PREDICTING THE STRENGTH OF SAWN PRODUCTS BY X-RAY SCANNING OF LOGS: A PRELIMINARY STUDY

Johan Oja
Ph.D.

Stig Grundberg[1]
Tech. Lic.

and

Anders Grönlund
Professor
Lulea University of Technology
Skelleftea Campus
SKERIA 3
S-931 87 Skelleftea, Sweden

(Received March 1999)

ABSTRACT

The aim of the study was to investigate the possibility of predicting the strength of centerboards from Norway spruce (*Picea abies* (L.) Karst.) saw logs, based on simulated X-ray LogScanner measurements. The study was based on eight logs. The logs were scanned using computed tomography (CT), four centerboards were sawn from each log, and the bending stiffness (MOE) and strength (MOR) of the boards were measured. The CT-images were used for simulations of the industrial X-ray LogScanner, resulting in simulated measurements of knot volume and the green density of heartwood. Finally, multivariate models were calibrated using Partial Least Squares (PLS) regression. These models predict bending strength and stiffness based on the variables measured by the simulated X-ray LogScanner. Both bending strength and modulus of elasticity were defined as the mean value of the four boards from each log.

The results were very promising, with strong models for prediction of both MOR (R^2 = 0.73) and MOE (R^2 = 0.94) mean values for all four boards from each log. The results indicate that the X-ray LogScanner can be used for the sorting of saw logs according to strength and stiffness. The next step should be to repeat the study on a larger sample of material.

Keywords: Grading, modulus of elasticity (MOE), modulus of rupture (MOR), partial least squares (PLS), scanning, saw logs, X-ray.

INTRODUCTION

The successful running of a sawmill is dependent on its ability to achieve the highest possible value recovery from the saw logs. Today many sawmills are increasing the amount of customer-adapted products. One such trend is that strength-graded lumber is becoming more common. The reason for this is, of course, that when using wood for construction purposes, it is important to know the strength (modulus of rupture, MOR) and stiffness (modulus of elasticity, MOE) of the material. When a sawmill wants to produce strength-graded lumber with special dimensions, it is very important to have chosen the right raw material; i.e., the sawmill must be able to predict the strength of the sawn products before the actual sawing operation. Thus there is a need for a nondestructive method that mea-

[1] Stig Grundberg is also working at Swedish Institute for Wood Technology Research in Skelleftea, Sweden.

Wood and Fiber Science, 32(2), 2000, pp. 203–208
© 2000 by the Society of Wood Science and Technology

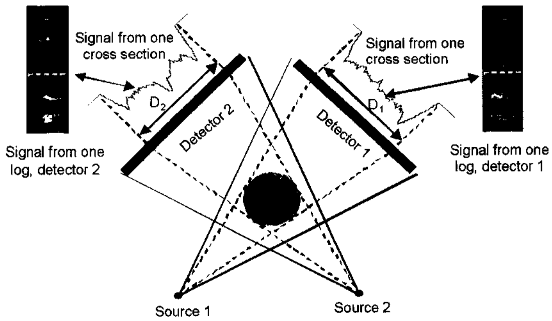

FIG. 1. Schematic description of the X-ray Log-Scanner described by Grundberg and Grönlund (1995).

sures properties of the log that correlate to the strength and stiffness of the sawn products.

Aratake et al. (1992) and Ross et al. (1997) show that it is possible to measure the MOE of a log using longitudinal stress wave techniques and that the MOE of the log correlates with the average MOE of the lumber from that log. Similar results are also obtained using ultrasonic measurements (Sandoz 1996). An alternative method would be to measure density and knottiness of the log and use these measures for predictions of the strength and stiffness of the lumber. It is well known that the density of wood and the size of the knots affect strength and stiffness (Kollman and Côté 1968). Kliger et al. (1995) show that the density together with knot area ratio can be used to explain variations in strength and stiffness of Norway spruce (*Picea abies* (L.) Karst.) beams. Grundberg (1994) found that, for industrial applications, the use of X-ray is a very suitable method of measuring internal properties of saw logs (e.g., knottiness and density). Grundberg and Grönlund (1998) show that knot volume of logs can be measured with an industrial X-ray LogScanner (Fig. 1), while Wang (1998) shows that there is a strong correlation between the green density of heartwood measured in CT-images and the dry density. Wang (1998) also shows that the correlation between dry and green density of sapwood is low due to the high moisture content of green sapwood. These facts make the green heartwood density an interesting variable, while green sapwood density is less interesting to measure. Consequently, it seems possible to measure density and knot volume of saw logs and use these measurements for predictions of the strength and stiffness of the sawn products.

Hence the aim of this study was to investigate the possibility of predicting the strength and stiffness of centerboards from Norway spruce saw logs on the basis of simulated X-ray LogScanner measurements of knot volume and green density of the heartwood.

MATERIAL AND METHODS

The study was based on eight logs of Norway spruce (*Picea abies* Karst). Two fast-grown and two slow-grown logs were taken from each of two sawmills, one in northern and one in southern Sweden. The logs were transported to Luleå University of Technology, Skellefteå Campus, where the logs were scanned in a medical computed tomography (CT) scanner (Siemens SOMATOM AR.T.). Each log was scanned every 10 mm with a 5-mm-wide X-ray beam. The CT-images (8-bit, 256 × 256 pixels) were then used for simulations of the X-ray LogScanner (Fig. 1) as described by Grundberg and Grönlund (1995). These simulations resulted in measurements of knot volume and the green density of the heartwood of the logs. After CT-scanning, four centerboards were sawn from each log using normal sawing patterns (cant sawing). The dimensions of the planed boards were, after drying to 12% moisture content, 45 × 145 mm. The boards were proof-loaded (Boström 1997), and after that, the bending strength and stiffness of the individual boards (MOR_{ind} and MOE_{ind}) were tested according to SS-EN 408 (Anon. 1995). Both proof-loading and testing of strength and stiffness were performed at SP Swedish National Testing and Research Institute in Borås. Nine boards were broken during the proof-loading and for these nine boards the MOR and MOE from the proof-loading were used as measures of bending strength and stiffness. For each log, the average and standard deviation of the strength (MOR_{mean}, MOR_{std})

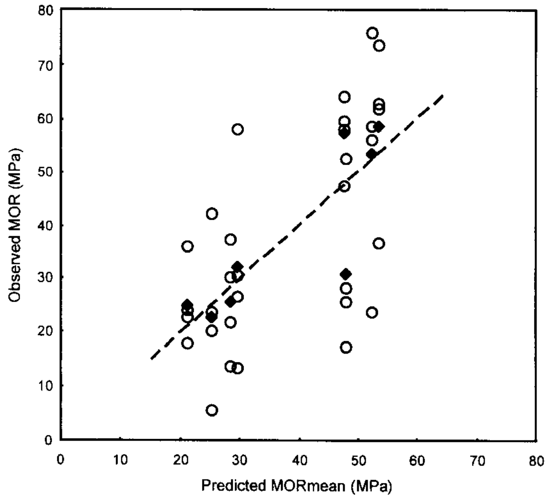

FIG. 2. Predicted and observed values of bending strength (MOR) for eight logs, a total number of 32 boards.

- ♦ MOR_{mean}, observed mean values for all boards from one log (R^2 = 0.73)
- ○ MOR_{ind}, observed values for individual boards (R^2 = 0.41).

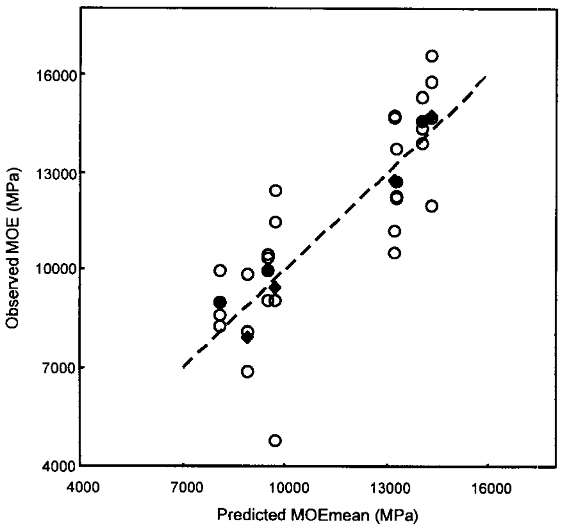

FIG. 3. Predicted and observed values of bending stiffness (MOE) for the boards from eight logs, a total number of 32 boards.

- ♦ MOE_{mean}, observed mean values for all boards from one log (R^2 = 0.94)
- ○ MOE_{ind}, observed values for individual boards (R^2 = 0.68).

and stiffness (MOE_{mean}, MOE_{std}) were calculated using the values from all boards.

Finally, multivariate models were calibrated using Partial Least Squares (PLS) regression (Geladi and Kowalski 1986) and the software program SIMCA 7.0 from Umetri AB (Anon. 1998). Partial least squares regression was chosen due to its ability to handle noisy and collinear data. These models use the knot volume (V_{knot}) and the green density of the heartwood ($Dens_{heart}$), measured by the simulated X-ray LogScanner to predict the average bending strength and stiffness of the boards from the same log. The predicted average strength and stiffness were also compared to the strength and stiffness of the individual boards, and the relationships between strength, stiffness, V_{knot} and $Dens_{heart}$ were studied.

The X-ray LogScanner also makes it possible to measure the knot volume in four different halves of the log (Oja et al. 1998a). This makes it possible to calculate mean value ($V_{knot,mean}$) and standard deviation ($V_{knot,std}$) of the knot volume in each log. An uneven distribution of knots in a log would be expected to cause variation in strength and stiffness of the boards from that log. Because of this, the relative standard deviation of the knot volume ($V_{rel,std} = V_{knot,std}/V_{knot,mean}$) was compared to the variation in strength (MOR_{std}) and stiffness (MOE_{std}).

RESULTS

Models based on the simulated X-ray LogScanner measurements of knot volume and heartwood green density were calibrated for both MOR_{mean} (R^2 = 0.73) and MOE_{mean} (R^2 = 0.94) (Figs. 2 and 3). The R^2-value of the model for prediction of MOR_{mean} is only slightly lower compared to the relation between MOE_{mean} and MOR_{mean} (R^2 = 0.76) (Table 1). This means that, in terms of R^2-values, the difference is very little between the accuracy of predictions of MOR_{mean} based on the simulated X-ray LogScanner measurements and the accuracy of predictions of MOR_{mean} based on actual measurements of MOE of the boards. It is also clear that both V_{knot} and $Dens_{heart}$ are

TABLE 1. *Correlation between predicted MOE and MOR, measured MOE and MOR, and measured knot volume (V_{knot}) and heartwood green density ($Dens_{heart}$). MOR_{ind} and MOE_{ind} are the measured bending strength and stiffness of individual boards. MOR_{mean} and MOE_{mean} are mean values for the bending strength and stiffness of all four boards from one log.*

Predicted variable	Measured variables	R^2
MOE_{mean}	V_{knot}, $Dens_{heart}$	0.94
MOE_{mean}	$Dens_{heart}$	0.74
MOE_{mean}	V_{knot}	0.70
MOE_{ind}	V_{knot}, $Dens_{heart}$	0.68
MOR_{mean}	V_{knot}, $Dens_{heart}$	0.73
MOR_{mean}	$Dens_{heart}$	0.59
MOR_{mean}	V_{knot}	0.53
MOR_{ind}	V_{knot}, $Dens_{heart}$	0.41
MOR_{mean}	MOE_{mean}	0.76
MOR_{ind}	MOE_{ind}	0.62
MOE_{std}	$V_{rel,std}$	0.62
MOR_{std}	$V_{rel,std}$	0.42

needed for the predictions of MOE_{mean} and MOR_{mean}. When V_{knot} or $Dens_{heart}$ is used alone, the R^2-values when predicting MOE_{mean} and MOR_{mean} become much lower (R^2 = 0.53–74) (Table 1).

When individual boards are studied, the correlation between predictions and measured values is weaker (Figs. 2 and 3). R^2 = 0.68 for MOE_{ind} and R^2 = 0.41 for MOR_{ind} (Table 1). The variation between boards from the same log can be explained partly by uneven distribution of knots. When the variation in knot distribution between different parts of a log is measured with the simulated X-ray LogScanner, there is a correlation between $V_{rel,std}$ and MOE_{std} (R^2 = 0.62) and MOR_{std} (R^2 = 0.42) respectively (Fig. 4, Table 1).

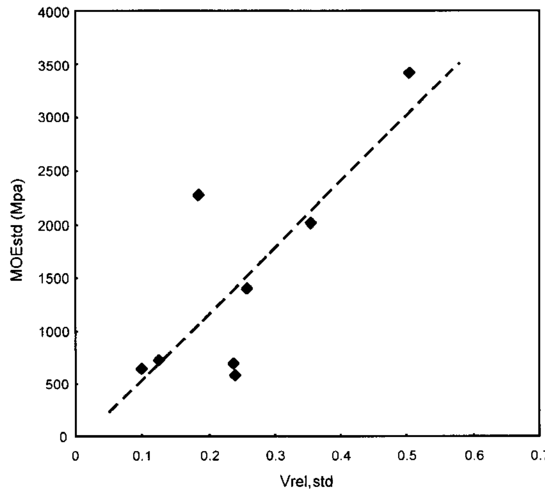

FIG. 4. The relation between the variation in bending stiffness (MOE) for boards from one log and the variation in knot volume between different parts of the log. For each log the standard deviation of the stiffness (MOE_{std}) was calculated using the values from all four boards. The relative standard deviation of the knot volume ($V_{rel,std}$) was measured with the simulated X-ray LogScanner.

DISCUSSION

The results are promising and indicate that the X-ray LogScanner can be used for sorting saw logs according to the expected strength and stiffness of the sawn products. The results also show that it may be possible to choose logs with little variation in stiffness between different boards from the same log.

The accuracy of the prediction of MOR_{mean} and MOE_{mean} in this study is high compared to earlier results based on dynamic methods (Aratake et al. 1992; Ross et al. 1997) or ultrasonic measurements (Sandoz 1996). This makes the results of the study very promising, even though the results should be treated only as indications because of the limited material (only eight logs). The possibility of using the X-ray LogScanner for strength sorting of saw logs is interesting since the X-ray LogScanner has the advantage of being able to measure a number of different properties of saw logs (Grundberg and Grönlund 1997, 1998; Oja et al. 1998a, b). This means that the sawmill can use the same equipment for a number of different purposes.

As already mentioned, the study is based on a very limited amount of material with a number of special properties. The fact that the logs are of approximately the same dimension and that all the logs have relatively large amounts of heartwood probably makes the predictions better than they would be for a larger and less homogeneous material. On the other hand, the large logs have other properties, e.g. large pith shakes and four boards from each log, that make it more difficult to predict the strength of the boards. The correlation between strength and stiffness of individual boards ($R^2 = 0.62$) is in accordance with Kliger et al. (1995), which indicates that the individual variations are approximately the same.

In this study, the X-ray LogScanner predicted the expected average strength of center boards from one log. The strength of an individual board is partly a result of the sawing position, i.e. from which part of the log the board is sawn (cf. Fig. 4). Therefore, one possible way of improving the predictions would be to use information about the sawing position to predict the strength and stiffness of individual boards. It is also possible to add information about the knot distribution, but in order to be meaningful such a study requires a larger sample of material.

The study was based on eight logs that were chosen in such a way (fast-grown vs. slow-grown) that there were two groups of logs, high and low MOE (Fig. 3). Compared to a normally distributed material, these two groups made the models stronger in terms of R^2-values. Therefore, a follow-up study should be based on a sample of material whose properties cover a broad continuum.

The study indicated that X-ray scanning of green saw logs makes it possible to sort the logs with respect to the expected average strength of the center boards. As the results were promising but based on a very limited material, the conclusion was that the study should be repeated on a larger sample of material.

CONCLUSIONS

- The results were very promising with strong models for prediction of both MOR ($R^2 = 0.73$) and MOE ($R^2 = 0.94$).
- The results indicate that an X-ray LogScanner can be used for sorting of saw logs according to strength and stiffness.
- The next step should be to repeat the study on a larger sample of material.

ACKNOWLEDGMENTS

Thanks are due to Lars Boström and Mikael Perstorper for providing the results of the testing of bending strength and stiffness. The project was financed by NUTEK and the Swedish Council for Forestry and Agricultural Research.

REFERENCES

ANON. 1995. SS-EN 408, Timber structures—Structural timber and glued laminated timber: Determination of some physical and mechanical properties. SIS Förlag AB, Stockholm, Sweden.

——— 1998. User's guide to SIMCA Version 7.0. Umetri AB. Umeå, Sweden. 230 pp.

ARATAKE, S., T. ARIMA, T. SAKODA, AND Y. NAKAMURA. 1992. Estimation of modulus of rupture (MOR) and modulus of elasticity (MOE) of lumber using higher natural frequency of log in pile of logs. Mokuzai Gakkaishi 38(11):995–1001.

BOSTRÖM, L. 1997. Proof-loading, en method för hållfasthetsklassificering av konstruktionsvirke. Projektrapport: Höghållfast konstruktionsvirke, optimering av förädlingskedjan med ny mätteknik och förbättrade logistiksystem, Section C, M. Perstorper, ed. 12 pp. Division of Steel and Timber Structures, Chalmers University of Technology. Göteborg, Sweden.

GELADI, P., AND B. R. KOWALSKI. 1986. Partial least-squares regression: A tutorial. Analytica Chimica Acta 185(1986):1–17.

GRUNDBERG, S. 1994. Scanning for internal defects in logs. Licentiate thesis 1994:14 L, Luleå University of Technology, Luleå. Sweden. 121 pp.

———, AND A. GRÖNLUND. 1995. The development of a LogScanner for Scots pine. Pages 39–50 *in* O. Lindgren, ed. Proc. 2nd International Seminar/Workshop on Scanning Technology and Image Processing on Wood. Technical Report 1995:22 T, Luleå University of Technology. Luleå, Sweden.

———, AND ———. 1997. Simulated grading of logs with an X-ray LogScanner—Grading accuracy compared with manual grading. Scand. J. For. Res. 12:70–76.

———, AND ———. 1998. Feature extraction with the aid of an X-ray LogScanner. Pages 39–49 *in* A. Grönlund, O. Hagman, and O. Lindgren, eds. Proc. 3rd International Wood Scanning Seminar, August 17–19, 1998. Lövånger, Sweden. Technical Report 1998:27, Luleå University of Technology. Luleå, Sweden.

KLIGER, I. R., M. PERSTORPER, G. JOHANSSON, AND P. J. PELLICANE. 1995. Quality of timber products from Norway spruce, part 3. Influence of spatial position and growth characteristics on bending stiffness and strength. Wood Sci. Technol. 29:397–410.

KOLLMAN, F. F. P., AND W. A. CÔTÉ. 1968. Principles of wood science and technology, vol. I. Solid wood. Springer-Verlag, Berlin, Germany. Pp. 292–375.

OJA, J., S. GRUNDBERG, AND A. GRÖNLUND. 1998a. Simulated control of sawing position based on X-ray LogScanner measurements. Pages 51–58 *in* A. Grönlund, O. Hagman, and O. Lindgren, eds. Proc. 3rd International Wood Scanning Seminar, August 17–19, 1998. Lövånger, Sweden. Technical Report 1998:27, Luleå University of Technology. Luleå, Sweden.

———, ———, AND ———. 1998b. Measuring the outer shape of *Pinus sylvestris* saw logs with an X-ray LogScanner. Scand. J. For. Res. 13:340–347.

ROSS, R. J., K. A. MCDONALD, D. W. GREEN, AND K. C. SCHAD. 1997. Relationship between log and lumber modulus of elasticity. Forest Prod. J. 47(2):89–92.

SANDOZ, J. L. 1996. Ultrasonic solid wood evaluation in industrial applications. Pages 147–153 *in* J. L. Sandoz, ed. Proc. 10th International Symposium on Nondestructive Testing of Wood, Lausanne, Switzerland, August 26–28, 1996. Swiss Federal Institute of Technology, Chair of Timber Construction. Lausanne, Switzerland.

WANG, X. 1998. Pulp log sorting based on growth rings and wood density obtained by image analysis of X-ray and optical data. Dr. Scient thesis, Image Processing Laboratory, Department of Informatics, University of Oslo, Norway. 103 pp.