SilviScan measurements on Maritime pine
French samples cut perpendicular to the fibres

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1 Summary

In France, a method has been developed to measure radial variations in wood density. From the data, also the number and widths of annual rings may be determined, as well as their bands of earlywood and latewood. Large numbers of samples have been produced and analysed in previous and current projects. Many samples are being preserved and further properties of the wood and its fibres may be measured, if suitable techniques are available. This would allow very efficient complementary research adding to the results of previous projects. It would also allow the investigation of additional properties in current projects and projects under preparation.

The SilviScan technology offers such additional possibilities. The SilviScan integrates three measurement principles: image analysis of fibre cross-sections, x-ray absorption and X-ray diffraction of wood, performed along radii from pith to bark. With SilviScan, radial variations of a large number of important properties of wood and fibres may be determined with high efficiency and resolution from samples of wood. Examples are:

- Wood density
- Fibre width (in radial and tangential direction)
- Fibre wall thickness
- Microfibril angle (MFA)
- Wood stiffness (estimated acoustic MOE)
- Ring widths, earlywood and latewood widths
- Content of juvenile and mature wood
- Other properties possible to calculate/estimate from properties listed above

A set of samples produced for analysis with the French method has been sent to STFI-Packforsk. The samples were taken from Maritime pine in France. The objective was:

1. to clarify if it is possible to use the SilviScan instrument on such samples in order to obtain data on additional properties.
2. to illustrate the information possible to obtain with SilviScan
3. to conclude on the usefulness of such additional data from existing and future French samples.

In this report, results from this study are presented. Procedures for further sample preparation have been developed to turn the French samples into a format possible to analyse with the SilviScan instrument.

A fast-grown and a slow-grown sample were selected. A large number of wood and fibre properties have been analysed. The annual rings and the earlywood and latewood bands of each ring have been identified and their widths have been determined. Averages have been calculated for the rings and their parts. The results are illustrated as functions of radial position and annual ring number.

The conclusion is that this information should be very useful in many types of projects, as a complement to the density data obtained with the French method.
2 Analysis of radial variation of wood and fibre properties

2.1 French method for measurement of wood density

In France, a method has been developed to measure radial variations in wood density (Polge 1966). From the data, also the number and widths of annual rings may be determined, as well as their bands of earlywood and latewood.

In figure 1, a set of samples prepared for analysis are shown. The samples are cut along radii or diameters of stem cross-sections. They are about 2.5 mm thick and cut with the”flat side” perpendicular to the axis of the tree and of the fibres.

![Figure 1. Samples of Maritime pine, prepared for measurement of the radial variation in wood density with the French method.](image)

When measured, the samples are put on top of an X-ray sensitive film and illuminated with X-rays, passing through the wood in the direction of the fibre axes and the lumens. The film is developed and put on a scanner, providing images of the variation in X-ray transmission. These variations are determined with image analysis and the radial variation in wood density is calculated. The method has been used and refined in many projects and a high efficiency has been reached.

Large numbers of samples have been produced in previous and current projects. Many of these samples are being preserved and possible to use for measurement of further properties of the wood and its fibres, if suitable techniques are available. This would open up for very efficient complementary research related to previous projects and for the investigation of additional properties in current projects.
2.2 SilviScan measurements for data on additional properties

One such possibility is use of the SilviScan technology (Evans et al. 1995; Evans 2006). With SilviScan, radial variations of a large number of important properties of wood and fibres may be determined with high efficiency and resolution from samples of wood. Examples are:

- Wood density
- Fibre width (in radial and tangential direction)
- Fibre wall thickness
- Microfibril angle (MFA)
- Wood stiffness (estimated acoustic MOE)
- Ring widths, earlywood and latewood widths
- Juvenile and mature wood
- And properties possible to calculate/estimate from properties listed above

In the autumn of 2007, a set of Maritime pine samples, see figure 1, was sent from AFOCEL (now FCBA) to STFI-Packforsk for analysis. The objective was to clarify:

4. If it would be possible to use the SilviScan instrument on samples produced for analysis with the French method in order to obtain data on additional properties.

5. The usefulness of such additional data from existing and future French samples.

In this report, results from this study are presented.

2.3 The SilviScan technology

The SilviScan measurements are performed on wood samples in the form of high precision strips prepared along radii from pith to bark, see figure 2.
The sample strip is polished on the top surface, to allow recording of a sequence of images of cross-sections of the wood matrix along the radius, showing cross-sections of fibres and other features. The sample strips are 2 mm thick (tangential direction in the wood matrix) and 7 mm high (longitudinal direction). They are produced with specially designed high precision twin-blade saws.

It is also possible to measure on similar samples from selected radial intervals, such as samples cut from battens of clearwood produced for mechanical testing of wood.

The SilviScan integrates three measurement methods performed in different units, see figure 3.

If all possible measurements are to be made, the following operations are performed:

1. First, the length, width and height of the sample strip seen in figure 2 are callipered. The sample is weighed and its average density is calculated, for later use in calibration.

2. Then, consecutive images of the polished top surface of the strip are scanned with a video microscope on the so called "Cell Scanner" (A). From these images, the fibre widths in the radial and tangential directions are determined as averages for radial intervals of 25 μm. The radial variation of the orientations of the annual rings is also determined. Images and data are compiled in a database common for the different measurement units.

3. Next, the radial variation in wood density is measured with X-ray absorption (B) as averages for radial intervals of 25 μm. During the measurement, information about the local orientation (angle) of the annual rings is obtained from the database and the sample is rotated to align the X-ray beam with the latewood
bands. This way, averaging across earlywood and latewood bands is avoided. More detailed information may be obtained about the position and widths of the rings and their content of earlywood and latewood and averages may be calculated for each such entity.

The measured density of the sample is calibrated for unknown differences in the X-ray attenuation of the wood, based on the gravimetrically determined average wood density for the whole sample, point 1 above.

Local information of fibre widths and wood density is combined to calculate the radial variation of fibre wall thickness, with more precise results than are possible to obtain with a microscopy only, due to its inherent limitations caused due the wavelength of the visible light.

4. In the third measurement unit, a focused X-ray beam is interacting with the wood structure, providing a radial sequence of diffraction patterns (C). From these diffractograms, the radial variation of the microfibril angle of the fibres is estimated.

By combining data on wood density and information from the diffractograms, also the wood stiffness may be estimated (acoustic MOE). The data may be provided as averages for intervals of 0, 2 mm, but normally larger intervals are of interest, typically 2-5 mm.

5. From these data, the radial variations of other properties may be calculated, such as fibre coarseness and fibre collapsibility.

6. Then, the interfaces between the annual rings are identified and also between their bands of earlywood and latewood, based on wood density or on relationships between fibre widths and wall thicknesses. Positions and widths of the annual rings and their earlywood and latewood parts are determined and averages may be calculated for each entity.

(This description of the method is valid for measurements on softwood. When hardwood samples are analysed, some of the procedures are modified, due to disturbances from, and characterisation of, vessel elements present in the wood matrix.)

The activities listed above will provide data on the radial variations of a broad spectrum of wood and fibre properties. Often all these properties are not relevant for a specific project, or are not necessary to determine with this high radial resolution. If they are not, the measurement sequence is adapted to the needs to reduce work load and costs.
3 Samples analysed

3.1 Modification for measurement on the French samples

The French samples are cut with the “flat” surface perpendicular to the axes of the fibres, whereas the SilviScan samples are cut with the “flat” surface in parallel with the fibre axes. Due to this difference, some extra preparation of the French samples is needed before mounting the samples on the SilviScan instrument.

The French samples are cut to a width of 7 mm with the same tool used for preparation of SilviScan samples. The length, width (7 mm) and thickness (~2.5 mm) of each sample is measured in many positions along the sample. The sample is weighed and its average wood density is calculated for use in calibration.

Then the 2,5 mm thick sample is glued on top of an about 5 mm thick bar of wood as a support. In this “composite”, the rings of the 2,5 mm top layer are oriented vertically as in a SilviScan sample. A 2 mm thick strip is cut with a twin-blade saw, resulting in a SilviScan-like sample strip, with part of the French sample at the top and a support below. This sample strip is analysed with the SilviScan according to the procedures described above, while seeing to it that only the upper French part of the sample is in the measurement zone in all steps of the measurement.

3.2 Selected samples

Two samples were selected to be analysed, one with 30 relatively narrow annual rings and one with 16 relatively wide rings. One radius per sample was analysed, see figure 4. In figure 5, the polished top surfaces of the samples ready for analysis on the SilviScan instrument are shown.
4 Results from analyses with SilviScan on French samples

This chapter shows measurement results from many wood properties.

4.1 Wood density, radial variation

Figure 6 shows the density variations of the two analysed samples. The samples are air-dried in the conditioned atmosphere of the laboratory, 23° C and 43% RH, resulting in a moisture content of about 8%. It should be noticed that this density, air-dry weight on air-dry volume, differs from the basic density, oven-dry weight on raw volume. As a rule of thumb, the air-dried density is about 25% higher than the basic density.

The figure shows very sharp latewood bands with densities between 700 to 1000 kg/m³. These very sharp latewood bands are achieved by rotating the sample, so that the local measurement of each ring is always performed perpendicular to the growth ring.

![Figure 6. Radial variations in wood density (air-dry) of samples 306-5 and 802-4](image)

4.2 Annual rings, earlywood and latewood

The different characters of the two selected samples are also obvious: Fast-grown versus slow-grown and a gradual decrease outwards in ring width. In figure 7 and 8, the widths of the annual rings are shown and also the widths of their seasonal parts. The upper parts of the figures shows the widths as a function of the distance from the pith, the lower part as a function of the annual ring number.
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Figure 7. Radial variation in width of annual rings, as well as their bands of earlywood transitionwood and latewood for the sample 802-4 of the slow-grown tree.

In these figures, the density variations have been used to identify the positions of the rings, defined by the interfaces between latewood and earlywood, which are very sharp thanks to the rotation of the samples. The total ring widths are shown with the dark-blue graphs. The width of the innermost ring is sometimes disputable as it depends on how
Figure 8. Radial variation in width of annual rings, as well as their bands of earlywood, transitionwood, and latewood for the sample 306-5 of the fast-grown tree.

You deal with the width of the pith. The same may be the case with the outermost ring, as it will not yet be fully formed if the sample is taken during the growth season.

There are many different definitions of earlywood and latewood (Olsson 2000). They can be defined based on radial variations in wood variations, light reflection in images...
and relationships between cell diameters, as the Mork definition (Mork 1928). The definitions can be based on absolute thresholds, like a fix density, or on relative threshold, like certain parts within each ring. You also have to consider how to deal with multiple peaks within the ring, and several other aspects.

The tools developed at STFI-Packforsk for analysis of the growth patterns based on SilviScan data include about 20 different definitions used in various projects, from the straightforward “fix density” alternative useful in wood technology investigations to Mork’s definition commonly used in morphological studies. For the illustrations given in this report, we wanted to give figures to the pronounced earlywood and pronounced latewood. In such cases, we often use a relative method based on density, including also a part of “transition wood”. Each annual ring is dealt with separately. Latewood is defined as the part of the ring with density larger than 80% of the span between the highest and lowest density in the ring. Earlywood is defined as the part with density below 20% of the span and “transition wood” is the part of the ring with density in between.

In the figures, the three parts of the rings are denoted LW_width, EW_width and TW_width. The figures show that the total ring widths decreases from the inner juvenile wood towards the outer more mature wood. The width of the latewood does not show this trend of reduction, the decrease is due to thinner bands of earlywood and transitionwood. It also shows that the typical within ring patter is not fully established in the innermost rings, where a very large part of the wood with this definition is found to be in a transition phase.

Below, graphs on the radial variation of different properties measured with SilviScan will be complemented with graphs for property averages of individual rings and their parts, according to the widths shown in figure 7 and 8.

### 4.3 Wood density, averages of rings, earlywood and latewood

Figure 9 shows the variations of wood density of the two samples as a function of the distance from pith (upper graph, same as figure 6) and as mean values for each growth ring and their earlywood and latewood bands (lower graph).

The variation with distance from the pith was commented already above. The lower graph shows similar trends for the two samples. The ring averages of the wood density, solid curves, decrease somewhat outwards for the innermost rings and then they start to increase. The ring averages are lower for the fast-grown tree. The pattern is the same for the earlywood bands (except for the first ring, which was dedicated a broad band of transitionwood, see above). The density of the latewood is obviously much higher. It also varies more. Reasons are weather effects during the late summer and autumn, possibly also effects of compressionwood.

In paragraph 4.8, comments are made related to within ring variations in the microfibril angle. Then it is concluded that some of these rings probably includes compressionwood.
Figure 9. Radial variation in wood density (air-dry) for the fast-grown and slow-grown sample and averages for the annual rings and their earlywood and latewood bands.
4.4 Fibre width

Figure 10. Radial variation in radial fibre width for the fast-grown and slow-grown sample and averages for the annual rings and their earlywood and latewood bands.

In figure 10 and 11 show the same way the variations in fibre width in the radial and tangential directions of the wood matrix. The fibre width in the radial direction decreases towards the end of the growth season, which contributes to the high density of the latewood bands. The radial width also increases from juvenile to mature wood,
which explains the initial decrease in density outwards in the innermost rings. Also for the fibre width in tangential direction there is an increase from juvenile towards mature wood. There are also seasonal variations, which are more or less visible. This is further commented below.
4.5 Fibre wall thickness

Figure 12 shows the corresponding figures for the radial variations in fibre wall thickness. It increases from juvenile to mature wood. The patterns are similar for the fast-grown and the slow-grown tree, but the walls are thinner in earlywood and for the ring average in the sample from the fast-grown tree, compared for corresponding rings.
4.6 Microfibril angle (MFA)

Figure 13 shows the radial variation in microfibril angle (MFA) for the two samples. Close to the pith, the MFA is about 30°. It decreases outwards to a stable level of about 15°. For the slow-grown tree, this level is reached in annual ring 5. For the fast-grown tree, the MFA is elevated in rings 5-12. There may be many reasons, such as thinning, fertilisation, compressionwood. Such irregularities are common for variations in MFA.
4.7 Wood stiffness

Figure 14. Radial variation in wood stiffness (est. acoustic MOE) for the fast-grown and slow-grown sample and means for the annual rings and earlywood and latewood bands.

The radial variations in wood stiffness (estimated acoustic MOE) for the fast-grown and slow-grown samples are shown in figure 14. The wood stiffness is related to wood density and MFA, resulting in an increase from juvenile to mature wood. The stiffness is clearly lower for the inner rings 1-12 of the fast-grown wood.
4.8 Comments

The high resolution of the data allows detailed studies of observed features and relationships. It is normally said that the microfibril angle is larger in earlywood than in latewood. Therefore, it may seem surprising that this is not the case for some of the annual rings of sample 306-5 from the fast-grown tree, see figure 13. In figure 15 below, graphs for wood density and MFA are shown together. One may then see that for most rings there is a decrease in MFA (green graph) from earlywood to latewood. For some annual rings, especially the one at 50 mm, MFA shows a very clear peak in the latewood. This is a broad ring which most likely includes compressionwood.

Another example is the difference between earlywood and latewood. Figure 11 shows that there is a clear and systematic variation in the radial fibre width for the sample 802-4 of slow-grown wood, but small and irregular differences for the sample 306-5. The violet graph in figure 15 provides further detail on this. For the inner two thirds of the sample, the variation is very noisy and irregular, but in the outer part the pattern is similar to that of the other sample.

![Figure 15. Radial variations in wood density, microfibril angle and radial fibre width for the fast-grown sample.](image-url)

Finally a comment on need for resolution: The upper parts of the figures 13 and 14 show the radial variation in MFA and estimated MOE expressed as averages of radial intervals of 0.2 mm. This resolution is sometimes interesting in research, but for studies related to properties of wood, a resolution of 2-5 mm it is normally sufficient, providing information with reduced variation, similar to that of the lower parts of the figures.
5 Conclusions

Samples of Maritime pine, produced with procedures commonly used in France for analysis of density variation, have been sent to STFI-Packforsk. One objective of this project was to verify that it is possible to further prepare these samples and analyse them with the SilviScan instrument of STFI-Packforsk, in order to get information also about a large number of additional wood and fibre properties. Another objective was to illustrate the usefulness of such additional data.

The results show that it is possible to analyse samples produced according to the French method with the SilviScan instrument, after processing of the fibres according to the procedures developed.

One alternative could be to analyse the total volume of samples produced for measurement with the French method for wood density in France and, based on the density data obtained, to select the samples to analyse samples to be analysed for additional properties with SilviScan.

It is, thus, also possible to return to samples stored from previous projects and analyse them with SilviScan, in order to obtain detailed information on a large number of additional wood and fibre properties.

Two samples from Maritime pine were selected, one with fast-grown wood and one with slow-grown wood. The samples were analysed for a large number of wood and fibre properties. A number of figures on the radial variations have been produced to illustrate the potential of the method.

When measuring on SilviScan, the samples may be rotated to provide very sharp information on the annual rings and their bands of earlywood and latewood. This feature has been used produce figures also with average properties of rings and their seasonal parts. This pre-evaluation of data can most often facilitate the continued specialised evaluation considerably.

It is concluded the possibility to analyse samples produced with the French procedure in previous and current projects for additional wood and fibre properties should be very useful.
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