1P5-19

Experimental and Numerical Observations of Piezoelectric Signal Generated in Cancellous Bone by an Ultrasound Wave

超音波によって海綿骨で発生する圧電信号の実験的・数値的観測

Atsushi Hosokawa† (Dept. Electr. & Comp. Eng., Nat. Inst. Tech., Akashi Coll.)

細川篤† (明石高専 電気情報)

1. Introduction

Bone formation driven by mechanical loads[1] can be accompanied by piezoelectric effect.[2] To realize effective healing of bone fracture using low-intensity pulsed ultrasound (LIPUS),[3,4] the piezoelectric effect under ultrasound irradiation should be elucidated. However, the piezoelectric properties at ultrasound frequencies in bone, particularly in cancellous bone with a porous structure, have not yet been well-investigated.

In this study, both experimental and numerical observations of piezoelectric signal generated in cancellous bone by an ultrasound wave were attempted. A piezoelectric cell (PE-cell) of cancellous bone[5] was used in the experiment, and a piezoelectric finite-difference time-domain (PE-FDTD) method[6,7] was used in the numerical simulation.

2. Experimental Method

The experimental observation of piezoelectric signal in cancellous bone under ultrasound irradiation was performed using the PE-cell of the bone. The PE-cell, in which two aluminum electrodes were set on the front and back surfaces of the parallelepiped specimen of bovine cancellous bone, was used as an ultrasound receiver.[5] The cancellous bone specimen, whose pores were saturated with air, was surrounded by brass plates to electrically shield, and the back space was filled with air. The dimension was $25 \times 25 \times 8.0$ mm^3. The porosity was about 0.7 (70%), and the trabecular orientation tended to be parallel to the thickness direction.

To generate a burst ultrasound signal, a one-cycle sine electrical signal at 1 MHz was inputted from a function generator to a $Pb(Zr,Ti)O_3$ (PZT) transmitter with an active area of Ø12 mm. The transmitted ultrasound wave was received by the PE-cell of cancellous bone in water. The distance between the PE-cell and the PZT transmitter was 30 mm. The ultrasound signal received by the PE-cell, that is the piezoelectric signal generated in cancellous bone, was observed by a digital oscilloscope after passing through a preamplifier and a low-pass filter. For comparison, the ultrasound signal received by a poly(vinylidene fluoride) (PVDF) receiver was also observed.

hosokawa@akashi.ac.jp

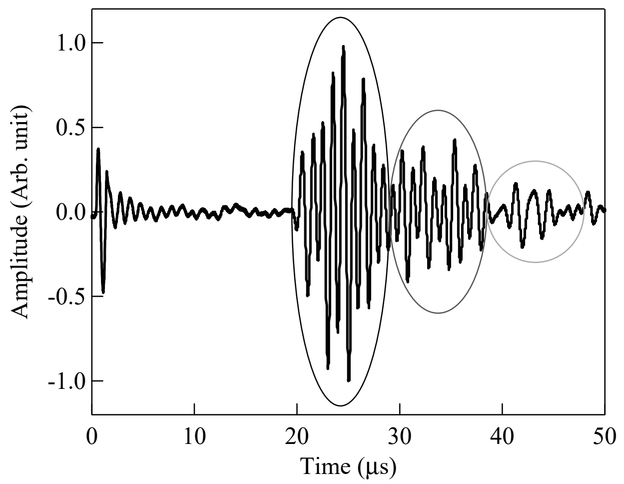
3. Numerical Method

The numerical simulation of the piezoelectric signal was performed using the PE-FDTD method,[6,7] which was an elastic FDTD method with piezoelectric constitutive equations. In the simulation, the cancellous bone model was reconstructed from the three-dimensional X-ray microcomputed tomographic image of the specimen used in the experiment. In accordance with the experiment, the air layer with a thickness of 1 mm was set at the back of the cancellous bone model. Moreover, the diameter of the transmitting surface and the distance between the transmitting surface and the cancellous bone model were the same with those in the experiment. However, to save computation time, the region of the cancellous bone model was limited, and the total region was reduced to $15 \times 15 \times 39$ mm^3 by setting perfectly matched absorbing layers (PMLs)[8] at the surrounding boundaries. Moreover, the brass plates in the PE-cell were omitted, and the elastic properties of the electrodes were ignored.

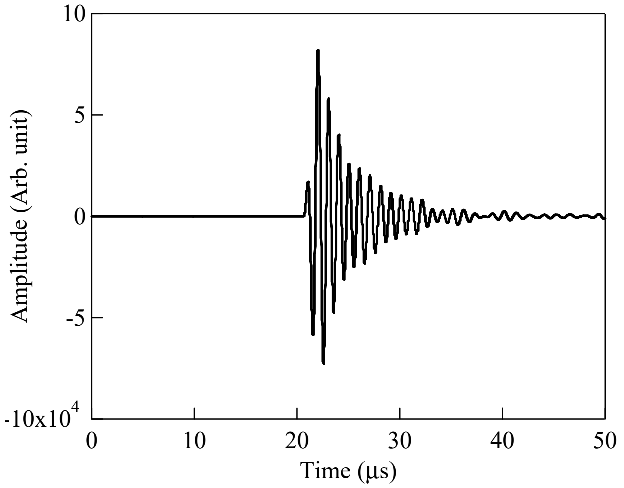
The signal received by the PVDF receiver in the experiment was used as the input ultrasound (or stress) waveform, but the magnitude of the sound pressure was not considered. The voltage between the electrodes was calculated as the output piezoelectric signal.

4. Results and Discussion

The experimental waveforms are shown in **Fig. 1**. Figure 1(a) shows the ultrasound signal received by the PE-cell of cancellous bone, which corresponds to the piezoelectric signal generated in cancellous bone. Figure 1(b) shows the signal received by the PVDF receiver. The simulated waveform of the piezoelectric signal is shown in



(a)



(b)

Fig. 1 Experimental waveforms of ultrasound signals received by (a) the PE-cell of cancellous bone and (b) the PVDF receiver. The signal in (a) corresponds to the piezoelectric signal generated in cancellous bone.

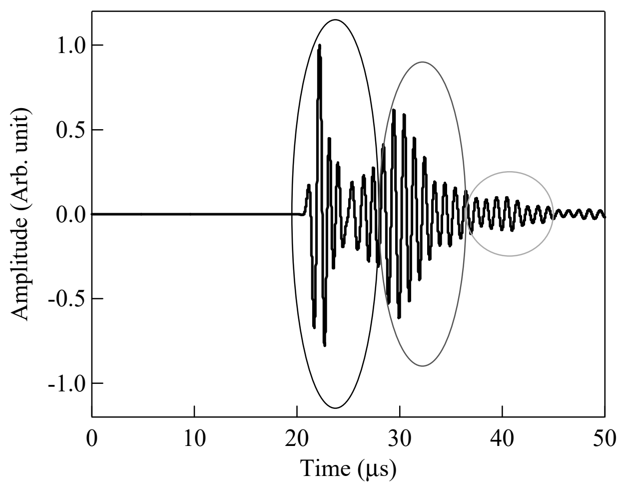


Fig. 2 Simulated waveform of piezoelectric signal generated in cancellous bone.

Fig. 2. In these figures, the amplitudes were normalized by the maximum amplitudes of the experimental and simulated piezoelectric signals in cancellous bone, respectively.

In the experimental waveform of Fig. 1(a), an electromagnetic noise was observed at 0–5 μs, and several signals (wave groups) were observed from 20 μs, unlike in the waveform of Fig. 1(b) received by the PVDF receiver. It was reported in the previous study[5] that these signals could be the piezoelectric signals generated by the multi-reflected ultrasound waves within the cancellous bone specimen. It was expected from the specimen thickness of 8.0 mm and the ultrasound speed of around 2000 m/s in cancellous bone that the signals due to the reflected ultrasound waves could appear from approximately 28 and 36 μs (note that these signals could be more separately observed when the wave number was large). Moreover, unlike in Fig. 1(b), it appeared that several waves overlapped in each signal. This was considered to be because the piezoelectric signals could be generated at various depths in the thickness direction.

In the numerical waveform of Fig. 2, the piezoelectric signals due to the reflected ultrasound waves and the signals generated at various depths could be observed. However, the numerical waveform was not sufficiently agreed with the experimental one, which appeared to be because of the inadequate parameter values used in the simulation.

5. Conclusions

In this study, the piezoelectric signal generated in cancellous bone by an ultrasound wave could be observed, both experimentally and numerically.

Acknowledgment

This study was supported by the Japan Society for the Promotion of Science through a Grant-in-Aid for Scientific Research (C) (Grant No. 17K06479).

References

1. A. M. Parfitt, J. Cell. Biochem. **55**, 273 (1994).
2. M. H. Shamos and L. S. Lavine, Clin. Orthp. **35**, 177 (1964).
3. L. R. Duarte, Arch. Orthop. Trauma Surg. **101**, 153 (1983).
4. S. Mitragotri, Nat. Rev. Drug Discovery **4**, 255 (2005).
5. A. Hosokawa, J. Acoust Soc. Am. **140**, EL441 (2016).
6. A. Hosokawa, Jpn. J. Appl. Phys. **54**, 07HF06 (2015).
7. A. Hosokawa, Jpn. J. Appl. Phys. **55**, 07KF03 (2016).
8. W. C. Chew and Q. H. Liu, J. Comput. Acoust. **4**, 341 (1996).