercial drying schedule used in this study, it can be useful to determine the appropriate drying time according to the species, thickness, and shape. It is suggested that the drying time should be controlled in step 3 of Table 2.

Generally, the initial MC may affect the final MC and its distribution after drying. Because the drying time was same for all specimens in this study, specimens with a low initial MC should have had a lower final MC than that of specimens with a higher initial MC. However, for the 15-cm-thick square timbers of red pine and pitch pine, although the initial MC was low, the final MC after drying was relatively higher, especially in the incised specimens. In this study, the specimens were exposed to ambient air during preparation before the drying test.

During air drying, pit aspiration reduces the permeability to approximately one-tenth to three-tenths of the initial permeability value (Erickson and Crawford 1959). Thus, based on the results, it was speculated that the study on the effect of initial MC on pit aspiration, drying time, and final MC of boxed-heart timber after drying is needed.

Surface Checks

More surface checks occurred in square timbers than in the round timbers, and this aspect was influenced noticeably by the timber thickness (Tables 5 through 7). As shown in Tables 3 and 4, shrinkage tended to decrease with increasing thickness.

Shrinkage is initiated by a change in MC and leads to the development of drying stresses, such as creep, tension set, and twisting stress (Kubojima *et al*. 2013). The creep and tension set are greatly affected by drying time and develop differently depending on species, type, thickness, and heart/sapwood ratio (Hwang and Park 2009; Yamashita *et al*. 2014; Lee *et al*. 2016c).

For round timbers, the entire surface is composed of tangential section and the distance to be traversed by moisture from the center to the surface for evaporation is shorter than that in the square timbers. Additionally, surface checks can occur when the twisting stress in square timber is suppressed by external forces during drying (Kubojima *et al*. 2013). Round timber is less affected than square timber by the external forces during drying. Because the moisture gradient between the surface layer and the inner layer increases with increasing thickness and the inner layer suppresses the shrinkage of the surface layer during drying (Lazarescu and Avramidis 2008), the tensile stress formed on the surface layer is not only greater with increasing thickness but also lasts for a longer time. Therefore, the difference in the internal stress behaviors due to the type and thickness of the wood was judged to be the cause of the variation in the occurrence of surface checks.

The incising and kerfing treatments had a significant effect on the occurrence of surface checks, in line with earlier reports (Lee *et al.* 2013, 2014, 2016a-c, 2017). The kerfing treatment contributed noticeably to the reduction in surface checks in square timber. The kerf widening rate was considered unrelated to the occurrence of surface checks. The results of incising treatment indicated that surface checks occurred differently according to species, type, and thickness of wood.

It was also observed that incising caused a phenomenon in which the incising connects to each other and develop into surface checks. As a result, it was concluded that incising is not a suitable pretreatment for surface checks. Kerfing was judged to be a more appropriate pretreatment for reducing surface checks in some cases.

Nevertheless, the surface check results indicated that pretreatment was not required for round timbers, nor for square timbers of thickness 12 cm or less. The kerfing treatment noticeably reduced the occurrence of surface checks only in the 15-cm-thick red pine and pitch pine square timbers. In general, the incising and kerfing treatments contribute to both the improvement in drying quality and in the development of an optimal drying schedule.

Table 5. Average Length and Number of Surface Checks in Square Timbers According to Surface Checks Width

Specimens			**Surface Checks Width (mm)**										**Total**	
			2		**3**		**4**		**5**		**6**			
			Length (cm)	**Number (Pieces)**	**Length (cm)**	**Number (Pieces)**	**Length (cm)**	**Number (Pieces)**	**Length (cm)**	**Number (Pieces)**	**Length (cm)**	**Number (Pieces)**	**Length (cm)**	**Number (Pieces)**
Red Pine	**9 cm**	**C**	19	0.8	-	-	-	-	-	-	-	-	**19**	**0.8**
		I	38	1.7	8	0.3	7	0.2	-	-	-	-	**53**	**2.2**
		K	10	0.7	-	-	-	-	-	-	-	-	**10**	**0.7**
		KI	-	-	-	-	-	-	-	-	-	-	**-**	**-**
	12 cm	**C**	85	2.8	6	0.2	-	-	-	-	-	-	**91**	**3.0**
		I	73	3.5	27	1.0	17	0.3	-	-	-	-	**117**	**4.8**
		K	37	1.8	-	-	-	-	-	-	-	-	**37**	**1.8**
		KI	-	-	-	-	-	-	-	-	-	-	**-**	**-**
	15 cm	**C**	197	9.0	102	3.7	115	2.3	24	0.3	17	0.3	**454**	**15.7**
		I	143	6.0	109	3.8	21	0.5	-	-	-	-	**274**	**10.3**
		K	21	1.2	-	-	-	-	-	-	-	-	**21**	**1.2**
		KI	6	0.3	13	0.2	-	-	-	-	-	-	**19**	**0.5**
Pitch Pine	**9 cm**	**C**	21	0.8	-	-	-	-	-	-	-	-	**21**	**0.8**
		I	10	1.0	2	0.2	-	-	-	-	-	-	**12**	**1.2**
		K	-	-	-	-	-	-	-	-	-	-	**-**	**-**
		KI	-	-	-	-	-	-	-	-	-	-	**-**	**-**
	12 cm	**C**	47	1.8	15	0.5	-	-	-	-	-	-	**62**	**2.3**
		I	8	0.5	-	-	-	-	-	-	-	-	**8**	**0.5**
		K	8	0.7	7	0.3	-	-	-	-	-	-	**15**	**1.0**
		KI	12	0.7	-	-	-	-	-	-	-	-	**12**	**0.7**
	15 cm	**C**	56	2.8	27	1.0	19	0.5	-	-	-	-	**102**	**4.3**
		I	120	5.5	69	2.2	7	0.2	-	-	-	-	**196**	**7.8**
		K	-	-	-	-	-	-	-	-	-	-	**-**	**-**
		KI	-	-	-	-	-	-	-	-	-	-	**-**	**-**

Table 6. Average Length and Number of Surface Checks in Round Timbers According to Surface Checks Width

Specimens			Surface Checks Width (mm)				Total	
			2		3			
			Length (cm)	Number (Pieces)	Length (cm)	Number (Pieces)	Length (cm)	Number (Pieces)
Red Pine	9 cm	C	11	0.7	-	-	**11**	**0.7**
		I	-	-	-	-	-	-
		K	-	-	-	-	-	-
		KI	-	-	-	-	-	-
	12 cm	C	-	-	-	-	-	-
		I	-	-	-	-	-	-
		K	23	1.0	7	0.2	**30.1**	**1.2**
		KI	-	-	-	-	-	-
	15 cm	C	17	0.3	-	-	**17**	**0.3**
		I	37	1.0	-	-	**37**	**1.0**
		K	-	-	-	-	-	-
		KI	-	-	-	-	-	-
Pitch Pine	9 cm	C	-	-	-	-	-	-
		I	-	-	-	-	-	-
		K	-	-	-	-	-	-
		KI	-	-	-	-	-	-
	12 cm	C	-	-	-	-	-	-
		I	8	0.2	-	-	**8**	**0.2**
		K	-	-	-	-	-	-
		KI	-	-	-	-	-	-
	15 cm	C	6	0.3	-	-	**6**	**0.3**
		I	-	-	-	-	-	-
		K	-	-	-	-	-	-
		KI	-	-	-	-	-	-

Table 7. Quantity of Specimens Without Surface Checks Over 2 mm Width

Specimens		Number (Pieces)			
		Red Pine		Pitch Pine	
		Square	Round	Square	Round
9 cm	C	4	5	5	6
	I	3	6	5	6
	K	5	6	6	6
	KI	6	6	6	6
12 cm	C	1	6	4	6
	I	2	6	5	5
	K	3	5	5	6
	KI	6	6	5	6
15 cm	C	0	4	3	5
	I	**0**	4	2	6
	K	5	6	6	6
	KI	5	6	6	6
Non-surface Checks		**40**	**66**	**58**	**70**
Surface Checks		**30**	**6**	**14**	**2**

Twist

Figure 3 shows that twist, especially in red pine, tended to decrease in the 12-cm- and 15-cm-thick specimens with the application of kerfing treatment. Conversely, twist was increased in the timbers treated by incising. This suggests that the incising and kerfing treatment can affect twist in wood.

Although juvenile wood displays severe shrinkage anisotropy, the twist occurrence of boxed-heart timber after drying is associated with the change in grain angle with respect to distance from the pith (Frühwald 2007). Many studies have reported that grain angle is the most important factor in the occurrence of twist and that kerfing treatment reduced the twisting of boxed-heart timbers from hemlock, radiate pine, and red pine (Frühwald 2006, 2007; Nilsson *et al*. 2007; Straže *et al*. 2011; Kubojima *et al*. 2013; Lee *et al*. 2016b, 2016c). In contrast, Lee *et al*. (2013, 2014) reported that kerfing had no effect on the twisting of 20-cm-thick red pine and Korean pine. In general, it was concluded that the kerfing treatment can contribute to the reduction of twisting, depending on the species and the thickness of the timber.

The incising treatment not only evenly distributes the tensile stress in the surface layer, but also reduces the distance moisture has to traverse from core to surface (Lee *et al*. 2016a). Tension set occurs at a position farther from the surface than in the absence of the incising treatment. Tension sets can affect warping that occurs with shrinkage because when a tension set occurs in the surface layer and the inner layer, the surface layer suppresses the shrinkage of the inner layer. The incising treatment may make a difference in the degree to which the surface layer suppresses the shrinkage of the inner layer. However, the incising treatment in this study did not show a clear trend of increase or decrease in twist.

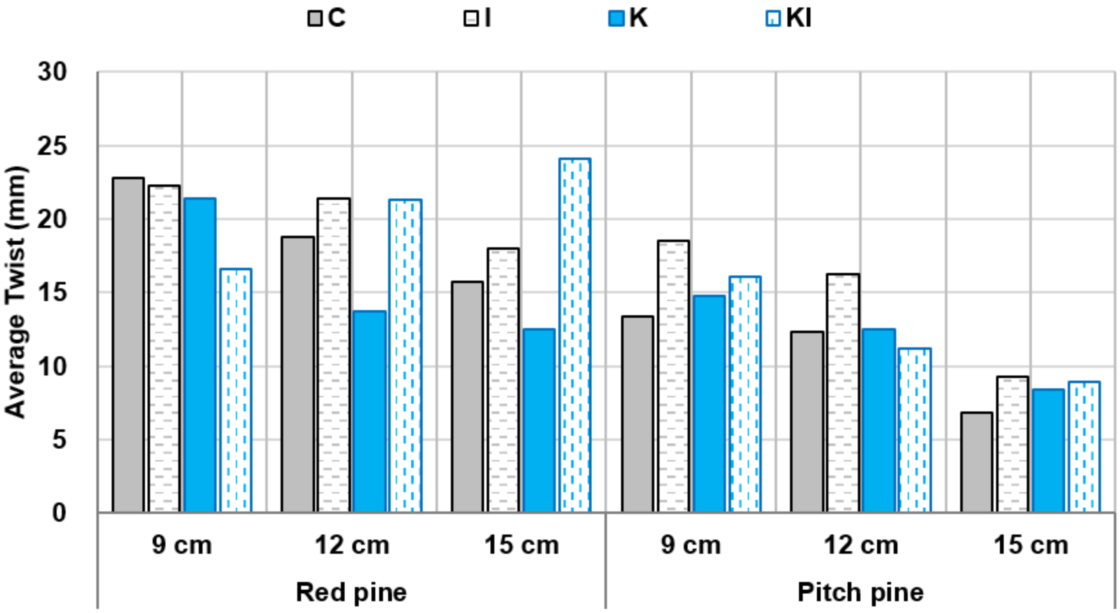

Fig. 3. Average twist of square timber according to species, size, and pretreatment condition

CONCLUSIONS

This study evaluated the effects of knife-incising and longitudinal kerfing pretreatments on the softwood timbers with cross-section less than 15 cm. The results could be used for commercial purposes because they were derived from a commercial dryer.

1. Depending on the specific species or thickness of specimens, the kerfing treatment was suitable as a pretreatment for reducing the occurrence of surface defects, and it contributed to the better reduction of twist in red pine than that in pitch pine.
2. The incising treatment affects the internal stress behavior of the wood but is not suitable as a pretreatment because it leads to the interconnections among the incising features leading to the development of surface checks.
3. The wood conditions, such as species, type, thickness, and initial moisture content (MC), were more important than pretreatment for the drying defects.
4. For the commercial use of the drying schedule used in this study, it can be useful to determine the appropriate drying time according to the species, thickness, and shape. Drying time should be controlled in step 3 of the drying schedule shown in Table 2.
5. The incising and kerfing treatments can be used to improve the drying quality and as a tool for deriving an optimal drying schedule.

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