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Feasibility of Ultrasonic Log Sorting in Manufacturing Structural Lamination from Japanese Cedar Logs*[1]

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ABSTRACT

Because Japanese cedar shows lower mechanical performance, glued-laminated timber (glulam) can be a better way to utilize Japanese cedar for structural purpose. However, low yield of higher grade lamination from log makes it difficult to design structural glulam. This study was aimed to increase the yield of higher grade lamination and provide higher efficiency of manufacturing structural lamination by ultrasonic log sorting technology. Logs were sorted by an existing log grading rule regulated by Korea Forest Research Institute (KFRI). It was found that the KFRI log grading rule contributed to finding better logs in viewpoint of the volumetric yield and it can reduce the number of rejected lumber by visual grading. However, it could not identify better logs to produce higher-grade products. To find an appropriate log-sorting-method for structural products, log diameter and ultrasonic time of flight (TOF) for the log were considered as factors to affect mechanical performance of resulting products. However, it was found that influence of log diameter on mechanical performance of resulting products was very small. The TOF showed a possibility to sort logs by mechanical performance of resulting products even though a coefficient of correlation was not strong (R = 0.6). In a case study, the log selection based on the ultrasonic TOF of the log increased the yield of the outermost tension lamination (E8 or better grade, KS F 3021) from 2.6% to 12.5% and reduced LTE5 (lower than E5 grade) lamination from 43.6% to 10.3%, compared with the existing KFRI log grading rule.

Keywords : log sorting, machine grading, MOE, ultrasonic, glued-laminated timber, lamination

1. INTRODUCTION

Recently, the demand for wood has increased because of the recognition of its low environmental stress such as carbon emission and sustainability, the market demand for wood is expected to increase steadily. A shortage of wood resources coupled with the demand to enhance the utilization of wood has led to an interest in fast growing species. Japanese cedar is one of the fast growing species, and it can grow well in the climates of Korea in the southern region and Je-Ju island.

The tree density of the Japanese cedar has in-

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creased and the harvestable amount steadily increases. Currently, Japanese cedar is being utilized asnon-structural and low value products such as blocks for pavements, handrails on sidewalks and packaging materials. On the other, Japanese cedar has been widely used for structural purposes in other countries, especially in Japan. However in Korea, it has not been used for structural purposes yet.

Because of its low mechanical performance and the market demand for long span design, glulam is considered as one of the best ways to utilize Japanese cedar. However, only 6.5% of sawn lamination is allowed as outermost tension side lamination and 65.3% of the lumber can be used as a lamination of structural glued-laminated timber by Korean standards (Oh and Lee, 2010). Inversely, in case of Japanese larch, most of the lumber had higher than 5,000 MPa of modulus of elasticity and it is possible to be used as a lamination (Korea Forest Research Institute, 1998; Shim *et al*., 2006).

Oh and Lee (2010) reported that 34.7% of Japanese cedar cannot be used as a lamination for Korean Standard (KS) glulam. Besides, the grading process is performed after sawing and drying and only after that it can be determined whether the lumber is suitable for structural lamination or not. Therefore, lumber of 34.7% can make the value of Japanese cedar drop seriously.

In manufacturing, the qualification of raw materials is one of the most important steps in the process because the raw material directly affects the quality of the final products. If precise log sorting technologies based on anticipated final product quality can be achieved, the yield of KS-allowed lamination might increase. Besides, because it might be possible to utilize un-sawn logs for other purposes, it would increase the entire yield of products from Japanese cedar and provide economic benefit to the wood industry directly.

The Korea Forest Research Institute provides a log grading rule (Korea Forest Research Institute 2007, KFRI notification No. 2007-2). The KFRI Log grading rule is aimed to estimate the value of logs and the rule classifies logs into three grades by defect characteristics and diameter. Unfortunately, this rule seems to be designed for volumetric yield and the surface quality of products but not for the mechanical performance of the products. To improve the efficiency in manufacturing Japanese cedar lamination for structural glulam, the most important point is considered to be the yield of higher grade lamination rather than the volumetric efficiency or surface quality.

Recently, several studies have been done to investigate the feasibility of using longitudinal stress wave techniques for evaluating log quality. Ross *et al*. (1997) examined the relationship between log measurements and the quality of lumber from balsam fir logs and eastern spruce logs. Green and Ross (1997) described the results from a series of studies using the same technique with Douglas-fir, western hemlock, and southern pine logs. Tsehaye *et al*. (2000) reported that acoustic log segregation provided the opportunity to send only the best quality logs to the saw mill.

For domestic Japanese cedar, Oh and Lee (2010) reported that the ratio of KS-allowed lamination was not enough and they investigated the feasibility of non-KS glulam. However, studies on increasing the yield of KS-allowed lamination by log sorting have not been done yet.

It is necessary to increase the yield of higher grade lamination and KS-allowed lamination for the value recovery of domestic Japanese cedar. This study was aimed to investigate the usefulness and feasibility of ultrasonic log sorting method.

Table 1. Statistics of log grade and lumber obtained by sawing the log

Log grade	No. of log	No. of lumber	No. of lumber per log
1	14	39	2.79
2	33	78	2.36
3	7	14	2.00
4	2	2	1.00
Sum	56	133	2.38

2. MATERIALS and METHODS

2.1. Materials

Japanese cedar (*Cryptomeria japonica*) grown in Seogwipo-si, Jeju, Korea was used in this study. Fifty-six Japanese cedar logs were prepared, to produce plain-sawn 38 mm by 140 mm lamination. The diameter of the top end was in a range between 170 mm and 260 mm. The diameter of the butt end was in a range between 230 mm and 390 mm. The average length was 3,736 mm (from 3,540 mm to 4,100 mm). The average moisture content was 58% and the moisture content of all the logs were higher than the fiber saturation point of 30%.

2.2. Experiments

The sample logs were graded by the existing log grading rule regulated by the Korea Forest Research Institute (KFRI notification No. 2007-2) and the Time of Flight (TOF) of ultrasonic wave was measured. After sawing, the quality of the sawn lumber was investigated by grading.

2.2.1. Visual Characteristics of the Log

The length and diameter at the end of the log and the size and location of defects such as knots, wane, cracks and decay were measured by naked-eye and the logs were graded by the log grading rule of the Korea Forest Research Institute. This rule classified the logs into three log grades by visual characteristics.

2.2.2. Ultrasonic Test of the Log

Transit time of longitudinal ultrasonic wave was measured by a PUNDIT-plus device for each log. Time of Flight (TOF) was calculated by dividing the time for the ultrasonic wave to move from one end of the log to the other end by the length of the log.

2.2.3. Grading Sawn Lumber

After the ultrasonic test, the logs were sawn to produce 38 mm by 140 mm lumbers. To get a good surface quality for gluing each other, the specimens containing decay and wane in wide face were removed. After drying, the lumbers were surfacing into 38 mm by 140 mm. The Modulus of Elasticity (MOE) of each lumber was measured by a conventional grading machine (MGFE-251, IIDA KOGYO co. ltd.). To investigate the effects of ultrasonic log sorting on lamination yield, the E-grade for each piece was determined by Korean Standard grading rule for structural lamination (Structural glued-laminated timber. Korean Standard F 3021).

The dimension of sawn lumber was 38 by 140 mm and this cross section can be used as dimension lumber as well as lamination for structural glued-laminated timber. Therefore, vis-

Table 2. Statistics of E-grade of sawn lumber from each log grade

E-grade[1]	Log Grade[2]								Sum
	1		2		3		4		
E11	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0
E10	0	(0.0)	1	(1.3)	0	(0.0)	0	(0.0)	1
E9	0	(0.0)	1	(1.3)	0	(0.0)	0	(0.0)	1
E8	1	(2.6)	3	(3.8)	0	(0.0)	0	(0.0)	4
E7	0	(0.0)	12	(15.4)	2	(14.3)	0	(0.0)	14
E6	10	(25.6)	16	(20.5)	3	(21.4)	2	(100.0)	31
E5	11	(28.2)	25	(32.1)	5	(35.7)	0	(0.0)	41
Lower than E5[3]	17	(43.6)	20	(25.6)	4	(28.6)	0	(0.0)	41
Sum	39		78		14		2		133

[1] MOE-based grade determined by Korean Standard grading rule for structural lamination (Korean Standard F 3021).
[2] The number of sawn lumber from each log grade by KFRI Log qualification rule (percentage in parenthesis).
[3] In KS F 3021, the lowest grade of lamination is E5.

ual grade for each piece was also determined by the visual grading rule for softwood lumber (Softwood structural lumber, KFRI notification No. 2009-1).

3. RESULTS and DISCUSSIONS

3.1. Influence of the Existing Log Grading Rule on the Productivity of Structural Lumber

Table 1 shows the statistics of log grades sorted by the KFRI log qualification rule. The better grade logs produced more number of pieces. In case of log grade 4, only one piece of lumber was produced by each log; however log grade 1 produced 2.79 pieces of lumber. The KFRI log qualification rule took into consideration the log diameter and defects such as curve and decay. The number of sawn lumber per log was increased with increases in log grade. From this result, it was found that the KFRI log qualification rule could identify logs which would result in a higher volumetric yield.

After sawing the logs, all pieces were graded by a conventional grading machine. When processing the lamination for structural glulam, this type of grading is usually applied. Table 2 shows the statistics of lamination grade from each log grade. Since a log grade of 4 did not produce enough number of pieces to analyze it, Fig. 1 shows only log grade 1, 2 and 3. The results show no difference between the log grades. Actually, log grade 1 produced the more piece of lower grade than E5 than the other log grade. Eventually, the KFRI log qualification rule could not identify high-value logs that would produce higher grade lamination. Therefore, it was concluded that this method was not good for the manufacture of lamination for structural glulam.

Because the KFRI log grading rule is based on the visible characteristics of defects such as knots, strong correlation between the log grade and the visual grade for the structural lumber was expected. However, it didn't show sig-

Table 3. Statistics of visual grade of sawn lumber from each log grade

	Log grade[1]								Sum
	1		2		3		4		
No. 1	9	(23.1)	18	(23.1)	2	(14.3)	0	(0.0)	29
No. 2	5	(12.8)	12	(15.4)	2	(14.3)	0	(0.0)	19
No. 3	11	(28.2)	15	(19.2)	2	(14.3)	1	(50.0)	29
Rejected	14	(35.9)	33	(42.3)	8	(57.1)	1	(50.0)	56
Sum	39		78		14		2		133

[1] The number of sawn lumber from each log grade by KFRI Log qualification rule (percentage in parenthesis).

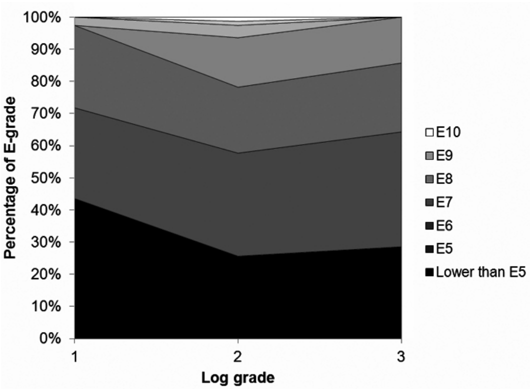

Fig. 1. Percentage of E-grade according to log grades.

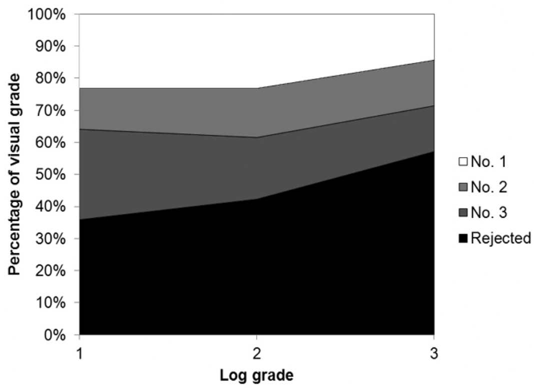

Fig. 2. Percentage of visual grade according to log grade.

nificant difference between the log grades (Table 3 and Fig. 2). The higher log grade yielded the smaller number of rejected lumber in visual grading. However, when comparing No. 2 & better grade lumber which is mainly used as structural lumber, the difference between the log grades was tiny enough to disregard. Actually, the log grade 2 produced larger numbers of No. 2 & better grade than log grade 1.

From these investigations, it was found that KFRI log grading rule contributes the volumetric yield of resulting products regardless of the mechanical performance and reduces the number of rejected lumber in visual grading. However, it could not identify the logs which would produce better structural products.

3.2. Possibility of Log Sorting for Structural Products

Time of flight (TOF) of ultrasonic wave moving from one end of the log to the other end was measured as well as visible characteristics such as knots, diameter and length. The TOF was expected to strongly correlate with stiffness of the sawn lumber and large diameter logs were expected to produce higher grade lumber because larger diameter logs have smaller probability to produce lumber containing juvenile wood around pith than small diameter logs. Wang *et al*. (2009) also reported the combination of TOF and log diameter gave the stronger correlation. Therefore, TOF and the di-

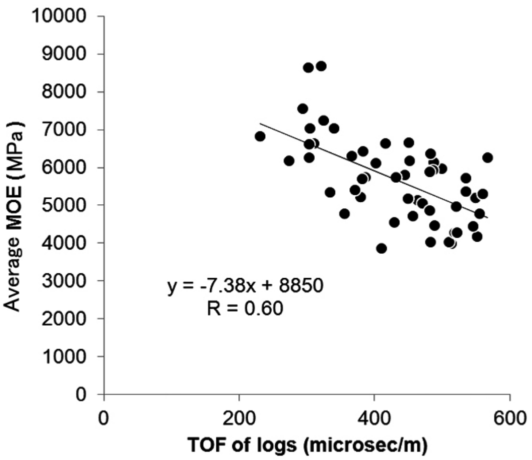

Fig. 3. Relationship between TOF of log and average MOE of sawn lumbers from the log.

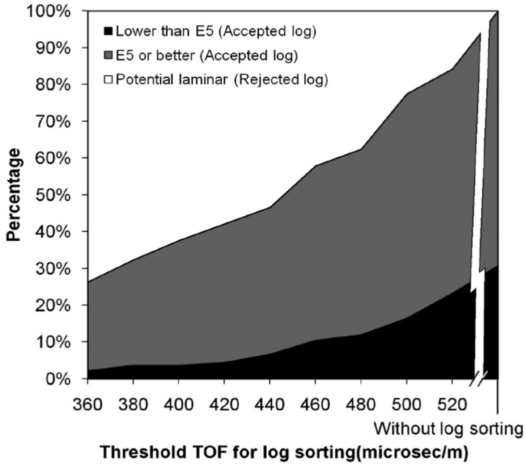

Fig. 4. Yield of KS-accepted lamination according to threshold TOF. Grade E5 is the lowest grade in Korean standards (KS F 3021). Potential laminationis the volume of potential lamination that would be obtained by sawing the rejected logs.

ameter of the log were selected as possible factors for the model to sort the logs. Multivariate regression analysis was carried out by commercial statistical software (SAS 9.0). In this analysis, the TOF and diameter of the log were used as independent variables and the average MOE of the lumbers sawn from the log were used as a dependent variable.

By this analysis, it was found that the TOF is a good predictor for performance of lumber, even though the coefficient of correlation was not high (R = 0.60). However the use of the log diameter as an independent variable did not differ from the case that didn't use the diameter as an independent variable in t-test at a significant level of 0.05.

Naturally, log diameter must have an effect on the yield and it has to be considered when selecting log and evaluating the potential value of log because the larger logs can produce the more pieces of lumbers. However, it was concluded that the influence of log diameter on the stiffness of sawn products is very small.

Fig. 3 shows the relationship between the TOF for each log and the average MOE of for pieces of lumber from the log. The correlation was not strong enough to predict the MOE of lumbers. However, it was considered to give a possibility of log sorting to improve the yield in the lamination manufacture for KS-standard glulam.

3.3. Value Increase by Ultrasonic Log Sorting

Even though the correlation between the TOF of the logs and the MOE of the sawn lumbers-was not strong, log sorting by the TOF order of the logs was attempted. As Fig. 4 shows, this log sorting caused a reduction in the total number of products because the logs with a higher TOF than the threshold were not sawn. However, ultrasonic log sorting method significantly reduced the percentage of lower grade than E5. When all logs were sawn without any log selection, the percentage of lower than E5 grade was 30.8% and it was similar to 34.7% of the

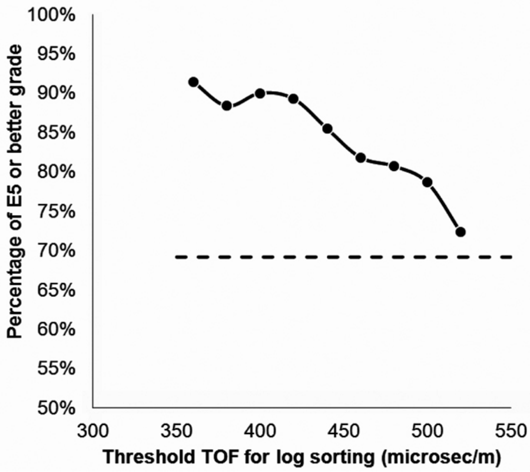

Fig. 5. Relation between threshold TOF and percentage of E5 or better lamination. Dot line is percentage of E5 or better lamination when processing all log without any log selection. Grade E5 is the lowest grade in Korean standards (KS F 3021).

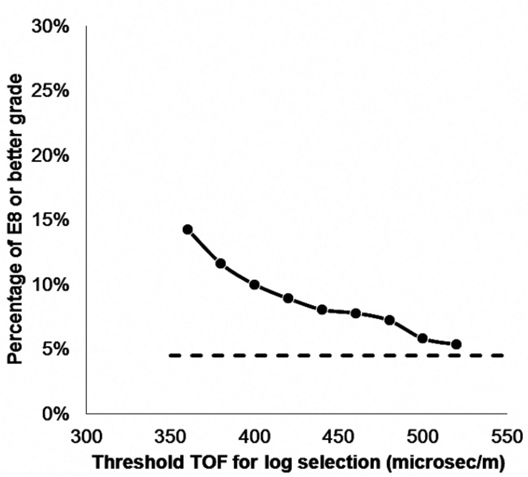

Fig. 6. Relation between threshold TOF and percentage of E8 or better grade. Dot line is percentage of E8 or better lamination when all log was sawn without any log selection. Grade E8 is the lowest grade allowed as the outermost tension lamination by Korean Standards (KS F 3021).

previous result (Oh and Lee, 2010). But when logs showing faster TOF than 440 μsec/m were selected, it dropped to 6.8% (Fig. 4). The E5 grade (5,000 MPa or higher MOE) is the lowest grade in KS F 3021 hence lamination lower than E5 grade should be re-processed to produce other products. Even though the number of products decreased by ultrasonic log sorting, the un-sawn logs could be used for other uses such as wood blocks of which mechanical performance is less important than glulam. However, once the logs were sawn into KS-not-allowed lamination, the lamination would have a lot of restrictions for reprocessing into other products. Moreover, because the sawing and drying process consume a lot of energy, the ultrasonic log sorting can increase the efficiency of the utilization of the logs and can save some energy by preventing lower quality logs to result in KS-not-allowed lamination from sawing and drying.

The selected logs gave much higher yield of E5 or better lamination which are allowed in KS-standard glulam manufacture and showed much higher yield of E8 or better lamination which is allowed as the outermost tension lamination by Korean Standards (Figs. 5 and 6). When sawing logs without any log sorting, the percentage of E8 or better grade was only 4.5% and E5 or better grade occupied only 69.2 percent. These low yields act as a restriction in structural design of glulam. However, ultrasonic log sorting increased both yield (Figs. 5 and 6).

If we assumed that 39 pieces of lamination would be produced, then log selection by ultrasonic TOF would be better than the existing method of the KFRI rule. Fig. 7 shows the difference between the two methods. The same number of logs was sampled by the two log-sorting-methods to produce 39 pieces of lamination. In the KFRI rule, logs of Grade 1 were selected. In the ultrasonic method, logs were selected by TOF order.

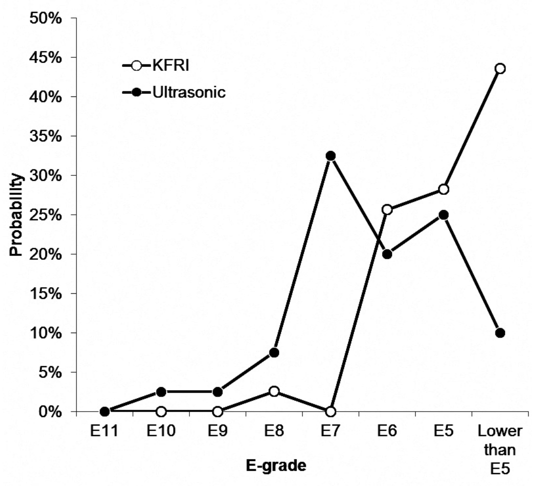

Fig. 7. Distribution of E-grade when logs were selected by two different methods.

The average MOE of lumber from logs of KFRI Log Grade 1 was 5,320 MPa but the ultrasonic method showed higher average of 6,651 MPa than KFRI rule. Besides the ultrasonic method produced more pieces of E8 or better grade even though the same number of logs was cut. In case of KFRI rule, E8 or better grade occupied only 2.6%, but ultrasonic log sorting method showed 12.5%. Ultrasonic log selection also produced much fewer pieces of lower grade than E5. The percentage of lower grade than E5 was significantly reduced from 43.6% to 10.3%.

To evaluate the value of a log, the diameters of the log and market price of each grade have to be considered. The determination of the threshold TOF may depend on an economic viewpoint such as the market price, producing plan and so on. Even though further studies are required to optimize this threshold TOF, the log sorting using ultrasonic wave gave a good possibility to improve the efficiency of wood resource utilization.

4. CONCLUSIONS

This study was one of the efforts to optimize the processing of domestic Japanese cedar and to increase the potential value of domestic wood resources. To enhance the utilization of Japanese cedar which needs to be manufactured into glulam due to its low mechanical performance, this study investigated the feasibility of log sorting by ultrasonic waves for manufacturing of structural lamination.

Even though the TOF of the log does not have strong relationship with the average MOE of the lamination, the log selection based on ultrasonic TOF showed the possibility to increase the efficiency of lamination manufacture. In a case study, the yield of E8 or better grade increased from 2.6% to 12.5% and the KS-not-allowed lamination decreased from 43.6% to 10.3%, when compared to the existing log grading rule regulated by Korean Forest Research Institute.

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REFERENCES

1. Oh, J. K. and J. J. Lee. 2010. Journal of Korean wood science 38(2): 85～93.
2. Shim, K. B., J. H. Park, and K. M. Kim. 2006. Journal of Korea Forest Energy 25(2): 49～54.
3. Ross, R. J., K. A. McDonald, D. W. Green, and K. C. Schad. 1997. Forest Products Journal 47(2): 89～92.
4. Tsehaye, A., A. H. Buchanan, and C. F. Walker. 2000. Wood Science and Technology 34: 337～344.
5. Korea Forest Research Institute. 1998. Development

of New Uses for Domestic Wood Resources pp. 210～213.
6. Korea Forest Research Institute. 2007. Log grading rule. KFRI notification No. 2007-2.
7. Korea Forest Research Institute. 2009. Softwood structural lumber, KFRI notification No. 2009-1.
8. Korean Standards Association. 2003. Structural glued-laminated timber. Korean Standard F 3021.
9. Green, D. W. and R. J. Ross. 1997. in Proceedings of the IUFRO all division 5 international conference. R. J. Barbour and K. E. Skog Ed., pp. 53～58, Washington, USA.