2P5-9

Effect of Ultrasound Direction on Piezoelectric Signal Generated in Cancellous Bone

超音波照射方向が海綿骨で発生する圧電信号に及ぼす影響について

Atsushi Hosokawa† (Dept. Electr. & Comp. Eng., NIT, Akashi College)
細川篤[†]（明石高専 電気情報）

1. Introduction

Bone formation can be driven by mechanical loads.[1] This mechanism has been applied to the medical healing of bone fracture by irradiation of low-intensity pulsed ultrasound (LIPUS) at a few megahertz.[2,3] Bone can behave as a piezoelectric material,[4] and the piezoelectric effects in bone can be associated with bone formation.[5] However, the piezoelectric properties in cancellous bone with a complicated porous trabecular structure are not sufficiently investigated.

In our previous study,[6] the piezoelectric signal in water-saturated cancellous bone have been experimentally observed by “a piezoelectric cell (PE-cell)” corresponding to an ultrasound receiver, and it was shown that the piezoelectric properties could be largely affected by the ultrasound properties. Moreover, it is known that the ultrasound properties can depend on the trabecular orientation.[7] In this study, to investigate the effect of the trabecular structure, the change in the piezoelectric signal with the angle of ultrasound irradiation was observed.

2. Method

The PE-cell of cancellous bone was used to experimentally observe piezoelectric signals in the bone. A cross-sectional view of the PE-cell is shown in **Fig. 1**. The PE-cell, in which a bovine cancellous bone is used as a piezoelectric element, can correspond to an ultrasound receiver. In the cancellous bone specimen used, the porosity was approximately 0.65 (65%). The plate-like trabecular elements were mainly oriented in two orthogonal directions, and the more strongly oriented direction was set the thickness direction perpendicular to the ultrasound-receiving surface. Bone marrow in the pores was removed, and the spaces were saturated with water.

The experimental arrangement is shown in **Fig. 2**. An ultrasound burst wave at 2 MHz was irradiated from a $Pb(Zr,Ti)O_3$ (PZT) ultrasound transmitter toward the PE-cell at an oblique angle θ to both trabecular orientations. The ultrasound

hosokawa@akashi.ac.jp

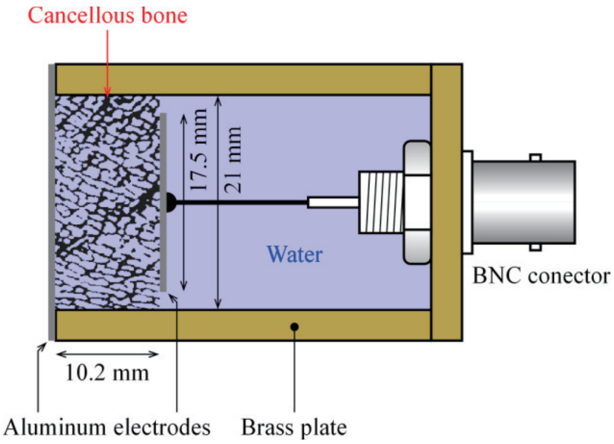

Fig. 1 A cross-sectional view of a PE-cell.

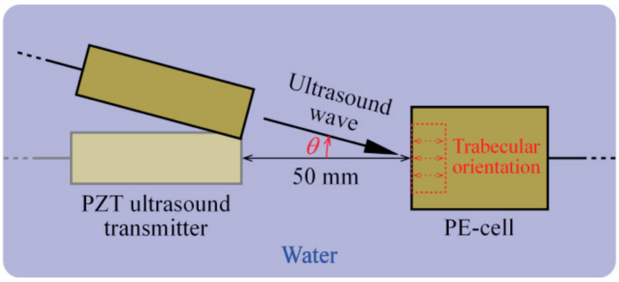

Fig. 2 Experimental arrangement of PZT ultrasound transmitter and PE-cell.

irradiation angle θ was varied in the range of ±30º at 5º intervals. The electric signal which was outputted from the PE-cell by receiving the ultrasound wave was observed.

3. Results and Discussion

At all ultrasound irradiation angles θ, the piezoelectric signals could be observed. The piezoelectric waveforms at θ = 0, -5, and -15º are shown in **Fig. 3**, in which the amplitudes are normalized by the maximum value at θ = 0º. The piezoelectric amplitude at θ = -5º was smaller than the amplitude at θ = 0º, but the amplitude at θ = -15º was larger. The variation of the piezoelectric amplitude with θ is shown in **Fig. 4**. The variations at the negative and positive angles of θ were not completely symmetric. However, the rough

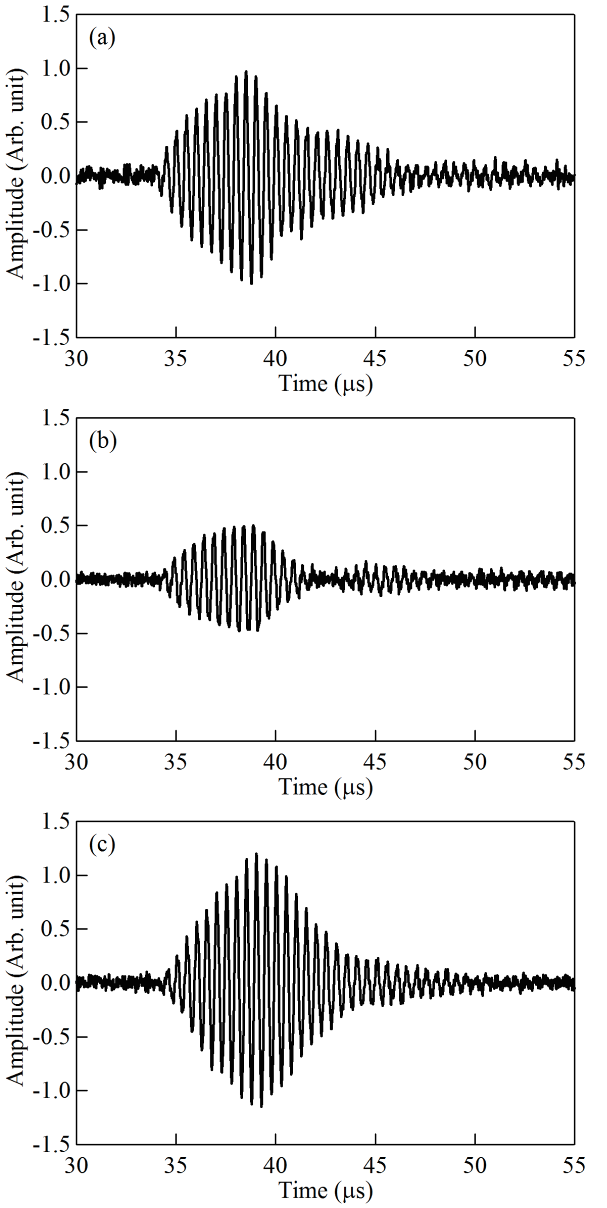

Fig. 3 Piezoelectric waveforms in cancellous bone at ultrasound irradiation angles of (a) 0, (b) -5, and (c) -15º.

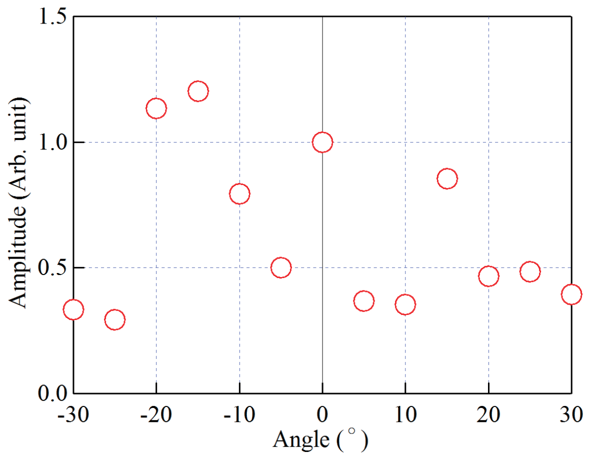

Fig. 4 Variation of piezoelectric amplitude in cancellous bone with ultrasound irradiation angle.

variations were similar, and the piezoelectric amplitude had large peaks at ±15º in addition to 0º.

The variation of the piezoelectric amplitude with the ultrasound irradiation angle was different from the directivity of an ordinary ultrasound receiver. This could be because of two properties; the ultrasound properties depending on the trabecular orientation and the piezoelectric properties in bone tissue. It is known that fast and slow waves can through water-saturated cancellous bone,[8] and it was suggested that the piezoelectric signal could be mainly associated with the slow wave propagation.[6] Moreover, it was shown that the amplitude of the slow wave, which can propagate mainly in the pore fluid, decreased as the ultrasound angle to the trabecular orientation became larger.[7] This could not necessarily match the results in the present study. On the other hand, it was shown that the side lobe of the piezoelectric amplitude in cortical bone became large owing to the piezoelectric anisotropy in bone tissue.[9] This could agree with the present results. Accordingly, it was considered that the piezoelectric properties in bone tissue could more largely affect the piezoelectric directivity in cancellous bone than the ultrasound properties.

4. Conclusions

The change in the piezoelectric signal in water-saturated cancellous bone with the angle of ultrasound irradiation was experimentally observed. The experimental results showed that the piezoelectric amplitude had large side lobe, which could be mainly caused by the piezoelectric properties in bone tissue.

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. L. R. Duarte, Arch. Orthop. Trauma Surg. **101**, 153 (1983).
3. S. Mitragotri, Nat. Rev. Drug Discovery **4**, 255 (2005).
4. M. H. Shamos and L. S. Lavine, Clin. Orthp. **35**, 177 (1964).
5. E. Fukada and I. Yasuda, J. Phys. Soc. Jpn. **12**, 1158 (1957).
6. A. Hosokawa and I. Kabeshita, Proc. Symp. Ultrasonic Electronics **39**, 1P5-1 (2018).
7. A. Hosokawa, *et al.*, Jpn. J. Appl. phys. **36**, 3233 (1997).
8. A. Hosokawa and T. Otani, J. Acoust. Soc. Am. **101**, 558 (1997).
9. A. Hosokawa, J. Acoust. Soc. Am. **142**, EL184 (2017).