

# Optimized Lamina Size Maximizing Yield for Cross Laminated Timber Using Domestic Trees<sup>\*1</sup>

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## ABSTRACT

The goal of this study was to find the optimum lamina size from red pine (*Pinus densiflora*) and Japanese cedar (*Cryptomeria japonica*) logs for the cross laminated timber (CLT) production. From visual inspection of the logs from two species, red pine log showed a larger knot and warp compared to the Japanese cedar. Different cross-sectional sizes of lamina (110 mm × 30 mm, 110 mm × 40 mm, 110 mm × 50 mm, 50 mm × 30 mm, 30 mm × 30 mm) from two species were analyzed for yield and grade. Regardless of the species, the optimized cross sectional size for maximizing the yield was 110 mm × 30 mm. In grading for the different size laminas from Japanese cedar and red pine, a higher percentage of the first and second grade was found from the 110 mm × 30 mm lamina cut.

*Keywords* : cross laminated timber, yield, grading

## 1. INTRODUCTION

In 2010, forest land was 6,369,000 ha in South Korea, which occupied about 63.7% of the entire land. Softwood land was 2,581,000 ha, which occupied 40.5%. The average wood resources that could be utilized were estimated to be 125.6 m<sup>3</sup> per 1ha (potential silvicultural species 2011). Red pine (*Pinus densiflora*) and Japanese cedar (*Cryptomeria japonica*) trees were the one of the main species in South Korea, occupying

1,467,000 ha and 106,726 ha, respectively (potential silvicultural species 2011).

The main use of the domestic wood resources was for producing plywood, particle board, and medium density fiberboard, and pulp. Only small portion of the domestic wood has been used for the structural materials. Although the demand of the wood framing building had been increased in South Korea, it was limited to a low-rise

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residential building. About 95% of the material used for the wood frame building in South Korea was still imported.

In European countries, high and mid-rise buildings have been constructed using cross laminated timber (CLT). CLT is a recently developed construction material made of wood. CLT is composed of lamina, which is suitable for utilizing the small diameter domestic tree. CLT is the one of the best ways to use domestic wood resources as a value-added product and expand wood frame building for various purposes. However, there is no study on CLT using domestic trees.

The goal of this study is to evaluate the optimized lamina size for maximizing yield from domestic red pine and Japanese cedar. Log and lamina characteristics including knot, diameter, and length were incorporated into the yield estimation. Three different widths of 110 mm, 50 mm, and 30 mm and three different thicknesses of 30 mm, 40 mm, and 50 mm were investigated.

## 2. Methods

### 2.1. Log Measurement

Log measurement and dimensional cutting were performed at SK Forest Co. Ltd located in Hwasun, JeollaNamdo, South Korea. Forty red pine logs and forty one Japanese cedar logs from JeollaNamdo province were used for the yield study. All logs were marked on the surface for tracking. Diameter, length, knot size and the location of the knots from each log were measured based on KS F 4475 (KS 2004). The volume of the logs was calculated according to KS F 2163 (KS 2009). The below Equation is used for calculating the volume of domestic log of which length is 6 m below.

$$V = D^2 \times L \times \frac{1}{1000000} \text{ (m}^3\text{)} \quad (1)$$

V: Volume of a log (m<sup>3</sup>)

D: Smaller end diameter from a log (mm)

L: length of a log (m)

### 2.2. Lamina Cutting

From forty one cedar logs, the first twenty logs were weighed and cut for the 110 mm × 30 mm lamina as many as possible. If the dimension of wood was not wide enough to cut 110 mm width, the width of 50 mm or 30 mm lamina was cut. Eleven logs were weighed and used to cut for the 50 mm × 30 mm lamina as many as possible. If the dimension of wood was not wide enough to cut 50 mm width, the width of 30 mm lamina was cut. Ten logs were weighed and used to cut for the 30 mm × 30 mm lamina.

From forty red pine logs, twenty logs were weighed and cut for the 110 mm × 30 mm lamina. Nine logs were weighed and used to cut for the 110 mm × 40 mm lamina as many as possible. Eleven logs were weighed and used to cut for the 110 mm × 50 mm lamina as many as possible. If the dimension of wood was not wide enough to cut 110 mm width, the wood was cut for producing the 50 mm × 30 mm or 30 mm × 30 mm lamina.

After cutting different sizes of lamina, the weight of the lamina and the weight of residuals were measured. The weight of sawdust was calculated by subtracting the weight of the lamina and residuals from the weight of the logs. To measure the moisture content and specific gravity of the log, six pieces from the residual were randomly selected.

### 2.3. Visual Grading

After all laminas were dried to 8% moisture content, visual grading based on KS F 3021 was conducted to analyze the effect of lamina size and species on the grade. The visual characteristics of edge knot size, ring shake, check, ring

width, bow, and twisting were recorded for each lamina.

### 3. Results and Discussion

#### 3.1. Log Characteristics

Table 1 shows the dimensional information of the Japanese cedar and red pine logs. The average diameter of the smaller end of the Japanese cedar logs was 167.1 mm with a coefficient of variation (cov) of 11%. The average diameter of the larger end of the Japanese cedar logs was 199.3 mm with a cov of 19%. The larger end ranged from 154.0 mm to 307.5 mm, which is categorized to the middle class log based on KFRI notification (2000). The average diameter of the smaller end of the red pine log was 200.8 mm with a cov of 23%. The average diameter of the larger end of the red pine log was 238.5 mm with a cov of 25%. The larger end

ranged from 157.0 mm to 455.0 mm mostly belongs to the middle class log. The average length of the red pine and Japanese cedar logs was 2.02 m and 1.99 m, respectively. Based on Equation 1, the total volumes of red pine and Japanese cedar logs were calculated to be 3.43 m<sup>3</sup> and 2.28 m<sup>3</sup>, respectively.

Table 2 shows the visual characteristics of the logs from red pine and Japanese cedar. Comparing to the Japanese cedar log, larger knot but less number of knots was found in red pine logs. All Japanese cedar logs were straight and did not have checks, whereas some red pine logs were bent and have checks in the both end. The specific gravity of the red pine and Japanese cedar was found to be 0.46 and 0.38, respectively. The average moisture content of the red pine and Japanese cedar was found to be 41.13% and 41.81%, respectively.

Table 1. Dimensional information of red pine and Japanese cedar logs

	Diameter (mm)		Length (m)	Volume of logs (m <sup>3</sup> )
	Larger end	Smaller end		
<i>Pinus densiflora</i>	238.5 (25%) <sup>2</sup>	200.8 (23%)	2.02 (8%)	3.43
<i>Cryptomeria japonica</i>	199.3 (19%)	167.1 (11%)	1.99 (10%)	2.28
<sup>1</sup> Diff	16%	16%	1%	33%

<sup>1</sup>Diff :  $(Pinus\ densiflora - Cryptomeria\ japonica / Pinus\ densiflora \times 100)$

<sup>2</sup>Coefficient of variation

Table 2. Visual characteristics of red pine and Japanese cedar logs

	SG	MC (%)	Knot size (mm)	Number of knot	Warp (mm)	Shake (mm)	
						Larger end	Smaller end
<i>Pinus densiflora</i>	0.46	41.13	19.1 (143%) <sup>2</sup>	1.48 (155%)	22.8 (116%)	170.0 (50%)	55.3 (37%)
<i>Cryptomeria japonica</i>	0.38	41.81	18.6 (162%)	2.46 (119%)	N/A	N/A	N/A
<sup>1</sup> Diff			2.61%	-66.21%	N/A	N/A	N/A

<sup>1</sup>Diff :  $(Pinus\ densiflora - Cryptomeria\ japonica / Pinus\ densiflora \times 100)$

<sup>2</sup>Coefficient of variation

### 3.2. Products Yield Based on Weight

Figure 1 shows the yield of the lamina, residuals, and sawdust based on the log weight. The yield of the lamina, residuals, and sawdust from red pine logs were 62.83%, 26.54%, and 10.61%, respectively. The yield of the lamina, residuals, and sawdust from Japanese cedar logs were 56.52%, 28.69%, and 14.78%, respectively.

For the 110 mm × 30 mm cut from red pine logs, the yield of the lamina, residuals, and sawdust at a basis of log weight was 66.22%, 22.51%, and 11.25%, respectively. For the 110 mm × 40 mm and 110 mm × 50 mm cut from red pine logs, the yield of the lamina, residuals, sawdust at a basis of the log weight was 56.00%, 34.67%, and 9.33%, respectively. Comparing the 110 mm × 30 mm cut, the 110 mm × 40 mm and 110 mm × 50 mm cut showed a higher percentage of residuals and a lesser percentage of sawdust. It can be speculated that the 110 mm × 30 mm cut can utilize the log more efficiently.

For the 110 mm × 30 mm cut from Japanese cedar logs, the yield of the products, residuals, and sawdust at a basis of log weight was 61.11%, 24.07%, and 14.81%, respectively. For the 50 mm × 30 mm and 30 mm × 30 mm cut from Japanese cedar logs, the yield of the products, residuals, sawdust at a basis of log weight was 52.46%, 32.79%, and 14.75%, respectively. Comparing the 110 mm × 30 mm cut, the 50 mm × 30 mm and 30 mm × 30 mm cut utilized the lesser amount of the log.

Based on weight, the lamina yield from red pine logs was 6.31% higher than that from Japanese cedar logs. It can be speculated that the difference of the lamina yield was the log characteristics and different size of lamina between red pine and Japanese cedar logs. For red pine logs, the utilization of the bent log could be increased by reducing the thickness of the lamina since the larger thickness may restrict the

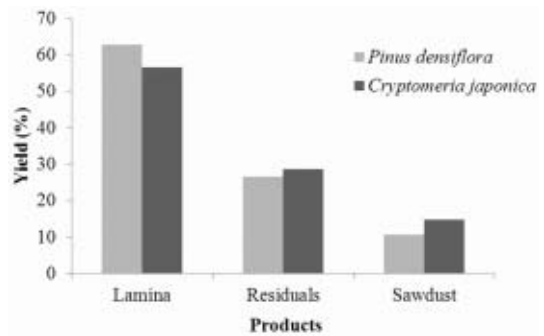


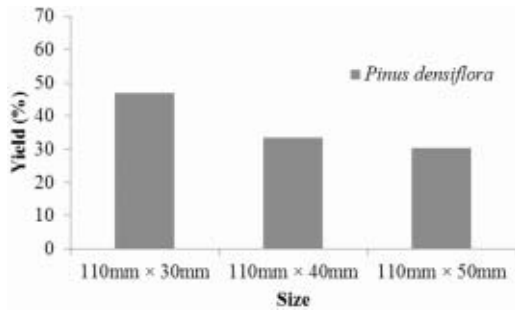
Fig. 1. Yield of the products from red pine and Japanese cedar logs based on products and log weight.

use of the bent log lengthwise. For Japanese cedar logs, the larger lamina required the less number of cutting process producing less sawdust, while the smaller lamina, the more cutting process with more sawdust. Regardless of the species, the highest yield was obtained when the 110 mm × 30 mm lamina cut was performed. However, it should be noticed that the weight-based yield calculation included the bad quality of the products.

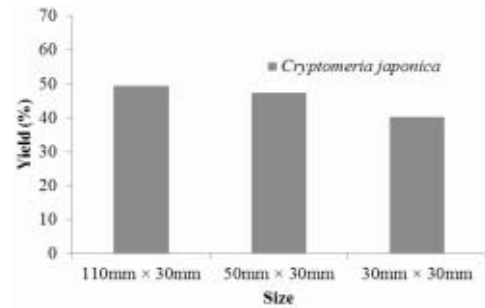
### 3.3. Products Yield Based on Volume

Figure 2 shows the yield of the different size lamina cut from red pine and Japanese cedar logs based on the specific lamina size and log volume. With the increment of the lamina thickness at a width of 110mm, the yield of the targeted size from red pine logs decreased from 46.83% to 30.12%. From the process of 110 mm × 30 mm lamina production, the yield of all size lamina including the 110 mm × 30 mm, 50 mm × 30 mm, and 30 mm × 30 mm was 53.91%. From the 110 mm × 40 mm production process, the yield of all size lamina including the 110 mm × 30 mm, 50 mm × 30 mm, and 30 mm × 30 mm was 40.69%. From the 110 mm × 50 mm lamina

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a) Yield of different size lamina cut from red pine



b) Yield of different size lamina cut from Japanese cedar

Fig. 2. Yield of different size lamina cut from red pine and Japanese cedar logs based on the lamina and log volume.

production process, the yield of all size lamina including the 110 mm × 40 mm, 50 mm × 30 mm, 30 mm × 30 mm was 38.09%. The total yield of all size lamina from red pine logs was 48.82%.

With decrement of lamina width at a thickness of 30mm, the yield of the targeted size from Japanese cedar logs decreased from 49.43% to 40.33%. From the 110 mm × 30 mm production process, the yield of all size lamina including the 110 mm × 30 mm, 50 mm × 30 mm, and 30 mm × 30 mm was 50.91%. From the 50 mm × 30 mm production process, the yield of all size lamina including the 50 mm × 30 mm, 30 mm × 30 mm was 49.21%. From the 30 mm × 30 mm production process, the yield of all size lamina was 40.33%. The total yield of all size lamina from Japanese cedar logs was 47.43%.

It is interesting to notice that the yield from the 110 mm × 30 mm lamina cut was higher than that from the 50 mm × 30 mm or the 30 mm × 30 mm lamina cut. From the yield results based on the volume, the optimized lamina size for maximizing yield was found to be the 110 mm × 30 mm for the red pine and Japanese cedar logs. Figure 3 describes the difference of yield estimated by the different size lamina cut. The average diameter of Japanese cedar logs

was 167.1 mm (Table 1). The width of 113.0 mm lumber can be obtained. From the 110 mm × 30 mm, 50 mm × 30 mm, 30 mm × 30 mm lamina cut, three, six, and nine laminas could be obtained, respectively. The cross sectional areas from the 110 mm × 30 mm, 50 mm × 30 mm, 30 mm × 30 mm lamina cut can be calculated to be 9,900 mm<sup>2</sup>, 9,000 mm<sup>2</sup>, and 8,100 mm<sup>2</sup>, respectively. Also, for red pine, from the 110 mm × 30 mm, 110 mm × 40 mm, 110 mm × 50 mm lamina cut, four, three, and two laminas could be obtained, respectively. The cross sectional areas from the 110 mm × 30 mm, 110 mm × 40 mm, 110 mm × 50 mm lamina cut can be calculated to be 13,200 mm<sup>2</sup>, 13,200 mm<sup>2</sup>, and 11,000 mm<sup>2</sup>, respectively. However, compared to the 110 mm×30 mm lamina cut, the 110 mm × 40 mm lamina cut could have more chance to show less yield estimation due to the log characteristics. For example, if one lamina could not be cut due to the bent log, the 110 mm × 30 mm lamina cut could lose 3,300 mm<sup>2</sup> but the 110 mm × 40 mm lamina cut could lose 4,400 mm<sup>2</sup>. The different yield results by the different size lamina cut from Figure 2 could be explained by these reasons.

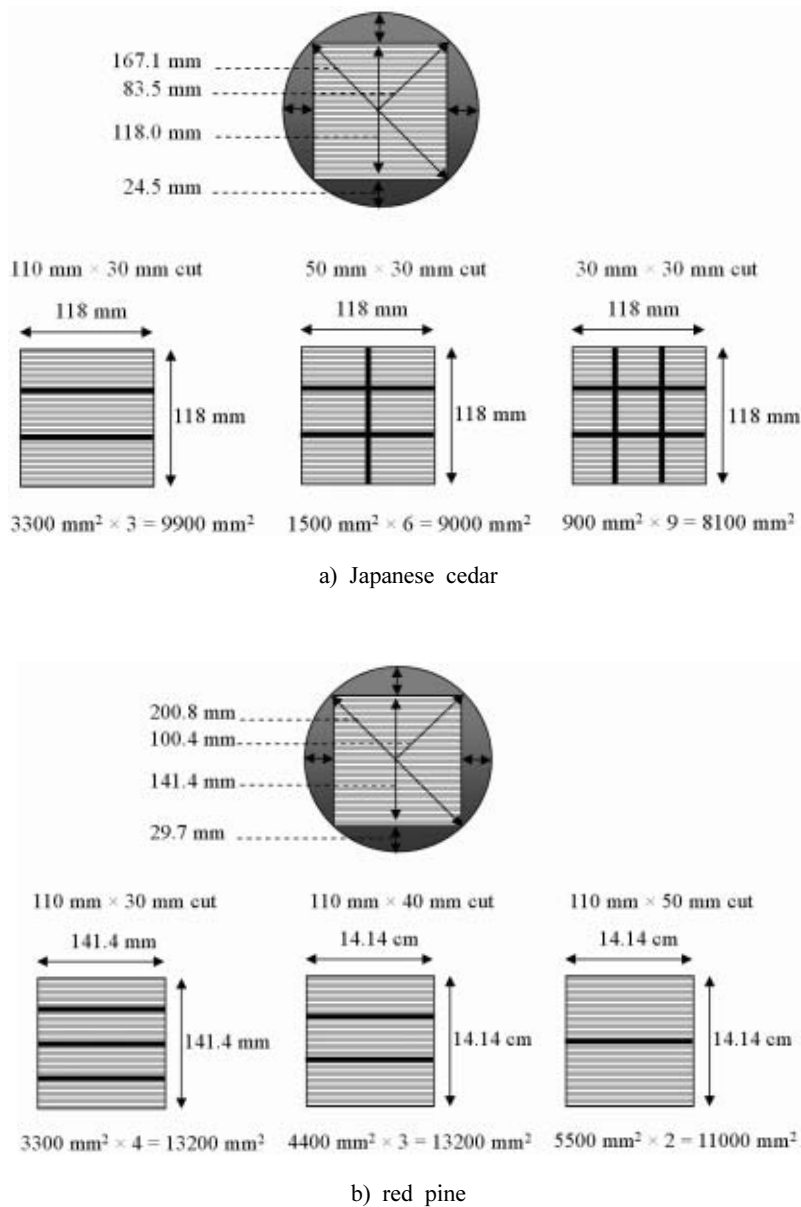


Fig. 3. Yield estimation from the different size lamina cut from Japanese cedar and red pine.

### 3.4. Grading of Different Size of Lamina

Table 3 shows the visual characteristics of the different size lamina cut from red pine and

Japanese cedar logs. For the red pine, a smaller edge knot, check, bow, and twisting were observed from the thicker lamina, whereas the trends of ring shake, check, and ring width ratio were not consistent with lamina thickness. For the

Table 3. Visual characteristics of the different size lamina cut from red pine and Japanese cedar logs

Characteristics	<i>Pinus densiflora</i>			<i>Cryptomeria japonica</i>		
	110 × 30 mm	110 × 40 mm	110 × 50 mm	110 × 30 mm	50 × 30 mm	30 × 30 mm
Edge Knot (mm)	22.6 (0.87) <sup>1</sup>	14.1 (1.19)	8.3 (1.45)	20.6 (0.42)	11.8 (0.90)	7.6 (1.36)
Ring shake (mm)	25.9 (1.15)	25.4 (0.51)	28.3 (0.39)	17.8 (0.83)	6.7 (0.83)	2.8 (3.70)
Check (mm)	51.6 (0.93)	178.0 (1.04)	108.9 (0.77)	100.4 (1.02)	30.0 (2.60)	12.9 (2.76)
Ring width ratio	35.2 (0.65)	46.7 (0.49)	39.6 (0.49)	37.0 (0.37)	41.9 (0.43)	37.4 (0.38)
Bow (mm)	13.5 (1.29)	10.9 (0.87)	8.1 (0.61)	6.7 (0.60)	5.2 (1.42)	13.0 (1.55)
Twisting (mm)	12.6 (0.99)	12.2 (0.78)	6.2 (0.82)	4.3 (1.43)	5.7 (2.28)	0.8 (4.49)

<sup>1</sup>Coefficient of variation

Table 4. Number of laminas at different grades from the different size lamina cut

Grade	<i>Pinus densiflora</i>			<i>Cryptomeria japonica</i>		
	110 × 30 mm	110 × 40 mm	110 × 50 mm	110 × 30 mm	50 × 30 mm	30 × 30 mm
1	50 (36.23) <sup>1</sup>	8 (40.00)	14 (63.64)	32 (35.67)	27 (33.75)	75 (51.02)
2	25 (18.12)	1 (5.0)	5 (22.73)	35 (46.67)	9 (10.98)	8 (5.44)
3	26 (18.84)	10 (50.0)	3 (13.64)	5 (6.67)	17 (20.73)	3 (2.04)
4	30 (21.74)	1 (5.0)	0	3 (4.00)	22 (26.83)	34 (23.13)
Out of grade	7 (5.07)	0	0	0	5 (6.10)	27 (18.37)

<sup>1</sup>Percentage of grade at the same size lamina cut

Japanese cedar, a smaller edge knot and check were observed from the lamina with the smaller width, whereas the larger bow was observed from the lamina with the smaller width. The ring width ratio and ring shake did not show a consistent trend with an increment width.

Table 4 shows the grade of different size of lamina from red pine and cedar logs. For the red pine, the highest percentage of the first and second grades was found from the 110 mm × 50 mm cut, whereas the lowest percentage of the first and second grade was found from the 110 mm × 40 mm cut. Since the grading was mainly determined by knot size and the average ring width, more amount of a higher grade for the red pine lamina could be obtained from the 110 mm × 50 mm cut.

For Japanese cedar lamina, the highest percentage of the first and second grade was found

from the 110 mm × 30 mm cut, whereas the lowest percentage of the first and second grade was found from the 50 mm × 30 mm cut. For the Japanese cedar, a larger width can have a smaller knot ratio at a given knot size.

For Japanese cedar, the 110 mm × 30 mm showed the ratio of the knot size to the width was the smallest compared to the other sizes. Considering the same thickness of the lamina, the 110 mm × 30 mm lamina cut showed the smaller knot ratio, resulted in more amount of a higher grade compared to the other sizes. 30 mm × 30 mm lamina cut showed the highest percentage of the first grade, which appears that the 30 mm × 30 mm lamina cut have more chance to avoid the knot.

Considering the yield of lamina from Figure 2 and the grades from Table 4, the 110 mm × 30 mm lamina cut produced the highest yield and

highest percentage of the first and second grade for domestic red pine and Japanese cedar logs.

## 4. Conclusions

This study was to analyze the optimized lamina size to produce the highest yield of lamina for CLT production from red pine and Japanese cedar logs. Three different widths of 110 mm, 50 mm, and 30 mm at a thickness of 30 mm from Japanese cedar were investigated. Three different thicknesses of 30 mm, 40 mm, and 50 mm at a width of 110 mm from red pine were investigated. Regardless of different two species, the 110 mm × 30 mm cut produced the maximum yield. The visual grading results showed that the highest percentage of the first and second grade of the lamina was obtained from the 110 mm × 30 mm cut from Japanese cedar whereas the highest percentage of the first and second grade was obtained from the 110 mm × 50 mm cut from red pine. However, considering both the yield and grade of lamina, the 110 mm × 30 mm lamina is the best cutting size for the red pine and Japanese cedar. From this study, it

can be seen the feasibility of the use of domestic species in lamina production for the CLT.

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