STRUCTURAL DIAGNOSTICS OF WOOD USING ACOUSTIC EMISSION: WAVE VELOCITY EVALUATION

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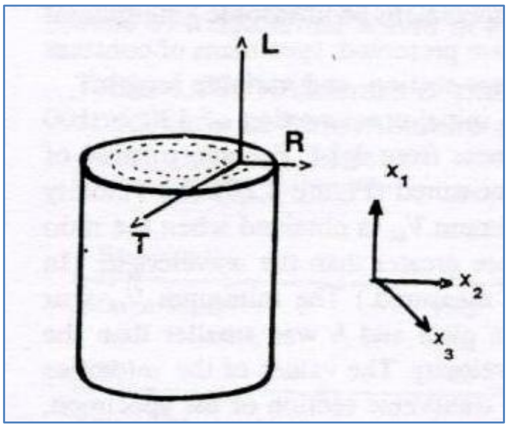
Summary: Presented paper describes preliminary study of acoustic emission (AE) signals generated using Hsu-Nielsen source (pentest) on selected wooden specimens of various tree species. The wave velocity study preceded comparative measurements of three-point bending test. Results of the study indicate significant attenuation phenomenon of the wood material as well as important role of internal wood structure orientation.

Key words: acoustic emission, AE, wood, bending test

INTRODUCTION



This preliminary study was focused on basic evaluation of wave propagation and velocity in wood specimens. As wood shows significant orthotropic property environment, it was crucial to find out the wave propagation behavior prior to the bending test experimental phase. Three major directions of wood properties are longitudinal, radial, and tangential (see Figure 1).

Figure 1: Simplified view of 3 principal directions [3]

In this study, the velocities were measured to obtain basic knowledge concerning wave propagation and velocity in wood specimens that are later to be used for static bending test monitored by AE.

MATERIAL AND METHODS

Acoustic Emission Method

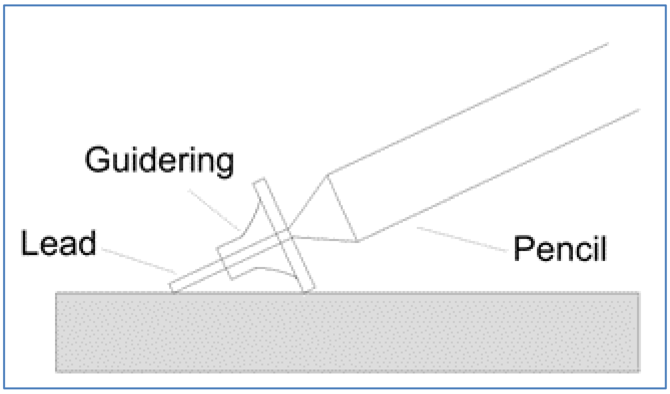
Acoustic emissions are the stress waves produced by the sudden internal stress redistribution of the materials caused by the changes in the internal structure. Possible causes of the internal-structure changes are crack initiation and growth, crack opening and closure, dislocation movement, twinning, and phase transformation in monolithic materials and fiber breakage and fiber-matrix debonding in composites. Most of the sources of AEs are damage-related; thus, the detection and monitoring of these emissions are commonly used to predict material failure.

In technical diagnostics, AE method has been used to monitor rotational part status (friction/cavitation cavitation of bearings and gears), detection of micro-cracks, pressure vessel defects, tubing system defects, aircraft structure evaluation/testing, and bridge status diagnostics. AE technique has proven useful in fatigue testing and destruction experiments. Major advantages of AE include continuous monitoring of the object, time savings, and forecast abilities of the concept. On the other hand, AE wave source is not always obvious, as the emitted energy may result from several phenomena inside of the part. Further variable factors include shape of the object, surface area, material structure, and homogeneity level. [2]

Many interesting applications for AE testing have been developed in recent years in wood science. The objective of the technique is to measure parameters for specific properties of the material under test. If the selection of the parameters is appropriate, they will correlate with the material characteristics. Furthermore, the correlation relationship will produce calibration curves that can be used to verify the quality of the material. In order to properly determine AE parameters, influence of wood species, moisture content a type of sensor should be taken into account. [3].

Pentest (Hsu Nielsen Source)

Pentest is a simple procedure that utilizes breaking of a 0,5 mm pencil lead on the surface of the specimen or solid under inspection. Such pentest generates strong broad-frequency pulse that can be used for sensor calibration and wave propagation monitoring purposes. This method has been used extensively in AE applications for sensor calibration/functionality verification tasks.



Pentest pulse can be easily recognized by the analyzer and visually checked on the oscilloscope. Figure 3 shows sample pulse and corresponding PSD (power spectral density) function on the right.

Figure 2: Pentest procedure schematics. Note the guide ring for proper position of the pencil.

The oscilloscope image shows the overall wave form of the signal, while the X axis covers a time interval of 2,5 milliseconds. The Y axis shows pulse “amplitude” in mV. As you can see, the pulse reveals common features of attenuation with time. For proper evaluation of the pentest results, it is crucial to set the gain so that the signal does not overflow the amplitude range.

On the other hand the PSD function shows distribution of energy over the frequency domain (similar to FFT with amplitudes). This display algorithm uses the Hanning window to extract the signal portion for PSD calculation. The sample depicted below shows two maximum peaks in the frequency domain. These correspond to approximately 10 kHz and 30 kHz.

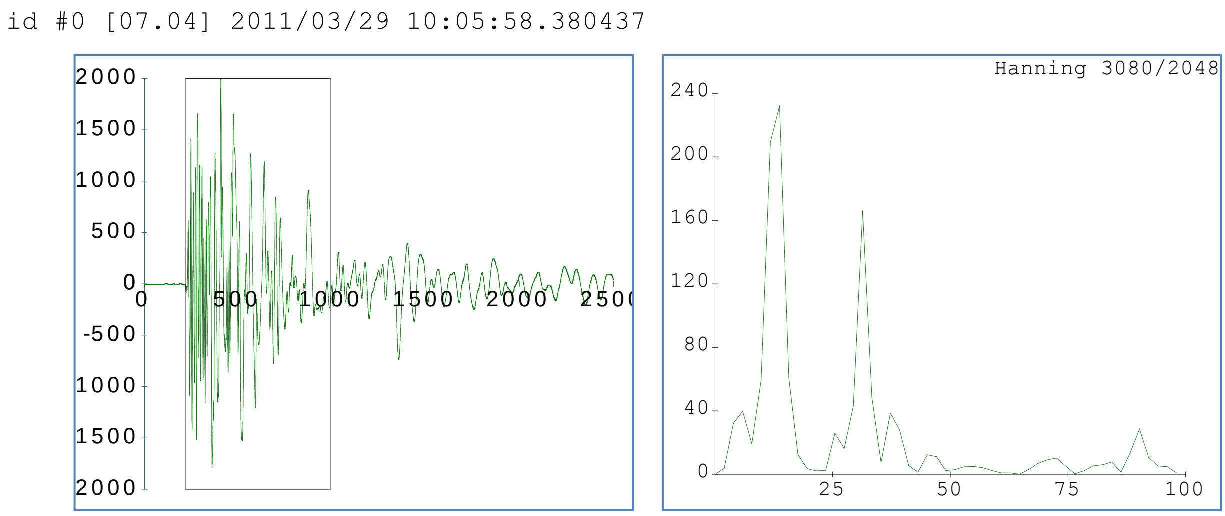


Figure 3: Oscilloscope and PSD function of a sample pentest pulse.

Experiment Setup and Procedure

The wave velocity was measured using Dakel XEDO AE analyzer and built-in function within the Dakel Daemon software. Two AE sensors have been used in the experiments. The sensors were carefully selected based on their frequency response over the frequency domain. Both channels featured pre-amplifiers with gain of 35 dB and special low frequency slot in the Dakel XEDO analyzer device. These slots were adjusted to cover the frequency range of 10 - 200 kHz. The Dakel XEDO analyzer featured the following configuration for both channels (see Table 1).

AE Parameter	**Value**
Sampling frequency	4 MHz
Gain (analyzer)	0 dB
Gain (pre-amplifier)	35 dB
Maximum Range	± 2000 mV
AE Event Start Threshold	1200 mV
AE Event End Threshold	1200 mV

Table 1: AE Parameters in Dakel Daemon software configuration.

The specimen surface was polished in the sensor attachment areas. To ensure effective acoustic coupling between the sensors and the specimen, silicon paste was slightly applied onto contact surface. The position of the specimens was determined by later bending test requirements: fiber direction length-wise, annual rings close-to-vertical on side cross-sections.

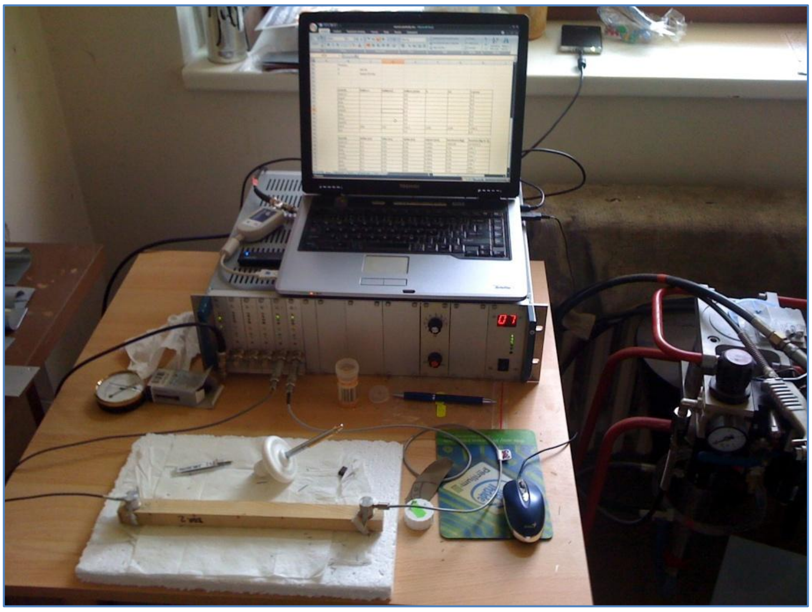


Figure 4: Piezoelectric sensors on the wood specimen. Photo by D. Varner

For the experiment, 10 specimens of 5 various tree species were used (dims 25 x 25 x 300mm). For each specimen, 2 sets of pentests (Hsu - Nielsen AE source, see above) were carried out. Each set included 10 to 20 pentest impulses. For the entire 10-item specimen set, total of approximately 380 pentests were completed.

The first set of pentest was performed on the radial face i.e. on the side perpendicular to annual ring direction. As the rings were vertical in this layout, this layout closely conforms to the position of specimen in the bending test machine. In this case, it is probable that the normal-to-surface component of surface wave goes in a direction parallel to annual rings. Supposedly, the wave velocity should be higher in this configuration.

The second set of pentest was performed on the tangent face i.e. on the side parallel to annual ring direction. Annual rings were horizontal. In this case, it is probable that the normal-to-surface component of surface wave goes in a direction perpendicular to annual rings. Supposedly, the wave velocity should be lower in this configuration.

The pentests were carried out according to Dakel Daemon software guidelines, i.e. two regions in the vicinity of each sensors were selected for the breaking of the lead. From acquired times of arrival to the sensors, the system was then able to calculate the velocity of the wave generated by the pentest.

Due to severe attenuation of the wood material, imperfections of the surface, and slight variations of the actual pentest procedure, not all impulses were captured by both sensors. Successful hits were registered by the system and corresponding wave velocities were calculated for both longitudinal directions of the specimen under test. Then, overall velocity was calculated for each longitudinal direction.

Density Calculation

It is known that the sound wave velocity is dependent on Young modulus and density of the material. The relationship is progressive for E and inverse for density:

$$c = \sqrt{\frac{E}{\rho}} \tag{1}$$

where c it the velocity of sound, E is Young modulus and ρ is the density.

In order to find a correlative parameter for the velocity values, density was calculated for each specimen using its dimensions and weight. This simple calculation provided second dataset for preliminary property assessment of wood specimens.

Ambient Conditions

The experiments were performed in a laboratory conditions featuring air humidity of 40% and ambient temperature of 25 degrees Celsius. No further correction of specimen moisture was used. This was due to preliminary nature of the experiment.

RESULTS AND DISCUSSION

It can be presumed that sound wave velocities in wood differ significantly in principal directions. The pentest pulse is registered by the sensors in form of a surface wave. This type of wave features low velocity as it combines longitudinal and transversal wave components. Each particle on the surface is subject to forward longitudinal component and perpendicular transverse component. As a result, the particles move along ellipsoidal path.

Bearing this assumption in mind, we can presume that the normal-to-face component of wave velocity deals with different directions of annual rings in the specimen. As noted above, the position of the specimen should affect the values of resulting surface wave velocity. During the experiment, wave velocity and density values were calculated as shown in charts 1, 2, and 3.

It can also be presumed that wave velocity is related to the density of the wood. The density values were highest for oak and beech. However, this data does not correspond to measured velocities in some case. For general purposes, the wood species may be divided into two groups:

- SOFTWOOD: for low density/high velocity specimens (pine, spruce, and poplar).
- HARDWOOD: for high density/low velocity specimens (oak and beech).

Following this simple schema, the SOFTWOOD group species should show higher velocities than the HARDWOOD group. However, Chart 1 shows unexpected position of spruce between the oak and beech specimens. This applies for configuration with annual rings in vertical direction (future bending machine configuration).

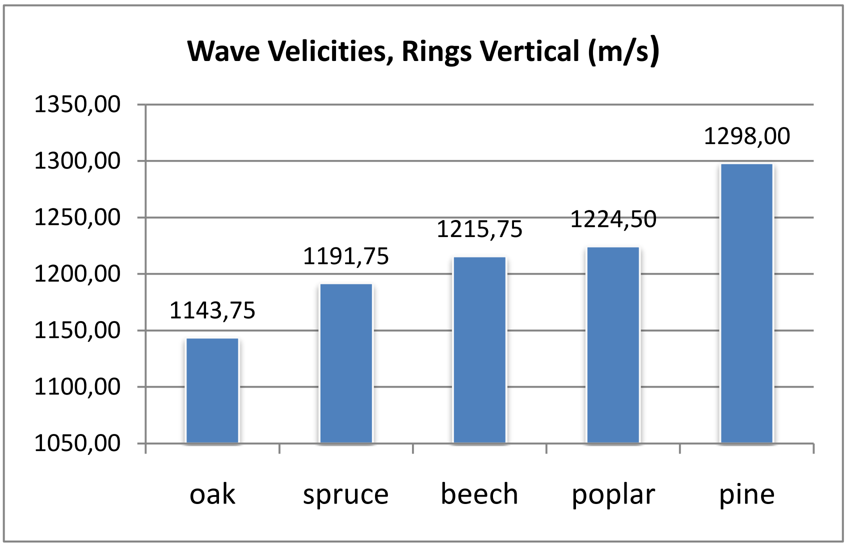


Chart 1: Wave velocities in configuration 1 (annual rings vertical).

Chart 2 shows wave velocities with horizontal annual rings. Even here, the HARDWOOD vs. SOFTWOOD group diversification does not look as expected. While oak specimen is in the right position, beech is again out of the range with rather high velocity value.

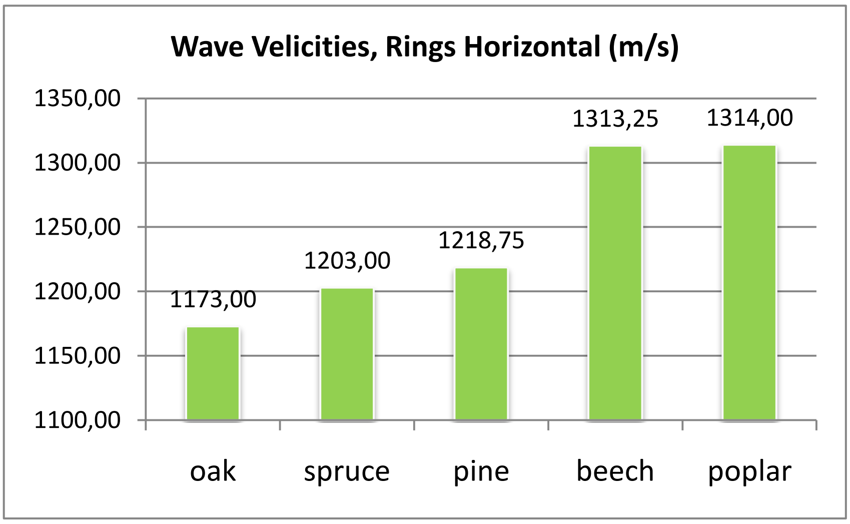


Chart 2: Wave velocities in configuration 2 (annual rings horizontal). Note that beech has showed rather high velocity values compared to oak.

Chart 3 shows density values for individual wood species. Here, the HARDWOOD group shows the highest values as expected. Therefore, the ambiguous results listed above do not result from any density variations.

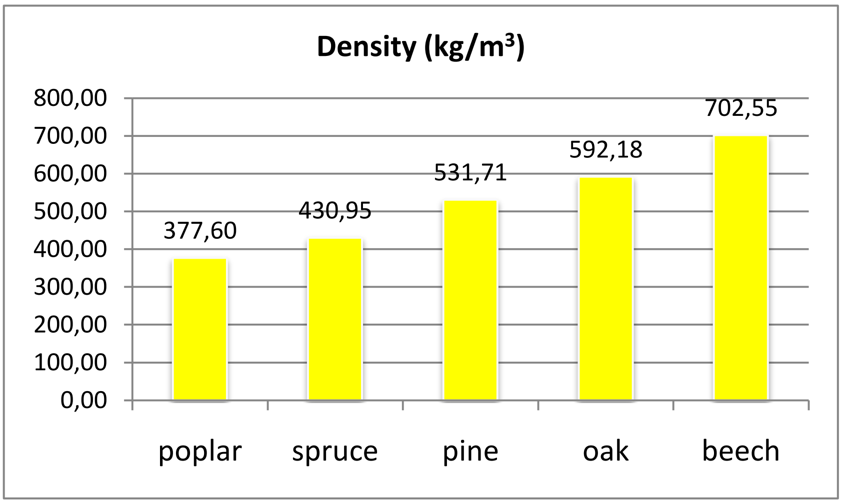


Chart 3: Density values calculated for the individual specimens using weight and volume.

As a result, it has become clear that AE measurements with wood material are much more challenging than with isotropic materials, e. g. steel. For future research, it is recommended to carefully select specimens to reduce non-standard conditions and property deviations as much as possible.

CONCLUSIONS

This preliminary study was focused on basic evaluation of wave propagation and velocity in wood specimens. Using simple experiment including pentest pulses and two sensors, wave velocities were measured on specimens intended for later bending test experiment. The study revealed several issues connected with the AE-in-wood concerning specimen selection and testing procedures.

As wood shows significant attenuation behavior, it was expected and verified that even a short source-to-sensor distance differences can substantially affect the strength (energy of the acquired signal). Thus, for future research, a fixed on-specimen point will be necessary for the bending tests to properly keep consistency of AE data. This new experience will be used in subsequent AE monitoring. A dissertation thesis is planned to cover the following phase of AE research.

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