Wood testing using Acousto-ultrasonic

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SUMMARY

The ultrasonic-based methods applied to wood have been quite intensively developed during the last decade. Basically, both the stress wave propagation and the natural frequency vibration methods have been used for timber grading.

In order to increase the sensitivity of the stress wave method, the acousto-ultrasonics, AUS, have been approached in the way to complete the initial time information. By joining time and spectral AUS data, exploratory researches have been supported as NDT of wood.

Tests have been made with transducers working in frequency range of 25 kHz. Coupling problems have been partially solved using conical penetrating transducers. An acquisition station was set up, connected to an oscilloscope, amplifiers and software able to compute the AUS spectral characteristics. The maximum voltage picks, the signal energy and the decrement function were selected NDE variables.

Applied to a sample of structural timber (solid wood), several AUS variables appear to be correlated to timber strength. Mechanical tests have confirmed the correlations. AUS variables added to the stress wave information give an increase of about 25% of the mechanical NDE of timber strength. This result is very interesting in terms of grading and reliability. The next step is to define a standard industrial acquisition method and to calibrate an applied exploitation model.

INTRODUCTION

In the European building domain, especially for structures, the use of wood is nowadays very limited. This is due, among other factors, to the difficulty of implementation of this raw and renewable material, whose mechanical characteristics are rather difficult to control, in view of their countless variability.

With the object of increasing the qualitative knowledge about this material, non destructive control methods based on ultrasound have been extensively developed during the last 10 years. These methods are based on the existence of a direct relation between the propagation velocity of the longitudinal ultrasound wave in a sample and its elastic properties. Alongside the longitudinal axis, this relation is represented by equation 1 :

$$v^2 = \frac{C_{11}}{\rho} \cong \frac{E_L}{\rho} \qquad (1)$$

v	:	propagation velocity of the longitudinal wave
C_{11}	:	first component of the rigidity matrix
ρ	:	density of the sample
E_L	:	longitudinal Modulus of Elasticity

Based on 580 beams of spruce and fir tested in four-point bending, a relation between longitudinal ultrasound propagation velocity and longitudinal modulus of elasticity [2, 3] has been established.

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Another test on 60 glulam timber, GLT, [4] allowed to evaluate the beam's MoE in the accuracy range of ± 4%. The relation between velocity and MoE is shown on figure 1:

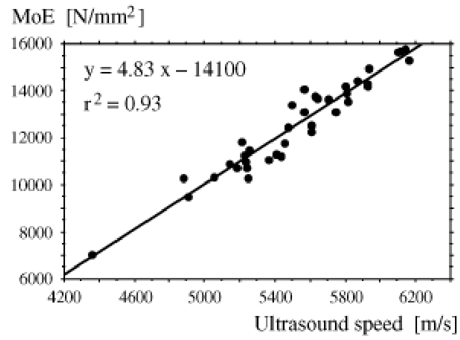

Figure 1 - Relation between ultrasonic average speed of laminate and MoE of glulam beams. The average is corrected using an inertia coefficient applied to the laminae in function of their location about the neutral plane[4].

In this calibration method, empirical function errors are eliminated by the n components system effect. For unit elements, regression coefficient is about $0.25 \leq r^2 \leq 0.50$ [3].

On the other hand, the relation obtained with the modulus of rupture (MoR) is less interesting. Whereas the modulus of elasticity gives an information on the sample global quality, which is also given by the velocity, modulus of rupture depends more often on a local defect, which has not a dominating influence on the propagation velocity of the ultrasonic wave, but which initiates the rupture mechanism.

Facing this problem, it has been tempted to increase ultrasound exploitation by looking at the characteristics of the transmitted signal in the temporal field [5], namely the maximum peak, the signal energy integrated on a defined time base and the signal attenuation starting at the maximum peak and measured with an exponential approximation as shown on figure 2.

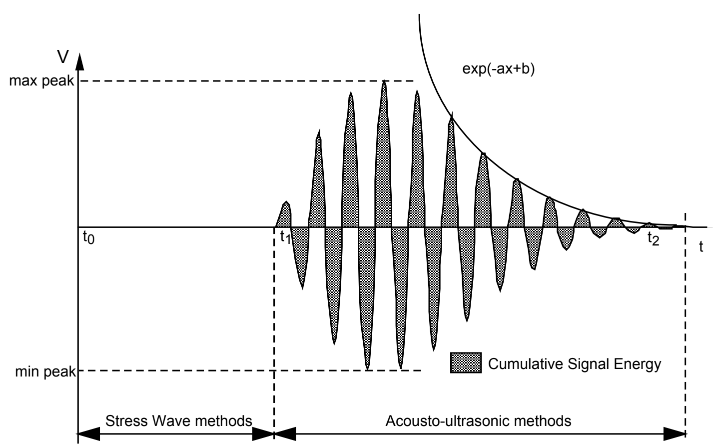

Figure 2 - Example of stress wave acoustic parameters: propagation time, maximum peak, energy and attenuation.

Exploitation of these parameters should allow to increase qualitative information obtained with the simple stress wave method. An acousto-ultrasonic method, more sensible and accurate in non destructive evaluation, could lead to applications in the whole wood transformation process, from the standing tree (pre-grading, decay detection) to sawing grading, or to panel quality control. For example, the figure 3 shows the absorption of the transmitted-wave energy according to the length of the wood sample (2) :

$$E_r = f\left(\frac{a}{l^n}\right) \pm \Delta tape \qquad (2)$$

E_r	:	referential energy
a	:	linear coefficient
l	:	length of the sample
n	:	exponent coefficient
Δtape	:	tape of values establishing the referential energy

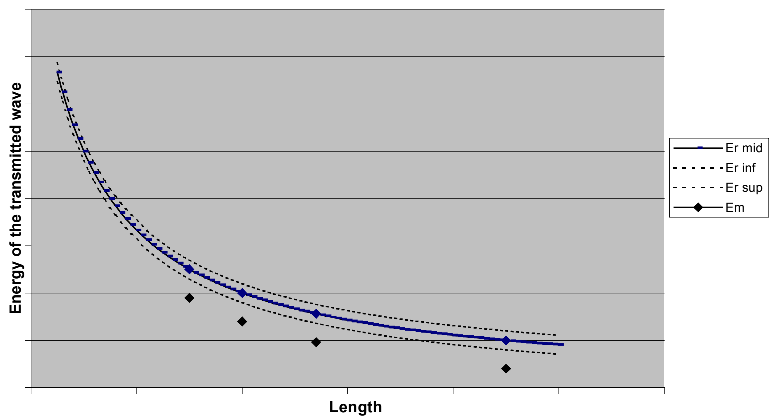

Figure 3 - Relationship between length of the tested beam (longitudinal measurement), and the energy of the transmitted wave.

The equation 3 relates the absorption rate observed for a longitudinal measurement.

$$T_{abs} = \frac{E_r - E_m}{E_r} \times 100 \qquad (3)$$

T_{abs}	:	absorption of energy in the beam
E_r	:	referential energy
E_m	:	measured energy
$E_{r\ inf}$	:	minimal value of the referential energy
$E_{r\ sup}$	:	maximal value of the referential energy
E_{rmid}	:	mean value of the referential energy

TESTS AND RESULTS

Tests have been performed with the sub-described testing station. They have been done on 9 x 16 cm beam samples. Two particular cases, on a board and on a tree section, are presented to demonstrate the sensibility of signal parameters on the fiber discontinuity, whatever the defects source.

DESCRIPTION OF THE TEST STATION

The test station is devided in three main elements :

- The ultrasound device Sylvatest® allows to send and receive a longitudinal ultrasound wave using two piezoelectric probes. It measures the duration of the stress wave course in the tested sample, with regard to its moisture content and temperature, which are also controled.

- A numerical oscilloscope, GOULD 1604, records the signal received from the probe, and samples it in about 1000 points.
- A Macintosh computer, with the data acquisition software LabView (National Instrument Corp.), registers sample signals. Then, the developed program on LabView allows to display the raw signal, to filter it, to make a fast Fourier Transform and to evaluate the attenuation. Moreover, it gives the values of maximum peak and signal energy.

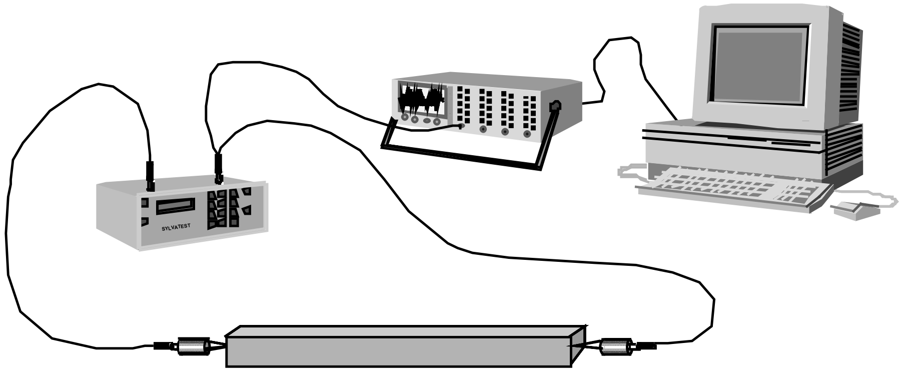

Figure 4 - Acousto-ultrasonic parameter acquisition equipment.

BEAM TESTING

32 beams (9 x 16 x 320 cm) have been tested with the data acquisition equipment, after having been stabilized during two months at a moisture content of 14%. The beams have been tested in four-point bending, to evaluate their modulus of elasticity and modulus of rupture. Parameters like stress wave velocity, maximum peak, integrated energy on a 500 ms time base and attenuation after the first peak have been measured. Correlations between precited parameters and mechanical properties are given in Table 1.

Table 1 - Correlations (r^2) between the ultrasound parameters and the mechanical properties, Modulus of Elasticity, MoE, and Modulus of Rupture, MoR, observed on 32 beams.

	velocity	Peak	Energy	a (attenuation)
MoE	0.583	0.321	0.23	0.461
MoR	0.25	0.416	0.293	0.561

Observation of this table shows that the ultrasound velocity gives a good information on the beams' MoE (r^2 = 0.583) and this is really a global quality representation of the tested samples. On the other hand, the relationship velocity versus modulus of rupture is significantly weaker (r^2 = 0.25).

Furthermore, it can be observed that other parameters (maximum peak, energy and attenuation) bring no more information to determine the elasticity and give even weaker correlations than the velocity, because the local sensibility does not affect so much MoE regarded as an average value.

With reference to MoR, maximum peak measurements give more interesting results (r^2 = 0.416) than velocity (r^2 = 0.25). This parameter is particularly sensible to explain beam strength.

Using attenuation as the NDE variable, the result is still better, but this parameter is difficult to estimate, due to the very instable form of the signal after the maximum peak.

However, both measures bring a precious complement of information related to wood mechanical propertie evaluation : the speed of the ultrasound giving a good correlation to the MoE, and the absorption of energy relating the singularities of the sample (standing tree, log, sawing…). The MoR, the main reference for the European standards concerning timber grade, is a combination of those values (4) :

$$\text{MoR} = f(\text{MoE}) + g(\text{E}) \quad (4)$$

MoR : Modulus of Rupture
MoE : Modulus of Elasticity
E : Energy of the transmitted wave

PARTICULAR OCCURRENCE OF ACCIDENTAL DISCONTINUITY

Tests have been realized on a 2 ∞ 17.5 ∞ 200 cm solid wood plank with high mechanical quality, in the middle of which a progressive saw cut has been performed. The depth of the board was 17.5 cm, its length, 2 m. The cut represented 12.5, 25, 37.5%, ... of the beam, up to the final cut. The results for velocity, maximum peak and energy are shown in Table 2. The loss percentage is calculated for each parameter.

Table 2 - Variable saw cut study in the middle of a board; influence on the velocity, maximum peak and energy measured horizontally in the middle of the section.

saw cut	**Propagation velocity (m/s)**		**Maximum peak (V)**		**Energy (V.s)**	
depth %	value	loss %	value ($x10^{-3}$)	loss %	value ($x10^{-3}$)	loss %
0	5698	0	2.80	0	1.43	0
12.5	5698	0	2.48	11.4	1.31	8.4
25	5698	0	2.33	16.8	1.28	10.5
37.5	5633	1.15	2.18	22.1	1.28	10.5
50	5510	3.30	2.07	26.1	1.26	11.9
62.5	5405	5.14	1.84	34.3	1.22	14.7
75	5376	5.65	1.81	35.4	1.16	18.9
87.5	5291	7.14	1.66	40.7	0.86	39.9
100	–		–		–	

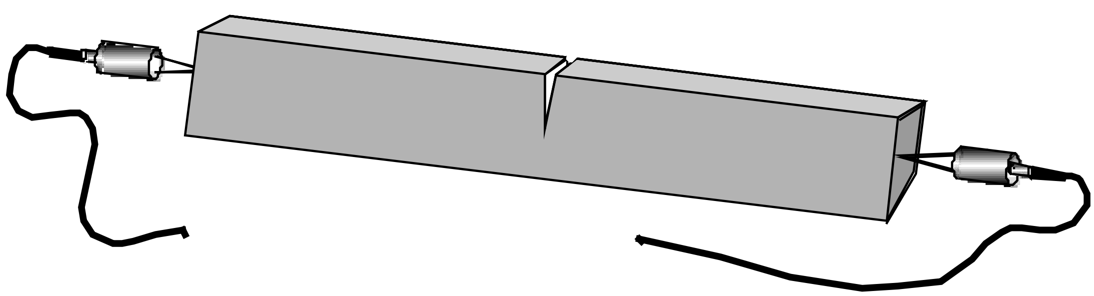

Figure 5 *- Modelisation of a wood discontinuity effect on the ultrasound parameters in a 2 m solid wood plane*

CONCLUSIONS

The study of stress wave parameters like maximum peak, energy and attenuation, has brought important information on beam mechanical property evaluation. Velocity alone is still very interesting for the global quality definition of tested samples, expressed by its modulus of elasticity.

For this global quality, signal parameters do not bring interesting improvement. Linear regression AUS results versus modulus of elasticity are even less interesting.

On the other hand, and despite measurement difficulties due mainly to coupling conditions, regression results with modulus of rupture are clearly increased, because of the better sensibility to local defects, that are mainly responsible of the rupture. This local defect sensibility is particularly significant in the case of a plank, with an artificial discontinuity (saw cut) or in the case of a tree section, where a centred hole was cut.

This study has brought out acousto-ultrasonic parameters interest for the non destructive evaluation of wood quality. Technological developments and systematic calibrations should allow its industrial application in several domains of wood transformation, like sawing grading and defect detection in standing trees.

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