JOURNAL OF THEORETICAL
AND APPLIED MECHANICS
4, 38, 2000

ULTRASONIC STUDIES OF SUSPENSION OF GLASS PARTICLES IN GEL

Radosław Drelich
Mariusz Kaczmarek
Józef Kubik

Department of Environmental Mechanics, Pedagogical University in Bydgoszcz
e-mail: radeko@wsp.bydgoszcz.pl

Main purpose of this paper is the experimental investigation of propagation of ultrasonic waves in suspensions of solid particles (glass beads) in gel. The dependence of phase velocity and attenuation coefficient on the volume fraction and size of solid particles was studied. Special attention has been focussed on determination of the role of size and volume fraction of solid particles on scattering of the waves at ultrasonic frequencies.

Key words: mixture, suspension, ultrasonic waves, scattering

1. Introduction

One of the main sources of attenuation of ultrasonic waves in nonhomogeneous materials, at ultrasonic frequencies, is the effect of scattering. This phenomenon is closely associated with the ratio of the wavelength to the characteristic size of nonhomogenities, and thus the scattering effects can give information about the microstructure of the material espatially of porous materials which are very important in many applications. In the well known models of solid materials where the loss of wave energy is associated not only with the dissipation of mechanical energy into heat but also with scattering, the attenuation coefficient α can be written as the sum $\alpha = \alpha_1 + \alpha_2$, where α_1 is related to attenuation due to the change of mechanical energy into heat, and α_2 denotes attenuation associated with the scattering effects (Obraz, 1983).

Materials in which the two sources of the attenuation are observed and well described are metals with randomly oriented grains. In such materials one can distinguish three kinds of scattering:

- Rayleigh scattering – when the wavelength, λ, is much higher than the average diameter of grains D_{av} $(\lambda \gg D_{av})$. The attenuation due to this kind of scattering is proportional to the third power of the average diameter of grains and fourth power of the frequency f, and can be expressed as
$$\alpha = C_1 D_{av}^3 f^4$$
- Stochastic scattering – when the wavelength is comparable with the average diameter of grains. The attenuation coefficient is proportional to the average diameter of grains, and is proportional to the second power of the frequency, i.e.
$$\alpha = C_2 D_{av} f^2$$
- Diffusion scattering – when the ratio of the wavelength and average diameter of grains is small $(\lambda \ll D_{av})$. The attenuation coefficient is the inverse of the average diameter of grains and does not depend on the frequency (Smith et al., 1981)
$$\alpha = \frac{C_3}{D_{av}}$$
In the above relations C_1, C_2 and C_3 are constants.

Ultrasonic studies of the effects of scattering for inhomogeneous materials, particularly porous materials, such as rocks and concrete, are difficult to analyse because of lack of good acoustical coupling between the sample and the transducers. Here, we have dealt witch a mixture of gel and glass beads where there is no problem of acoustical coupling and which can be helpful in understanding and modelling of the scattering effects in porous materials.

The purpose of this paper is experimental determination of the influence of the volume fraction of solid phase (glass beads) and the diameters of the inclusions on the phase velocity and the attenuation coefficient of ultrasonic waves. The discussion is focussed on dispersion of the phase velocity and dependence of attenuation of longitudinal waves upon the frequency, within the frequency range from about 0.7 MHz to 3 MHz.

2. Experimental setup

The experiments have been performed for the mixtures of the SONOBAX ultrasonic gel with controlled amount of glass beads. The preparation of the material included:

- separation of glass beads of the chosen average diameters: 110, 300, 470 μm
- preparation of suspension of ultrasonic gel with 20, 30, 40, 60% of volume fraction of solid particles, and
- stabilization of the mixtures for 48 hours in a refrigerator to reduce the amount of air bubbles.

Particular attention was paid to the preservation of homogeneity of the samples, i.e. equal distribution of glass particles. The pulse transmision technique and ultrasonic spectroscopy have been applied to determine the ultrasonic waves parameters in the frequency range from 0.7 to 3 MHz (Fig.1).

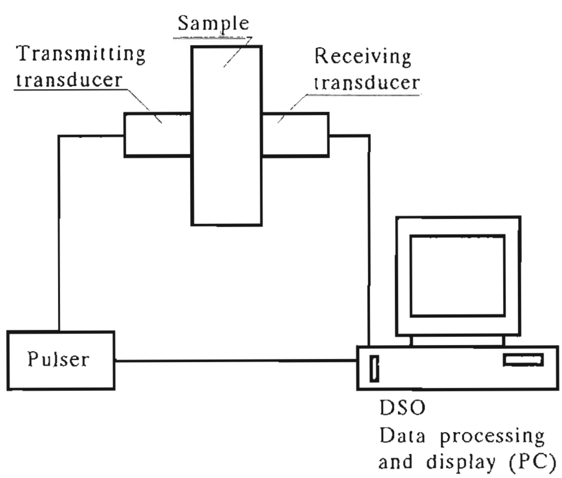

Fig. 1. Experimental setup for the ultrasonic technique

The signals for two samples of different thicknesses L_1 and L_2 (Fig.2) are measured and the spectral analysis is applied to find the amplitude (Fig.3) and phase spectra (Fig.4), which enable us to determine the wave parameters (Yew and Chen, 1978).

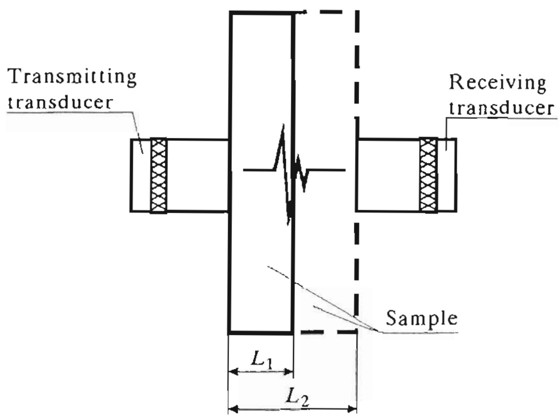

Fig. 2. Idea of determination of the ultrasonic wave parameters

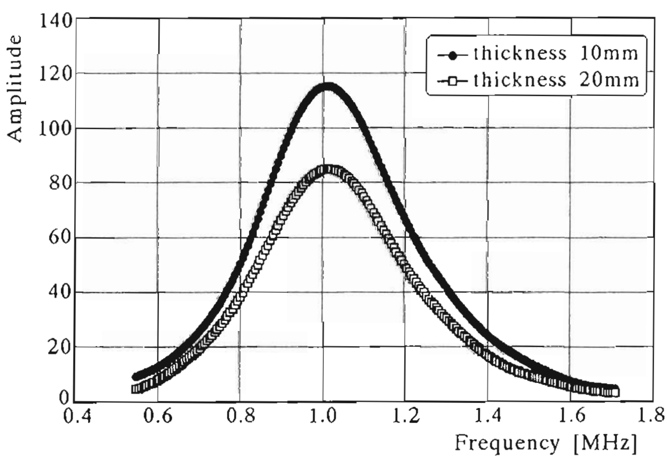

Fig. 3. Amplitude spectra for thicker and thinner samples

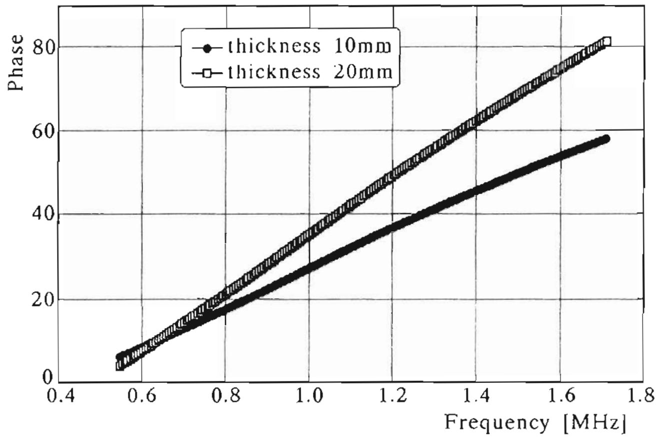

Fig. 4. Phase spectra for thicker and thinner samples

3. Results and discussion

The investigations have been performed in two steps. First the attenuation coefficient and phase velocity for the ultrasonic gel which consists of 99.5% of water have been determined. In this case, the phase velocity has approximately a constant value, equal to about 1550 m/s (Fig.6), and the attenuation coefficient is also constant and equal to about 0.008 Neper/mm (Fig.5).

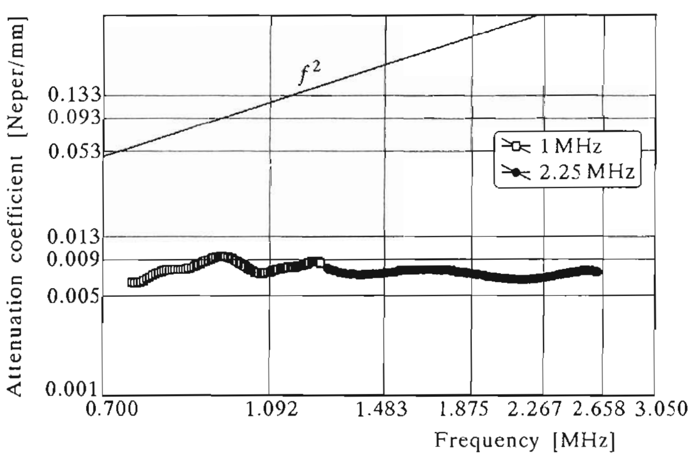

Fig. 5. Attenuation measured for gel

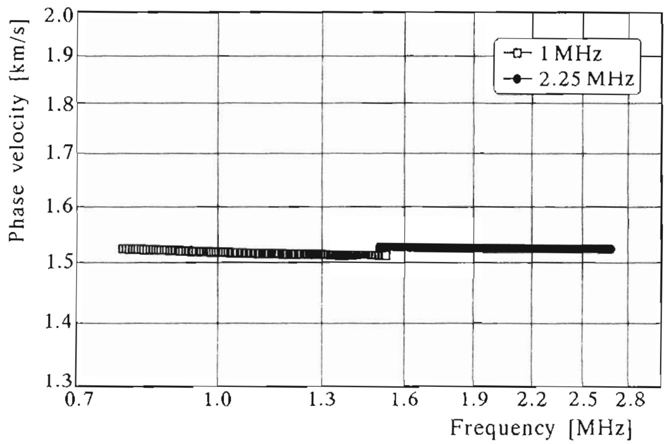

Fig. 6. Wave velocity in gel

In the second step, the investigations have been done for the mixtures of gel and solid particles (glass beads) with given volume fractions of the solid phase. In Fig.7 the attenuation coefficient determined for the mixture, where the average diameter of glass beads is 300 μm, is shown.

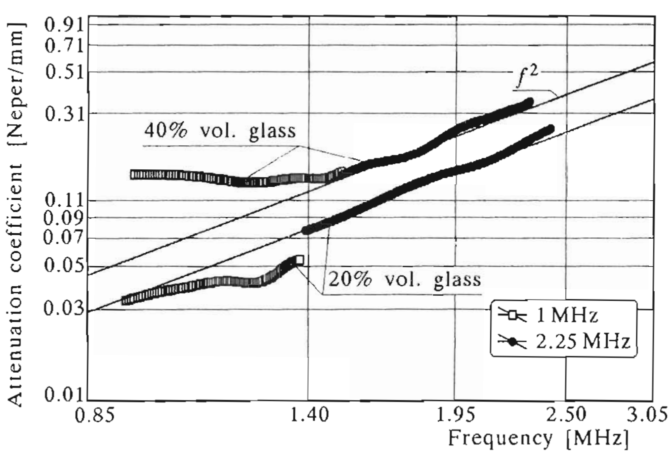

Fig. 7. Attenuation for suspension of glass beads in gel. Volume fraction of glass: 20%, 40%. Average diameter of beads: 300 μm

It can be seen that in the range of low frequencies, the attenuation has approximately a constant value, and starting from 1.4 MHz, the coefficient of attenuation increases proportionally to the second power of frequency. Analy-

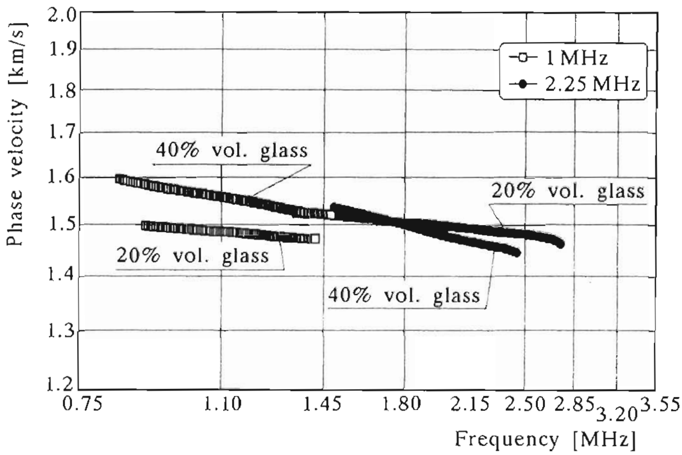

Fig. 8. Phase velocity for suspension of glass beads in gel. Volume fraction of glass: 20%, 40%. Average diameter of beads: 300 μm

zing such a behavior one should notice that at 1.4 MHz, the size of inhomogenity (0.3 mm) is about 4 times smaller than the wavelength ($\lambda = 1.1$ mm) and then the stochastic scattering does appear. For the same material, in Fig.8, the frequency dependence phase velocity with negative dispersion in the whole range of frequency is shown. The results for ultrasonic parameters determined for the suspensions of gel and glass beads of average diameter 470 μm and with different volume fractions are shown in Fig.9 and Fig.10.

It is worth noticing that higher volume fraction of the solid phase is associated with higher attenuation of the waves. The phase velocities show negative dispersion independently of the volume fraction and it can be seen that higher volume fraction of the solid phase promotes the increase of the wave velocity.

Summarizing the experimental data one can conclude that the suspensions of glass beads in gel can be used as a model material for the measurements of the scattering effects. Independently of the size of grains and their volume fraction, one can observe the transition from the non-scattering region to the scattering region of the attenuation coefficient. The experimental data can be helpful in understanding and modelling materials with more complicated structure such as porous materials, e.g. bone tissues, where the scattering appears and influences the propagation of ultrasonic waves.

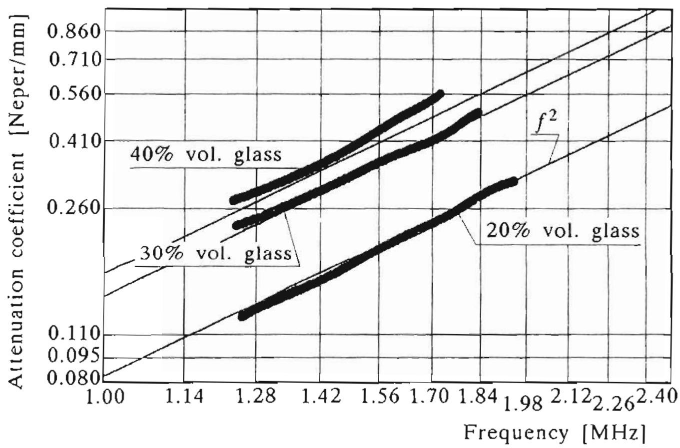

Fig. 9. Attenuation for suspension of glass beads in gel. Volume fraction of glass: 20%, 30%, 40%. Average diameter of beads: 470 μm

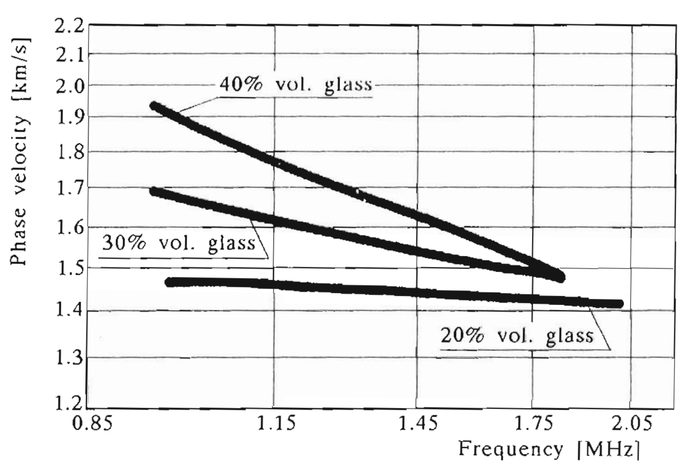

Fig. 10. Phase velocity for suspension of glass beads in gel. Volume fraction of glass: 20%, 30%, 40%. Average diameter of beads: 470 μm

References

1. ANSON L.W., CHIVERS R.C., 1993, Ultrasonic Velocity in Suspensions of Solids in Solids – a Comparison of Theory and Experiment, *J. Phys. D: Appl. Phys*, **26**, 1566-1575
2. ATKINSON C.M., KYTOMAA H.K., 1992, Acoustic Wave Speed and Attenuation in Suspensions, *Int. J. Multiphase Flow*, **18**, 4, 577-592
3. BRAMANTI M., 1999, An Ultrasound-Based Simple Noninvasive Procedure for Abrasive Slurries Efficiency Control, *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, **46**, 2
4. DRELICH R., KOCHAŃSKI J., KACZMAREK M., KUBIK J., 1999, Badanie wpływu rozpraszania na parametry propagacji fal ultradźwiękowych w spiekach szkła, *Zeszyty Naukowe Katedry Mechaniki Stosowanej, Politechnika Śląska*, **10**, 99, 71-76
5. OBRAZ J., 1983, *Ultradźwięki w technice pomiarowej*, WN-T, Warszawa
6. RIEBEL U., LOFFLER F., 1989, On-Line Measurement of Particle Size Distribution and Particle Concentration in Suspensions by Ultrasonic Spectrometry, *Chem. Eng. Technol.*, **12**, 433-438
7. SMITH R.L., REYNOLDS W.N., WADLEY H.N.G., 1981, Ultrasonic Attenuation and Microstructure in Low-Carbon Steels, *Metal Science*, **15**, 554-558
8. YEW E.H., CHEN C.S., 1978, Experimental Study of Dispersive Waves in Beam and Rod Using FFT, *J. Appl. Mechanics*, **45**, 940-942

Ultradźwiękowe badania mieszaniny żelu i kulek szkła w stanie zawiesiny

Streszczenie

W pracy przedstawiono wyniki badań eksperymentalnych propagacji fal ultradźwiękowych w zawiesinie utworzonej z mieszaniny żelu ultrasonograficznego i cząstek szkła. Istotą pracy jest zbadanie dyspersji prędkości fazowej i zależności współczynnika tłumienia od częstotliwości fal podłużnych. Szczególnie skoncentrowano się na określeniu roli efektów rozproszeniowych w takich materiałach w funkcji wielkości ziaren i udziału objętościowego frakcji stałej w zakresie częstotliwości od 0.7 MHz do 3 MHz.

Manuscript received March April 6, 2000; accepted for print June 6, 2000