Estimating The Structural Capacity of Skin-timber

Kim, Gwang-Chul

Kang, Chun-Won
Department of Housing environmental design, College of Human Ecology, Chonbuk National University

Matsumura, Junji
Laboratory of Wood Science, Division of Sustainable Bioresources Science, Department of Agro-environmental Sciences, Faculty of Agriculture, Kyushu University

https://doi.org/10.5109/18844

出版情報：九州大学大学院農学研究院紀要. 55 (2), pp.287-295, 2010-10-29. Faculty of Agriculture, Kyushu University
バージョン：

J. Fac. Agr., Kyushu Univ., **55** (2), 287–295 (2010)

Estimating The Structural Capacity of Skin–timber

**Gwang–Chul KIM[1]*, Chun–Won KANG[1]
and Junji MATSUMURA[2]**

Laboratory of Wood Science, Division of Sustainable Bioresources Science,
Department of Agro–environmental Sciences, Faculty of Agriculture,
Kyushu University, Fukuoka 812–8581, Japan
(*Received June 23, 2010 and accepted July 9, 2010*)

In Korea, the market for wood products used in construction has been growing rapidly. Public opinion polls show that for wooden structures, Koreans prefer post–and–beam type construction with structural timber and exposed structural members because of its good appearance.

Skin timber is expected to have good drying properties, improved efficiency of chemical injection, and good dimensional stability. To learn about the mechanical properties of skin timbers, we prepared various miniature skin timber specimens for pine and larch. Bored skin timber samples with five different boring diameters and non–bored sample specimens were used to determine their mechanical strength loss as a factor of the boring diameter. We found a relationship between strength characteristics and boring diameter that was highly significant statistically in the case of pine but not highly significant in the case of larch which has large variation in strength performances among groups. We developed a number of types of estimating equations for pine and larch, but a linear function was selected as the estimating equation for residual strength versus boring diameter because of its convenience. The coefficient of determination and regression equation were 0.97, $y=-1.7664x+49.046$ for pine and those values for larch were 0.87, $y=-2.4285x+68.599$, respectively.

Keywords: Skin timber, post–and–beam, boring diameter, estimating equations, coefficient of determination

INTRODUCTION

Skin timber can be defined to be a cylindrical or rectangular timber which has had more than 90% of its cross–sectional area bored out. Until now it has not been defined or reported on in the scientific literature because the studies about skin timber have been conducted by restricted researchers (Zhao, 2006; Lee, 2007a and 2007b). The characteristic differences between center–bored timber, which exists today, and skin timber, which is not yet being commercially produced, are shown in Table 1.

In Korea, the market for wood products used in construction has been growing rapidly. The Yearbook of Transport and Maritime Affairs (Ministry of Transport and Maritime Affairs, 2007) reported that the total area of authorized wood construction projects grew from merely 88,000 m^2 (649 buildings) in 1995 to 474,000 m^2 (5,700 buildings) in 2006. This represents a growth of more than 400% over a ten–year period, and the total value had doubled just since 2005. The report concluded that there has been an increasing movement in Korea toward building with wood.

Wood construction as a percentage of total new construction grew from 0.24% in 2004 to 0.46% in 2006. This phenomenon seems to have stemmed mainly from such trends as an increasing focus on personal welfare, healthful society, circular society, and an increased value put on one's relation with nature, and it is predicted that this preference for wood construction will continue to grow.

Public opinion polls show that for wooden structures, Koreans prefer post–and–beam construction with structural timber and exposed structural members. This is quite different from the United States and Canada, where most houses and many other types of building are done mainly with wood–frame construction.

A 2007 survey, 'Direction of Korean–style Wood Construction' (Korea Forest Research Institute, 2007), reported that both 63% of suppliers and 98.3% of consumers prefer a post–and–beam method, large structural timbers, and exposed structural members to light frame construction, such as 2×4 construction or pre–fabricated construction.

This tendency, which is peculiar to Korea, calls for large timbers of from 15×15 cm to 30×30 cm in size to be assembled in the traditional way with maximum exposure of structural members, which leads to a variety of difficulties related to processing the materials. The processing requires careful control both of the moisture content and of dimensional stability because there should be no appearance of degradation caused by checking or blue stain, and the structural reliability of the joints must be assured. Furthermore, the timbers cannot exude resin after construction is finished, as it could stain clothes that came in contact with the exposed timbers.

As a results, Koreans are pushing for more complicated structures made with structural timber that resemble the traditional Korean–style wood constructions

[1] Department of Housing environmental design, College of Human Ecology, Chonbuk National University, Jeonju 561–756, Korea
[2] Laboratory of Wood Science, Division of Sustainable Bioresources Science, Department of Agro–environmental Sciences, Faculty of Agriculture, Kyushu University, Fukuoka 812–8581, Japan
* Corresponding author (E–mail: gckim@chonbuk.ac.kr)

Table 1. The characteristic differences between center bored timber and skin timber

		skin timber	center–bored timber	remarks
area ratio		approximately 0.9	approximately 0.4	·closely related to drying and chemical injection properties
drying properties	drying rate	fast	slow	
drying properties	check occurrence	little	severe	
drying properties	final moisture content	lower than 6% possible	lower than 12% impossible	
chemical injection properties	treatment depth	superior	bad	·values are just expected ones
chemical injection properties	injection time	short	somewhat long	·values are just expected ones
chemical injection properties	chemical reduction	excellent	average	·values are just expected ones
uses	interior	possible	impossible	
uses	exterior	possible	possible	
Comparative advantages		·insulation ·light weight ·wide area of humidification ·acceptance ·convenience of construction ·drying properties ·injection properties ·make up for the weak points of other materials ·latent uses	·structural capacity	

rather than the types of wooden construction found in Japan and the United States. Another factor is a recent amendment of a law that will allow wood construction to be taller and larger, which will require structural members to become even larger. This amendment, which was confirmed and announced in 2005, increases the allowed roof height for wood construction from 13 m to 18 m, and increases the height of the from 9 m to 15 m. This amendment reflected improvements in construction methods and progress in the manufacturing of wood construction materials in Korea. Consequently, wooden buildings will be higher and larger, and it is expected that demand for such buildings will increase dramatically. One result of this trend, however, is that it will be necessary to increase the cross–sectional areas of structural members in order to improve their mechanical properties, and so the demand for larger structural timber will be increase. Thus it will be important to develop production methods that can ensure a stable supply of such large–scale structural timbers. In particular we can expect an increasing demand for large structural timbers—at least 15×15 cm in cross section—that are beautiful in appearance and have great structural reliability.

One obstacle to supplying this demand is that large structural timbers are likely to develop check during drying because of the presence of pith and juvenile wood and because moisture must flow a long distance from the core to the surface. Moreover, a much longer drying time is required, and it is difficult to dry such timbers below 19% moisture content which is a safety limit for the degradation. Injecting preservatives and fire–retardant chemicals is also difficult in such large timbers. Thus as the timbers get larger, the degradation in the appearance becomes more of a problem, cracks and strength losses in the joints are more likely, the timbers lose some of their durability and insulation properties, and the cost of wood structures built with these timbers increases.

It was for these reasons that skin timber is being developed. Skin timber is expected to have good drying properties, improved efficiency of chemical injection, and good dimensional stability. At the same time it will be necessary to develop a variety of applications of skin timbers, not just as structural members for building construction but also living necessaries and industrial goods.

To learn about the properties of skin timbers, we prepared a variety of miniature skin timber specimens for pine and larch, including bored samples with five different boring diameters and a non–bored sample, and tested these specimens to determine their loss of mechanical strength loss as a factor of the boring diameter. The results are intended to serve as the basis for developing equations to estimate the residual strength of a sample with a given boring dimension.

MATERIALS AND METHODS

We selected pine and larch, which are widely used as structural members in Korea, for the study sample.

Density was measured according to the standard of KSF 2198, and compressive strength was tested according to the standard of KSF 2206–2004–06. The size of the samples used in the compressive strength test was 20×20×30 mm, in accordance with to KSF 2206.

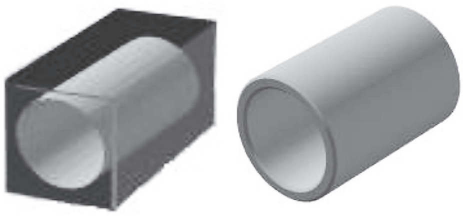

Fig. 1. A feature of rectangular and cylindrical skin timber.

We loaded the samples either parallel with or perpendicular to the grain. The testing machine was an R&B model Unitech STM, whose maximum capacity is 10 tons. The boring diameters were 2.5 mm, 4 mm, 6 mm, 8 mm, and 10 mm, and non–bored samples were prepared as controls. Each group included 5 samples.

Table 2. The boring diameter and residual area ratio

Width (mm)	Length (mm)	Area (mm^2)[a]	Boring dia. (mm)	Circle Area (mm^2)[b]	b/a (%)	Residual area ratio (%)
20	20	400	2.5	4.9	1.2	98.8
20	20	400	4	12.6	3.1	96.9
20	20	400	6	28.3	7.1	92.9
20	20	400	8	50.2	12.6	87.4
20	20	400	10	78.5	19.6	80.4

RESULTS AND DISCUSSION

Figure 2 shows the load–deformation curve for a non–bored pine sample subjected to a compressive strength test for pine, with the load applied parallel to the grain. All of the samples with the load applied parallel to the grain showed a similar pattern; the sample ruptured after reaching the ultimate strength beyond the proportional limit

When the load applied perpendicular to the grain, the response was different from that of the parallel case (Fig. 2.). In particular, the load showed steady increase of deformation without large increase after reached ultimate strength beyond the proportional limit. Fig. 3 is load–deformation curve for a test of compressive strength when the load was applied perpendicular to the grain on a pine sample with no bored.

When the load was applied perpendicular to the grain, the load–deformation curve increased slightly after the inflection point, which implies that the tissue had already lost mechanical performance. For this reason, the ultimate strength has no meaning, but the proportional–limit strength is important to the case when the load is

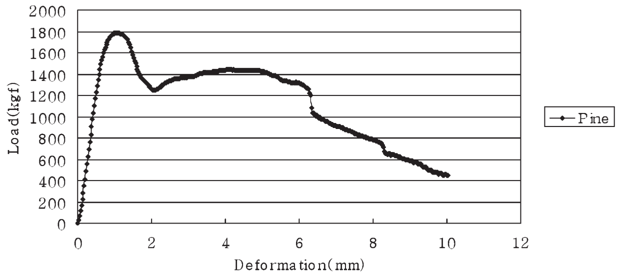

Fig. 2. The load–deformation curve for a load parallel to the grain.

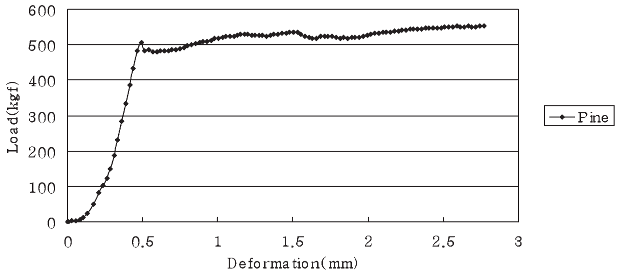

Fig. 3. The load–deformation curve for a load perpendicular to the grain.

applied perpendicular to the grain.

Comparison among boring ratios

Both the ultimate compressive strength and the proportional–limit strength should be calculated for those cases when the load is applied parallel to the grain, but, following KSF standards, only the proportional–limit strength needs to be calculated when the load is applied perpendicular to the grain. Nonetheless, when the load was applied perpendicular to the grain we calculated the ultimate compressive strength as well in order to be able to make comparisons between the two situations.

In the case of compression loads applied parallel to the grain, there was no difference between non–bored specimens and those specimen that had minimum–diameter boring; this was true for both pine and larch (Fig. 4). It is already widely known that, unlikely other strength kinds, compressive strength is not affected by minor area loss. In case of pine, the compressive strength of the 2.5 mm–diameter–boring specimen was higher than that of the non–boring specimen, but that could easily have been caused by natural variations in the strength of the specimens.

For pine, the compressive strength decreased as the boring area increased. In other words, the reduction of the residual area caused a loss of support, leading to a loss of strength as the boring area increased. We discuss estimates of strength loss with an increase in the boring area in later part of this paper.

For larch, the loss of strength as the boring area increased was not so straightforward. Nonetheless, once the boring diameter exceeded 6 mm, the strength decreased as the boring diameter increased. It is possible that boring with diameters of 2.5 mm and of 4 mm had an insignificant effect from the point of view of the

Table 3. Mechanical properties of specimens(Unit: MPa)

	Parallel to grain				Perpendicular to grain			
	Pine		Larch		Pine		Larch	
	Compressive strength	Proportional limit strength	Compressive strength	Proportional limit strength	Compressive strength	Proportional limit strength	Compressive strength	Proportional limit strength
Non–boring	40.97	34.53	50.19	44.5	6.91	4.3	9.09	6.53
2.5 mm	44.16	35.47	46.06	41.67	11.99	6.82	8.73	6.22
4 mm	41.56	33.72	48.42	43.11	9.26	7.53	10.62	5.93
6 mm	40.23	34.31	55.09	49.13	3.9	3.5	4.5	3.12
8 mm	34.37	27.5	47.05	42.34	6.55	5.38	5	3.58
10 mm	31.04	25.43	45.38	38.11	4.66	4.12	5.21	3.55

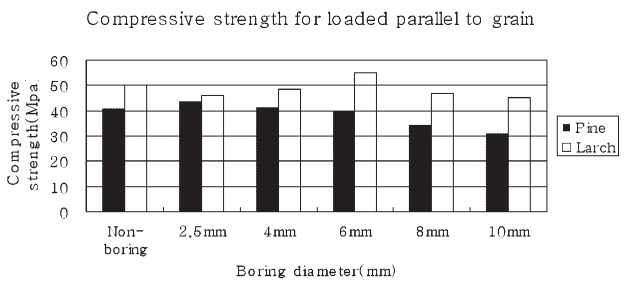

Fig. 4. Compressive strength for the parallel loaded to grain.

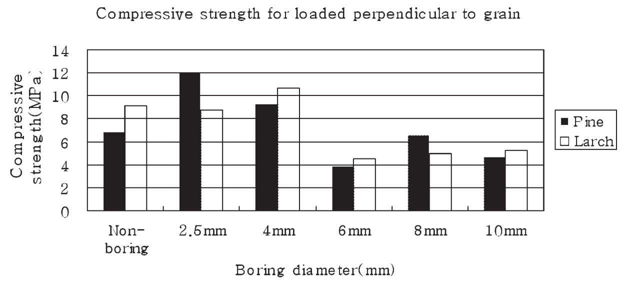

Fig. 6. Compressive strength for the perpendicular loaded to grain.

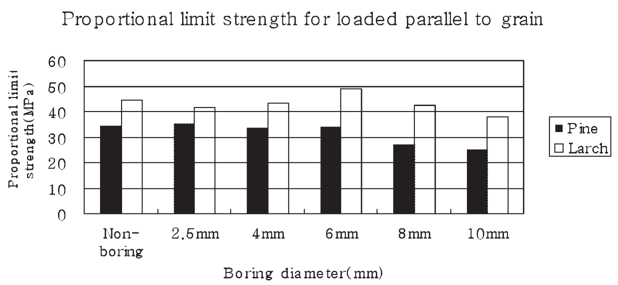

Fig. 5. Proportional–limit strength for loads parallel to the grain.

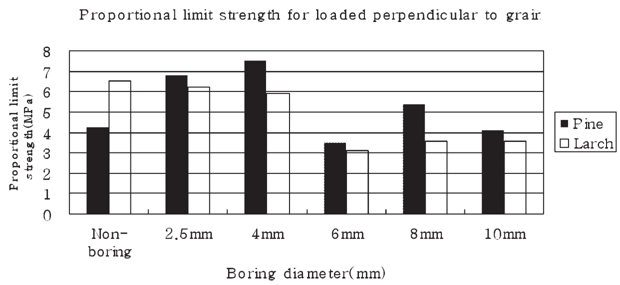

Fig. 7. Proportional limit strength for the perpendicular loaded to grain.

residual area. So, we conducted an additional analysis of the strength of the samples including only those samples where the boring diameter was over 6 mm–diameter.

As shown in Fig. 5, the proportional–limit strengths for loads parallel to the grain showed a pattern similar to that in Fig. 4 because of the similar behavior of the ultimate load and the proportional–limit strength when the load was applied parallel to the grain.

For loads perpendicular to the grain, the compressive strength varied according to micro–structural characteristics rather than to the boring diameter, as can be seen in Fig. 6. As mentioned above, the concept of ultimate strength had no meaning when the load was applied perpendicular to the grain. The proportional–limit strength decreased somewhat as the boring ratio increased, but taken as a whole, the samples showed a more flexible tendency than when the load was parallel to the grain. This can be seen in Fig. 7.

The samples with a boring diameter of 6 mm had noticeably less compressive strength than the other specimens when the load was applied perpendicular to the

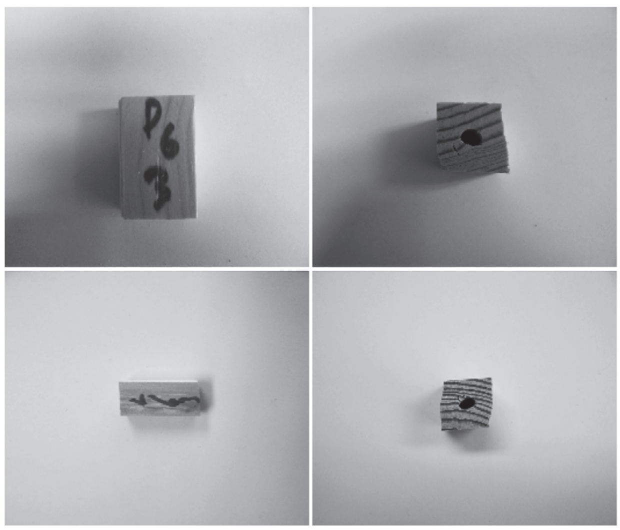

Fig. 8. Failure configuration for loads perpendicular to the grain (Top: pine, bottom: larch).

grain. It can be concluded that there was a severe failure around the hole in this sample that caused the lower strength performance. These results are shown in Fig. 8.

Statistical significance test of strength performance versus boring area ratio

A test of statistical significance was performed in order to examine the differences in strength properties among the non–bored specimen and the five bored specimens. We chose to use analysis of variance because there was one control group and five test groups with different boring diameters. The confidence level was set at 95%. The MS Statistical tool of MS Excel was used for the analysis.

–Test of statistical significance for strength performance versus boring area ratio for pine–(compressive strength parallel to the grain)

Because the F value of 11.10 was greater than the reject limit of 2.62, we concluded that there were significant differences among the compressive strengths as the boring diameter varied in the pine samples. (Appendix 3.2.1.1)

–Test of statistical significance for strength performance versus boring area ratio for pine–(compressive strength perpendicular to grain)

Because the F value of 5.74 was greater than the reject limit of 2.62, we concluded that there were significant differences among the specimens for loads applied perpendicular to the grain. (Appendix 3.2.1.2) If the non–bored specimen was excluded in order to predict the strength loss as the boring diameter increased and the significance test was conducted only for the bored specimens, a higher coefficient of determination would have been produced.

The results of the significance test for both the cases parallel and perpendicular to the grain, with the non–bored specimen excluded, are as follows: It shows a considerable increase compared with the data that did include the non–bored specimen. The F value increased from 11.10 to 24.33 for loads parallel to the grain and increased from 5.74 to 9.05 for loads perpendicular to the grain. (Appendix 3.2.1.3)

–Test of statistical significance for strength performance versus boring area ratio for larch– (compressive strength parallel to grain)

As expected, there was no statistical significance in the strength versus the boring diameter when all the samples were included. However, when the samples with boring diameter less than 4 mm were excluded, the significance test showed that the F value had risen considerably, from 1.24 to 3.40.(Appendix 3.2.2.1) Thus we concluded that there was indeed a significant change in strength as the boring diameter increased.

–Test of statistical significance for strength performance versus boring area ratio for larch– (compressive strength perpendicular to grain)

There was a clear effect as the boring diameter changed in the situation when loads were applied perpendicular to the grain, but the differences had no regularities and thus it seemed that deriving an estimating equation would be difficult. (Appendix 3.2.2.2)

Estimation of strength loss as the area of boring increases

It is expected that the mechanical properties of the samples would decrease as the diameter of boring increases, because the larger the boring area becomes, the less area there is to bear the load. It is desirable to test as many specimens as possible, but it is difficult to test a sufficient number of full–scale specimens. Thus our goal was to derive an estimate of strength loss based on data from the tests of the non–bored specimen and the specimens with five different boring diameters. Although there are certainly differences between how a full–size specimen behaves and the behavior of these small specimens, still our data should help us understand the tendencies in the strength characteristics as the residual areas get smaller.

–Estimate of strength loss as the area of boring increases for pine

Fig. 9 shows the estimates of compressive strength as a function of boring diameter when the load is parallel to the grain. Either linear function or 2nd–order polynomials provide relatively good accuracy, but we chose to develop a 3rd–order polynomial and an exponential function for more exact estimates.

As shown in Table 4, four different types of estimating equation were developed for compressive strength versus the boring diameter for pine.

We found that the 3rd–order polynomial and the 2nd–order polynomial functions had greater accuracy for making estimates than the linear function or the exponential function, according to the coefficient of determination and experimental data for estimates. The 3rd–order polynomial has the highest coefficient of determi-

Table 4. Estimating equations for the strength capacity of pine (loaded parallel to the grain)

Type of estimation equation	Estimation equations	R^2
Linear	$y=-1.1556x+44.595$	0.73
2nd polynomial	$y=-0.2104x^2+0.9661x+41.602$	0.95
3rd polynomial	$y=0.0028x^3-0.6259x^2+2.4494x+41.017$	0.98
Exponential	$y=45.071e^{-0.0313x}$	0.73

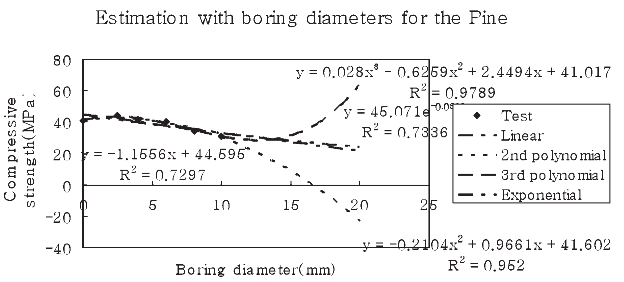

Fig. 9. Estimating equations for the compressive strength versus boring diameter (pine).

nation, but the estimation of strength is impractical when certain points (beyond 15mm) exceed. Also, for convenience, the linear equation can provide strength estimates with reasonable accuracy.

As can be seen in Fig. 9, the residual area ratio in case of 20 mm–diameter boring—that is, the maximum boring diameter used in this study —is 20%, and a considerable loss of performance is expected. In this case, it is estimated that the compressive strength can reach about 50 percent of its original strength. However, further study is needed to provide a more exact analysis of performance in the case of full–scale skin timber. Fig. 10 shows the results from the compressive strength test for all bored specimen; the non–bored specimens were excluded, as they produced the most variation for pine. With the exception of the non–bored specimen, it is possible to make estimates with high accuracy. In this case, the four estimation equations produced a high–accuracy equation that had a coefficient of determination approximately equal to 1. This is shown in Table 5.

It is impractical for 2nd polynomial function which predict a perfect loss of strength under 20 mm, and for 3rd polynomial which predict the increase of residual strength beyond 15 mm, besides, exponential function is not efficient in terms of convenience of use. Therefore, the linear estimating equation offers both accuracy and convenience and is considered suitable for predicting compressive strength as a function of boring diameter.

–Estimates of strength loss as boring diameter increases for larch

The linear equation, 2nd–order polynomial function, and exponential function all produced low coefficients of determination when applied to estimating compressive strength in larch as a function of boring diameter of boring, which was different from the case for pine. The details are shown is Fig. 11. The coefficient of determination for the 3rd–order polynomial estimating equation was 0.49, but it shows the residual strength of the material disappearing before the boring diameter reaches 15mm, so it is unreasonable for estimates.

For boring diameters of 2.5 mm and 4 mm that missing part of the sample is very slight and so has a minor influence on compressive strength. So, if additional

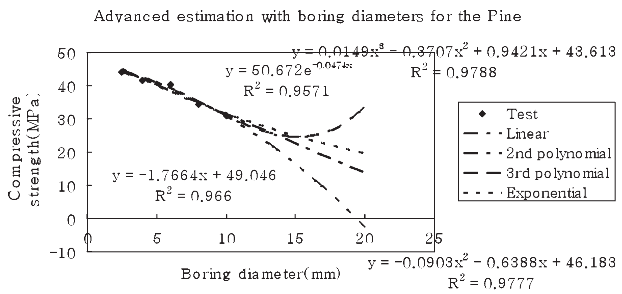

Fig. 10. Advanced estimating equations for compressive strength versus boring diameter (pine).

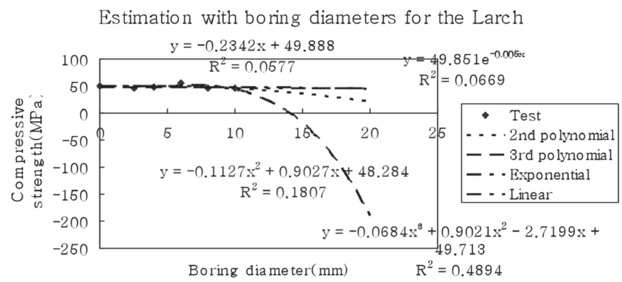

Fig. 11. Estimating equations for compressive strength versus boring diameter (larch).

Table 5. Advanced estimating equations for the strength capacity of pine (loaded parallel to the grain)

Type of estimation equation	Estimation equations	R^2
Linear	$y=-1.7664x+49.046$	0.97
2nd polynomial	$y=-0.0903x^2-0.6388x+46.183$	0.98
3rd polynomial	$y=0.0149x^3-0.3707x^2+0.9421x+43.613$	0.98
Exponential	$y=50.672e^{-0.0474x}$	0.96

Table 6. Advanced estimating equations for the strength capacity of larch (loaded parallel to grain)

Type of estimation equation	Estimation equations	R^2
Linear	$y=-2.4285x+68.599$	0.87
2nd polynomial	$y=-0.7953x^2-15.153x+117.38$	1.00
Exponential	$y=72.218e^{-0.0485x}$	0.88

advanced estimating equation were developed without data below 4 mm of diameter of boring, another results can be obtained. The linear equation, the 2nd–order polynomial function, and the exponential function can provide more accurate estimates.

The 2nd–order polynomial function produced a high coefficient of determination, but it predicts an increase in residual strength as the boring diameter goes beyond 15 mm, so it is clearly unsuitable. As the exponential function has no advantages compared with the linear estimating equation, which is more convenient, the linear estimation equation is suitable for predicting the compressive strength as a function of the boring diameter.

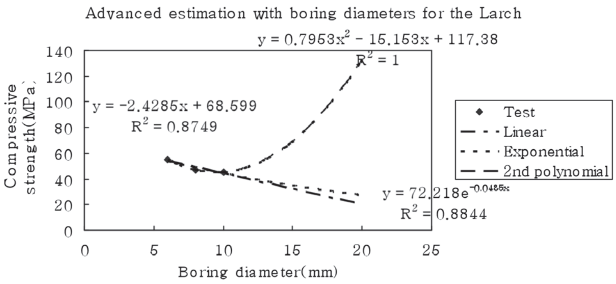

Fig. 12. Advanced estimating equations for the compressive strength versus boring diameter (larch).

CONCLUSION

The ultimate object of this study was to improve the quality of structural timber and to contribute to a stable supply by helping improve the performance of post–and–beam products that use skin timber. We were unable to test full–scale specimens because of poor study conditions, so we used small–scale specimens. We observed the strength performance as the boring diameter increased, testing for loads applied both parallel and perpendicular to the grain.

We found a relationship between strength characteristics and boring diameter that was highly significant statistically in the case of pine but not highly significant in the case of larch which has large variation in strength performances among groups. Therefore, it should be needed to complement study with enough number of specimens and the investigation of wood micro–structure. We developed a number of types of estimating equations for pine and larch, but a linear function was selected as the estimating equation for residual strength versus boring diameter because of its convenience. The coefficient of determination was 0.97, and $y=-1.7664x+49.046$ was the estimating equation of compressive strength versus boring diameter for pine with the load applied parallel to the grain. The coefficient of determination was 0.87, and $y=-2.4285x+68.599$ was the estimating equation for compressive strength versus boring diameter for larch with the load applied parallel to the grain.

ACKOWLEDGEMENT

This study was carried out with the support of 'Forest Science & Technology Projects (Project No. 140201001)' provided by Korea Forest Service

REFERENCES

An annual report of construction statistics. 2007 The Ministry of Construction and Transportation.(in Korean)

An annual report for forestry tendency. 2007 The office of Forestry. (in Korean)

Breyer, D. E. 1993 *Design of wood structures*. McGraw–Hill, New York, USA.

Canadian Wood Council. 1995 *Wood design manual*. CWC, Canada

KSF 2198. Determination of density and specific gravity of wood. (in Korean)

KSF 2206–2004–06. Method of compression test for wood. (in Korean)

Korean Building Code. 2006 Kimoondang.(in Korean)

Nam–Ho Lee. 2007a Effect of Vapor–dam Treatment on the Air Circulating oven Drying Characteristics of Bamboo Tubes *J. of Korean Wood Sci. &Tech.* **35**(1): 11–16 (in Korean)

Nam–Ho Lee. 2007b Effect of Vapor–dam Treatment and End–coating Treatment on the air Circulating oven Drying Characteristics of Green Stocks for Korean Traditional Double–headed Drum. *J. of Korean Wood Sci. &Tech.* **35**(1): 17–26 (in Korean)

The research on the future of Korean–style wooden building. 2007 The Korea Forest Research Institute (in Korean)

Xue–Feng Zhao. 2006 A Study on Drying Mechanism of Cylindrical–tube Wood. Chonbuk National University. Master's thesis: 1–59 (in Korean)

Yeo, H. M. *et al.* 2007 Effect of center boring and kerf treatment on kiln–drying of larch square and round timber. *Forest Products J.* **57**(11): 85–92

APPENDIX

3.2.1.1
3.2.1.2

Summary

Groups	Count	Sum	Average	Variance
Column 1	5	204.8527	40.97055	36.4097
Column 2	5	220.8244	44.16489	7.293316
Column 3	5	207.798	41.55959	2.251863
Column 4	5	201.1277	40.22555	8.508606
Column 5	5	171.829	34.36581	5.172539
Column 6	5	155.1944	31.03889	6.816006

3.2.1.3

Anova

Source of variation	SS	df	MS	F	P value	F critical
Between groups	615.001	5	123.0002	11.10577	1.27E–05	2.620654
Within groups	265.8081	24	11.07534			
Total	880.8091	29				

3.2.2.1

Summary

Groups	Count	Sum	Average	Variance
Column 1	5	34.52811	6.905622	16.08486
Column 2	5	59.94754	11.98951	10.24044
Column 3	5	46.31081	9.262162	6.356753
Column 4	5	19.47785	3.89557	4.422808
Column 5	5	32.75097	6.550193	6.190193
Column 6	5	23.28415	4.65683	3.846664

Anova

Source of variation	SS	df	MS	F	P value	F critical
Between groups	225.4359	5	45.08717	5.738506	0.001277	2.620654
Within groups	188.5669	24	7.856953			
Total	414.0027	29				

Summary (loaded parallel to grain)

Groups	Count	Sum	Average	Variance
Column 1	5	220.8244	44.16489	7.293316
Column 2	5	207.798	41.55959	2.251863
Column 3	5	201.1277	40.22555	8.508606
Column 4	5	171.829	34.36581	5.172539
Column 5	5	155.1944	31.03889	6.816006
Column 6	5	23.28415	4.65683	3.846664

Anova

Source of variation	SS	df	MS	F	P value	F critical
Between groups	584.6349	4	146.1587	24.32547	1.93E-07	2.866081
Within groups	120.1693	20	6.008466			
Total	704.8042	24				

Summary (loaded perpendicular to grain)

Groups	Count	Sum	Average	Variance
Column 1	5	59.94754	11.98951	10.24044
Column 2	5	46.31081	9.262162	6.356753
Column 3	5	19.47785	3.89557	4.422808
Column 4	5	32.75097	6.550193	6.190193
Column 5	5	23.28415	4.65683	3.846664
Column 6	5	23.28415	4.65683	3.846664

Anova

Source of variation	SS	df	MS	F	P value	F critical
Between groups	224.88	4	56.22001	9.051144	0.000242	2.866081
Within groups	124.2274	20	6.211371			
Total	349.1075	24				

3.2.2.2

Summary

Groups	Count	Sum	Average	Variance
Column 1	5	250.9407	50.18813	17.26066
Column 2	5	230.2912	46.05823	105.7436
Column 3	5	242.1197	48.42394	66.24302
Column 4	5	275.4445	55.0889	10.93833
Column 5	5	235.2546	47.05092	88.93599
Column 6	5	226.875	45.37501	18.94992

Anova

Source of variation	SS	df	MS	F	P value	F critical
Between groups	319.3135	5	63.86269	1.243789	0.319975	2.620654
Within groups	1232.286	24	51.34526			
Total	1551.6	29				

Summary

Groups	Count	Sum	Average	Variance	
Column 1	5	5	275.4445	55.0889	10.93833
Column 2	5	5	235.2546	47.05092	88.93599
Column 3	5	5	226.875	45.37501	18.94992

Anova

Source of variation	SS	df	MS	F	P value	F critical
Between groups	269.629	2	134.8145	3.403712	0.06747	3.885294
Within groups	475.297	12	39.60808			
Total	744.926	14				

Summary

Groups	Count	Sum	Average	Variance
Column 1	5	45.44639	9.089279	1.349984
Column 2	5	43.66022	8.732044	13.30638
Column 3	5	53.07886	10.61577	26.71136
Column 4	5	22.49617	4.499233	3.337077
Column 5	5	25.00459	5.000919	1.030449
Column 6	5	26.04276	5.208552	3.187577

Anova

Source of variation	SS	df	MS	F	P value	F critical
Between groups	168.3975	5	33.67951	4.130527	0.007555	2.620654
Within groups	195.6913	24	8.153804			
Total	364.0888	29				