Ultrasonic imaging of wood structure

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Abstract

The purpose of this report was firstly to obtain an ultrasonic image with a thin (2 mm thickness) solid wood specimens, without a special preparation of the surface, which are used currently for X - rays microdensitometric technique, and secondly, to obtain an ultrasonic image of a very thin microscopic section (12µm), fixed between two glass lamellae. This specimen is the classic specimen used for optical microscopic studies of wood anatomic structure.The images were obtained with the scanning acoustic microscope, SONOSCAN - C - SAM D 9000, in a frequency range between 100 MHz and 230 MHz , for two species : spruce and oak. The image resolution was between 10µm and 25 µm. It was observed that it possible to establish a relationship between the amplitude of the ultrasonic signal and the corresponding microdensitometric value of different anatomical elements.

Keywords : scanning acoustic microscopy, , wood imaging , X-ray microdensitometry

1 Introduction

Scanning acoustic microscopes allow the imaging of wood structure through the ultrasonic reflectivity of the sample, measured point by point and displayed on a screen. As for optical microscope, for acoustical one the resolution is obtained by focussing radiation to a diffraction limited spot. Nevertheless, the main interest of developing acoustic microscopic ultrasonic technique is determined by the fact that subsurface images can be obtain, because the ultrasonic waves can penetrate the opaque wood surface.

Today the use of acoustic microscopy technique is well established. The field of application of this technique as an advanced nondestructive testing is very wide. Studies of wood structure are relatively scarce today. Imaging of wood structure of oak, spruce and pine was obtained in the reflection mode using lens focused at 200 MHz. [1, 2, 3] The image resolution was of 6 µm in a scanning dimension ranging between 50µm and 5 mm.

Details of oak round ring porous growth pattern, zones of fibers and multiseriate rays were clearly seen in all three anisotropic planes. The anatomical details observed in spruce and pine are : the latewood, the earlywood , the medulary rays and the pits. Very clearly the diameter of the pit can be seen. More recently, images of the gelatinous layer of tension wood were obtained at 600 MHz frequency, with a resolution of 2µm. [3]. The characterization of the interfaces between different layers of the cellular wall , and between the wall and the amorphous layer containing a big amount of lignin, is an enormous progress in the advancement of wood science.

At frequencies higher the 1 GHz the wavelength in water is of 0.8µm, which means that this submicrometer resolution is approaching that of an optical microscope. In this case, a dominant role in image contrast is played by the Rayleigh waves, which are excited at the surface of the sample. The ultrasonic signal depends on the value of the surface wave velocity in the sample. An other interesting point is the fact that this wave contains longitudinal and shear components, each of which decays exponentially with depth. The sensitivity to the discontinuities of the structure can become much more higher, because of the differences between the anisotropic elastic properties of fibers that can have different orientations and consequently can be seen with different contrast.

2. The aim of the study

The aim of this study has been to explore the capability of the ultrasonic microscope SONOSCAN - C - SAM D 9000, in reflection mode, to produce images of wood structure at microscopic level in both softwood and hardwood species.

Following anatomic elements were analyzed :

- annual ring width, proportion of earlywood and latewood in annual ring,

- characteristic anatomical elements such as : tracheids, vessels and fibers, uniseriate and multiseriate medulary, parenchyma cells .

It is interesting to compare the ultrasonic data of these images with the X- ray microdensitometric data of the same specimen, namely to relate the ultrasonic signal (amplitude) with X-ray microdensitometric values.

3. Material and Method

3.1 Specimens

Specimens of two species were selected : oak and spruce. The specimens are barrettes of 2 mm thickness, cut with the length in radial direction of the tree.

The specimens were presented to the ultrasonic scanning in the same way as for radiographic inspection. The ultrasonic energy travel in longitudinal direction and the image obtained is the ultrasonic image of wood structure obtained by scanning in the transversal anisotropic plane, showing several annual rings with different width and with different proportion of earlywood and latewood zones. Each zone from the ultrasonic image can be related with the corresponding zone of the X-ray microdensitometric graph.

To facilitate the comparison between the images obtained on barrettes of 2 mm thickness and on microscopic sections, of 12 µm thickness both specimens were cut from the same block. The microscopic section was then mounted between two glass lamellae and fixed with a natural resin (Canadian balsam).The thickness of the upper glass lamella that cover wood section was of 0.2 mm thickness.

3.2 Acoustic microscope

The ultrasonic images were obtained with scanning acoustic microscope SONOSCAN C- SAM D-9000, which allows the measurement of acoustic impedance of samples. The larger the echo and the greater the image contrast is obtained when, larger impedance difference across the interface can be measured. Digital image analyzer used 30 algorithms to quantify the interface data The image is comprised of thousand or millions pixels, depending upon the size of the scan area and the pixel density. In our case, by scanning immersed wood specimens in water, 1024 x 960 pixels were used for an images of 20x16 mm. Each pixel corresponds to an echo from a XY position on the sample. The echoes from each scan position are displayed as brightness gray scale (on which the echo size can be seen), or as color scale (on which the echo polarity can be seen) .

The piezoelectric transducers used were of 100 MHz and 230 MHz, operating in reflection mode. The image resolution was between 15µm and 25µm, depending of transducers frequency. A digital waveform display the ultrasonic echoes arrived from different anatomical elements of wood. Relative amplitude of each echo can be quantified. The scan size can vary between 1.3x1.3 mm² and 76x76 mm².

For imaging 256 level grey scale is available as well as 32 color enhancement maps.

The spatial resolution is dependent on the characteristics of the material tested, transducer frequency and working distance .

4. Results

4.1 Structural features on specimens of 2 mm thickness

As regards the structure of oak (Figure 1), the following anatomical characteristics are observed in the annual ring:

- two main zones, the earlywood with large round vessels of 100-500 µm diameter, representing about 20 % from the total annual ring width, and the latewood zone composed from small vessel of 24-70 µm diameter,
- typical pattern of fibers and parenchymial cells ,
- in a position perpendicular to the vessel raw , the medulary rays of about 500-1000µm, wide,

The structure of spruce is much more simple, with a wide zone of earlywood and a very narrow zone of latewood. In latewood the tracheids are very small in diameter < 20 µm. In earlywood the tracheids are larger of about 40µm diameter. The medulary rays are very narrow, composed from one cellular raw.

The imaging of spruce structure with 100 MHz frequency is shown in Fig. 2, .on which five complete annual rings were imaged. In each ring the zone of ealywood (dark) is well differentiated from the zone of latewood (clear).The ring no 3 has a characteristic aspect of a false ring, with a very thin zone of latewood in the middle of the annual ring width.

The corresponding X-ray microdensitometric profile is seen in Fig. 3. To each point from the ultrasonic image a corresponding value of density can be attached and the position of each ring can be co-located on acoustic image and on microdensitometric profile.

Acoustic imaging seems to be much more sensitive to the presence of the compression wood than X-ray densitometric technique.

4.2. Structural features on specimens of 12 μm thickness.

The second part of this report is related to the imaging of a spruce microscopic section of 12μm thickness mounted between two glass lamellae with Canadian balsam. The images were obtained with 230 MHz frequency, with a resolution of 15μm. The image is clear and the differences between the earlywood and the latewood are well defined. The nonuniform distribution of Canadian balsam can be well seen on the lower left corner of the image.

The successful approach of imaging very thin wood section (12 μm) normally used in classical optical microscopy in all laboratories over the world, with scanning acoustic microscope, open a very large field of investigation for the characterization of local elastical properties of wood on existing specimens.

In further studies, for quantitative comparison of acoustic and light microscopic images, there is a need to establish correlation between the acoustical image parameters and light microscopy image parameters of the same section, using statistical procedures (calculation of Pearson correlation coefficient and coefficients of partial correlation for different variables such as the aria of the cells, the area of the lumena, the intercellular spaces, the velocity, the attenuation slope; etc as well as more complex factorial analysis, principal component analysis, etc). Similar studies were performed for the characterization of human tissue in laboratory conditions.

4.3 Amplitude of the signal and wood microdensitometric components

The X ray microdensitometric technique gives the range of variation of the density values between 350 kg/m^3 and 1200 kg/m^3, in an annual ring.

The microscope used in this experiment allows the determination of the relative amplitude of the signal in each point of the image. The maximum of reflection was obtained from the vessels in oak, full of sap, for which the density has low values. The minimum of reflection was obtained from the latewood zones. Table 1 gives some data related to the characteristic densities and attenuation values for different anatomical elements .

Indeed, because the scanning acoustic microscope measured amplitude, and values of velocities and attenuation can be derived, it is possible to make quantitative measurements of the properties of the sample, focussing in different zones to put in evidence certain anatomical elements.

The use of cylindrical lens that excite surface waves in one direction allow to make accurate measurements of the surface wave velocity and attenuation . However, spherical lens excite surface waves in all directions over the sample, and in the case of wood which is an anisotropic material, variations in the surface wave velocity will give information about the material properties in different anisotropic directions. These aspects need to be developed in further studies.

5. Concluding remarks

In this study it was demonstrated that it is possible to produce high resolution images of wood structure, in the frequency range between 100 MHz and 230 MHz. The images were produced in reflection mode with a resolution between 10μm and 25 μm, depending on frequency used.

It was also observed that it is possible to establish relationship between the amplitude of the ultrasonic signal and the X-ray microdensitometric components of wood.

6. References

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Table 1 Relative amplitude of ultrasonic signals and densitometric parameters for different elements

Anatomical elements	Density X –rays (kg/m3)	Ultrasonic signal amplitude
Spruce latewood	900	1.6
Spruce intermediate	700	1.8
Spruce earlywood	400	2.7
Oak - latewood	1200	1.5
Oak-vessels, earlywood	300	3.5

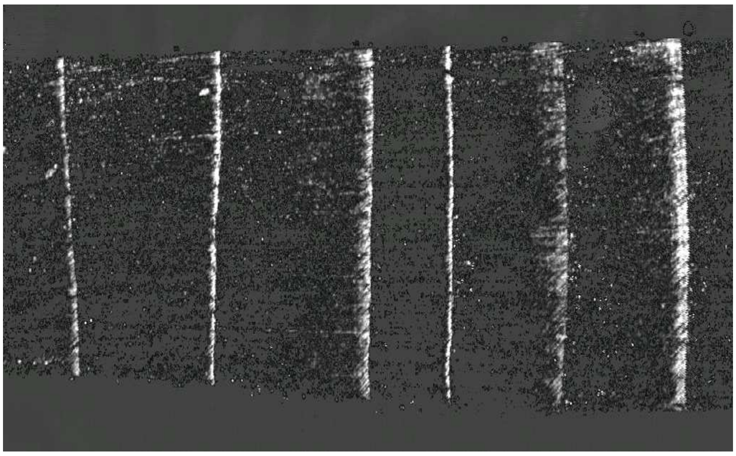

Figure 1 Acoustic microscopic image of oak at 100 MHz

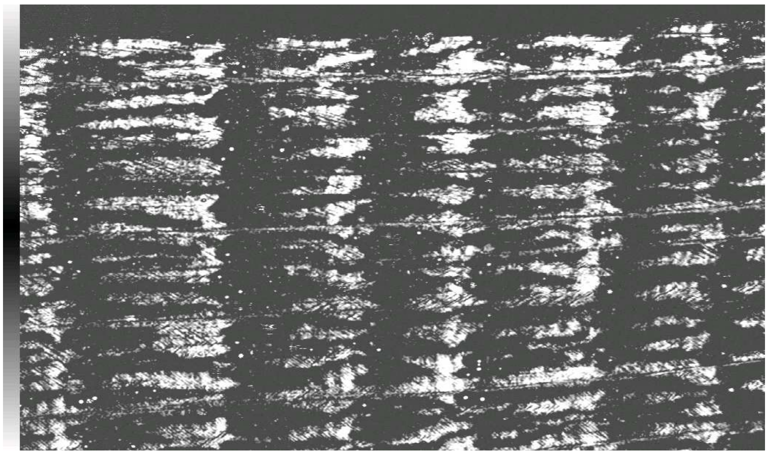

Figure 2 Acoustic microscopic image of spruce at 100 MHz

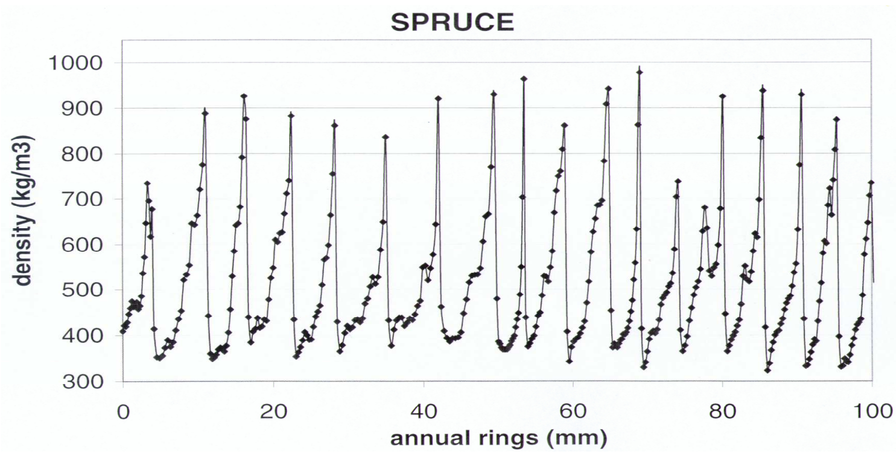

Figure 3 X –ray microdensitometric profile of spruce