3Pa2-7

Estimation of the phase velocities of the shear waves of water and aqueous solution of glycerol at normal temperature and pressure by attenuation measurement of the leaky T(0,1) mode guided wave

漏洩 T(0,1)mode ガイド波の減衰測定を用いたグリセリン水溶液の横波位相速度の推定

Tatsuya Nanba[1‡], Masashi Ishikawa[1], and Hideo Nishino[1]
([1]Tokushima Univ.)
南葉達也 [1‡]，石川真志 [1]，西野秀郎 [1] ([1] 徳大院)

1. Introduction

The leaky T(0,1) mode guided wave (LTGW) [1] propagates in an axial direction of a tube embedded in surrounding material having the shear modulus. The energy of the LTGW leaks into the surrounding material as the shear wave, therefore the attenuation coefficient is dependent on its shear wave velocity of the material. Previously, the phase velocities of the shear waves of the petrolatum antocorrosion grease having high viscosity in several temperatures were estimated [2] to be from 78 m/s to 277 m/s depending mainly on the temperature conditions using the attenuation measurement of the LTGW. In this paper, estimations of the phase velocities of the shear waves of water and aquaous solution of the glycerol were carried out in the same measurement manner with the LTGW under normal temperature and pressure. In comparison with the petrolatum antocorrosion grease, the attenuation coefficient of the LTGW propagating in the liquid-loaded pipe was very low because of the very low viscosity. It was confirmed under normal temperature and pressure that the estimated phase velocities of the shear waves of water ranged from 2 m/s to 4 m/s depending on the frequency and those of the 100% glycerol ranged from 11.5 to 25.2 m/s.

2. Leaky T(0,1) mode guided wave (LTGW)

The characteristic equation [1] of the LTGW is as follows:

$$\left.\begin{aligned} &\frac{\rho' k_p}{\rho_p k'}\frac{\beta}{\alpha}\frac{H_1^{(1)}(\beta r_2)}{H_0^{(1)}(\beta r_2)}\{J_0(\alpha r_2)Y_1(\alpha r_1)-J_1(\alpha r_1)Y_0(\alpha r_2)\} \\ &\quad +\{J_1(\alpha r_1)Y_1(\alpha r_2)-J_1(\alpha r_2)Y_1(\alpha r_1)\}=0 \\ &\quad\quad \alpha^2=k'^2-k^2,\quad \beta^2=k_p^2-k^2 \end{aligned}\right\} \quad (1)$$

,where ρ', ρ_p, k', k_p, r_1, and r_2 are densities of the liquid and tube, shear wavenumbers of the liquid and tube, and inner and outer radii of the tube, respectively. H, J, and Y are Hankel, Bessel, and Neumann functions, respectively. The wavenumber k of the LTGW normally takes a complex number. The imaginary part of the solution indicates the attenuation coefficient of the LTGW. Therefore, in a reverse approach using the theory of the LTGW, the shear wave velocity of the surrounding material can be estimated with measured attenuation coefficient.

Corresponding: hidero.nishino@tokushima-u.ac.jp

3. Experiments for the attenuation measurements

Figure 1 shows the experimental apparutus. In all the experiments, temperature is at 26±0.5˚C. A pair of the ring-shaped sensor system composed of 4-sensor-elements were used for the torsional transmitter and reciever, which were located on the both ends of the tube. 19-mm outerdiameter and 2-m length SUS304 tubes (wall thickness=0.5, 1.0, and 2.0 mm) were used. The middle part, 400-mm-region, of the tube was dipped into the water and the glycerol (85wt% and 100% glycerol). The viscosity of the 85wt% aqueous solution is 1/10 viscosity of the 100% glycerol. Attenuations without the liquids were also measured in order to compensate the attenuations purely due to the liquids.

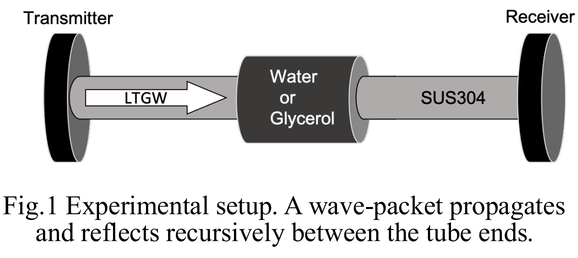

Fig.1 Experimental setup. A wave-packet propagates and reflects recursively between the tube ends.

4. Results and estimations of shear wave velocities

Figures 2(a) and 2(b) show the 100 kHz RF time domain signals propagating in 1.0-mm-thick tube buried in water and the 100% glycerol, respectively. It can be seen that the attenuation with 100% glycerol takes larger than that with water. The attenuation coefficient at 100 kHz as a function of wall thickness of the tube buried in 100% glycerol was shown in **Fig. 3**. The attenuation takes larger at a thinner wall thickness. This feature of the attenuation due to the wall thickness is underpinned by the theory of the LTGW. The circles indicate experimental results and the line indicates the theoretical attenuation calculated with the phase velocity, $v_t = 18.7$ m/s, of 100% glycerol. This value, v_t, was determined so as to take the nearest squared distance between the experimental and theoretical attenuations. In the calculations, densities of water, 85wt% and 100wt% glycerols and tube are 1000, 1221, 1260 and 7800 kg/m^3, respectively, and shear wave velocity of tube is 3120 m/s.

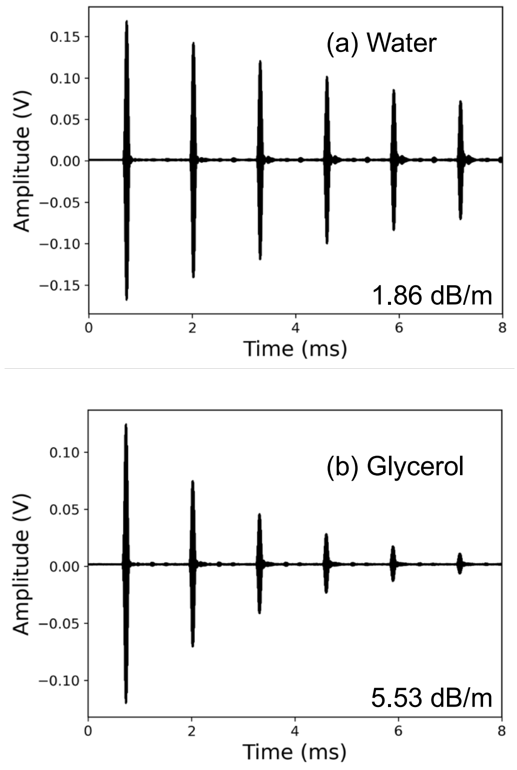

Fig. 2 Observed waveforms with 1.0-mm-thick tube at 100 kHz; (a) in water and (b) in 100wt% Glycerol.

The attenuation coefficient as a function of frequency for 100wt% glycerol was shown in **Fig. 4**. Three lines in Fig. 4 indicate, respectively, the attenuation coefficients observed for three different wall thicknesses (0.5, 1.0, and 2.0 mm) pipes. In all the cases, even in any conditions not shown here, the attenuation always increases with increase in frequency and that takes always larger value at a thinner wall thickness.

Figure 5 shows the phase velocities for water, 85wt% and 100wt% aqueous solution of glycerols as a function of frequency. It was confirmed clearly that, in all the cases, the phase velocities increased monotonically with increase in frequency. The phase velocity of the shear wave of water takes at around 2 or 3 m/s in the frequency region at 26±0.5˚C.

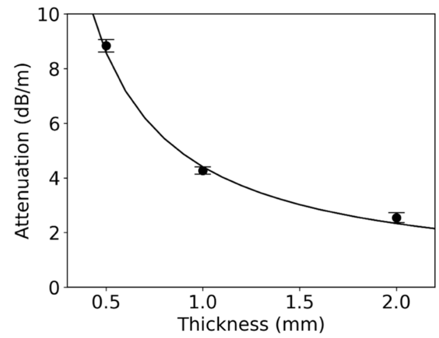

Fig. 3 Attenuation coefficient as a function of tube wall thickness (f = 100 kHz).

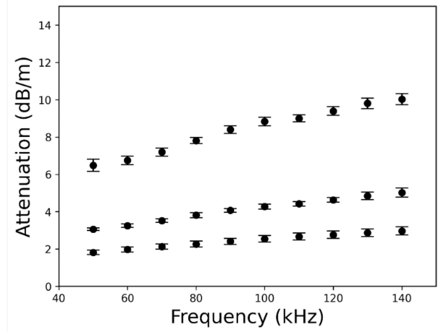

Fig. 4 Attenuation coefficient of 100wt% glycerol as a function of frequency.

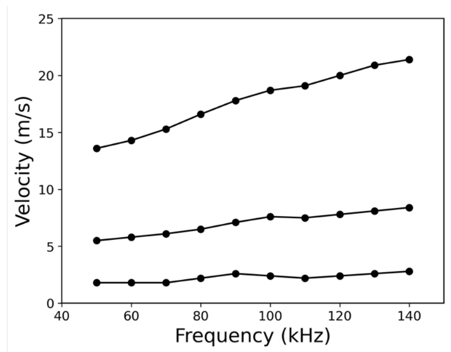

Fig. 5 Estimated phase velocities of water, 85wt% and 100wt% glycerols as a function of frequency

5. Conclusion

In this paper, a novel method of estimating the phase velocity of the shear wave of liquid material having an extremely small shear modulus is presented. The estimation is carried out utilizing the relationship between the attenuation of the leaky T(0,1) mode and the phase velocity of the shear wave of surrounding material of an embedded tube. As a result, the phase velocity of shear wave in water was at around 2 or 3 m/s in the frequency range from 20 to 200 kHz at 26±0.5˚C.

References

1. H. Nishino, K. Tateishi, M. Ishikawa, T. Furukawa, and M. Goka: Jpn. J. Appl. Phys. **57** (2018) 07LC02.
2. J. B. Segur and H. E. Oberstar: Industrial Eng. and Chem. **43** (1951) 2117-2120.