Effect of Crosscutting Crooked Sugi (*Cryptomeria japonica*) Logs on Sawing Yield and Quality of Sawn Lumber

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Abstract

The objective of this study was to develop an efficient method for using crooked sugi (*Cryptomeria japonica* D. Don) logs by crosscutting the logs prior to sawing. We investigated the effect of crosscutting crooked logs on the sawing yield and the quality of sawn lumber and proposed an effective processing method. The sawing yield and the quality of sawn lumber were improved by crosscutting the logs one time. An economic analysis based on the processing intensity required for crooked logs, subjected to one-time crosscutting, and crook-free medium-quality logs was conducted. When the price of sawn lumber obtained from the crooked logs was equal to that of medium-quality logs, the net revenue obtained from crooked logs became nearly equal to that of medium-quality logs. The results demonstrated that the crooked logs could be used effectively by one-time crosscutting.

Sugi is the most popular planted species in Japan, accounting for about 40 percent of the country's planted forests (Statistic Department 2008). Thinning is important for maintaining the health of planted sugi forests and for promoting the production of material of adequate quality (size, width of annual rings, etc.). Sugi is thinned at about 15, 25, and 35 years, and it is commercially harvested at 40 to 50 years (final cutting age). The size (diameter at breast height) of material at the first thinning, the second thinning, and the third thinning are 11 to 12 cm, 15 to 16 cm, and 22 to 23 cm, respectively (Anonymous 2001). In Japan, the tree is typically cut into sawlog lengths (the normal lengths are 3.0 and 4.0 m) in the forest. The log is cut out (bucked) from the tree, avoiding the sections containing sweep and crook as much as possible. When the amount of log sweep approaches 5 cm, the sweep section will often be cut from the tree with consideration given to the log yield, sawlog lengths, and quality (diameter) of the log. It is difficult to undertake thinning because of the poor recovery volumes and financial returns obtained from these sweepy logs. Furthermore, the number of unused logs and log sections left in the forest after thinnings is increasing since they are small and crooked with very limited commercial use, and their price has declined. Therefore, the development of an efficient method for using crooked sugi logs is desirable for the Japanese forestry and wood industries.

The density, in dry condition, of sugi is 0.34, and the average modulus of elasticity and modulus of rupture of sugi are 7.14 kN/mm^2 and 40.8 N/mm^2, respectively (Anonymous 1983). More than 80 percent of sugi logs are processed in sawmills, and almost all sawn lumber is used for construction. Although crooked logs are usually used for boards or small-size squared timber, developing an increased demand for the use of crooked logs in the production of structural wood/lumber should overcome the problem described above.

Recently, some sawmills have produced the studs or lamina from crooked logs using newly developed bandsaw machines with curve sawing systems (Fujita 2004, Murata 2006). Although some researchers reported high performance when curve sawing (Wang et al. 1992, Francis et al. 2001, Pierre and Carl 2004, Honorio et al. 2006), the technology requires a large investment for sawmills.

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On the other hand, crosscutting crooked logs prior to sawing might give us a new way to resolve the problem. Because the sweep of logs is reduced by crosscutting, it would be possible to saw crooked logs using a normal sawing system without decreasing yield. The sawn lumber obtained from short logs can be used as truss members in large wooden buildings, for instance. However, this will negatively affect sawmill productivity because two processing stages (crosscutting and then sawing) are needed. The low price of the crooked logs is an important point to consider in this analysis. There is a possibility that profit is obtained even if productivity decreases.

In this study, we investigated the influence of a crosscutting pattern of crooked sugi logs on the sawing yield and the quality of sawn lumber. We propose an effective processing method for crooked logs based on the results of an economic analysis.

Methodology

Sawing test

Eighty-eight crooked sugi logs 3.0 m in length that were grown in Tochigi Prefecture were used for the experiments. After the logs were debarked, measurements were taken of the top-end diameter (D_t), butt-end diameter (D_b), top-end eccentricity (E_t; distance between the geometrical center of the top end and pith), butt-end eccentricity (E_b; distance between the geometrical center of the butt end and pith), and the size of the log sweep (H_1; H_2 for a log with double sweep; Fig. 1).

The log sweep degree was calculated by Equations 1 and 2 (the latter for a log with double sweep) based on the Japanese Agricultural Standard (Food Safety and Consumer Affairs Bureau 1996):

$$\mathrm{LS} = \frac{H_1}{D_t} \times 100 \quad (1)$$

or

$$\mathrm{LS} = \frac{H_1 + H_2}{D_t} \times 1.5 \times 100 \quad (2)$$

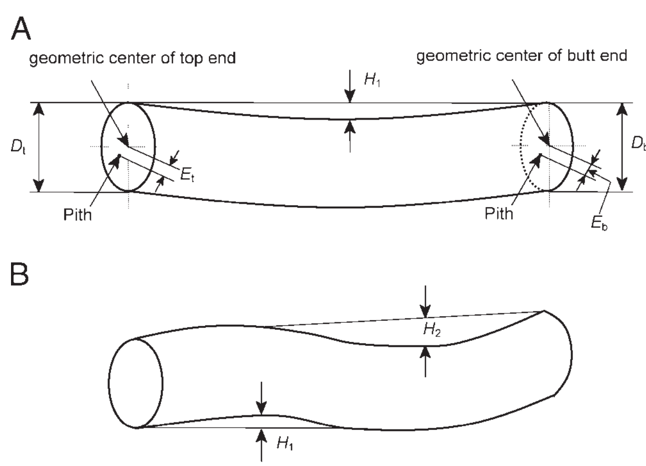

Figure 1.—Measurements taken on each log: (A) log with a single sweep and (B) log with double sweep. D_t = top-end diameter; D_b = butt-end diameter; E_t = top-end eccentricity; E_b = butt-end eccentricity; H_1 and H_2 = size of log sweep.

where

LS = log sweep degree (%),

H_1 and H_2 = size of the log sweep (cm), and

D_t = top-end diameter (cm).

The logs were divided into two groups, A and B, according to log sweep to examine the influence that the degree of sweep exerted on the yield and the quality of sawn lumber. The logs were arranged sequentially in the order of log sweep. Beginning with the log with the minimum log sweep the first 44 logs were classified as Group A, and the remaining 44 logs (up to the maximum log sweep) were classified as Group B. Four kinds of crosscutting patterns labeled as CCP-0, CCP-1, CCP-2, and CCP-3 were applied to 11 randomly selected logs from each of the two log groups. These crosscutting patterns are shown in Figure 2.

After crosscutting, each log was sawn according to the sawing pattern shown in Figure 3. Arranging each log so that the position of the maximum sweep would be located at the vertical top, a squared timber with a cross-sectional size of 10.5 by 10.5 cm was sawn from the center of the log. The scantling or thin boards were sawn from the outer part of the log.

After sawing, the size of warp in the direction of the maximum log sweep, top-end eccentricity, and presence of wane were measured (Fig. 3) on the squared timber. The degree of warp of the squared timber was calculated using Equation 3:

$$\mathrm{WS} = \frac{H_s}{L} \quad (3)$$

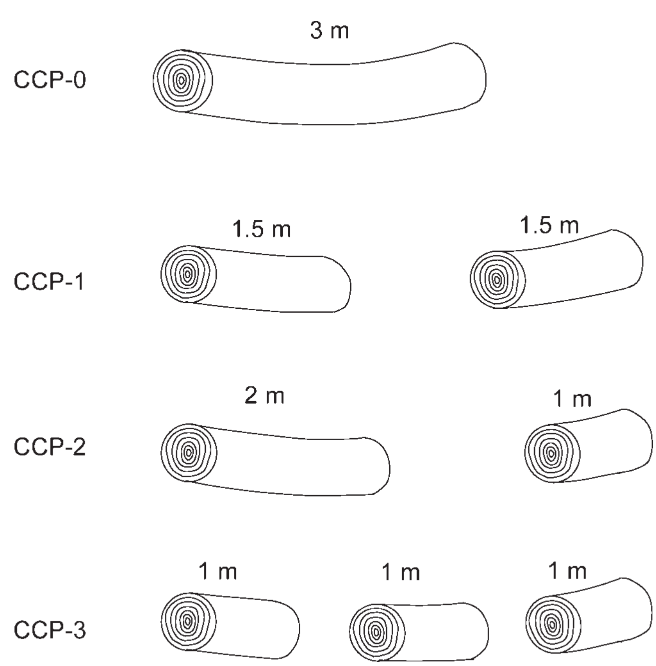

Figure 2.—Crosscutting patterns used in study: CCP-0 = no crosscuts; CCP-1 = the log is crosscut into two short 1.5-m-long logs; CCP-2 = the log is crosscut into one 2.0-m-long log and one 1.0-m-long log; CCP-3 = the log is crosscut into three short 1.0-m-long logs.

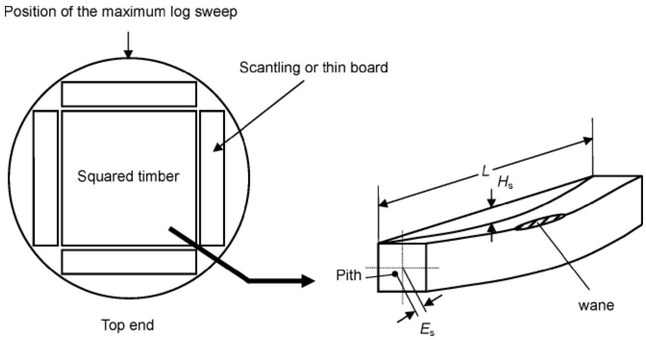

Figure 3.—Sawing pattern and measuring method for the squared timber. H_s *= size of warp in the direction of the maximum log sweep;* L *= length of squared timber;* E_s *= top-end eccentricity.*

where

WS = degree of warp of the squared timber (mm/m),
H_s = size of warp in the direction of the maximum log sweep (mm), and
L = length of squared timber (m).

The volume of the log before crosscutting was calculated by Equation 4 based on the Japanese Agricultural Standard (Food Safety and Consumer Affairs Bureau 1996):

$$V_0 = \frac{D_t \times D_t \times 3.0}{10,000} \quad (4)$$

where

V_0 = volume of the log before crosscutting (m^3) and
D_t = top-end diameter of log (cm).

The sawing yield was calculated by Equation 5:

$$SY = \frac{\sum V_i}{V_0} \times 100 \quad (5)$$

where

SY = sawing yield (%),
V_0 = volume of the log before cross-cutting (m^3), and
V_i = volume of each piece of lumber (m^3).

The difference in the sawing yield according to the crosscutting method was statistically analyzed using analysis of variance.

Revenue estimation

An analysis was carried out comparing the expected value of the lumber obtained from crosscut short logs with sweep/crook with the expected value of the lumber obtained from medium-quality logs 3.0 m in length. The estimated lumber revenue, minus the price of the log, associated with sawing crooked logs and medium-quality logs was calculated using Equations 6 and 7:

$$PA_c = \left\{\frac{3,600\,\text{s/h}}{ST_c \times (NC+1)} \times WT \times OD \times V_{avg}\right\} \times \{SY_c \times SLP_c - LP_c\} \quad (6)$$

$$PA_m = \left\{\frac{3,600\,\text{s/h}}{ST_m} \times WT \times OD \times V_{avg}\right\} \times \{SY_m \times SLP_m - LP_m\} \quad (7)$$

where

PA_c = estimated net revenue associated with sawing the crooked logs (Japanese Yen [JPY]),
PA_m = estimated net revenue associated with sawing the medium-quality logs (JPY),
NC = number of crosscuts,
ST_c = sawing time required for the short-length log that was obtained by crosscutting a crooked log (s),
ST_m = sawing time required for a 3.0-m-long medium-quality log (s),
WT = actual working time (h/d),
OD = number of operating days (d/y),
V_{avg} = average volume of a sawn log (m^3),
SY_c = sawing yield of the crooked log (%),
SY_m = sawing yield of the medium-quality log (%),
SLP_c = price of sawn lumber obtained from the crooked logs (JPY/m^3),
SLP_m = price of sawn lumber obtained from the medium-quality logs (JPY/m^3),
LP_c = price of the crooked log (JPY/m^3), and
LP_m = price of the medium-quality log (JPY/m^3).

The values of these parameters, used in calculating the potential revenue associated with the different types of logs and processing scenarios, were collected by literature research and investigation of the market.

Results and Discussion

Sawing test

The average and standard deviations, based on the sample of 88 sugi logs, for the five log parameters—top-end diameter, butt-end diameter, top-end eccentricity, butt-end eccentricity, and degree of log sweep—are presented in Table 1. The median value for log sweep was 13 percent (i.e., the 44 Group A logs had less than 13 percent sweep, and the 44 Group B logs had more than 13 percent sweep).

Figure 4 shows the variation of sawing yield for the different crosscutting patterns and log sweep groups. As shown in this figure, sawing yield appears to increase with additional crosscutting regardless of log sweep. Although the sawing yield of Group A was higher than that of Group B for logs that were not crosscut (CCP-0), there was little difference between the two sweep groups when the logs were crosscut using CCP-1, CCP-2, and CCP-3. The sawing

Table 1.—Specifications of log used.[a]

	D_t (cm)	D_b (cm)	E_t (mm)	E_b (mm)	LS (%)
Avg	17.4	19.9	6.7	9.3	19.1
SD	1.29	1.43	4.43	4.84	8.73

[a] D_t = top-end diameter; D_b = butt-end diameter; E_t = top-end eccentricity; E_b = butt-end eccentricity; LS = log sweep degree.

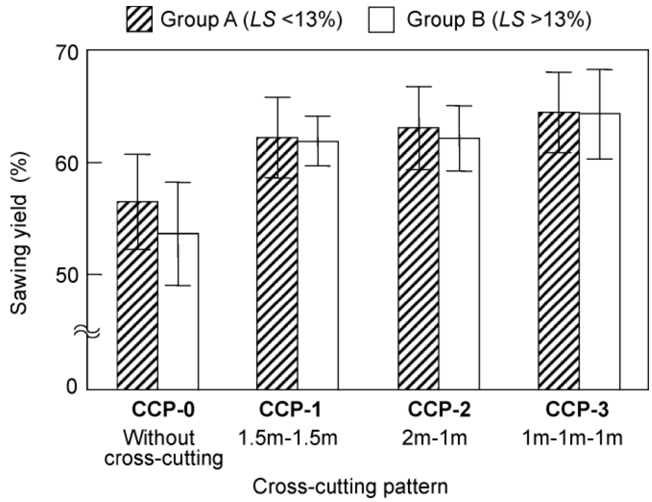

Figure 4.—Variation of sawing yield (SY) with crosscutting pattern and the log sweep degree.

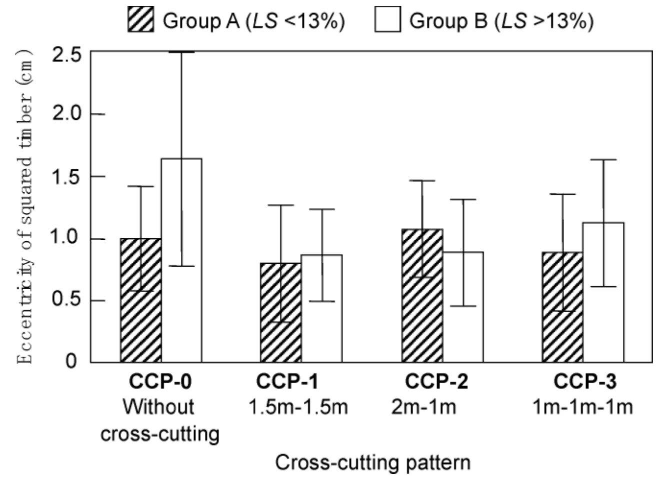

Figure 6.—Variation of the eccentricity (E_s) of squared timber with crosscutting pattern and the degree of log sweep.

yields measured for CCP-0 and CCP-1 and for CCP-0 and CCP-2 were statistically significant at the 0.10 level for both Groups A and B. The sawing yields of CCP-1 and CCP-2 were not significantly different. Similarly, although sawing yields increased slightly for CCP-3 compared with CCP-1 and CCP-2, the differences were not significant ($\alpha = 0.10$).

Figure 5 shows the variation in the degree of warp of squared timber for different crosscutting patterns and log sweep groups. There was no relationship between the crosscutting pattern and degree of warp. Overall, the degree of warp for timber sawn from Group B logs (logs with greater amounts of sweep) was larger than for Group A logs.

Figure 6 shows the variation of the eccentricity of squared timber for different crosscutting patterns and log sweep groups. Although the eccentricity of squared timber of Group B was larger than that of Group A when the logs were not crosscut, the difference between the two groups was minimal for logs subjected to crosscutting (i.e., CCP-1, CCP-2, and CCP-3).

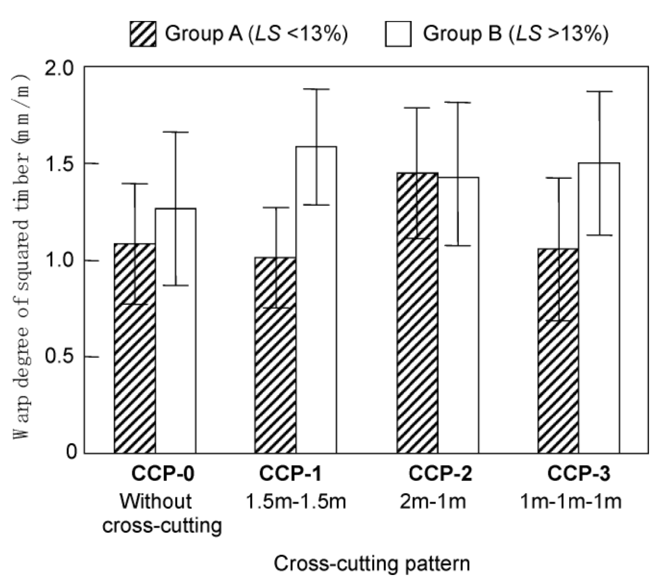

Figure 5.—Variation in the degree of warp (WS) of squared timber with crosscutting pattern and the degree of log sweep.

Figure 7 shows the variation of the ratio of squared timber with wane for different crosscutting patterns and log sweep groups. The ratio of squared timber with wane was larger for Group B than for Group A for every crosscutting pattern. This wane ratio decreased dramatically for both log sweep groups when the logs were crosscut prior to being sawn.

When thinking about an appropriate number of crosscuttings, these results suggest that the sawing yield and the quality of sawn lumber can be sufficiently improved by just one-time crosscutting.

Lumber revenue comparison results

Murata et al. (1989) reported in a previous survey that the sawing yield of medium-quality (crook-free) sugi logs was about 64 percent. As shown in Figure 4, the sawing yield for the crooked logs also approached 64 percent when preprocessed with a single crosscut, which effectively serves to ''straighten'' the two logs derived from the crosscutting operation. Thus, the revenue associated with sawing the crooked logs subjected to one-time crosscutting

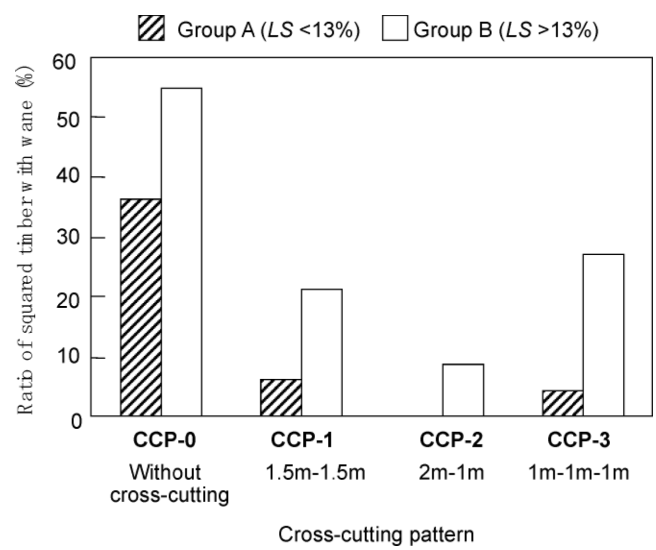

Figure 7.—Variation of the ratio of squared timber with wane with crosscutting pattern and the degree of log sweep.

Table 2.—Values of parameters used in estimating lumber revenues expected when crosscutting logs with sweep/crook compared with revenues achieved when sawing medium-grade straight logs.[a]

Parameter	Value
ST_m (s)	78.6
ST_c (s)	53.4
WT (h/d)	6.5
OD (d/y)	240
V_{avg} (m^3)	0.088
SY_m (%)	64.0
SY_c (%)	62.3
LP_m (JPY/m^3)[b]	13,200
LP_c (JPY/m^3)[b]	9,800
SLP_m (JPY/m^3)[b]	35,000

[a] ST_m = sawing time required for a 3.0-m-long medium-quality log; ST_c = sawing time required for the short-length log, which was obtained by crosscutting a crooked log; WT = actual working time; OD = operating days; V_{avg} = average volume of a sawn log; SY_m = sawing yield of sawing the medium-quality log; SY_c = sawing yield of the crooked log; LP_m = price of a medium-quality log; LP_c = price of a crooked log; SLP_m = price of sawn lumber obtained from the medium-quality logs.

[b] Values for LP_m, LP_c, and SLP_m are from September 2009.

(i.e., CCP-1) was calculated and compared to the revenue associated with sawing medium-quality logs.

In this calculation, the following assumptions were considered.

- A fully automated twin bandsaw machine was used.
- The respective times required to saw a 3.0-m-long log and a 1.5-m-long log were estimated according to the time measurements made at a sawmill (Ikami et al. 1995).
- The ratios of logs with 14, 16, 18, and 20 cm top-end diameter were all 26 percent (near to the ratio of logs used for the sawing test).

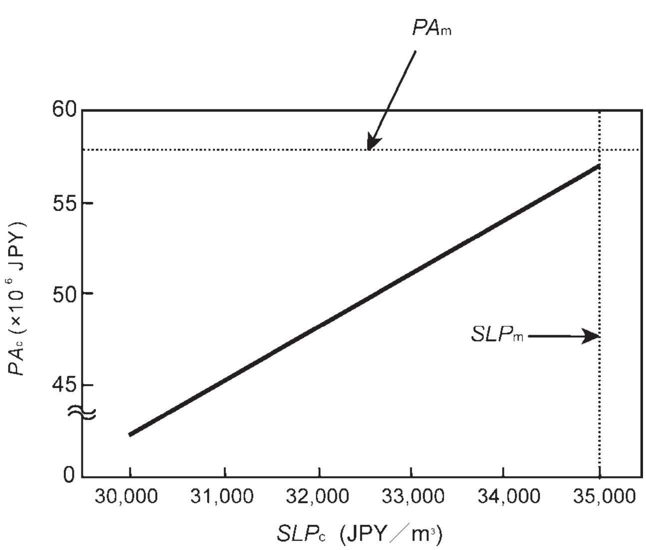

Figure 8.—Relationship between the price of sawn lumber obtained from the crooked logs and the processing amount. SLP_c = the price of sawn lumber obtained from a crooked log; SLP_m = the price of sawn lumber obtained from a medium-quality log; PA_m = the amount of processing required for a medium-quality log; PA_c = the amount of processing for a crooked log.

The values of each parameter used in calculating the net revenues are shown in Table 2.

Figure 8 shows the relationship between the price of the sawn lumber obtained from the crooked logs and the expected revenue per year. Figure 8 also shows that when the price of sawn lumber obtained from the crooked logs is equal to the price of sawn lumber obtained from the medium-quality logs (i.e., 35,000 JPY/m^3), the profitability associated with sawing the crooked logs became nearly equal to that associated with sawing the medium-quality logs. This result indicates that the application of crosscutting to crooked logs is economically viable.

From the results of the sawing test and the calculation of profitability, we may conclude that the crooked logs could be used effectively by one-time crosscutting.

Summary and Conclusion

This study investigated the effect of crosscutting of crooked sugi logs on the sawing yield and the quality of sawn lumber, and an effective processing method was proposed. The sawing yield and the quality of sawn lumber obtained from the crooked log were improved by one-time crosscutting. An economic analysis based on the processing required for crooked logs, subjected to one-time crosscutting, and crook-free medium-quality logs was conducted. When the price of sawn lumber obtained from the crooked logs could be equal to that from the medium-quality logs, the net revenue associated with sawing the crooked logs became nearly equal to that associated with sawing with the medium-quality logs. From the results of the sawing test and the calculation of net revenues, we may conclude that the crooked logs could be used effectively by one-time crosscutting.

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