On-line stiffness prediction of green pinus radiata lumber using FT-NIR to aid saw pattern selection

D.Marston,[a] **R.Meder,**[b] **A.Thumm,**[b] **B.Prescott,**[a] **and A.Schmidt**[c]

[a]*Biolab Limited, P.O.Box 31-044, Lower Hutt, New Zealand*

[b]*NewZealand Forest Research Institute Limited, Private Bag 3020, Rotorua, New Zealand*

[c]*Previously with Bruker Optik GmbH, Rudolf-Plank-Str.-27, D-76275, Ettlington, Germany*

Introduction

The milling of Pinus radiata structural grade lumber is a marginal cost process and any decrease in the amount of product down-grade arising from sub-standard product performance would dramatically alter the overall profitability of a saw milling operation. It is therefore in the interest of the sawmill to recover as much structural material as possible from the low stiffness zone (juvenile) core without increasing the amount of off-grade material produced. In practice the corewood is not commonly processed to produce structural timber, instead it is boxed out by cutting a central board 100–150 mm wide and diverted to lower value industrial grade products such as boxing or fence palings. It is widely recognised, however, that in individual cases radiata pine corewood does contain material that, if recovered, would meet structural grade requirements (Figures 1 & 2).

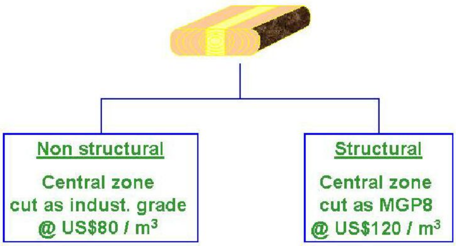

Figure 1. Non-structural and Structural Sawn Pinus radiata lumber values.

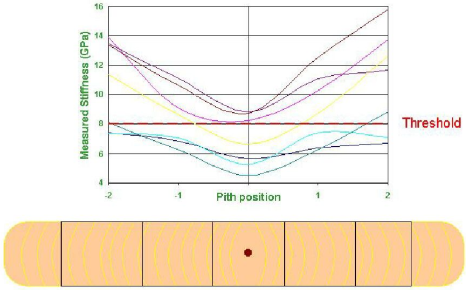

Figure 2. Typical stiffness profiles of Pinus radiata cants.

Suitable technology for the on-line identification of the individual logs or cants that could be processed to recover the higher value structural material is currently unavailable. Although current systems based on ultrasonic propagation time do provide a good tool for pre-selection based on log density, they suffer from the inability to provide spatial information in profile across a log. A key to improved best practices for lumber production is therefore a better understanding of the potential grade recovery in a log or cant before breakdown. Through this a decision can be made whether the core of a log will be cut into structural or non-structural material.

Copyright 2004 NIR Publications. All rights reserved.

Laboratory screening trials using increment core samples also show potential for using NIR as a predictive measure of stiffness.[1] Hoffmeyer and Pedersen[2] have earlier shown NIR has the ability to predict the density and strength (*MoR*) of spruce in small clear test pieces and boards while similar trials on radiata pine small clear test pieces and mini-LVL test pieces have shown the potential for predicting stiffness (*MoE*).[3,4]

Unlike previous laboratory scale trials, this trial has investigated the full-scale commercial use of NIR at an intervention point further back again in the value chain. By scanning the cant after primary break-down and before ripping, it is possible to establish a profile of potential stiffness recoveries across the cant before set-up of the cutting profile. It would allow the decision to be made to either cut the cant through for recovery of 100 × 50 mm structural material from the corewood, or to box the central region, say as 100 × 100 mm or 120 × 100 mm for use in industrial grade products.

Materials and methods

Sample selection

A commercial sawmill (>100,000 m^3 sawn-out production) located in the central North Island of New Zealand was the site for the trial. Run-of-mill radiata pine logs were selected prior to primary breakdown on the basis of ultrasonic propagation time to ensure as wide a range of log stiffness as possible was represented in the trial. These logs were marked on the end to allow identification. The corresponding cants (100 or 200 mm thick × 4.8 m) were recovered after primary breakdown and removed from the process chain to a storage deck where they were scanned. No input was provided by the research team into the selection of the opening face cutting pattern. A total of 180 cants were selected during the course of the two-week trial. After scanning, the cants were colour coded to enable the relative position of boards within each cant to be reconstructed following secondary breakdown.

NIR spectroscopy

A gantry was constructed above the storage deck (Figure 3) that enabled the NIR instrument to traverse the length of the cant at a speed of approximately 2 m s^{-1} during which eight spectra were averaged. Each 4.8 m cant was scanned green on one surface using the Bruker Matrix-E™ FT-NIR spectrometer (Bruker Optik, Ettlingen, Germany). Spectra were acquired over the spectral range 10,000–4000 cm–1 (1000–2500 nm) at 16 cm^{-1} resolution.

Figure 3. Photo showing the gantry and Matrix-E NIR traversing the cant.

The cants were scanned along the mid-point between the visible pith at either end. Scans were also performed at constant 50 mm offsets to one side of the centre line (Figure 4). The cants were then labelled, marked and returned

Copyright 2004 NIR Publications. All rights reserved.

to the process chain to be ripped to 50 mm boards on a Schurmann gang saw, with the aim to recover boards centred on the pith. This process was prone to some error, as the saw lines did not always follow parallel to the scan lines.

No special consideration was given to the presence or size of knots, which, given the rate at which the NIR was scanning and traversing the length of the cants, would not contribute significantly to the overall averaged scan. The surface area of knots on a board, as compared to the clear area, is relatively small and would only have had a minor influence on the averaged spectrum of a scan line. Knots do, however, have an influence on the stiffness in a bending test. For reasons of practicality, the resulting error from this was accepted as part of the overall error in this study.

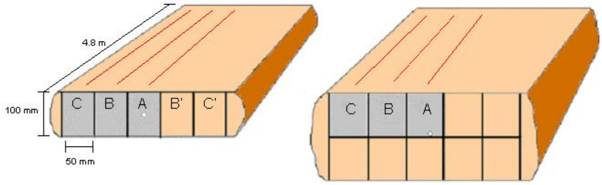

Figure 4. Position of scanned regions of the (left) 100 mm and (right) 200 mm cants viewed end-on showing location of pith, scan lines, saw lines and position labels.

Stiffness testing

The individual boards were recovered post ripping from the green chain, the paint marks enabling their relative position within each cant to be reconstructed and then each board was uniquely labelled on one end identifying both the cant and position in cant. After batch kiln-drying (120°C/90°C), the 200 mm boards were ripped to 100 mm. All the resulting and original 100 mm rough-sawn boards were gauged to 97 × 47 mm. The long span modulus of elasticity ($L\ MoE_j$) was determined on each board by testing on edge, as a joist, using a Grade 1 Baldwin universal test machine with a span of 4.5 m (load applied from above at two points, 1650 mm and 3150 mm). Checks were also made to ensure the stiffness of scanned and non-scanned areas correlated according to the cant symmetry (Figure 5).

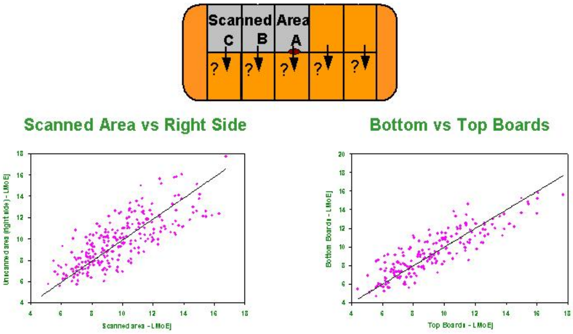

Figure 5. Correlation of stiffness of scanned vs non-scanned boards for 200 mm deep cants.

Multivariate calibration

In summary, this study used the PLS technique of modelling using *The Unscrambler* v7.01 (CAMO A/S, Oslo, Norway, www.camo.no). No weighting or pre-processing was applied to the data, which was used in the range 1100–2500 nm. The final number of latent variables selected for incorporation into the prediction model was chosen by the software as being the latent variable that gives the first minimum y residual variance when using full cross-validation. Full cross-validation using 20 segments with 20 samples each was used unless otherwise mentioned.

Copyright 2004 NIR Publications. All rights reserved.

Results and discussion

Between marking and numbering of the cants and the stiffness measurement of the boards there are several processes (e.g. drying and gauging), during the course of which some samples and sample numbers were destroyed. Consequently, reliable matches of spectral and physical data are available for 409 individual boards, representing 152 cants of the original 180 cants.

Figure 6 shows the predicted versus measured calibration plot based on the PLS regression of NIR spectra versus long span MoE_j for all the recovered boards. It shows that boards from 200 mm cants (closed circles) are predominantly above the 1 : 1 target line (black line) which means they tend to be over predicted (i.e. they are predicted to be stiffer than they actually are). This was to some extent expected since less corewood is exposed in a 200 mm cant. Furthermore, the boards recovered in some cases were sawn across adjacent scan lines, so that the spectrum does not truly correspond to the edge of the board. No attempt has been made to account for this error and its true effect on the model accuracy is unknown.

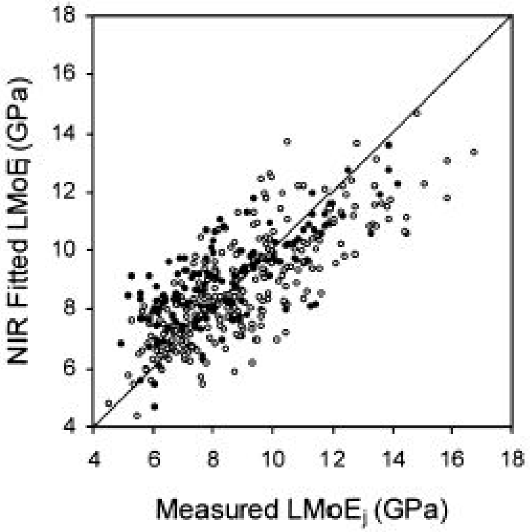

Figure 6. Calibration plot of predicted versus measured stiffness value (open circles = 100 mm cants, closed circles = 200 mm cants, *n* = 411, 12 latent variables, R^2 = 0.53, *RMSEP* = 1.47).

The stiffness analysis of the cants by NIR can be used to decide sawing patterns: cants with high core stiffness will be cut in a way that includes the core into the structural material; cants with low corewood stiffness will be cut in a way that avoids the core material being cut into structural grades. The stiffness of the corewood is predominantly described by the scan taken at position A, which is central over the pith. The spectra from boards from position A and its respective prediction of stiffness were then used in a theoretical decision making process.

The timber produced from a saw milling operation is graded according to various standards for use in certain construction applications. This grading is generally made according to stiffness with cut-off values used to segregate timber into populations with a certain average. As an example, for boards to meet the Australia/New Zealand Standard of MGP-8 they need to have an *average* stiffness of 8 GPa.[5]

A series of cut-off values was examined for the distribution of accepted and rejected cants they yield. This means, if the prediction of the A-board of a cant was below the respective cut-off, the cants would be rejected from a higher yield sawing pattern and vice versa. Table 1 shows the yields for the different cut-off values for the 100 and 200 mm cants.

The average stiffness of accepted and rejected boards shows a good separation in distinctly different populations for all cut-off values. The unexpectedly high value for rejected boards for the 6.5 GPa cut-off is caused by the model being poorly defined in that region due to low sample numbers being available for model construction. For the structural grade MGP-8 the accepted

Copyright 2004 NIR Publications. All rights reserved.

boards need to have an average stiffness of 8 GPa. This is achieved when a cut-off value of 7.5 GPa is applied.

Table 1. Average stiffness (GPa) for accepted and rejected boards with respect to the cut-off value (n = number of boards).

Cut-off value of NIR prediction	Average real stiffness rejected A-boards	SD rejected A-boards	n	Average real stiffness accepted A-boards	SD accepted A-boards	n
6.0	6.1	1.0	17	7.5	1.3	129
6.5	6.5	1.0	34	7.6	1.4	112
7.0	6.5	1.0	45	7.7	1.4	101
7.5	6.7	1.2	71	7.9	1.3	74
8.0	6.8	1.1	91	8.2	1.3	55
8.5	6.9	1.2	108	8.4	1.3	38

This means that if all boards with a predicted stiffness of 7.5 GPa or greater are accepted for upgrade, the accepted boards will have a stiffness distribution suitable for MGP-8. At this cut-off level about 50% of boards would be upgraded, namely 74 boards of 145 boards.

In order to account for the relationship between the NIR spectra and stiffness of the samples it is necessary to consider the regions of the spectrum that are selected by the PLS regression as giving rise to the greatest variance in the measured stiffness. This is best shown in Figure 6.

This shows a representative NIR spectrum (solid line) for comparison and the three loadings of the regression that describe the greatest variance in the *MoE* data (32%). The most prominent peaks are due to the O-H vibration arising from water at 1445 and 1940 nm and the broad cellulose peak at 2100 nm. The predominant peaks in these latent variables (aside from the water peaks) are several smaller cellulose bands at 1820, 2347 and 2488 nm while there is one combination band at 2270 nm that could be attributed to lignin. However, the overall conclusion is that the variance in cellulose absorbances in the NIR spectra is the governing feature giving rise to correlation with the observed long span stiffness measurements.

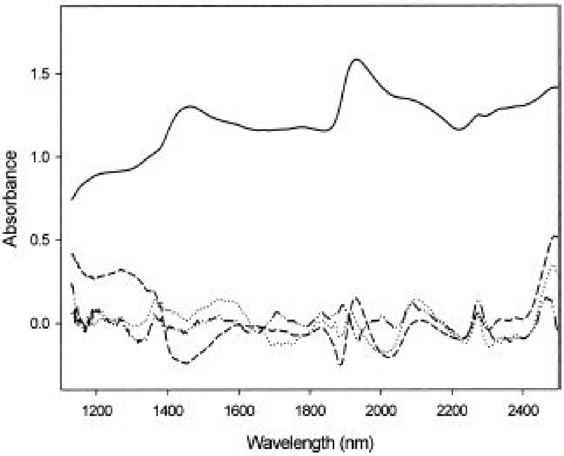

Figure 6. Representative spectrum (solid line) and loading weights for the three latent variables that describe the greatest variance in the *MoE* data (32%) (LV3 = dashed – –, LV5 = dotted ····, LV9 = dot-dashed ·· – – ··).

Conclusions

Near infrared spectroscopy has been used in a commercial saw milling operation to provide spatial information of the stiffness profile across radiata pine cants of varying thickness. In spite of

Copyright 2004 NIR Publications. All rights reserved.

the harsh operating environment the results show the potential of the Bruker Matrix-E FT-NIR to predict the stiffness of individual pieces of lumber recovered from the cant after secondary breakdown into final product. Practical application of the technology would allow segregation of lumber into populations based on average stiffness classes, enabling low stiffness material to be removed from the high value structural lumber processing stream.

Acknowledgements

The authors would like to thank the management and operators of the sawmill for all their assistance and co-operation during the trial and for allowing us to publish the results of the study. We would also like to gratefully acknowledge the assistance of Bruker Optik, Germany, for providing the Matrix-E for the trial and Tony Davies for permission to reproduce parts of this article from JNIRS (Meder, Thumm & Marston, JNIRS, (2003), 11(2), article in press).

References

1. L.R. Schimleck, R. Evans, J. Ilic and A.C. Matheson, Can. J. For. Res. 32, 129 (2002).
2. P. Hoffmeyer and J. Pedersen, Holz Roh Werkst. 53, 165 (1995).
3. A. Thumm and R. Meder, J. Near Infrared Spectrosc. 9, 117 (2001).
4. R. Meder, A. Thumm and H. Bier, Holz Roh Werkst. 60, 159 (2002).
5. Australian Standard/New Zealand Standard, AS/NZS 1748 (1997).

Copyright 2004 NIR Publications. All rights reserved.