Sapwood Moisture Content Measurements in Scots Pine Sawlogs Combining X-ray and 3D Scanning

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ABSTRACT

Wood industry of today deals with large volumes in an almost automatic process, which is not fully adapted to the variability of the raw material. Consequently, it is crucial to sort the wood according to material properties in order to process the wood efficiently and to obtain high quality end products. One material property which could be used for sorting is the moisture content of the sapwood, an important parameter for both the processing and the end products.

Most large Swedish sawmills are using 3D scanners for quality sorting of Scots pine (*Pinus sylvestris* L.) sawlogs based on outer shape. Recently, some sawmills have also invested in X-ray log scanners in order to sort the sawlogs based on inner properties. It has previously been shown that, by combining raw data from industrial 3D and X-ray log scanners using path length compensation, green sapwood density and dry heartwood density can be estimated.

In this study, the dry heartwood density was used to find an estimate of the dry sapwood density, thus allowing the calculation of the sapwood moisture content. The log scanner data used in this study was simulated from 560 Scots pine sawlogs which had previously been scanned in a computed tomography (CT) scanner. The estimated sapwood moisture contents were then compared to reference values calculated by drying samples to 9% moisture content.

It was found that the moisture content estimate could be used to separate the logs into two groups with high and low moisture content, correctly identifying all logs with very low moisture content as dry logs. Out of all logs, 70% were correctly classified. The moisture content estimate could also be compared to the dry density dependent maximum moisture content and used to identify logs that have actually started to dry.

INTRODUCTION

Wood is a biological material with great variations in material properties between individual logs as well as within the same log. The wood industry of today deals with large volumes in an almost automatic process, which is not fully adapted to the variability of the raw material. Thus, the sawn wood also shows a great variability in material properties and a large share of the production carries combinations of dimension and grade not meeting customer demands (Grönlund 1992).

In order to reduce the production of off-grade products, the sawlogs may be sorted according to specific material properties or predicted grade of the sawn goods prior to actual sawing. This enables the sawmill to saw each log into dimensions where the grade of the log is best utilized, in this way improving the value of the sawn wood.

Sorting of the logs according to certain material properties also helps the sawmill to adjust the process so that the wood can be processed efficiently and the highest possible quality of the end products can be obtained. Examples of such material properties are the sapwood moisture content and the density.

In the drying process, boards with similar density and moisture content distribution show similar behaviour and, by sorting the boards upon those parameters prior to the drying, well adapted drying schedules with respect to time, energy consumption and quality of the final product can be constructed (Johansson et al. 2003). Having known initial moisture content in the batch, over-drying can be decreased when using fixed schedules and the prediction of the finishing time can be done more accurately when using adaptive schedules (Larsson & Morén 2003).

In most large Swedish sawmills sawing Scots pine (*Pinus sylvestris* L.), optical three-dimensional (3D) scanners are used for quality sorting of sawlogs based on outer shape (e.g. Grace 1994, Jäppinen & Nylinder 1997, Oja et al. 1999). Recently, some sawmills have also invested in X-ray log scanners, able to determine inner properties of the logs such as knot structure (Pietikäinen 1996, Grundberg & Grönlund 1998), heartwood content (Skatter 1998, Oja et al. 2001) and density (Oja et al. 2001).

Because most sawmills installing an X-ray scanner already have a 3D scanner present, the combination of both scanners can be used to sort logs with improved precision (Skog 2009). Skog and Oja (2009) showed that the combined 3D X-ray method can be used to predict both green sapwood density and dry heartwood density in Scots pine sawlogs.

It should be possible to use the dry heartwood density to find an estimate of the dry sapwood density and the dry and green sapwood densities could then be combined to obtain the sapwood moisture content in the log. Sorting the logs based on this information would give batches with more homogeneous material properties, which would be helpful when optimizing the processing of the logs.

The aim of this study has been to develop a sapwood moisture content calculation model and to evaluate the feasibility of this method for sorting of sawlogs.

MATERIALS AND METHODS

Calculation of reference values

The development of moisture content calculation algorithms requires a set of sawlogs with well defined green and dry densities. In this study, the CT scanned logs of the Swedish pine stem bank (Grundberg et al. 1995) have been used. The stem bank contains a total of 560 Scots pine sawlogs (165 butt logs and 395 upper logs), for which cross-sectional CT images are available every 10 mm within knot whorls and every 40 mm between whorls, giving a good knowledge of the green density in the logs. For each log, a knot-free cross-section around 400 mm from the log was chosen and a reference value for the green sapwood density $\rho_{u,u}$ was calculated by taking the average over the cross-section.

In the stem bank, CT images of slices cut out from the butt end of every log and conditioned to 9% moisture content are also available. In these pictures, the average sapwood density at 9% $\rho_{9,9}$ was calculated and used to find a reference value for the dry sapwood density $\rho_{0,0}$.

This value was calculated using the relation between the density $\rho_{u,u}$ at moisture content u and the dry density $\rho_{0,0}$:

$$\rho_{u,u} = \frac{m_u}{V_u} = \frac{(1+u)\cdot m_0}{(1+\alpha_u)\cdot V_0} = \frac{(1+u)}{(1+\alpha_u)}\rho_{0,0} \qquad (1)$$

where m_u is the mass, V_u is the volume and α_u is the swelling coefficient at moisture content u. The swelling coefficient was calculated using:

$$\alpha_u = \alpha_{\max} \cdot u/u_{FSP} \quad \text{for} \quad u < u_{FSP} \qquad (2a)$$
$$\alpha_u = \alpha_{\max} \quad \text{for} \quad u \geq u_{FSP} \qquad (2b)$$

where $\alpha_{\max}$ and u_{FSP} are the swelling coefficient and the moisture content at the fibre saturation point. The average values for Scots pine were used, $\alpha_{\max}$ = 14.2% (Esping 1992) and u_{FSP} = 28% (Kollman & Côté 1968).

By inserting the reference values of the green sapwood density and the dry sapwood density in equation (1) and using the swelling from equation (2b), the reference value for the green sapwood moisture content was found.

Prediction of sapwood moisture content using the 3D X-ray method

Industrial 3D and X-ray data for the logs was simulated from the CT images. The simulated data files were then combined using the 3D X-ray technique and the average green sapwood density of each log was calculated as described by Skog and Oja (2009).

From the combined data, the dry heartwood density 400 mm from the butt end of each log was also calculated (Skog & Oja 2009) and a linear model predicting the dry sapwood density from the dry heartwood density was developed. Separate linear models for butt logs and upper logs were used.

Finally, a prediction of the green sapwood moisture content was calculated by combining the average green sapwood density and the predicted dry sapwood density using equations (1) and (2b).

Evaluation of results

A linear model between the predicted and the reference sapwood moisture contents was developed and predictability R^2 and root mean square error (RMSE) were calculated. A threshold value at 145% predicted moisture content was used to separate the logs into two groups with lower and higher moisture content respectively.

Calculated moisture contents were also compared to the theoretical maximum moisture content for saturated wood (Esping 1992):

$$u_{\max} = \frac{1560 kgm^{-3} - \rho_{0,u}}{1.56 \cdot \rho_{0,u}} \qquad (3)$$

To express $u_{\max}$ as a function of dry density, the relation $\rho_{0,u} = \rho_{0,0}/(1+\alpha_{\max})$ was applied*. The average value of the swelling coefficient at FSP was used, $\alpha_{\max} = 14.2\%$.

RESULTS AND DISCUSSION

For all 560 logs, the green density of the sapwood was predicted with a precision of $R^2 = 0.65$ and RMSE = 25 kgm^{-3}, Figure 1 (Skog & Oja 2009). For two outlier logs, the green density of the reference cross-section is much lower than the predicted log average, probably due to local drying of the log.

The dry density of the sapwood was predicted with a precision of $R^2 = 0.47$ and RMSE = 43 kgm^{-3} for 553 (98.8%) of the logs, see Figure 2. The logs failing to be predicted were all large butt logs, which was expected, because for very large diameters, the X-ray detector touches bottom. In this study, the dry sapwood density was predicted from the dry heartwood density using separate linear models for butt logs and upper logs. For the reference data, the predictability between dry heartwood and dry sapwood densities was found to be $R^2 = 0.57$. The dry heartwood density in turn can be predicted with $R^2 = 0.85$ using the 3D X-ray technique (Skog & Oja 2009). This means that most of the observed uncertainty when predicting the dry sapwood density is due to the poor predictability between the dry heartwood and the dry sapwood densities.

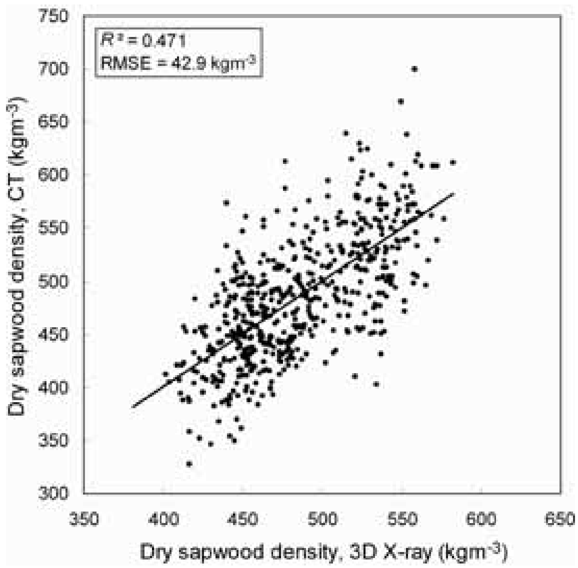

Figure 2: Sapwood dry density in 553 Scots pine sawlogs, measurements in CT images versus predictions from simulated X-ray and 3D log scanner data.

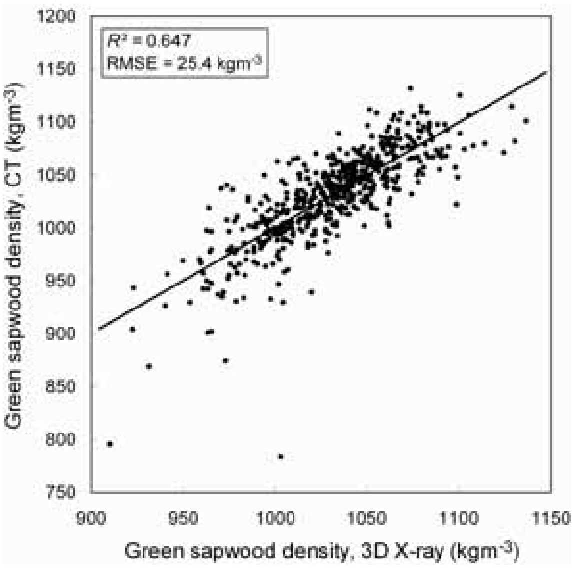

Figure 1: Sapwood green density in 560 Scots pine sawlogs, measurements in CT images versus predictions from simulated X-ray and 3D log scanner data.

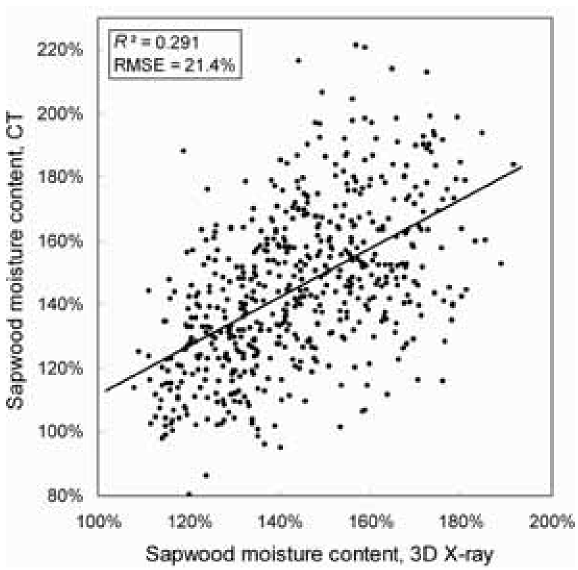

Figure 3: Sapwood moisture content in 553 Scots pine sawlogs, measurements in CT images versus predictions from simulated X-ray and 3D log scanner data.

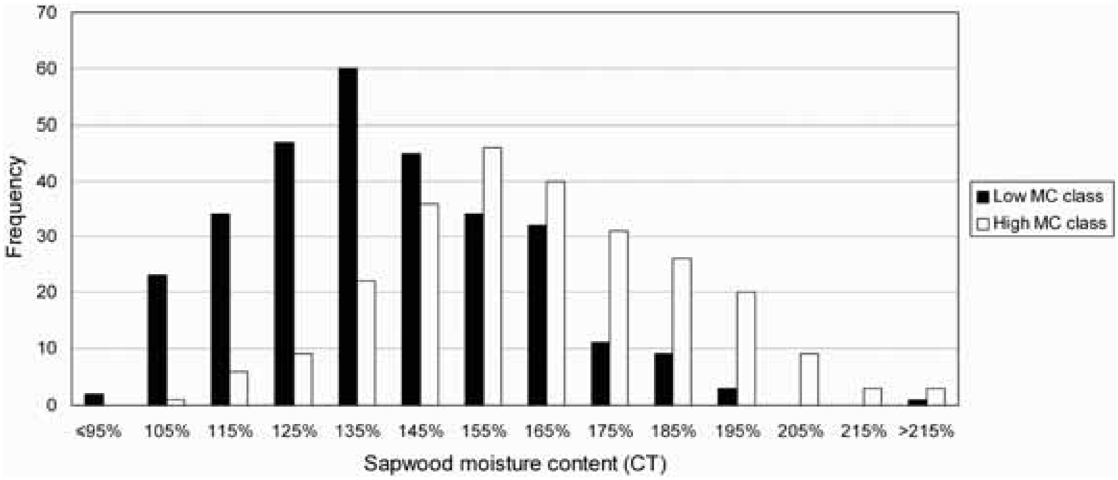

Figure 4: Observed sapwood moisture content (value from CT images) for 553 Scots pine sawlogs, separated into two classes depending on the sapwood moisture content predicted from simulated X-ray and 3D log scanner data.

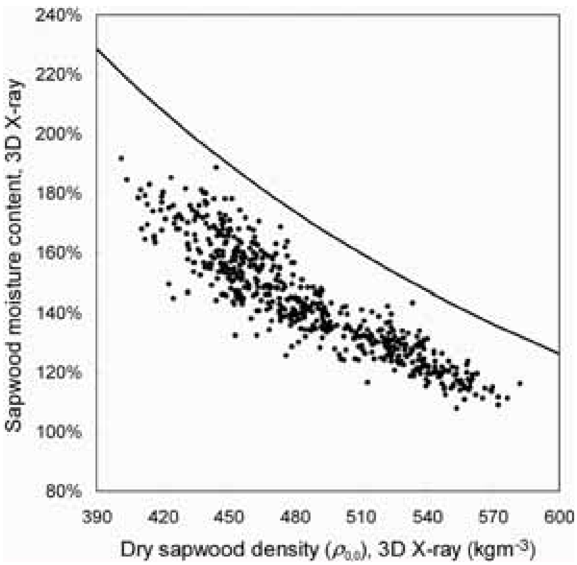

Figure 5: Estimated moisture content as a function of estimated dry density in the sapwood of 553 Scots pine sawlogs. The solid line represents the theoretical maximum moisture content of saturated wood.

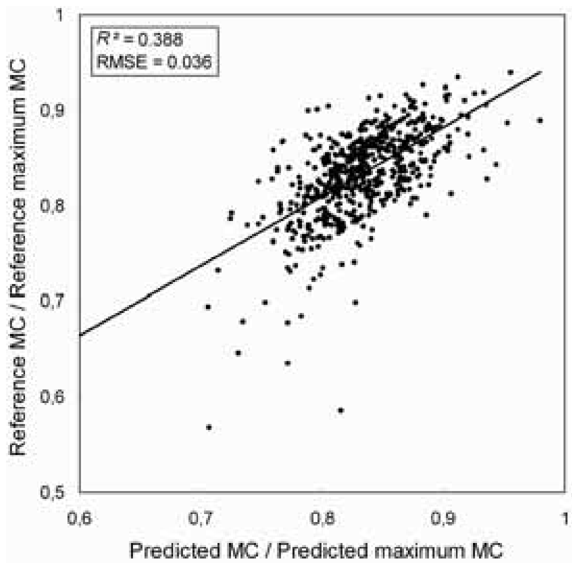

Figure 6: Sapwood moisture content relative to the theoretical maximum moisture content of saturated wood, measurements in CT images versus predictions from simulated X-ray and 3D log scanner data for 553 Scots pine sawlogs.

When combining the predicted green and dry sapwood densities, the sapwood moisture content could be calculated with a precision of $R^2 = 0.29$ and RMSE = 21%, Figure 3.

The reference moisture content was calculated by comparison of the dry density at the butt end and the green density 400 mm from the butt end. Dry CT images were only available at the butt end but due to local drying at the log ends, green CT images could not be taken at the same position. Instead, the position 400 mm from the butt end was chosen for the green images in order to avoid the log end drying but still to be as close to the end as possible. By choosing this position, the impact of local dry density variations was minimized. However, especially for butt logs there may still be a considerable dry density variation over the distance of 400 mm, causing some uncertainty in the reference values used.

The predicted moisture content was calculated by comparison of a dry sapwood density prediction evaluated 400 mm from the butt end of the log and the average green sapwood density of the whole log. The average sapwood density of the log was used because it was found to be the best available estimate of the green sapwood density 400 mm from the log end (Skog & Oja 2009). This means that the prediction model tries to predict an average moisture content in the region around 400 mm from the log end whereas the reference value is a mix of two local values taken 400 mm apart. Thus, the local variations near the log end contribute to the uncertainty in the prediction of the sapwood moisture content presented in Figure 3.

The result when using the predicted moisture content to separate the logs into two groups is shown in Figure 4. Because the logs used in this study were all scanned directly after felling, the logs have not dried out and most logs have a moisture content around the used threshold value of 145%. Thus, the separation between the two groups is not very clear, however, all logs with very low moisture content were correctly classified as dry logs. Out of all logs, 70% were correctly classified.

When plotting the moisture content against the dry density, Figure 5, it can be seen that most of the observed variation in moisture content is caused by the varying dry density of the logs and that the moisture content follow a curve of the same shape as the theoretical maximum value, equation (3), as shown by the solid line in Figure 5.

By comparing the calculated moisture content to the theoretical maximum, it should be possible to identify logs that have low moisture content due to drying of the sapwood. Figure 6 shows the ratio between calculated moisture content and maximum moisture content, the reference ratio measured in the CT images could be predicted with a precision of R^2 = 0.39 and RMSE = 0.036. The two outliers, with reference values around 0.6, are the two logs with very low green density references, probably caused by local drying at the cross-section of the green CT image.

Comparing calculated and maximum moisture contents could prove to be a very useful way of identifying logs that have been stored for a long time before arriving at the sawmill. A proper evaluation of this method would however require testing on a more diverse population of logs, containing both logs with full sapwood moisture content and logs with reduced sapwood moisture content.

CONCLUSIONS

By combining 3D and X-ray scanning in the log sorting station, it is possible to measure the green sapwood density and to estimate the dry sapwood density and the moisture content in Scots pine sawlogs.

The moisture content estimate could be used to separate the logs into two groups with high and low moisture content, correctly identifying all logs with very low moisture content as dry logs. Out of all logs, 70% were correctly classified.

The estimate can also be compared to the dry density dependent maximum moisture content and used to identify logs that have actually started to dry. However, this method need still to be evaluated for a population of dry logs because most logs in this study was of full moisture content.

ACKNOWLEDGEMENTS

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REMARK

[*] In the version of the paper published in the printed proceedings, equation (3) was incorrectly used directly with $\rho_{0,0}$. The mistake has been corrected in this on-line publication and Figures 5 and 6 have been updated.

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