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EXPERIMENTAL STUDY OF THE PROPAGATION OF ELASTIC WAVES IN A TWO CONTINUOUS SOLIDS HETEROGENEOUS MATERIAL

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INTRODUCTION

Heterogeneous materials are of a great importance in physics of disordered systems and in particular, in civil engineering where the determination of the mechanical properties of cements and concretes is necessary. The recent development of piezocomposite transducers [1] for applications where the shape of the emitting surface has to be controlled, involves also the study of the propagation of acoustic waves in solid/solid composite materials. Mainly theoretical articles on the mechanical properties of heterogeneous media have been proposed [2-4]. The object of this paper is to present experimental results on the propagation of elastic waves in continuous solid/solid heterogeneous materials. The interpretation is given in the framework of two theoretical models using the mathematical formulation of Biot's theory [5].

SAMPLE PREPARATION AND PRELIMINARY TESTS

The concept used for the preparation of the samples is simple. It consist in saturating an "host" solid matrix by a fluid able to solidify afterwards. This fluid becomes therefore a "guest" solid. Guest solids like epoxy resins or glues are not usable because the solvant that they contain when they are at the liquid state cannot evaporate without creating bubbles in the host matrix. The solidification must be controlled by another phenomenon such as a chemical reaction or as a variation of temperature. This applies well for polymeric gels or waxes. Two samples have been prepared: a consolidated open-cell carbon foam of porosity 0.972 saturated by a low viscosity red wax and a consolidated glass matrix of porosity 0.467 saturated by bee wax. The host matrix and the wax are first put in an oven at a temperature of about 120°C. Then the sample is cooled under vacuum to ambient temperature and the wax solidifies in the pores of the host solid. The samples are cylindrically shaped; their diameter and thickness are respectively of 8 cm and 2.75 cm for the carbon foam and of 10 cm and 2.5 cm for the glass matrix. Weighting and acoustic tests are made to measure densities and some of the elastic properties of the components. The elastic coefficients of the host matrices and of the waxes can be determined by measuring, before saturating the samples, the velocity of longitudinal and transverse waves in each component taken separately. The measurable parameters are summarized in table 1.

EXPERIMENTS

Experiments consist in the transmission of short acoustical pulses (less than 1 μs duration) through the sample. Both longitudinal and transverse waves are investigated in a frequency range of [0-1 MHz] using 1 inch diameter transducers in emission and reception. Figure 1 shows the signals detected by the longitudinal (fig. 1a) and the transverse (fig. 1b) receiver for the sample of carbon foam saturated by red wax. The signals obtained for the sample of porous glass saturated by bee wax are shown in figure 2. In each figure, an oscillation occur after the first signal detected. These oscillations are interpreted in the next section.

Table 1

	Longitudinal velocity (m/s)	Transverse velocity (m/s)	Density (kg/m^3)	Volumic ratio (%)
Carbon matrix	1805	663	42	2.8
Red wax	2245	1073	966	97.2
Glass matrix	1660	1190	652	53.3
Bee wax	1970	956	970	46.7

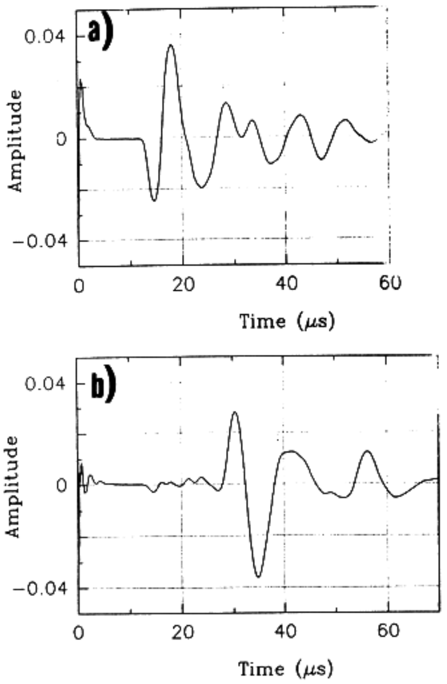


Figure 1 - a) Longitudinal and b) transverse signals observed in a carbon foam saturated by a low viscosity red wax.

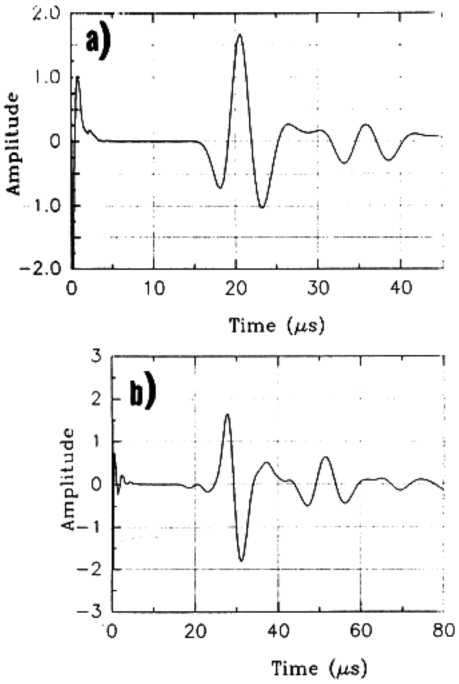
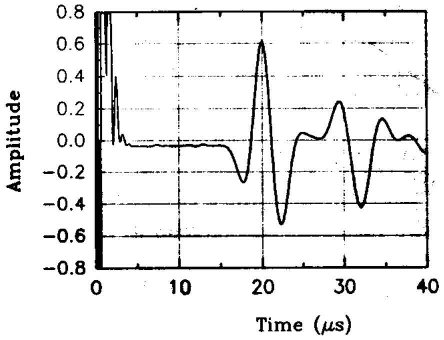


Figure 2 - a) Longitudinal and b) transverse Signals observed in a glass matrix saturated by bee wax.

THEORETICAL FRAMEWORK AND INTERPRETATION

An extension of Biot's theory to frozen porous media has been proposed recently [6] where ice and liquid water can coexist when the medium is partially frozen. In the limit case of a totally frozen medium, the liquid water content is put to zero and the model can describe the propagation in an heterogeneous material composed of two continuous solids. If the existence predicted by this model of several longitudinal and transverse waves in frozen porous media has been confirmed [7], still no investigation known by the authors has been performed in the general case of heterogeneous materials. In fact, the oscillations observed in figures 1 and 2 are interpreted as an extra longitudinal and an extra transverse wave propagating in a two solids heterogeneous material under the condition that the two solids are connected. This result seems to be confirmed observing the signals in figures 3 and 4 where the high frequencies have been favored to isolate the signals. The use of 5 MHz transducers shows explicitly the presence of two longitudinal waves in the sample of bee wax-saturated glass matrix (fig. 3). The first signal arrives at about 16 µs and the second at about 26 μs. For transverse waves (fig. 4), an high pass filter of cut off frequency 100 kHz has been used to discriminate the second signal arriving at about 43 μs.



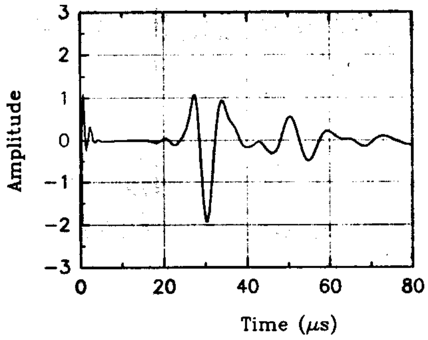


Figure 3 - Longitudinal signals in a glass matrix saturated by bee wax detected with a 5 MHz transducer.

Figure 4 - Transverse signals in a glass matrix saturated by bee wax observed with an high pass filter of cut off frequency 100 kHz.

If the model of Leclaire et al.[6] can predict qualitative results for heterogeneous media, some theoretical difficulties of compatibility of the deformations of the two solids appear when there is no more liquid water. Furthermore, the model is unable to describe attenuation of the type encountered here. For this reason, we have developed a theoretical model describing the propagation in heterogeneous materials. Only the results are given; a more detailed version will be presented elsewhere. The model is an extension of Biot's theory including the possible solid/solid elastic coupling and energy losses in the two solids by internal frictions. Figure 5 and 6 show the wave velocity and attenuation of two longitudinal waves calculated with the data of table 1 for the red wax-saturated carbon foam. Similar curves can be calculated for the transverse modes. The velocities are normalized by a reference velocity of 2199 m/s for longitudinal waves and 1044 m/s for transverse waves. The elastic coefficients of carbon and of the red wax matrix are evaluated from the experimental data and with the help of a simple model: for a consolidated medium of porosity p, the elastic coefficient R_{ms} of a matrix is always less than the Hashin-Sthrikman upper bound [2]: (1-p)R where R is the corresponding elastic coefficient of the solid that forms the matrix. The approximation made by assimilating R_{ms} to (1-p)R is thought to be quite good here since the two matrices are consolidated. The numerical value of the reference frequency for the longitudinal and transverse waves are respectively 1.02 MHz and 539 kHz. In fact, this frequency and attenuation are functions of the viscosity of the two solid matrices. Having no available values, we have arbitrarily assumed viscosities of the order of 100 Pa/s for the carbon matrix and of 1000 Pa/s for the red wax matrix. For this reason, no available comparison between theoretical and experimental values of attenuation is possible here. Nevertheless, the theoretical curves (fig. 6) give interesting qualitative informations.

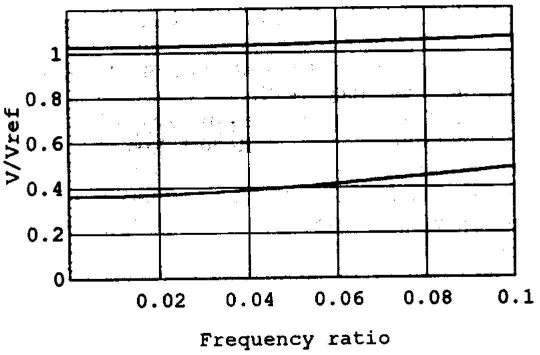


Figure 5 - Theoretical velocities of the two longitudinal modes as functions of the frequency.

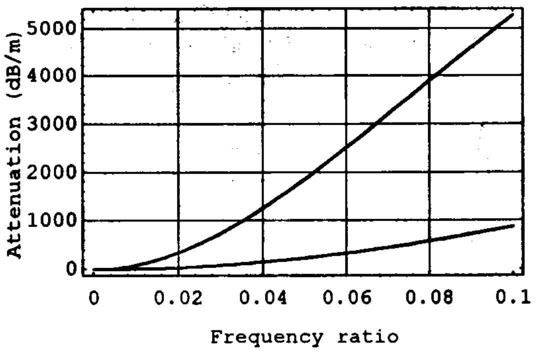


Figure 6 - Attenuation of the two longitudinal modes calculated as a function of the frequency.

They show that the high frequencies are attenuated and that the signals observed in figures 1 and 2 contain essentially low frequency components. Thus a comparison is possible between the experimental and the theoretical velocities in the low frequency limit since the latter are independent of the parameters that govern attenuation.

The comparison is made for the sample of carbon foam saturated by red wax. The experimental values of velocities for the longitudinal modes (fig. 1a) are 2299 and 877 m/s while the corresponding theoretical values (fig. 5) are respectively 2199 and 769 m/s. For the transverse modes, the experimental values are 1150 and 565 m/s while the theoretical values are 1044 and 282 m/s. If the agreement between theory and experiment is quite good for the first longitudinal and transverse waves, the difference is more important for the two extra signals. This difference is explained as follow: since the attenuation of the low frequencies is low (fig .6), the extension in time of the signals is large and the two signals are not well separated. The beginning of the second wave and therefore its velocity are not precisely determined.

CONCLUSION

The experimental study of the propagation of elastic waves in heterogeneous materials shows that two longitudinal and two transverse waves seems to propagate in a two continuous solids material. The applications should concern civil engineering for the determination of the mechanical properties and absorption of cements and concretes. The results might also be of a great interest for the conception and the development of piezocomposite transducers.

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