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Wood characterization using the power spectral density and phase velocity of ultrasonic signals

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Abstract— **The application of non-destructive testing (NDT) in the analysis of trees in forest plantations permits the evaluation of the wood quality, the internal defects in development or pest attack and its characterization for application as solid wood and its products. These techniques have been constantly improved with the use of computers, electronics and agricultural control levels in order to provide tools to the specialists in integrated management. The ultrasound has been used in agriculture as NDT to determine the elasticity modulus of juvenile and mature wood of pinus and other species. This study aimed to the evaluation of new techniques for characterization of wood using parameters such as the power spectral density (PSD) and phase velocity of ultrasonic signals propagating in wood. The tests were performed using a pair of ultrasonic transducers with central frequency of 50 kHz (083-067-038, GE) which were connected to an ultrasonic pulser/receiver (5077PR, Olympus). The transmitting transducer was coupled to the samples of pinus using ultrasound gel and excited with negative pulses of short duration (5 µs) and high amplitude (-400 V) to generate longitudinal and shear waves. The ultrasound signals that propagated through the samples were received by the receiving transducer, amplified (20 to 40 dB), acquired in a digital scope (MSO4104B, Tektronix) and then transferred to a microcomputer. The tests have been done with 10 reference samples (healthy) and 10 attacked by wood wasps, with small holes in the bark. The transducers were placed on the samples in the axial, radial and inclined modes. The data were processed using the Matlab (Mathworks Inc.) to determine the power spectral density (PSD), the root mean square deviation index (*cRMSDdB*) and the phase velocity between the reference and attacked samples. The *cRMSDdB* calculated between the PSD of the reference and the attacked samples were generally higher for samples with higher degree of damage, however, in some cases, they were lower due to the presence of wood knots. The phase velocities were calculated in the frequency range 1-200 kHz and generally show higher values for the reference samples. The group velocities were also calculated and the results were in the range 1200-3000 m/s, indicating that these parameters can be used for wood characterization.**

Keywords- ultrasound; material characterization; wood quality; pinus.

I. INTRODUCTION

The use of non-destructive testing (NDT) for material characterization in several areas has grown continuously due to reduced costs, sample preservation, and mainly due to the short time necessary to obtain the results.

Some researchers evaluated the ultrasound technique for measuring the elasticity modulus of wood samples and found that the method has good sensitivity in identifying damage to their structure [1-4].

Gan et al. [5] presented a technique for inspecting wood samples using air-coupled transducers, images were generated using the chirp coded signals to excite the transmitting transducer and the waves transmitted through the sample were captured by a planar receptor and processed using pulse compression swept frequency multiplication (SFM). The authors indicated that the method has high sensitivity to identify changes in the structure of the wood. Brancheriau et al. [6-7] also investigated techniques for wood samples imaging using ultrasound.

In the agricultural area, NDT techniques have been used to analyze trees samples from forestry areas in order to evaluate the wood quality, the presence of defects in growth or pest attacks so that they can properly be used as solid wood and its products [8]. The main products of this segment make up the packaging market, of toiletries and beauty, paper for printing and writing, medium density particleboard (MDP), medium density fiberboard (MDF), oriental standard board (OSB) and hardboard. The industries in this sector are important suppliers of raw materials for the industries of furniture. The market for wood panels lies in expansion in Brazil and worldwide, with major investments to biological, physical and chemical control agents, such as rain, sun and especially the pests, which can affect the wood durability [9].

Among the pests that attack pinus, the wood wasp is one of the most harmful (*Sirex noctilio* F., 1793) (Hymenoptera: Siricidae) and it is present since 1988 in reforestation of pinus in southern Brazil [10]. In its origin region (Europe, Asia and North Africa), *S. noctilio* is a secondary pest, however, in countries where it was introduced (New Zealand, Australia, Uruguay, Argentina, Brazil and South Africa), has become the main pest of pinus forests [11]. To slow the spread of *S. noctilio* and keep the pest population below the economic injury level, the adoption of measures for effective and continuous monitoring and control is required [12].

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This work aimed at evaluating new techniques for characterization of pinus wood using parameters such as power spectral density (PSD) and the phase velocity of ultrasonic waves propagating thought the sample in order to identify damage presence due to pests.

II. Material and Methods

The development of this work has been done using 20 wood samples of *Pinus taeda* L. with lengths of approximately 80 cm and diameters around 18 cm. Ten samples were damaged by wood wasps (*S. noctilio*) and 10 not attacked samples were used as reference. The samples were obtained in pinus reforestation areas in the state of Paraná and the tests were performed at the Entomology Laboratory of the Brazilian Agricultural Research Corporation (EMBRAPA FORESTS), located in Colombo, Paraná, Brazil.

The tests were performed using a pair of ultrasonic transducers with central frequency of 50 kHz (083-067-038, GE) which were connected to an ultrasonic pulser-receiver (5077PR, Olympus). The transmitting transducer was coupled to the pinus samples using ultrasound gel and excited with negative pulses of high amplitude (-400 V) and with short duration (5 µs) to generate longitudinal and shear waves. The ultrasound signals that propagated through the samples were received by the receiving transducer, amplified (20 to 40 dB), acquired in a digital scope (MSO4104B, Tektronix) and then transferred to a microcomputer to be processed using the Matlab (Mathworks Inc.). Fig. 1 shows the block diagram of the system used to do the tests.

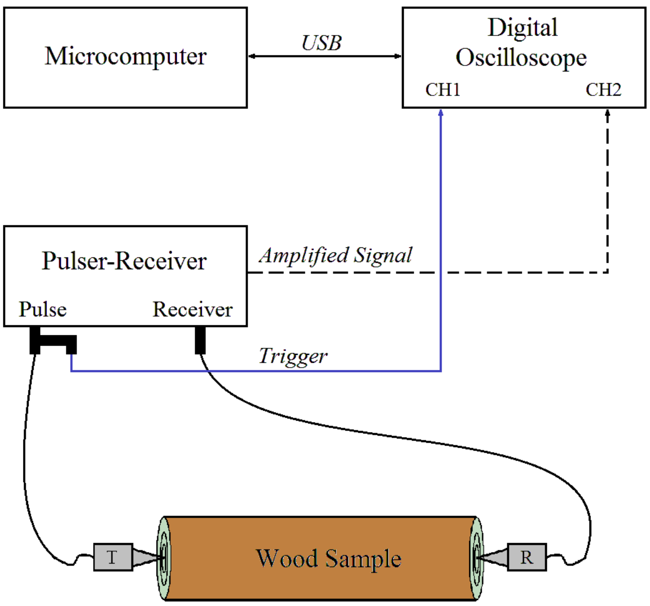
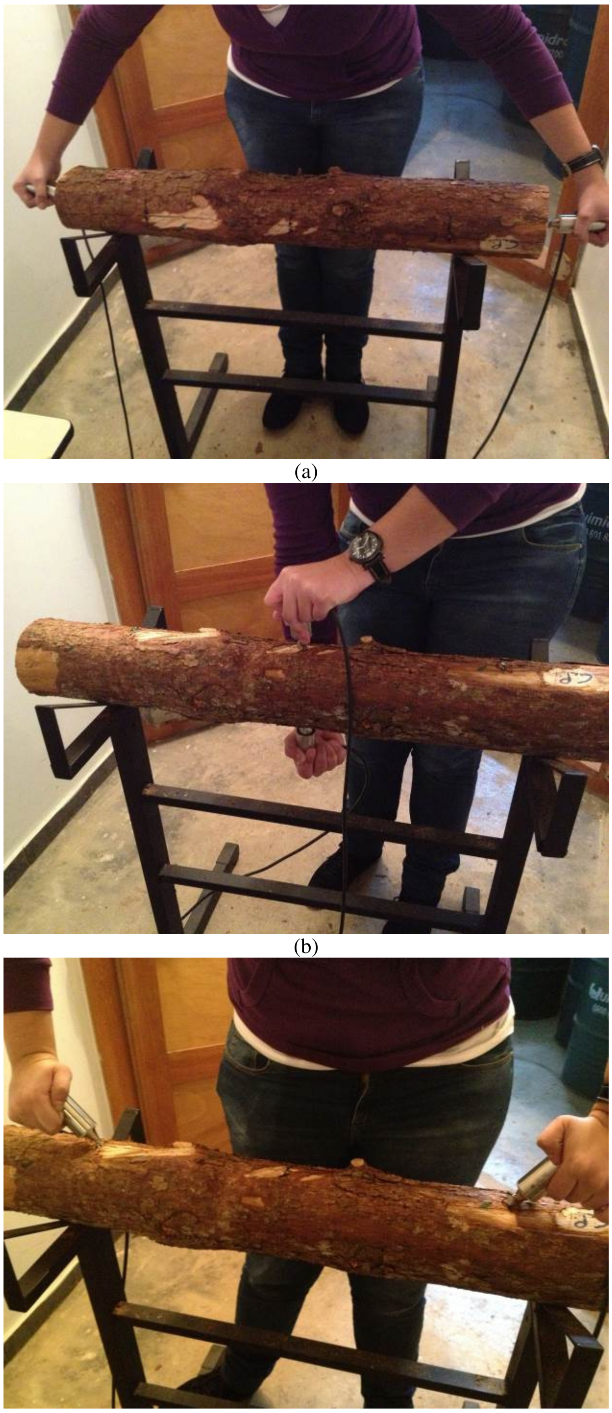


Fig. 1. Block diagram of the system used to collect data on wood samples indicating the connection of the pulser-receiver output (Pulse) to the transmitter transducer (T) that is excited with high voltage pulses. The same signal that excites the transmitter is used to trigger the digital oscilloscope on channel 1 (CH1). The captured signal at the receiver transducer (R) is conditioned (amplified) on the receiver unit of the pulser-receiver, acquired on channel 2 (CH2) of the scope and transferred via USB to a microcomputer to be processed

Fig. 2 shows the positioning of the transducers in the pinus samples to perform the tests in the axial (Fig. 2a), radial (Fig. 2b) and inclined (Fig. 2c) modes. The received signals were used to determine the power spectral density (PSD), the root mean square deviation index (*cRMSDdB*) and the phase velocity between the reference and attacked samples.



(a) (b) (c)

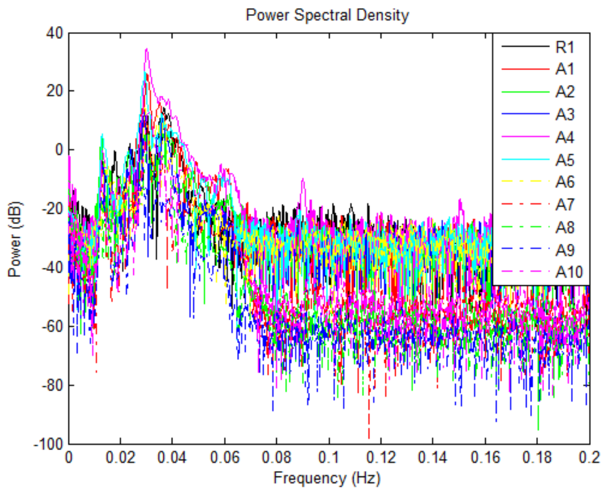
Fig. 2. Positioning of the ultrasound transducers (transmitter and receiver) to do the tests with the wood samples using: (a) axial, (b) radial and (c) inclined modes.

The *cRMSDdB* index of the power spectral density between the reference and attacked samples was calculated using (1), where *Pyyr* is the PSD of the reference, *Pyyc* is the PSD of the attacked sample and *N* is the number of points used to calculate the PSD of the acquired ultrasound signal that, in this work, was 5000. The phase and group velocities were determined as in [13].

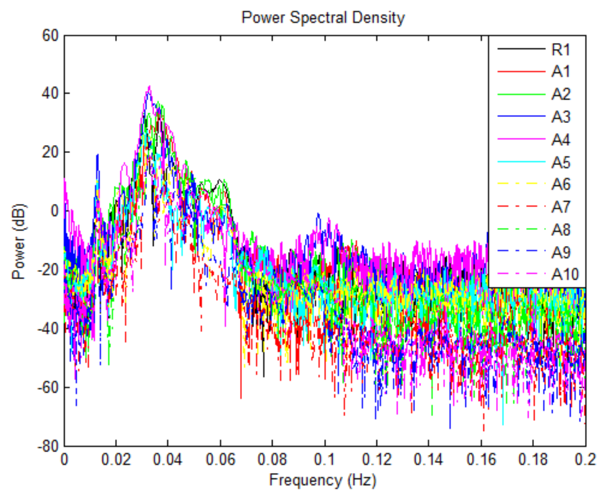
$$cRMSdB = \sum_{i=1}^{N} \sqrt{\frac{[Pyyr(i) - Pyyc(i)]^2}{Pyyr(i)^2}} \qquad (1)$$

III. Results and Discussion

Fig. 3 shows the PSD obtained for the transducers placed in the axial and inclined modes in the pinus samples attacked by the wood wasps (A1-A10) and in a reference sample (R1).



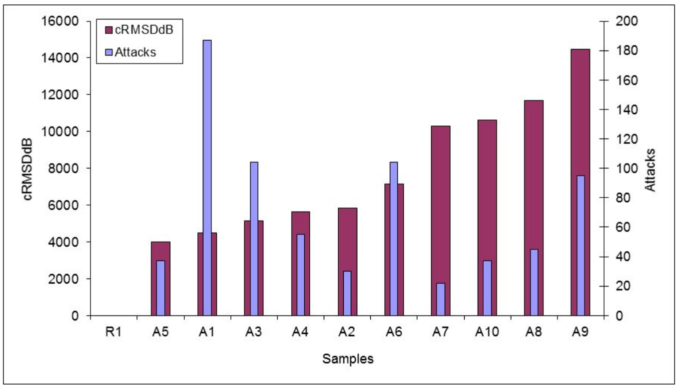
(a)



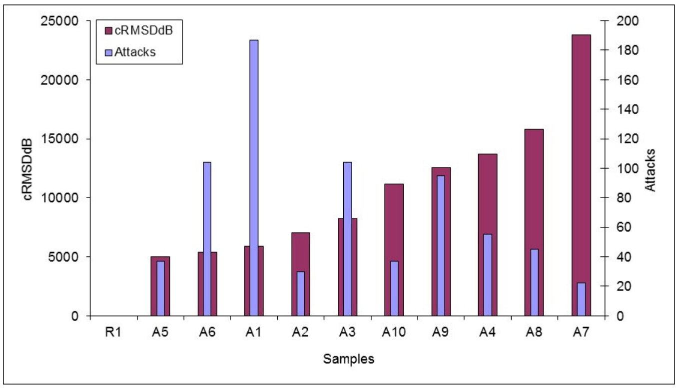
(b)

Fig. 3. PSD calculated for the attacked pinus samples (A1-A10) and a reference sample (R1), with the ultrasound transducers placed in the (a) axial and (b) inclined modes.

Fig. 4 shows the c*RMSDdB* calculated between the PSD for the reference and the attacked samples in the same modes presented in Fig. 3. The number of attacks by wood wasps found in the attacked samples is also shown.



(a)



(b)

Fig. 4. *cRMSDdB* calculated between the PSD for the reference (R1) and the attacked pinus samples (A1-A10), with the ultrasound transducers placed in the (a) axial and (b) inclined modes.

It was observed that the *cRMSDdB* calculated between the PSD of the reference and the attacked samples were generally higher for samples with higher degree of damage, however, in some cases, they were lower due to the presence of wood knots.

The tests with the transducers placed in the radial mode did not show good results. This was because, in the radial mode, the ultrasound waves propagate in the same direction in which the wood wasps make the galleries to deposit their larvae. Thus, if the transducers are positioned in a region where there was no damage, it is not possible to correlate the *cRMSDdB* with the presence of damage on the wood.

Fig. 5 shows the phase velocities calculated in the frequency range 1-200 kHz for the reference and seven attacked pinus samples, with the transducers positioned in the axial mode. It is possible to observe that they generally have higher values for the reference sample. However, this pattern can also be changed due to the presence of wood knots or due to a larger number of galleries which are filled by air that has ultrasound propagation velocity lower than the green wood.

The group velocities were also calculated and the results were in the range 1200-3000 m/s.

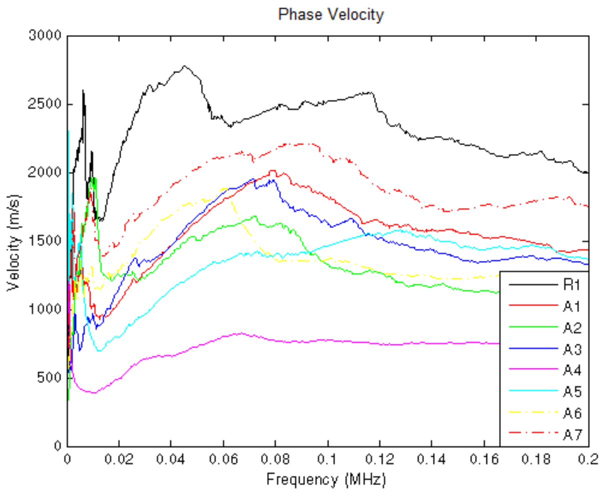


Fig. 5. Phase velocities in the frequency range 1-200 kHz for the reference (R1) and seven attacked pinus samples (A1-A7), with the transducers positioned in the axial mode.

IV. Conclusion

The results of this work show that the determination of the root mean square deviation index (*cRMSDdB*) between the power spectral density (PSD) of reference wood samples and samples attacked by wood wasps can help to identify the presence of pests in reforestation forests of pinus**.**

Further work must be performed to establish an appropriate test protocol in order to prevent false positives or false negatives, which can occur mainly due to the presence of wood knots. The results also enable the technique to be evaluated in the characterization of other types of materials.

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