ACOUSTICAL LETTER

Measurement of longitudinal attenuation coefficient in human hair

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(*Received 19 February 2008, Accepted for publication 11 April 2008*)

Keywords: Attenuation, Longitudinal wave, Human hair, Thread
PACS number: 33.80.Cs, 43.80.Ev, 43.35.Cg [doi:10.1250/ast.29.332]

1. Introduction

The measurement of the speed with which a longitudinal elastic wave travels along a thread whose diameter is less than 0.2 mm has been previously presented [1]. An ultrasonic vibration was excited in a sample thread knotted to a perforated glass bead that had been bonded to the end of a 300 kHz thickness-mode longitudinal transducer. The ultrasound was received with another 300 kHz transducer to which the other end of the thread had been knotted. The sound speed was derived from the distance between the two transducers divided by the time interval between the transmitting and receiving signals. In addition, an advanced method to excite and detect the ultrasound by pinching the thread with a pair of semicylindrical transducers has also been presented [1]. In this paper, the attenuation coefficient of a human hair is measured using the latter method.

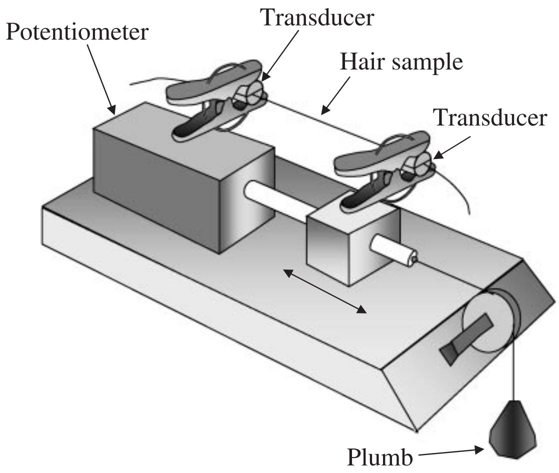

Fig. 1 Experimental setup.

2. System and method

An ultrasound transmitting and receiving system for a human hair sample is illustrated in Fig. 1. To excite the longitudinal ultrasonic 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 with thickness and radius of 6 mm and 5 mm, respectively, into two equal parts. A clothespeg fixed on the chassis of a linear potentiometer is used to hold one of the transducers. Both transducers are driven by one-cycle voltages with an amplitude of 8 V. Another clothespeg fixed on the moving shaft of the linear potentiometer holds the other transducer. A hair sample longer than 6 cm is inserted between the two transducers bonded to the clothespegs, and the ultrasound wave is then transmitted and received. The distance l between the two transducers is measured with the potentiometer. Tension is applied to straighten the hair with a 34 g plumb connected to the moving shaft of the potentiometer, where a fishing line connected at its tip transmits the gravity with the help of a pulley. An example of a received signal is shown in Fig. 2(a), where the wave duration is elongated due to multiple reflections taking place in the system as well as the transient responses of the transducers. Waves within 50 μs from the rising time directly associated with the attenuation in the hair are observed here. The waveform of the first 50 μs does not change with l. Employing one of the waveforms of the first 50 μs as a reference signal, the maximum value R_m of the cross-correlation function R for the received signal obtained for various l, as shown in Fig. 2(b), is regarded as the receiving amplitude.

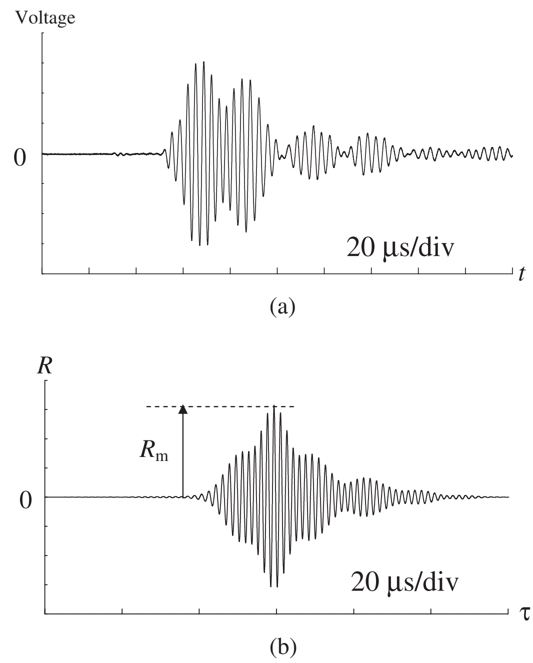

Fig. 2 Determination of received signal amplitude: (a) received signal, (b) cross-correlation function.

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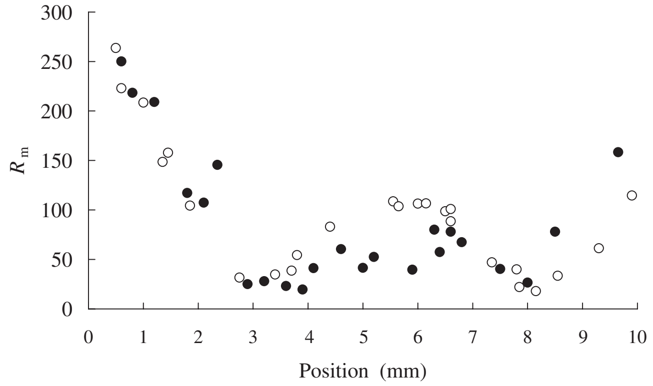

Fig. 3 Dependence of received signal amplitude on radial position of transducer.

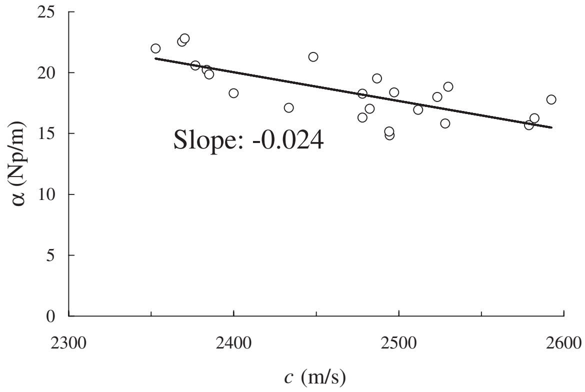

Fig. 5 Relation between sound speed and attenuation of 23 hair samples.

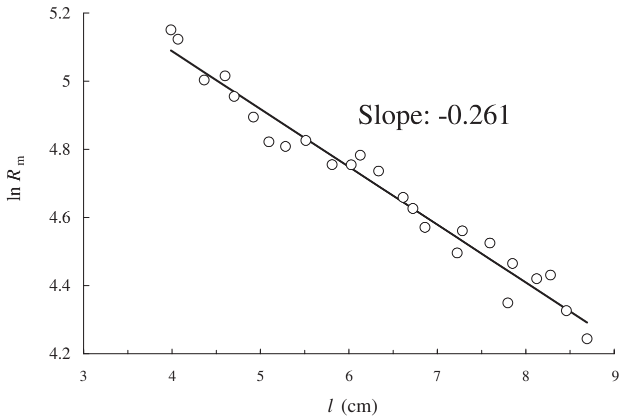

Fig. 4 Example of measurement of α for curly hair of 22-year-old female.

Changing the position of the receiving transducer to pinch the hair within a 10 mm width, the receiving amplitude is observed for a single hair sample at the same length l. The results are shown in Fig. 3. Because of the superposition of transducer vibrations other than the thickness longitudinal mode, the receiving sensitivity depends on the radial position of the transducer. The receiving amplitude is enhanced at the outer hull and seems to be more reproducible than at the center. Thus, the receiving amplitude of the longitudinal wave is obtained under the condition of a hair pinched at 1 mm from the outer fringe of the receiving transducer. The position pinching hair on the transmitting transducer is kept constant at the center.

3. Measurement results

The attenuation coefficient α was measured for 39 samples of human hairs donated from 39 persons. Figure 4 shows an example of the plots for the amplitude measured at various distances l between the transmitting and receiving transducers for a single hair. The abscissa represents l and the ordinate denotes the natural logarithm of R_m. As anticipated from Fig. 3, the data are scattered. Approximating these plots with a straight line by the least-squares method, the negative slope of the line yields α. For the

Table 1 Measured attenuation coefficients for 39 hair samples.

Sample	Age	Gender	α(Np/m)	Dyed?	Remark
1	15	M	16.1	No	TM
2	18	F	16.9	No	CN
3	21	F	17	No	MA
4	10	F	17.1	No	OT
5	21	M	17.7	Yes	HN
6	53	F	18	Yes	JN
7	22	F	19.2	Yes	KY
8	52	F	19.3	Yes	SN
9	61	F	19.3	Yes	AK
10	52	F	19.8	Yes	TS
11	59	M	19.9	No	SS
12	57	F	20.0	Yes	OY
13	2	F	20.2	No	WM
14	22	F	20.3	Yes	HU
15	42	F	20.4	Yes	AN
16	51	F	20.5	Yes	OI
17	63	F	20.6	Yes	UF
18	34	F	20.9	Yes	MS
19	43	F	21.0	Yes	KK
20	22	M	21.2	Yes	YK
21	36	F	21.2	Yes	MI
22	16	M	21.3	No	TM
23	30	F	21.4	No	HN
24	59	M	21.6	No	SS
25	42	F	21.9	No	AW
26	23	M	21.9	No	YM
27	50	M	21.9	Yes	TY
28	65	F	21.9	No	BO
29	22	F	22.8	No	AK
30	40	F	23.0	Yes	MO
31	23	F	23.8	No	MW
32	53	F	23.9	Yes	BS
33	22	F	24.2	No	YF
34	21	M	24.3	No	HF
35	22	M	25.0	No	KS
36	22	F	25.2	Yes	MA
37	22	F	26.1	No	YN
38	22	M	27.7	No	SS
39	52	M	28.2	No	OS

example shown in Fig. 4, α is derived to be 26.1 Np/m. The measurement results obtained through this procedure are summarized in Table 1. The value of α ranges from 16 to 28 Np/m and individual differences are found. This value of α is smaller than that of polystyrene and is almost the same as that of cranial bones [2,3]. While no differences due to age or gender are found, a trend of low attenuation is found in dyed hairs.

The sound speed can also be measured using the present system. Both the sound speed and attenuation were measured for 23 hair samples separately prepared. The relation between these variables is shown in Fig. 5. A trend of low attenuation with increased sound speed is found, which agrees with the previous result that hair damaged by dying has a higher sound speed [1]. The correlation coefficient $r = -0.733$ between c and α represents a clear negative correlation.

4. Conclusions

The attenuation coefficient of 300 kHz ultrasonic waves traveling in a human hair was measured from the relation between the receiving amplitude and traveling distance. The measured values for individual hairs were spread over a relatively wide range between 15 and 28 Np/m.

References

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