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Theme: Ultrasonic characterization of materials. The case of polymers

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Abstract

During ultrasound inspection by echo mode in polymeric materials, there is a modification of the acoustic parameters such velocity and attenuation of the transmitted wave. This work lies in the study of propagation properties and the attenuation of ultrasonic waves with a view to simultaneous evaluation of propagation velocities and attenuation of ultrasound in polymeric materials. We modeled the propagation of the ultrasonic wave through these materials, using Szabo's theoretical formulation. This reflects the frequency dependence of the absorption phenomenon and takes into account both natural and pure real integer frequency power factors. These measurements were made in echo mode, using ultrasonic transducers in a frequency band between 1 and 4 MHz. This allowed us to establish a law linking the absorption coefficient to the frequency and to assess the evolution of the phase velocity in the same frequency range, for the different types of materials studied. The results obtained are in line with those obtained by numerical simulation. The absorption phenomenon varies from one material to another. It is more significant towards high frequencies. It is also related to the distance travelled by the acoustic wave. For some materials such as polyamide and Plexiglas, the absorption coefficient has been determined with considerable precision. The results obtained further encourage the generalization of these ultrasonic methods for a real characterization of new materials.

Keywords: *ultrasound, propagation, waves, ultrasound attenuation, materials viscoelastic.*

1. Introduction

When an ultrasonic wave passes through a material, we notice a decrease in its amplitude and a change in its shape. These are caused by the loss of ultrasonic energy.

Energy loss is manifested by an attenuation of ultrasonic intensity I. Several factors contribute to this attenuation such as absorption, refraction, reflection and diffusion.

In this study we are interested in the study of absorption.

2.Origins of ultrasound wave absorption:

The phenomenon of absorption in viscoelastic materials is mainly associated with three mechanisms: viscous friction and molecular relaxation, thermal conduction.[1]

Frequency-dependent attenuation according to a power law[2], defined by $\alpha(f)=\alpha_0 f^n$

Where α_0 is the attenuation coefficient having as unit Np/m.Hz^n and n a positive real number

3.Modelling the absorption phenomenon:

In order to simulate the absorption phenomenon in viscoelastic and fluid materials, we used the causal time model proposed by Szabo.
becomes verifiable for all powers of the frequency.
The phase velocity c(ω) is written as follows:[2][3]

$$\frac{1}{c(f)}=\frac{1}{c(f_0)}+\alpha_0\tan\left(\frac{\pi n}{2}\right)\left(\left|f\right|^{n-1}-\left|f_0\right|^{n-1}\right) \quad (n\ even)$$

$$\frac{1}{c(f)}=\frac{1}{c(f_0)}-\frac{2\alpha_0}{\pi}f^{n-1}\left(\ln\left|f\right|-\ln\left|f_0\right|\right) \quad (n\ odd)$$

4.Experimental Study:

The principle of ultrasonic characterization methods is to generate ultrasonic waves in the medium to be studied and to detect reflected or scattered signals.
The determination of material elasticity constants by ultrasound is based on the determination of propagation rates. This calculation requires the measurement of the time interval.

a).The principles steps in an experimental study:

1- The samples we used are made of polyamide cylinders of different thicknesses and Plexiglas plates.
2- Place the sample in a tank filled with water, which is connected with the ultrasonic scanner (VariUs)
3- Scan the sample by transducer.(3.4MHz)

4- The signal received by the transducer is processed by a microcomputer through a GPIB bus. A program developed under MATLAB.

Fig(1): Experimental Device (Variable Ultrasonic Scanner "VariUS")

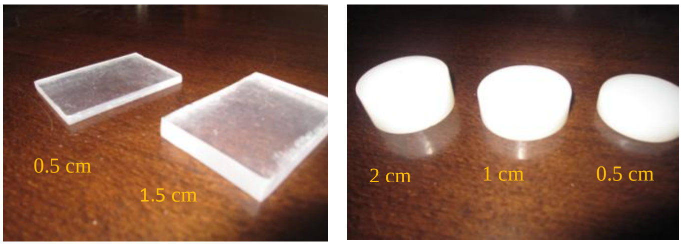


Figure (2): Samples of: (a) Plexiglas and (b) polyamide used

b). Velocity measurement :

The relationship to obtain the propagation rate for polyamide is written as:

$$c_{écha} = \frac{1}{\frac{1}{c_{eau}} - \frac{\Delta t}{2\Delta z}}$$

Δt the difference between the flight times of the signal reflected on the back side of the large and small sample respectively.(The cross-correlation method).[4]

$\Delta z=(z_2-z_1)$ different thicknesses between large and small samples.

The relationship to obtain the propagation velocity is:

$$C_{écha} = \frac{\Delta d}{\Delta t}$$

Where Δd refers to the difference between the distances travelled by the two echoes.

Δt : time taken by the wave to travel back and forth in this thickness

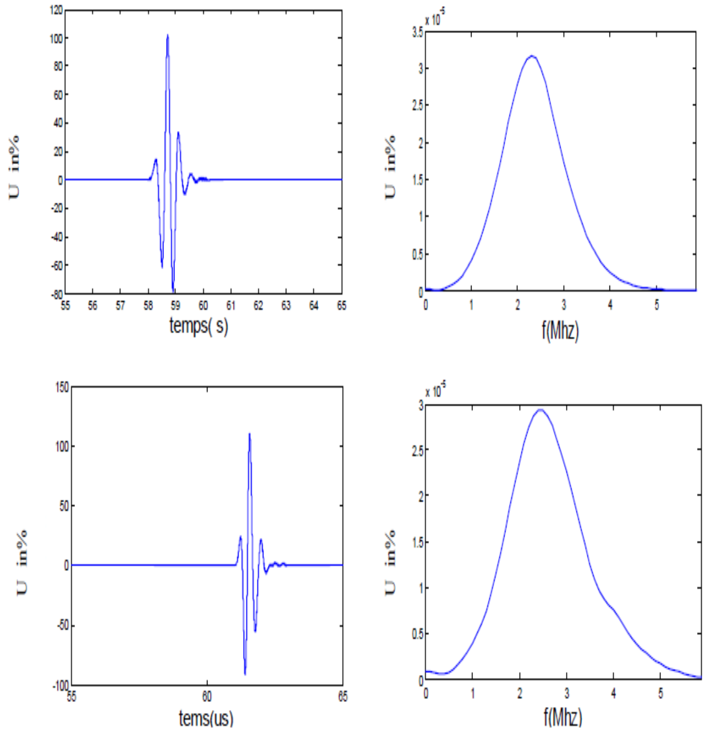


Figure (01): Evolution of echoes in polyamide samples with thickness e= 20, 15 mm

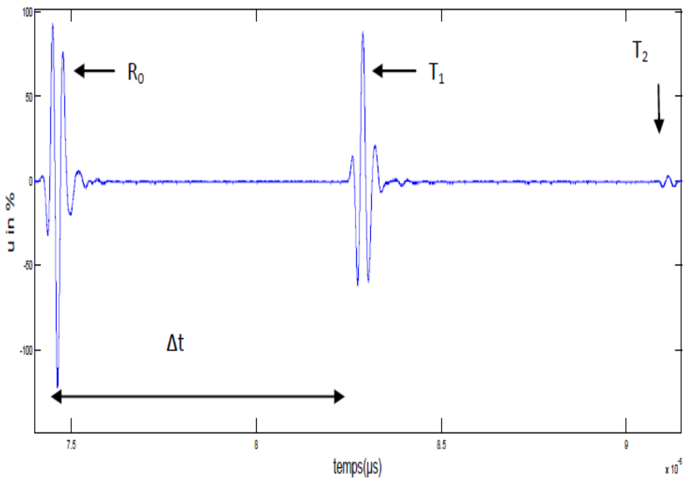


Figure (02): Time signal of the echoes of the ultrasonic wave in Plexiglas immersion.

Results obtained :

The results are summarized in the tables:

For Plexiglas			
	Time difference(µs)	**longitudinal velocity (m/s)**	**Transverse velocity (m/s)**
R_0-T_1	8.23	2429.7	887.68
R_0-T_2	8.24	2425.4	884.63
T_1-T_2	16.47	2427.6	886.15
mean value	---	2427.6	886.15
Reference value	---	2690	1320
e %		9.75	32.86
For polyamide			
Signal(10mm)-signal(15mm)	2.98	2664.6	1053.2
Signal(20mm)-signal(15mm)	2.88	2589.2	1000.1
Mean value	---	2626.9	1026.65
Reference value	---	2620	1080
e %		0.26	4.93

Table (01): Longitudinal, transverse velocities and time differences measured by Matlab.

c).Phase velocity measurement:

The relationship to obtain the phase velocity for polyamide is:

$$c_{écha}^{p}(\omega) = \frac{1}{\frac{\arg\left(\frac{p_p}{p_g}\right)}{2\omega\Delta z} + \frac{1}{c_{écha}}}$$

The phase velocity for plexiglass is then:

$$c_{écha}^{p}(\omega) = \frac{1}{\frac{\arg\left(\frac{p_p}{p_g}\right)}{4\omega\Delta z} + \frac{1}{c_{écha}}}$$

P_p and P_g amplitudes of the spectra of the small and large sample respectively (obtained by Fourier transform of the time signal.

In figures 03 and 04, we compared the simulated phase velocity (szabo model) and experimental phase velocity in the case of plexiglass and polyamide as a function of frequencies, respectively.

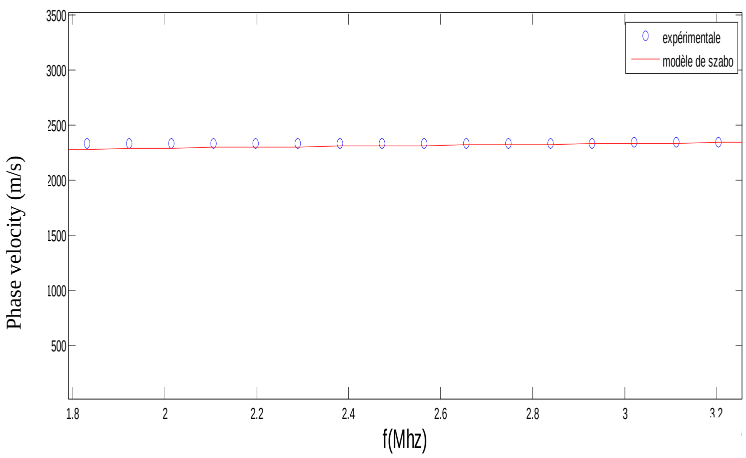
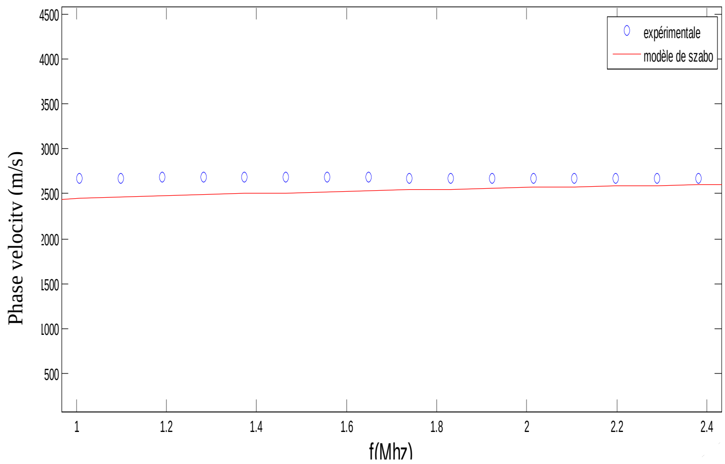


Figure (03): Phase velocity variation as a function of frequency for Plexiglas (o) experimental, (—) theoretical (szabo model).



polyamide (o) experimental, (—) theoretical (szabo model).

The theoretical and experimental results give identical points. These results confirm that the dispersion is very low or negligible.

d).Measurement of attenuation:

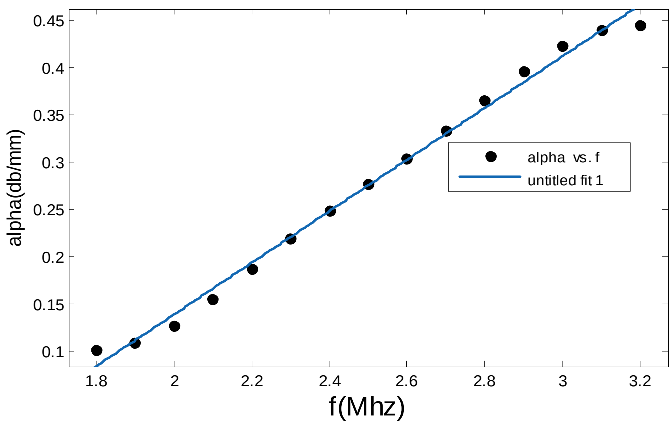
The attenuation of ultrasonic waves was measured by dividing the amplitude spectra.

the attenuation coefficient in the latter is written:

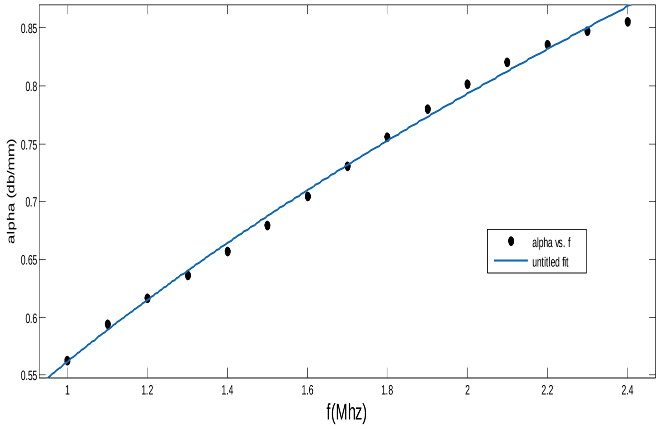
$$\alpha_g(neper/m) = \frac{1}{2\Delta z} ln\left(\frac{|P_p|}{|p_g|}\right)$$

$$\alpha_g(db/m) = \frac{1}{2\Delta z} 20log_{10}\left(\frac{|P_p|}{|p_g|}\right)$$

P_p and P_g amplitudes of the specters of small and large samples respectively (obtained by Fourier transform (FFT) of the temporal signal)



Figure(05): Curve representing the variation of attenuation as a function of frequency for two successive echoes that have travelled propagation distances z= 40 mm and 20 mm in a Plexiglas sample. [α = 0.27 ƒ -0.40]



Figure(06): Curve representing the variation of attenuation as a function of frequency for two successive echoes that have travelled propagation distances z=30 mm and 20 mm in a polyamide sample. [α = 0.39 ƒ 0.96]

Taking into account the attenuation due to diffraction which is equal to[5]:

$$\propto_d \ [db/m] = 1.7\frac{c^p_{écha}}{a^2 f}$$

where is **a** the transducer radius and ***f*** frequency.

$c^p_{écha}$ The phase velocity.

the attenuation due to absorption is then:

$$\alpha_{abs} = \alpha_g - \alpha_d$$

Results :

	Plexiglas	Polyamide
α_0 Without correction (atténuation)	0.27	0.39
α_0 With correction (absorption)	**0.23**	**0.37**
n	**1**	**0.98**

Table (02): Results of the curve fit (Attenuation and absorption in (dB/mm.MHz) and exponent n for plexiglass and polyamide.

The results obtained show that the evolution of attenuation as a function of frequency is linear.

e).Determination of viscoelasticity coefficients:

Elasticity constants :

For isotropic solids, the elasticity tensor c is independent of the direction of propagation. From there, the relationship between him and the acoustic wave velocities Vl (**longitudinal velocity**)and Vs (**Transverse velocity**) is given by [6]:

$$V_s = \sqrt{\frac{c_{44}}{\rho}} = \sqrt{\frac{c_{11} - c_{12}}{2\rho}}$$

$$V_l = \sqrt{\frac{c_{11}}{\rho}}$$

The calculated values of tensor C are summarized in the following table:

Note: ρ the density measured in the laboratory((LPM-UATL).) is:

Plexiglas ρ_{plex}=1020.5kg/m^3.

Polyamide ρ_{poly}=1140kg/m^3.

	C_{11}(Gpa)	C_{44}(Gpa)	C_{12}(Gpa)
Plexiglas	6.01	0.80	4.41
Polyamide	7.86	1.20	5.46

Table (04): the elasticity constants of plexiglass and polyamide.

The Young's modulus and the poisson coefficient can be calculated from the longitudinal and transverse velocities by applying the following relationships.

Young's modulus

$$E = \frac{\rho V_S^2 (3V_l^2 - 4V_S^2)}{V_l^2 - V_S^2}$$

Poisson's ration

$$\nu = \frac{V_l^2 - 2V_S^2}{2(V_l^2 - V_S^2)}$$

	E(Gpa)		ν		
	Reference value	Measured value	Referenc value	Measured value	er (%)
Plexiglas	2.24 à 3.24	2.28	0.37	0.42	13.51
polyamide	1.59 à 3.79	3.38	0.41	0.40	2.43

Table (05): Measured modulus of elasticity.

f).Determination of viscosity coefficients :

The results obtained during the measurement of velocities and attenuations allowed us to determine the viscosity coefficient (η) in Plexiglas and polyamide as a function of frequency. The relationship between viscosity and attenuation and phase velocity is given by:

$$\eta = \frac{\rho V_l}{2\alpha}$$

the figures (07) (08) show the results of this calculation with the fit curves.

These fit curves give a power law of viscosity as a function of frequency.

These coefficients are summarized in Table (07)

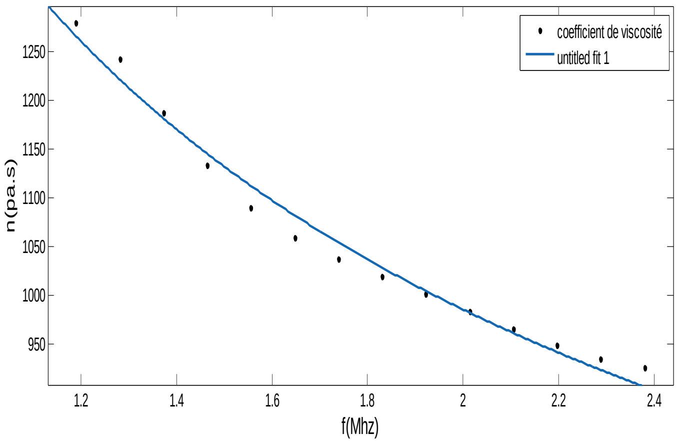
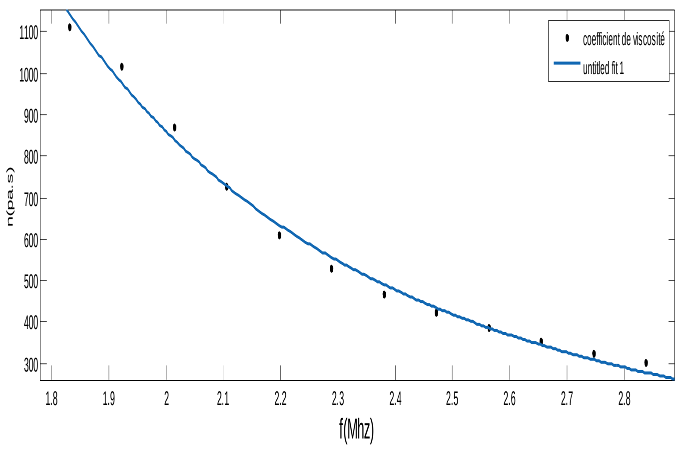


Figure (07): Curve representing variation of the viscosity coefficient as a function of frequency for polyamide. [η(f)=η0*fb] ,η0=1.36*103(kg/m.s.MHz) ,b= -0.49.



Figure(08): Curve representing variation of the viscosity coefficient as a function of frequency for plexiglass .[η(f)=η0*fb] ,η0= 1.22*103 (kg/m.s.MHz) ,b= -1.42.

	η_0 $(kg.m^{-1}.s^{-1})$
Plexiglas	$1.22 * 10^3$
Polyamide	$1.36 * 10^3$

table (07): Table representing the viscosity coefficient of plexiglass and polyamide.

5).Discussion

To verify the measured results, they were compared to other experimental results but due to measurement errors, there is a difference between the measured values and the other. This is due to: Sampling accuracy, variability of the sample, measurement time of flight using the cross-correlation function and approximation of the transversal velocity by fitting experimental values of velocities. The difference in values may be due to the state condition of the samples, the number of tests and the method of manufacture. The difference can also be attributed to the calculation method.

6).Digital simulation of experimental signals:

Figure (09) shows a comparison between an experimental signal and a theoretical signal, for a frequency of 3.4 MHz and a propagation distance of 10 mm.

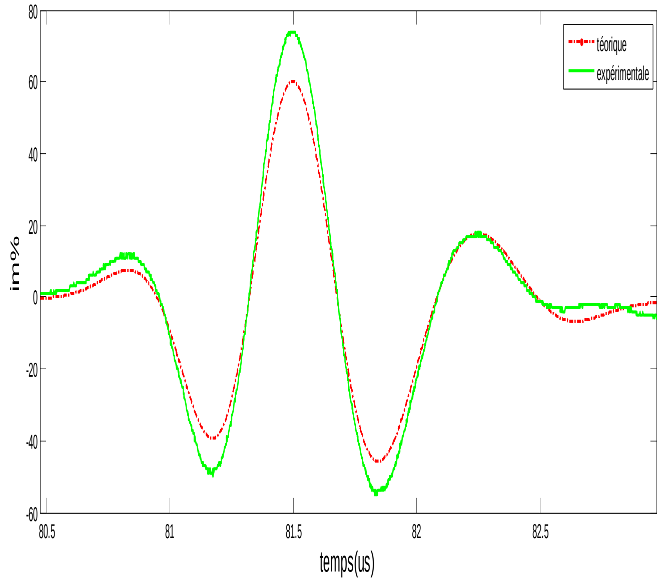


Figure (09): Comparison between an experimental signal and a theoretical signal for a transducer frequency f = 3.4 MHz and a depth of z = 10mm

We notice that the signals are comparable in their amplitudes and arrival times.

7).Conclusion

Estimation of the acoustic parameters of materials by ultrasonic reflection techniques remains a delicate field because it requires provisions for measurements adapted to the phenomena generated by such a propagation medium.

Indeed, the characterization of a material is based on a good estimate of ultrasonic measurements that is reduced to the time and frequency domain of the propagation waves through it. Thus, knowledge of these characteristics has led to the identification of the elasticity and viscoelasticity properties of the materials studied in plexiglass and polyamide.

In addition, for a better estimation of the flight time of the emitted wave on which all the other properties of the material depend, the results are obtained from good estimates considered very satisfactory in relation to the scientific literature.

The results obtained further encourage the generalization of these ultrasonic methods for a real characterization of new materials.

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