# SPECIMEN ORIENTATION FOR THE CALIBRATION OF DIRECT SCANNING X-RAY WOOD DENSITOMETERS

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ABSTRACT

It was found that specimen orientation has considerable effect on the calibration of direct scanning X-ray wood densitometers. A comparison between various orientations was made and verified by a test. Optimum calibration is accomplished when the specimens are made in such a way that the radiation beam is passed through the wood in the tangential direction and scans it in the radial direction.

*Keywords:* X-ray, densitometer, calibration.

## INTRODUCTION

It is important in X-ray wood densitometry to calibrate the relationship between the density of wood specimens and the attenuation of ray intensity. The calibration of the direct-scanning X-ray wood densitometer is based on the well-known equation:

$$I/I_0 = e^{-\mu\rho t} \tag{1}$$

where

$I$—intensity of the attenuated X-ray;
$I_0$—intensity of the unattenuated X-ray;
$\mu$—mass attenuation coefficient;
$\rho$—density of the specimen;
$t$—thickness of the specimen.

Once $I$, $I_0$, $t$, and $\rho$ are measured, $\mu$ can be calculated as:

$$\mu = -\frac{1}{\rho t}\ln\left(\frac{I}{I_0}\right) \tag{2}$$

The previous studies on calibration of the X-ray wood densitometer were focused mainly on the variation of mass attenuation coefficient among and within wood species, and the effects of moisture content and various radiation sources (Moschler and Dougal 1988; Malan and Marais 1992; Cown and Clement 1983; Liang and Guan 1990). It was found during the construction of a wood densitometer in our institute that specimen orientation has a considerable effect on calibration of the X-ray wood densitometer (Guan et al. 1995).

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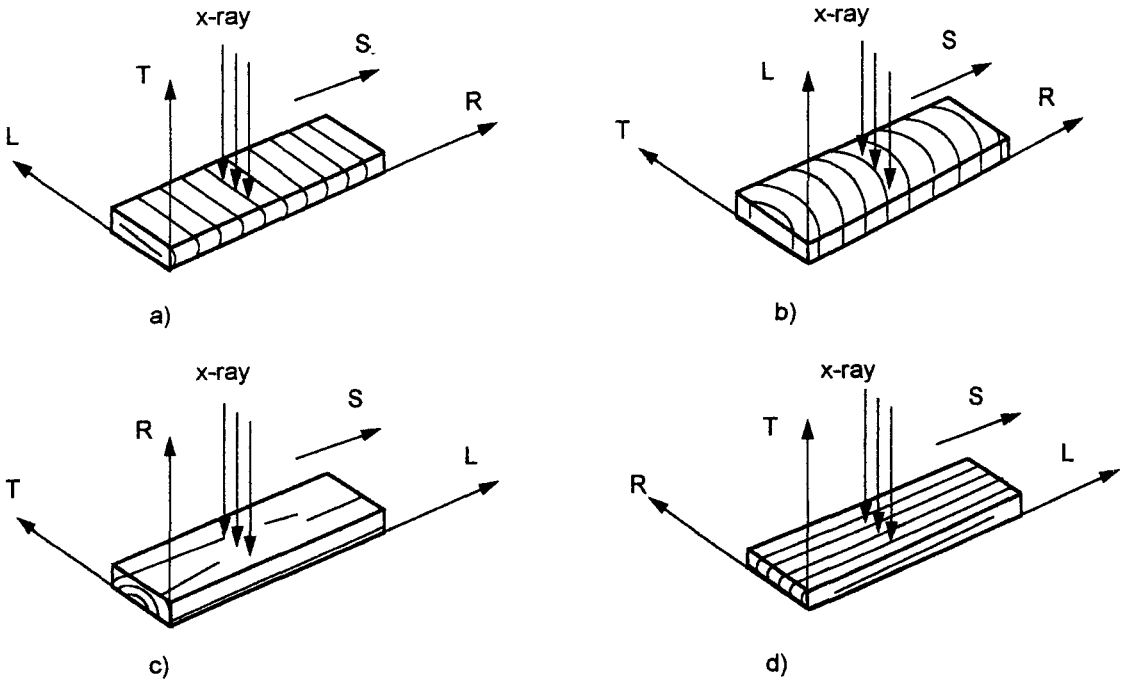


FIG. 1. Schematic diagrams of various specimen orientations. R = radial direction, T = tangential direction, L = longitudinal direction, S = scanning direction.

As shown in Fig. 1, test specimens can be scanned with respect to various grain orientations. Scanning scheme a) shows the radiation beam passing through the tangential direction of the wood and the specimen being scanned along the radial direction. For scheme b), the beam passes through the wood in the longitudinal direction and the specimen is scanned in the radial direction. Scheme c) is for the beam passing through the radial direction of the wood and the specimen being scanned along the longitudinal direction. Scheme d) is for the beam passing through the tangential direction of the wood and the specimen being scanned in the longitudinal direction.

Commonly specimens shown in Fig. 1-a) or b) are prepared for wood density measurement with the X-ray densitometer with scanning in the radial direction of the wood. However, in calibrating the densitometer, the scanning is usually in the longitudinal direction and the specimens are prepared as shown in Fig. 1-c) or d) (Hoag and Mckimmy 1988; Choi 1987).

The objective of this study was to determine the effects of specimen orientation on densitometer calibration and density determination.

## ANALYSIS

The two main issues for evaluating the specimen orientation effect on calibration of the X-ray densitometer are accuracy of the calibration and the ease of specimen preparation.

The main point for the accuracy of calibration is that the density of the scanned part of the specimen be equal to the average density of the whole specimen. Usually the density obtained by the gravimetric method is the average density for the whole specimen, while only part of the specimen is scanned by the radiation beam in the calibration test.

In the case of the scanning schemes c) and d) in Fig. 1, wood density along the specimen length can be expected to be constant, so there

is no problem with the accuracy of calibration. However, there may exist density variation across the specimen width. As for scanning scheme d), the specimen width is along the radial direction of the specimen; and it is well known that density variation in the radial direction, especially between earlywood and latewood transition within growth rings, is large for many wood species. As for scanning scheme c), the specimen width is in the tangential direction, where there is less density variation. However, if there exists a large radial density variation, the specimens should be prepared with surfaces parallel to the annual ring. It can be seen that advantage lies in scheme a) and b), because wood fibers or tracheids on the tangential section are relatively straight and parallel to each other, so there will be less variation. In these two schemes, the specimens for calibration are prepared in the same way as the specimens for measuring density with the X-ray densitometer. Therefore the error caused by the differential attenuation due to the anisotropic wood structure that relates to the difference of scanning schemes used in the calibration and measurement tests can be avoided. According to Moschler and Winistofer (1990), scheme a) is more reasonable than scheme b), considering the accuracy of the X-ray measurement affected by the heterogeneity of wood within the X-ray aperture area and the ease of specimen preparation.

However, for scheme a), the specimen's length is in the radial direction of the wood, in which there exists relatively large density variation. Therefore the specimen has to be scanned over its whole length. This will generate another problem: Since the radiation beam is of certain width, and there is an abrupt transition at the specimen ends from the specimen to air, an error may be introduced in the density profiles near the specimen ends. This is called "edge effect" by some previous researchers (Laufenberg 1986; Moschler and Winistorfer 1990). However, if the specimen has a proper length and is well prepared, the edge effect can be ignored.

The edge effect is demonstrated in Fig. 2.

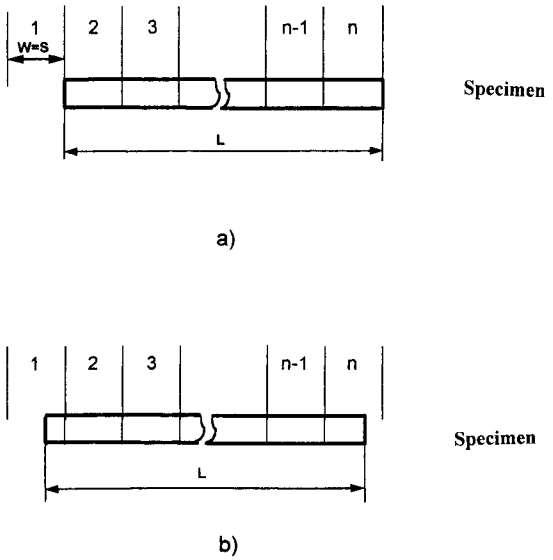


FIG. 2. Schematic diagrams of the edge effect.

A specimen with length L is scanned step by step from 1 to n by a radiation beam with width W, which is equal to S, the step-increment of scanning. In Fig. 2-a), the edge of the radiation beam coincides with the specimen edge as the beam enters and leaves the specimen. In this case, no edge effect will be involved. If the beam edges do not coincide with the specimen ends as demonstrated in Fig. 2-b), values in the density profile measured at step 1 and step n are not pure wood specimens density. An additional point will be added at step 1, while the density value at step n will decrease; then the density profile toward the specimen ends will change, and the total values of density will tend to decrease the total values of density measured. It can be expected, however, that if W is equal to S, and specimen ends are perpendicular to the specimen length, the density profile changes are limited to one step at each end, and changes at the two ends can compensate each other to a certain degree. Therefore, the sum of all the measured density values along the specimen length will have little variation if the specimen is long enough. In our case, a specimen with 150–200 scanning steps will be long enough. Based on the analysis described above, the fol-

lowing procedure was made for the calibration test by using scanning scheme a):

1) Determine the gravimetric density of the wood specimen ($\rho_g$);
2) Scan the specimen with the X-ray wood densitometer to obtain $I_0$, and $I_i$, where $i$ = the step's number;
3) Assume the mass attenuation coefficient as $\mu$ = 18 cm$^2$/g; (based on the radiation source $^{55}$Fe, from Table 2, *Wood and Fiber Science* 20(3), 1988, p.301);
4) Calculate the density values at each step and sum the values corresponding to $\mu$ = 18 cm$^2$/g;
5) Calculate the mean density of the specimen by Eq. 3

$$\rho' = -\frac{S}{L}\frac{1}{\mu t}\sum_{i=1}^{n}\ln\left(\frac{I_i}{I_0}\right) \quad (3)$$

where $n$ = the number of the steps where $I_i < I_0$, including the steps effected by the edge effect.

6) Calculate the actual value of the mass attenuation coefficient for calibration ($\mu_{cal}$) by:

$$\mu_{cal} = \frac{\mu\rho'}{\rho} \quad (4)$$

A computer program has been developed for this procedure and installed in our densitometric analysis system.

## EXPERIMENTAL

In order to prove the analysis result described above, a comparison test between the scanning schemes a) and c) was made. Only scanning schemes a) and c) are compared here because scheme b) is not as good as a) and can be replaced by scheme a), and specimens in scheme d) usually have greater density variation along their width than those in scheme c).

The species tested in this study was larch (*Larix olgensis*). The specimens were prepared for different cases as shown in Table 1.

The specimens were 15 mm in length, 6 mm in width, and 1.0–1.2 mm in thickness, with a maximum thickness variation of 0.02 mm within each specimen. The radiation source of the densitometer is $^{55}$Fe. The cross section of the radiation beam is 0.1 × 2.5 mm. The scanning step increment is 0.1 mm. Each specimen was scanned three times at two positions along the specimen width near the two edges. The difference between the mass attenuation coefficients obtained at the two positions was taken as an indicator of the reliability of calibration. The calibration procedure for scheme a) was implemented as described in "Analysis." After eliminating data obtained near the specimen ends to avoid the edge effect, the mass attenuation coefficient for scheme c) can be calculated by:

$$\mu = \frac{\sum_{i=1}^{m}\ln\left(\frac{I_0}{I_i}\right)}{\rho_g m} \quad (5)$$

where $m$—the number of data for $I_i$ after eliminating the data near the edges.

TABLE 1. *Specimen preparation for the comparison test.*

| Code | Specimen preparation methods | Notes |
|---|---|---|
| A | Specimen prepared as shown in scheme a) of Figure 1. | Specimens were carefully prepared to satisfy the grain orientation parallel to the surfaces |
| C1 | Specimen prepared as shown in scheme c) of Figure 1. | Specimens were carefully prepared to satisfy the annual ring layers parallel to the surfaces |
| C2 | Specimen prepared as shown in scheme c) of Figure 1. | Specimens were prepared with annual ring layer at an angle of 4 ~ 5 degree with respect to surface, and with a narrower latewood zone. |
| C3 | Specimen prepared as shown in scheme c) of Figure 1. | Same as C2 except for the latewood zone was wider, so in this case, at one edge, the latewood zone is intact, while at the other end it is not. |

TABLE 2. *Difference in the mass attenuation coefficients between two positions along the width of the specimens prepared for different cases.*

| Code of specimen preparation methods (cf. Table 1) | Scanning position | Mass attenuation coefficient ($cm^2$) | |
|---|---|---|---|
| | | Mean value | Difference between positions |
| A | 1 | 18.07 | 0.03 |
| | 2 | 18.04 | |
| C1 | 1 | 17.85 | 0.37 |
| | 2 | 18.22 | |
| C2 | 1 | 18.47 | 0.73 |
| | 2 | 17.74 | |
| C3 | 1 | 18.46 | 2.22 |
| | 2 | 16.24 | |

The results in Table 2 show that specimen orientation does have a considerable effect on the accuracy of calibration. When scheme c) is used, great care should be taken to make annual ring layers parallel to the specimen surfaces, which makes c) more difficult to manage than scheme a). For instance, if the annual ring layer twists because of the irregular growth in any year, then at one end of the specimen they are parallel to the surfaces while at the other end they are not.

## CONCLUSIONS

1. Specimen orientation, which determines the ways the radiation beam scans the specimens, have considerable effect on calibration of the scanning X-ray wood densitometer.
2. Scanning scheme a) has greater advantages of ensuring the accuracy of calibration with easier specimen preparation. It is suggested that scanning scheme a) be used for specimen preparation both for calibrating the densitometer and for measuring the microdensity.

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