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Measurement of the Acoustic Nonlinearity Parameter *B*/*A* in Human Hair
毛髪における音響非線形パラメータ *B*/*A* の測定

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1. Introduction

The measurement method of the sound speed of a longitudinal sound wave in and the density of a thread such as a human hair was previously presented[1]. The method for measuring the attenuation coefficient for the longitudinal wave in a human hair was also presented[2]. In this paper, the acoustic nonlinearity parameter *B*/*A* in human hair is measured in a similar manner.

2. Acoustic Nonlinearity in Human Hair

Figure 1 shows an example of stress-strain curves for human hair. There exists an elastic limit near the stress of 130 MPa in the dry hair. The strain does not exactly increase in proportion to the stress even lower than the limit, but is slightly greater than expected by the proportionality. Namely the elasticity decreases with stress (negative pressure). The resultant lower sound speed is the same property as that of liquid media at a negative pressure. Thus, by measuring the reduced sound speed due to stress, the acoustic nonlinearity parameter *B*/*A* that is similarly defined as in liquid is derived.

Since the cross-sectional area of human hair is as small as 1.5×10^{-8} m^2, a stress as large as 130 MPa can be realized by applying a stress with a plummet of only 200 g. Hence the *B*/*A* may be evaluated by the sound speed reduction due to the stress caused by a small plummet loading.

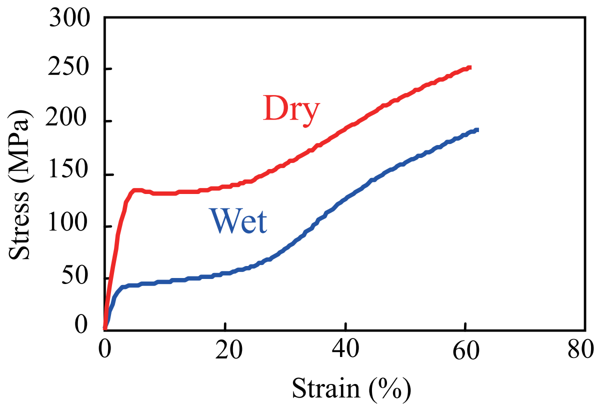

Fig.1 An example of stress-strain curve of human hair; courtesy of Kao Corporation.

3. Measurement of Sound Speed Change

Figure 2 shows the structure of the system to measure the sound speed change of human hair under loading. To detect the small change in the sound speed, the previous system[1-3] was improved. Two wooden clothespins are firmly fixed 10 cm distant from each other on a thick board. To excite the longitudinal wave in a human hair, the hair is pinched with a pair of semicylindrical PZT transducers that were made by splitting a 300 kHz cylindrical transducer. The transducers for the transmitter T and the receiver R are installed in both clothespins. The L-form guides attached at both sides of the clothespins effectively stabilize the transducer distance by preventing its lateral motion. Further, a slit is provided between T and R so that the sound wave does not propagate in the board. A plummet pulls the hair whose another end is fixed. Whenever the loading is changed, the clothespins are opened so that the sample hair expands and contracts without any restraint from the transducers.

Examples of measurement results for the sound speed c_l in the human hair at various loadings are shown in **Fig. 3**. Since the measured values for each

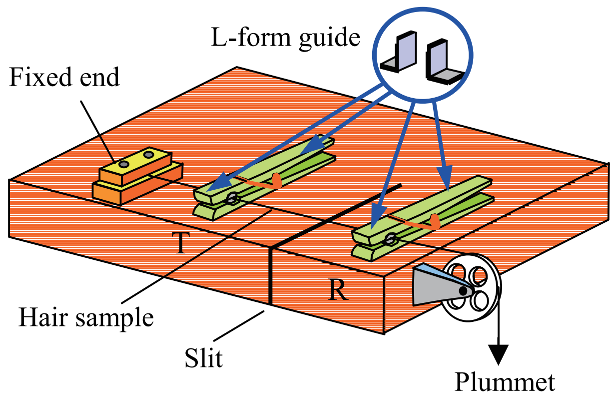

Fig. 2 Measurement system for the stress dependence of sound speed in hair.

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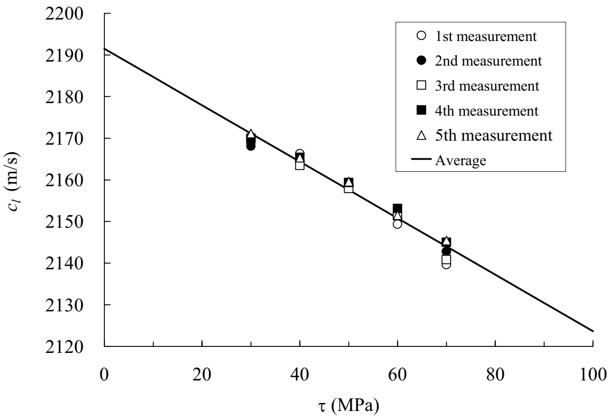

Fig. 3 Measured example of sound-speed change due to static stress; dyed 68-μm diameter sample of 51 years old female.

sample scatter somewhat, the line to approximate the average of 5 measurements is obtained by the least-squares method. It is seen that the sound-speed change rate $\Delta c_l/\Delta\tau$ becomes -0.68 m/sMPa.

4. Determination of *B*/*A*

In terms of nonlinearity parameter B/A, the change Δc in the sound speed due to the pressure change P is given in liquid as

$$\Delta c = \frac{B}{2A}\frac{P}{\rho_0 c_0} = \frac{B}{2A}\frac{c_0\rho}{\rho_0}, \tag{1}$$

where ρ_0 and c_0 are the density and the sound speed both at the equilibrium condition, and ρ is the density change. To estimate the B/A in a solid hair, the relation between $\Delta\tau$ and the volume strain $\rho/\rho_0=-(S_1+S_2+S_3)$ is needed. Setting the z direction along the hair, the stress in the hair that can be treated as a thin bar is $T_1=T_2=0$ and $T_3=\Delta\tau$. Assuming an isotropic medium, then

$$S_1 + S_2 + S_3 = (1-2\sigma)\frac{\Delta\tau}{\rho_0 c_l^2}, \tag{2}$$

where σ is Poisson's ratio. Since the sound speed c_l along the thin bar and c_0 are related proportionally by $c_l/c_0=[3(1\text{-}2\sigma)]^{1/2}$, $\Delta c/c_0=\Delta c_l/c_l$ is assumed. Summarizing the above results, the B/A is evaluated from the measurement value for $\Delta c_l/\Delta\tau$ by the following equation.

$$\frac{B}{A} = -\frac{2\rho_0 c_l}{1-2\sigma}\frac{\Delta c_l}{\Delta\tau} \tag{3}$$

The value σ=0.34 of polystyrene[4] is used for the Poisson's ratio that is not measured here, and the density ρ_0=1245 kg/m^3 is applied for all the samples[1]. **Table 1** lists the measured values of $\Delta c_l/\Delta\tau$ and the calculated values of B/A for various samples. The obtained B/A values are scattered in the range 12-19. The average of 15.3 is higher than the B/A in polymer materials[5]. The measurement of σ may be needed for higher precision. The correlation is not found with any known items including the gender and age of the donator.

5. Conclusion

The nonlinearity parameter B/A in human hair was measured with the change in the sound speed due to loading. Relatively high B/A value with high individual difference was obtained. Mr. Hiroyuki Taguchi at Global R&D, Biological Science of Kao Corporation is thanked for his instruction on the property of human hair.

References

1. S. Saito, Y. Shibata, A. Ichiki and A. Miyazaki: Jpn. J. Appl. Phys. **45** (2006) 4521.
2. S. Saito, Y. Fukuda and H. Nakajima: Acoust. Sci. & Tech. **29** (2008) 332.
3. S. Saito: Cho-Onpa Techno **20**(2) (2008) 103 [in Japanese].
4. O. Nomoto: *Cho-Onpa Gijutsu Binran* (Nikkan Kogyo Shinbun, 1966) p.1353 [in Japanese].
5. S. Saito and Y. Motohashi: Jpn. J. Appl. Phys. **47** (2008) 7380.

Table 1 Measurement result for various human hair samples.

Sample	Gender	Age	Dyed?	Diameter (μm)	$\Delta c_l/\Delta\tau$ (m/sMPa)	c_l (m/s)	B/A
1	M	23	No	62	-0.80	2193	13.7
2	M	23	No	73	-1.07	2153	17.9
3	F	22	Yes	80	-1.01	2205	17.7
4	M	23	No	70	-0.88	2197	15.0
5	M	22	Yes	70	-0.82	2044	13.0
6	M	19	Yes	90	-1.12	2226	19.4
7	F	20	Yes	72	-0.93	2269	16.4
8	M	20	Yes	98	-1.09	2262	19.2
9	M	21	Yes	85	-0.68	2231	11.8
10	M	20	No	82	-0.81	2284	14.4
11	M	16	No	83	-0.67	2384	12.4
12	F	51	Yes	68	-0.68	2191	11.6