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Development of Tissue-mimicking Materials using Segmented Polyurethane Gel and Their Acoustic Properties

セグメント化ウレタンゲルによる生体擬似組織の開発とその音波物性

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1. Introduction

There have been developed various ultrasound phantoms, which are essential to quality control of ultrasound scanners; a few characteristics of existing phantoms are even unsatisfied to accomplish the international standard. Existing phantoms are composed of hydrogels, or organogels. The gel materials have disadvantages such the change in quality with time by bleeding water or oil as dispersion medium. We developed a permanent gel originating from one component Segmented Polyurethane Gel (SPUG) with liquid alkaline oxide segments without any dispersion medium and reported their application to ultrasound phantoms[1)].

The tissue mimicking-materials for the phantoms should have values for acoustical quantities as specified in Table I[2)].

Table I Specification of tissue-mimicking material in IEC standard[2)]

Sound velocity	(1540 ± 15) m s^{-1}
Attenuation (one-way passage)	$(0.5 \pm 0.05) \pm 10^{-4} \times f$ dB m^{-1} Hz^{-1}
Attenuation	$(0.75 \pm 0.05) \times 10^{-4} \times f$ dB m^{-1} Hz^{-1}
Characteristic acoustic impedance	$(1.60 \pm 0.16) \times 10^{6}$ kg m^{-2} s^{-1}
Backscatter coefficient	$(1 \text{ to } 4) \times 10^{-28} \times f^4$ m^{-1} Hz^{-4} sr^{-1}

In the other hand, acoustic properties of typical SPUG without beads are shown in Table II. The SPUG has not values for acoustical quantities specified in IEC standard.

To mach the acoustical quantity of SPUG with IEC specification, we have proposed a new type of material that is SPUG dispersed with two kinds of plastic particles.

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Table II Typical physical properties of the SPUG

Sound velocity	1378 (m s^{-1})
Density	1.019 (10^3 kg/m^3)
Attenuation (one-way passage)	$(0.07) \times 10^{-4} \times f$ dB m^{-1} Hz^{-1}

2. Materials and Methods

The density a_0 of gel dispersed with plastic particles is given by the following equations.

$$a_0 = a_1 x_1 + a_2 x_2 + a_3 x_3, \quad (1)$$

where a_1, a_2, and a_3 are densities of the gel dispersed without particles, the particles 2 and 3, k_1, k_2, and k_3 are volume ratios of the gel or the particles.

From the values shown in Table II and III, a_1=1.019 (10^3 kg/m^3), a_2=1.05 (10^3 kg/m^3), and a_3=1.19 (10^3 kg/m^3) are given.

Table III Physical properties of the powders

	PMMA	Polystyrene
Sound velocity (m s^{-1})	2475	1840
Density (10^3 kg/m^3)	1.19	1.05

Adiabatic compressibility b_0 of gel dispersed with plastic particles is given by the following equations.

$$b_0 = b_1 x_1 + b_2 x_2 + b_3 x_3, \quad (2)$$

where b_1, b_2 and b_3 are adiabatic compressibilities of the gel , the particles 2 and 3, respectively. k_1, k_2 and k_3 are volume ratios of the gel, the particles 2 and 3.

Compressibility b_n is given by following equations.

$$b_n = 1/a_n C_n^2, \quad n=0, 1, 2, 3, \quad (3)$$

where C_n is acoustic velocity.

Contour plots of a_0=1.05 (10^3 kg/m^3) and C_0=1540 (m/s) in k_2, and k_3 plane shown in Fig.1 are given by Eqs. (1), (2), and (3). The contour lines cross at x_2=0.082 and x_3=0.374.

The graph indicates that the SPUG with volume ratios 0.082 and 0.374 of Polystyrene and PMMA particles possesses acoustic velocity of 1540 (m/s) and density of 1.05 (10^3 kg/m^3).

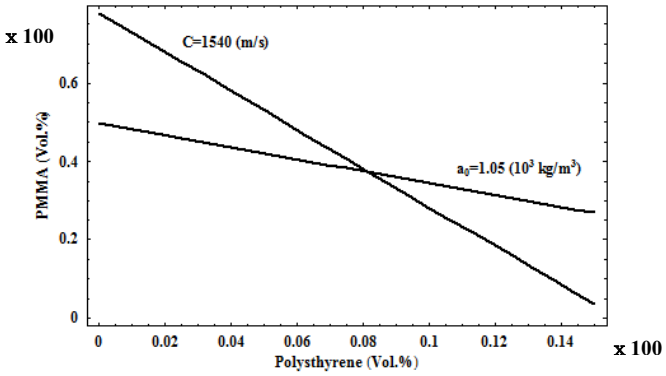

Fig. 1 Contour plots of a_0=1.05 (10^3 kg/m^3) and C_0=1540 (m/s).

Attenuation constant of the gel dispersed with particles can be obtained theoretically by Urick's equation[7]. The model is based on the fact that the particles are completely spherical. The SEM images of PMMA and polystyrene particles used for experiments are shown in Fig.2 and3.

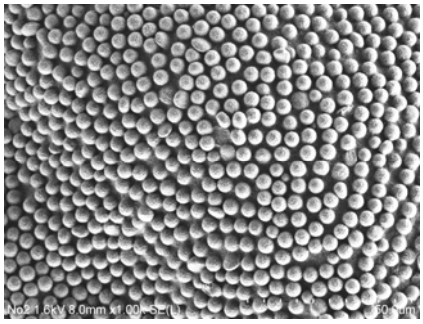

Fig. 2 SEM image of PMMA particles.

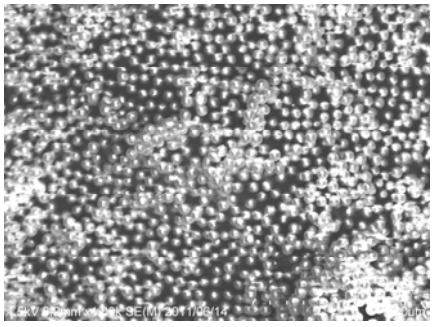

Fig. 3 SEM image of Polystyrene particles.

3. Experimental

Change of acoustic velocity of SPUG at room temperature after a sufficiently long time is shown in Table IV.

Stableness of SPUG over a month was confirmed with experiments.

Table IV Change of acoustic velocity of SPUG with time At room Tem.

The date	Acoustic velocity (m/s)
1.23	1383
1.30	1380
2.5	1386
2.15	1383
2.30	1382
Change with passes of time	1382.8+3.2,-2.8 0.15%Max

The SPUG did not change in weight without any mold over a month.

It has been confirmed with experiments that physical properties of SPUG with particles can be predicted theoretically.

4. Conclusion

A tissue-mimicking material has been developed with stable properties in time for phantoms, providing well satisfied IEC standard, whose acoustic properties can be theoretically predicted.

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