Laser-ultrasonic Poisson's ratio assessment of non-conducting isotropic materials with temporal convolution effects corrected

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Abstract: We present a correction technique of the temporal convolution effects related to the source parameters for optimising the measurement of the Poisson ratio by the laser-ultrasonic method.

1. INTRODUCTION

The laser-generation of ultrasound has been widely demonstrated as a promising technique in the field of the mechanical characterization of materials.[1,2]

The use of a laser is associated to three convolutions related to the source parameters (the spot size, the pulse duration and the wavelength of the excitation).[3,4] These convolutions introduce delays on the acoustic waves' arriving times and consequently affect the values of the elastic constants. We can eliminate these effects by optimising the experimental conditions so that the excitation becomes a point-like irradiation with an infinitly short pulse duration. But the risk of damaging the sample (particularly, low damage-threshold materials) obliges a compromise between the spatial distribution and the pulse duration of the excitation. The convolution effects are thus still present. Another solution consists in introducing correction factors (numerically determined) in the acoustic waves' arriving times. The elastic constants are then calculated using parametric expressions.

In the following, we are going to develop this second approach, show how we can evaluate the Poisson ratio using a parametric expression, present and discuss experiments performed on a BG-18 glass sample.

2. THE LASER-GENERATION OF ULTRASOUND IN A THERMALLY NON-CONDUCTING MATERIAL

In a thermally non-conducting material (like glasses, ceramics, polymers,...), the temperature elevation field is governed by the optical absorption.[5] In the case of an isotropic sample, the mechanical displacements generated at the epicenter, result from four convolutions: three related to the laser-source and one depends on the mechanical properties of the sample.

The displacement field can be expressed as follows:

$$\mathbf{u}(t) = \mathbf{u}_1(\beta) * \mathbf{u}_2(\sigma) * \mathbf{u}_3(\tau) * \mathbf{u}_4(\nu) \tag{1}$$

where β is the absorption coefficient, σ the radius at 1/e of a spatially Gaussian irradiation, τ the rise time of the laser-pulse and ν the Poisson ratio, * is the convolution symbol.

A 2-D model recently developed in our laboratory[5], calculates the displacement field with very satisfaying accuracy and calculation time. It is very adequate for our parametric studies. In this model the temporal convolutions are represented by four nondimensional parameters

$p_1 = \beta d$ (2) $p_2 = d / \sigma$ (3) $p_3 = \tau / t_l$ (4) $p_4 = (1-2\nu) / (2-2\nu)$, (5)

d is the sample thickness and t_l the longitudinal wave arriving time. Using a dimensionless time variable ($t^* = t/t_l$), the displacement field and the arriving times are then expressed as follows:

$u(t^*) = u\,(p_1, p_2, p_3, p_4)$ (6) $t_{l,t} = f\,(p_1, p_2, p_3, p_4)$ (7)

3. ANALYSIS OF THE CONVOLUTION EFFECTS ON THE ACOUSTIC WAVES'ARRIVING TIMES

Figures 1a and 1b represent the longitudinal and the shear waves' arriving times as a function of the spot size for a given pulse duration. Two behaviors of the arriving times are clearly observed: the first for the point-like sources negligible delays are noted, and the second for large sources; the introduced delays become more and more significant with the spot size. The shift of the shear arriving time is more notable than the one of the longitudinal arriving time.

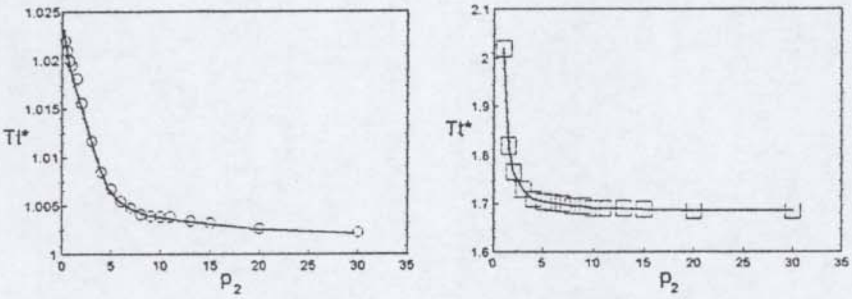

Figure 1: t^* and t^* as a function of p_2, $p_3 = 0.01$

4. THE PARAMETRIC EXPRESSION OF ν

In the case of negligible convolution effects, we easily prove that the parameter p_4 is related to the arriving times ratio $r = t_t / t_l$ through the relation:

$$r = a.(p_4)^{-b} \tag{8}$$

with a = 1 and b = 0.5. When the convolution effects are significant, the coefficients a and b will depend on the parameters p_1, p_2, p_3 and the equation (8) will be a parametric one. The corresponding parametric expression of ν deduced from equations (2) and (8) is:

$$\nu = \frac{1 - 2 \cdot \left(\frac{r}{a}\right)^{-\frac{1}{b}}}{2 - 2 \cdot \left(\frac{r}{a}\right)^{-\frac{1}{b}}} \tag{9}$$

The coefficients a and b are numerically calculated from a log-log representation of r as a function of p_4, the values of the parameters p_1, p_2, p_3 used in the simulations are determined from experiment. The variation of the parameters a and b as a function of p_1 and p_2 are shown in the figures 4 and 5. From these plots, We can see that the point-source regime is reached at $p_2 = 10$.

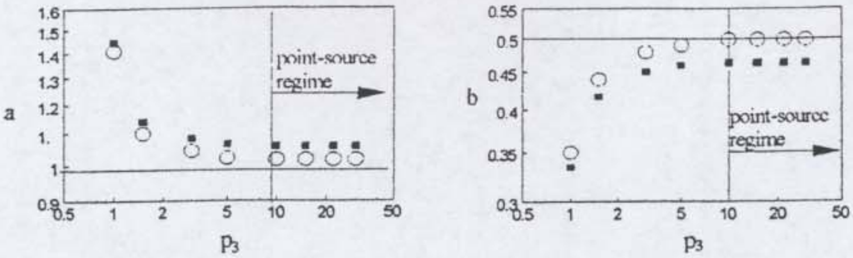

Figure 2: Effects of the spot size on the coefficients a and b for a short pulse duration: $P_3 = 0.015$ (○○) and a long one : $P_3 = 0.0 75$ (▪ ▪).

5. EXPERIMENT

Two experiments with two different pulse durations (a short one and a long one) have been performed on BG-18 Schott glass sample. The physical properties of the sample (given by the manufacturer) and the experimental conditions are reported in table 1.

The experimental setup is represented in figure 3. The excitation source is a pulsed monomode Nd:YAG (1.064 μm), the surface displacements (figure 7) are detected by an Ultra-*Optec* I/O heterodyne interferometer. The coefficients a and b are calculated for each experiment (table 2) using the measured arriving times ratio and the experimental values of p_1, p_2, p_3. The Poisson ratio has been determined for each experiment, the results (before and after correction) are reported in table 2 . The value of ν measured by the piezoelectric pulse echo technique and the one given by the manufacturer are also reported in this table. The difference between the corrected and the noncorrected values are notable in the second case, this proves that the convolution effect is too-significant to be neglected. The corrected values of ν are in good agreement with the one measured by the pulse echo technique. This demonstrates the validity of our technique.

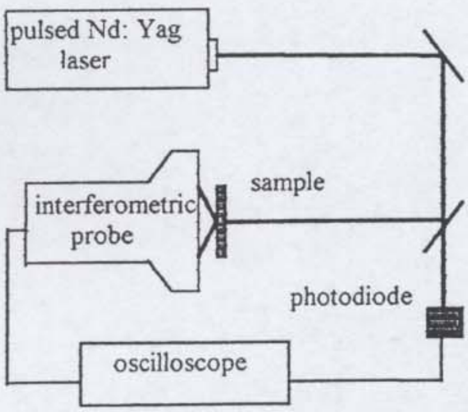

Figure 3. Experimental setup

Table 1: Physical properties of BG-18 glass sample and experimental conditions

Physical properties	
Density - ρ (kg/m^3)	2680
Poisson ratio - ν	0.225
Absorption coefficient - β (m^{-1})	9709
Thickness - d (mm)	3.098
Experimental conditions	
Beam radius - σ (mm)	2
Rise time - τ (ns)	6 and 16

Figure 4: Experimental displacement curves solid line (P_3=0.03) dashed line (P_3=0.012)

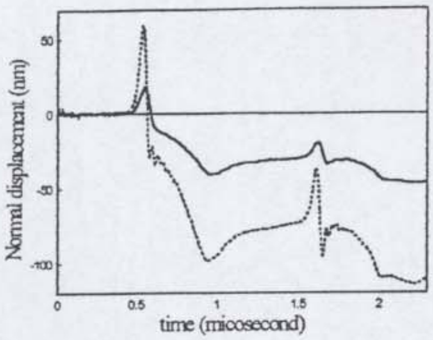

Table 2: Waves' arriving times, coefficients a and b and the measured values of ν for two values of τ (6 ns and 16 ns).

Rise time τ (ns)	Longitudinal arriving time (ns)	Shear arriving time (ns)	Coefficients a	b
6	540	550		
16	943	985	1.061	0.479

ν			
Laser-ultrasonics Before correction	After correction	Pulse-echo method (measured)	Given by the manufacturer
0.24	0.22		
0.25	0.228	0.228	0.225

6. CONCLUSION

The analysis of the effects of two source parameters (the spot size and the pulse duration) on the acoustic waves' arriving times demonstrates the importance of minimizing the convolution effects for optimal determination of the elastic properties of materials by the laser-ultrasonic technique. As an alternative to the experimental minimization of the convolution effects, we have proposed a numerical correction technique. The Poisson ratio of a BG-18 glass sample has been evaluated, results were in good agreement with those obtained by the piezoelectric pulse echo method.

This approach is particularly interesting for industrial applications when the measurement has to be repeated at the same spot or performed on low damage-threshold materials (like polymers or polymeric matrix composites).

In future work, we intend to investigate two other convolutions related respectively to the optical absorption and the viscoelasticity and analyse their effects on the features of the generated displacements.

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