PROBABILISTIC IMPROVEMENT OF CRACK PROPAGATION MONITORING BY USING ACOUSTIC EMISSION: APPLICATION TO WOOD COMPONENTS

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Abstract
In this work, the acoustic emission is used as a measurement technique to detect and locate the progress of the crack tip in a wooden specimen subjected to thermo-hygro-mechanical stresses. Under these stresses, the material response results in the release of energy in the form of transient elastic waves that are recorded by acoustic emission sensors. The post-processing of these acoustic signals is used to detect the position of the crack. There are many parameters that can affect the accuracy of acoustic emission such as noise signals, geometry, wood specie, etc. Consequently, this study combines repetitive tests and probabilistic approaches to characterize uncertainties and improve the acoustic emission protocol. In the experimental program, breaking of graphite mines at various known positions simulated acoustic sources. The differences between the real and detected positions are used to calibrate the tests and to improve the configuration of the sensors.

Keywords:
Acoustic emission; Wood material; probabilistic approaches; crack monitoring;

1 INTRODUCTION

Recent years witnessed a dynamic development of the acoustic emission (AE) method. It finds a wider and wider application in many industrial applications, mainly to monitor the structural health of equipments/structures.

AE is a useful methodology, which allows evaluating damage level during loading of a specimen or a part. AE signals are generated from the sudden release of elastic waves at the damage sources.

Due to complexity and multi-parameter nature of AE signals, the accurate localization (time and spatial positions) of wave sources is needed.

Before the AE signals recording, pencil lead breaking is a long established standard as a reproducible artificial acoustic emission source. Often, this type of source is also referred to as the Hsu-Nielsen source, based on the original works of Hsu [Hsu 1981] and Nielsen [Sause 2011]. The pencil lead breaking test results will be used herein to evaluate the effectiveness of the AE measurements for spatial localization of acoustic sources. The effectiveness will be evaluated in terms of the probability of detection [Schoefs 2012].

2 ACOUSTIC EMISSION TESTS

Acoustic Emission (AE) Technique is a useful tool for non-destructive testing. It represents the generation of transient elastic waves in a material subjected to load (mechanical, environmental, etc.) or following a change in material properties [Hamdi 2013], [Li 2015].

Within the framework of the ANR project CLIMBOIS, the AE is used:

- to identify failure mechanisms of wood materials,
- to identify and detect early warning signs of crack propagation in wood material,
- to monitor crack propagation and then, to measure crack length within the wood specimen,
- to evaluate acoustic emission measurements as well as crack length reliability, and to propose constitutive laws based on the correlation between mechanical behavior and AE activities within the wood material.

This paper focuses on evaluating the reliability of the AE measurements for crack tip location.

2.1 Experimental procedure

The experimental procedure consists of quantifying the accuracy of the estimated locations following the generation of AE waves at the known positions within the wood specimen. These positions simulate the crack tip positions (AE sources).

AE waves are generated at various pre-defined known positions by normalized Hsu-Nielsen sources (2H – 0.5 mm pencil lead) according to EN 1330-9 standard [Hsu 1981], [Sause 2011]. The pencil lead breaking test allows evaluating the AE wave propagation velocities within the wood specimen. The AE wave propagation velocities strongly depend on propagation direction (along or perpendicular to the grain) within the orthotropic material.

To evaluate the reliability of AE measurements, we compare the known crack tip and AE estimated positions (given by the location algorithm program). Several tests are repeated at the same known position to quantify measurement and material uncertainties in terms of the probability of detection (PoD).

2.2 AE equipment and specimen

To both generate and analyze the AE waveforms, the characteristics and instrumentation settings used to carry out the pencil lead breaking tests are:

- A four-channel AE system AEDSP manufactured by MISTRAS Group (Fig. 1).
- Four piezoelectric sensors with a frequency range 125 – 750 kHz. Each sensor is coupled to the specimen by silicone grease.
- Four preamplifiers with gain set at 40 dB.
- Data acquisition threshold set at 45 dB.

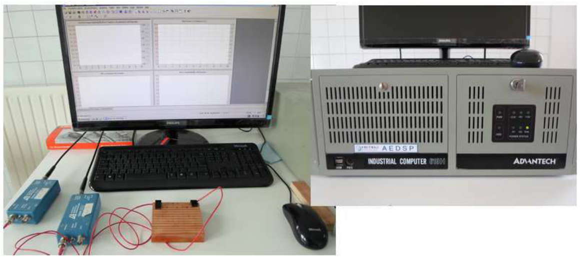

Figure 1: The four-channel AE system (MISTRAS Group).

The pencil lead breaking tests are performed on a softwood (Douglas) specimen (Fig. 2). Six measures on four lines (L1 to L4) are selected. At each 24 known positions (Hsu-Nielsen sources), the pencil lead breaking is performed at least ten times to record enough AE signals for probabilistic analysis.

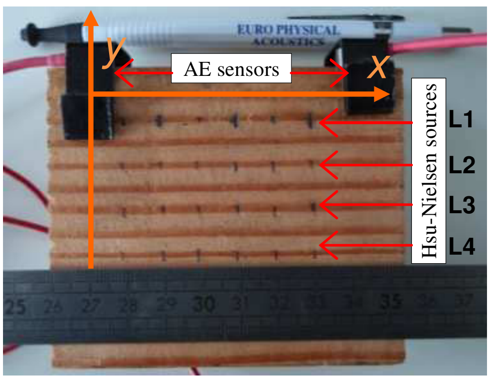

Figure 2: Wood specimen – AE sensors – Pencil lead

A linear localization algorithm is selected to locate the estimated AE sources. In these tests, the pencil lead breaking tests were first used to evaluate the AE wave propagation velocities in both directions (perpendicular and along the grain). In the perpendicular to grain direction, the measured wave propagation velocity is 2200 m/s; whereas the measured wave propagation velocity along the grain is 8000 m/s (the best results were obtained with this velocity when comparing the known positions with the AE positions). In *Figure*, it can be seen that the sensors are placed on the latewood (darker toned wood), and could explain the high wave velocity along the grain.

3 PROBABILITY OF DETECTION (POD)

Each pencil lead breaking is denoted as an event *d*. Fig. 3*Figure 3* shows the parameterization considered in the present study. The events *d* are positioned at *j* known points (x_j, y_j). 24 positions are considered in this study ($j \in [1; 24]$). *n* measurements are realized at each *j* location. Each measure provides a k^{th} AE coordinates $(\tilde{x}_{j,k}, \tilde{y}_{j,k})$.

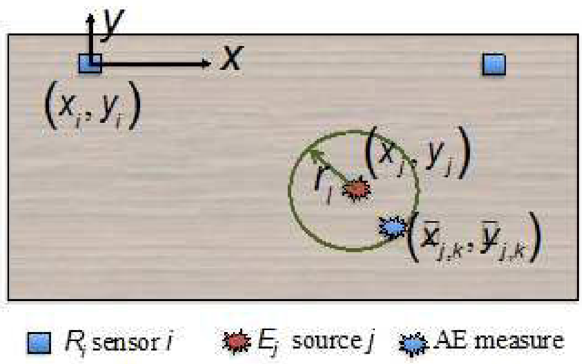

Figure 3: Problem parameterization

Among all uncertainty sources, the event *d* is considered as deterministic in intensity and position (by considering a positioning error less than 0.5 mm). The events *d* are repeated to quantity the measurement error that integrates the uncertainties related to the sensor and the source position for a fixed AE configuration AE_{con} (distance between sensors, post-treatment algorithm, velocity along the grain, etc.). Given that the real position is known, it is possible to quantify the bias and the uncertainty for each position or configuration. This information is useful to determine the best configuration or position that minimizes the measurement error in terms of the Probability of Detection (PoD) [Schoefs 2012].

Considering that the material is heterogeneous, the material uncertainties are integrated to each measure point. In addition, if tests are considered as equally probable and sufficiently representative of real situations, the PoD or a position *j* is then written with respect to the membership of the measured position of the source to a circle of radius r_l centered on the exact coordinates of the source (*Figure 3*):

$$PoD_{j,AE_{con}}(d, r_l) = P\left(\sqrt{\left(x_j - \tilde{x}_{j,k}\right)^2 + \left(y_j - \tilde{y}_{j,k}\right)^2} \le r_l \middle| d\right) \quad (1)$$

The value of r_l can be considered as the required detection threshold for the localization of the tip. This study will focus on a fixed AC configuration, AE_{con}. The current configuration of the sensors (Section 2.2) only allows for estimating the position of the source in one dimension. Consequently, we focus on the detection of the position in the *x*-direction for fixed (deterministic) values: $\tilde{y}_1 = -1.5\,\text{cm}$, $\tilde{y}_2 = -2.6\,\text{cm}$, $\tilde{y}_3 = -4\,\text{cm}$, and $\tilde{y}_4 = -5\,\text{cm}$ (L1 to L4 lines in Figure 4). In such a case, eq. (1) becomes:

$$PoD_{j,AE_{con}}\left(d, r_l\right) = P\left(\left|x_j - \tilde{x}_{j,k}\right| \le r_l \middle| d\right) \qquad (2)$$

In this study the PoD is directly evaluated from the *n* repetitions of the AE measurement at each *j* position.

4 EXPERIMENTAL RESULTS

4.1 AE measurements

Fig. 4 compares the AE measures with the known positions for each line. Taking into account the symmetry of the problem and results, we grouped the measures relative to symmetric positions with respect to the sensors – i.e., 2 and 7 cm, 3 and 6 cm, and 4 and 5 cm. It also increased the number of measures by point by improving the assessment of the PoD.

In all cases it is noted that there is a scatter between real and AE positions. The scatter seems to increase when the sources are far away from the sensors. With the exception of line 3, it is also observed that in most part of cases the AE positions underestimate the real positions.

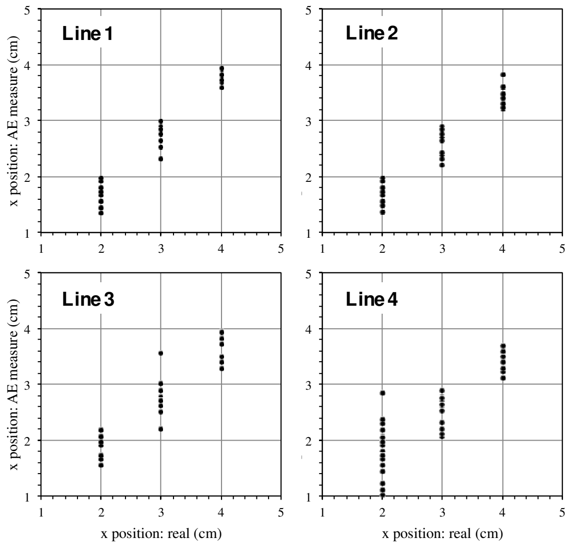

Figure 4: Known positions vs. estimated positions

4.2 Probability of Detection

Fig. 5 presents the PoD for the considered positions and a detection threshold of r_l = 0.1 cm. For this threshold, the PoD varies between 0.2 and 0.8. The PoD remains about 0.5 when the sources are located between the two sensors (Line 1). The worst detections are located over the Lines 2 and 3 were the PoD < 0.4. However, it is observed that the PoD is larger for the Line 3 and increases when the source is located close to the middle of the sensors (*x* = 4 cm).

Fig. 6 shows the PoD for the considered positions and a larger detection threshold r_l = 0.3 cm. In comparison with results of *Figure*, the PoD varies between 0.45 and 1 indicating that AE technique seems to be more performing for such a threshold value. *Figure* follows a similar trend than Fig. 5 with maximum PoD for Line 3 varying from 0.6 to 1. These results indicate that it is possible to determine zones where the PoD is larger of the AE crack tip measurements. Each zone could be dependent on the configuration of the AE technique (distance between sensors, post-treatment algorithm, velocity along the grain, etc.) and/or material properties (type and geometry of timber specimen, presence of nodes, etc.). Although considering these factors is beyond the scope of this paper, further studies will focus on some of these points.

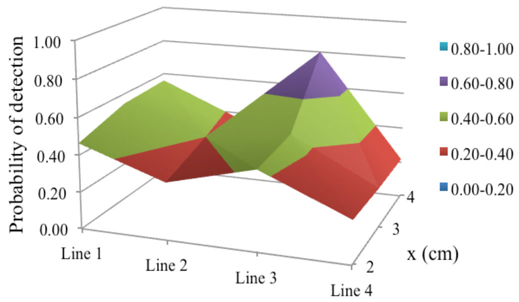

Figure 5: Probability of detection for all positions and a detection threshold r_l = 0.1cm

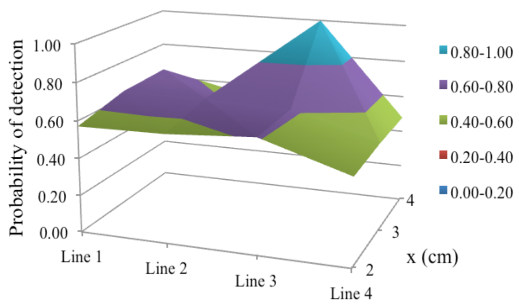

Figure 6: Probability of detection for all positions and a detection threshold r_l = 0.3 cm

5 CONCLUSIONS AND FURTHER WORK

The pencil lead breaking tests are performed on a softwood (Douglas) specimen (Fig. 2). Six measures on four lines (L1 to L4) are selected. At each 24 known positions (Hsu-Nielsen sources), the pencil lead breaking is performed at least ten times to record enough AE signals for probabilistic analysis.

The results show scattering between known and AE positions. Probably due to attenuation of AE signals, the scattering seems to increase as the wave sources are far away from the sensors.

Given that the real position is known, it is possible to quantify the bias and the uncertainty for each position or configuration. This information is useful to determine the best configuration or position that minimizes the measurement error in terms of the Probability of Detection.

The results indicate that it is possible to determine zones where the PoD is larger for AE crack tip measurements. Each zone could be dependent on the configuration of the AE technique (distance between sensors, post-treatment algorithm, velocity along the grain, etc.) and/or material properties (type and geometry of timber specimen, presence of knots, etc.). Although considering these factors is beyond the scope of this paper, further studies will focus on some of these points.

6 ACKNOWLEDGMENTS:

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