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High amplitude vibration test of polymers at ultrasonic frequencies
超音波周波数におけるポリマー材料の大振幅振動試験

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1. Introduction

Polymers usually appear to be good at absorbing vibration because of their large mechanical loss. However, some of functional polymers have the characteristics of low mechanical loss, low elastic moduli, and low densities, which are applicable to ultrasonic devices as the elastmors. In recent report, an airborne ultrasonic transducer with the polymer-based elastomer was tested and higher sound pressure was obtained than the metal-based transducers [1]. For further applications, it is of significance to measure the mechanical loss of the polymers under ultrasonic frequency and large vibration amplitude. In this study, being based on the original defination of the mechanical quality factor (Q factor), the mechanical loss of some typical polymer bars in flexural vibration is measured.

2. Material and Method

Figure 1 shows a vibrating bar in flexural deformation. A part between the cross sections L_1 and L_2 is selected as the sampling part with the vibration velocity distribution $v(z)$. The effective vibration power flow across the areas L_1 and L_2 are P_1 and P_2, respectively. The original definition of the Q factor is the ratio of the maximum reactive energy E_k to the dissipated energy for the period E_p in the sampling part [2],

$$Q = \frac{2\pi \cdot E_k}{E_p}. \tag{1}$$

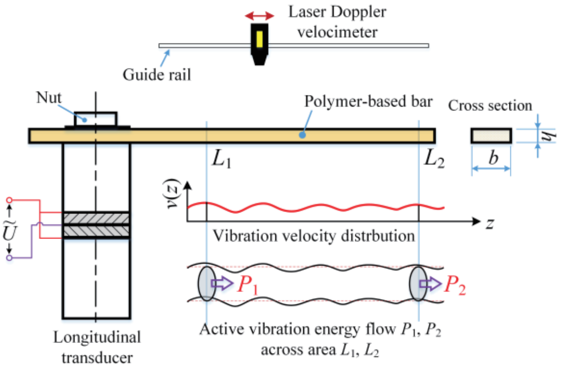

Fig. 1 Measurement of Q factor using the vibration velocity distribution on a vibrating bar.

The maximum reactive energy E_k and the dissipated energy E_p are calculated from the vibration velocity distribution $v(z)$. We assume that the deformation of one point on the vibrating bar is a composition of a translational motion in vertical direction with a vibration velocity v and a rotational motion with an angular velocity φ. Thus, the maximum reactive energy E_k is expressed as [2],

$$E_k = \frac{1}{2}\rho bh\int_{L_1}^{L_2} v^2 dz + \frac{1}{24}\rho bh^3\int_{L_1}^{L_2} \varphi^2 dz, \tag{2}$$

where ρ is the density of the material, b and h are the width and thickness of the specimen. The dissipated energy E_p is calculated as the decrease in the vibration energy flow from L_1 to L_2 along the z-axis [2],

$$E_p = \frac{2\pi}{\omega_0}\left(P_1 - P_2\right), \tag{3}$$

where ω_0 is the angular frequency. The effective vibration power flow P is estimated from the time averaged value as [3],

$$P = \frac{1}{2}\mathrm{Re}\left(V \cdot v^* - M \cdot \varphi^*\right), \tag{4}$$

where V and M are the shearing force and bending moment acting on the cross section. The asterisk indicates the complex conjugate. v is the vibration velocity at one point of the vibrating bar. The rotation angle φ, the shear force V, and the bending moment M are calculated from the vertical vibration velocity v using the Bernoulli-Euler model:

$$\varphi = \frac{dv}{dz}, \tag{5}$$

$$\frac{dV}{dt} = EI_z \cdot \frac{d^3 v}{dz^3}, \tag{6}$$

$$\frac{dM}{dt} = EI_z \cdot \frac{d^2 v}{dz^2}, \tag{7}$$

where E is the elastic modulus and I_z is the second moment of the cross-sectional area.

3. Experimental setup

Longitudinal transducers with the natural frequencies of 30, 42, 65, and 90 kHz were prepared to generate ultrasonic-frequency vibrations. One end of the polymer-based bar was fixed on the top of the transducer using a bolt. Thus,

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a flexural wave was generated on the bars. The dimensions of the polymer-based bars were 300 mm in length, 10 mm in width, and 1 mm in thickness. A laser Doppler velocimeter (NLV1232, Polytec, Germany) mounted on a guide rail was used to record the vibration velocities at different positions. The amplitude and the phase difference between the vibration velocity and the input signal were measured by a lock-in voltmeter (5560, NF electronic instruments, Japan). The Q factors of the polyacetal (POM)-, acrylonitrile-butadiene-styrene (ABS)-, polyether ether ketone (PEEK)-, and polyphenylene sulfide (PPS)-based bars were investigated in this study.

4. Experimental results

Figure 2 shows the experimental results of the Q factors for the PPS-, PEEK-, POM-, and ABS-based vibrating bars when the maximum vibration velocity is varied from 50 to 550 mm/s at the driving frequency of 40.99 kHz. The Q factor of the PPS-based bar was approximately 350 at the maximum vibration velocity of 50 mm/s. As the vibration velocity raised, the Q-factors of the PPS-, PEEK-, POM-, and ABS-based vibrating bars decreased. The Q factor of the PPS-based vibrating bar fell to approximately 150 at the maximum vibration velocity of 550 mm/s. The Q-factor of the PEEK-based vibrating bar was around 90 at the maximum vibration velocity of 50 mm/s. The Q factors of the POM- and ABS-based bars were around 20 at the maximum vibration velocity of 50 mm/s, which were only 0.06 times of the maximum Q factor of the PPS-based vibrating bar.

Figure 3(a) demonstrates the Q factors of the PPS-based vibrating bar as a function of the maximum vibration velocities at the frequencies of 28.30, 40.99, 63.84, and 90.23 kHz. The maximum Q factor reached approximately 460 when the driving frequency was 28.30 kHz and the maximum vibration velocity was 550 mm/s. When the maximum vibration velocity was smaller than 250 mm/s, the Q factors had little changes. In contrast, the Q factors decreased sharply when the maximum vibration velocity exceeded 250 mm/s especially at the driving frequencies of 28.30 and 40.99 kHz. The maximum Q factor of the PEEK was around 115 and the Q factors fell down as the vibration velocity became larger as Fig. 4(b) shows.

5. Conclusions

In this study, we proposed a method for evaluating the mechanical loss of the polymers in flexural vibration and measured the Q factors of some functional polymers. The experimental results show that the Q factors of polymers decrease as the frequencies and the vibration velocities increase. At the driving frequency of 28.30 kHz, the Q factor of the PPS-based vibrating bar reaches approximately 460 when the maximum vibration velocity on the bar is smaller than 50 mm/s. These results indicate that PPS is a substantial material of the metals as the elastomer in ultrasonic devices.

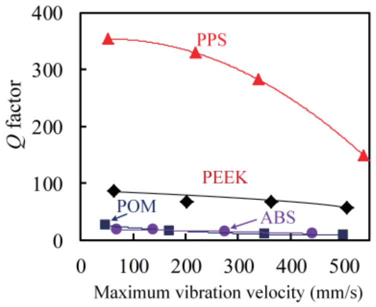

Fig. 2 Measurement results of Q factors for the PPS-, PEEK-, POM-, and ABS-based vibrating bars as a function of the maximum vibration velocity at the driving frequency of 40.99 kHz.

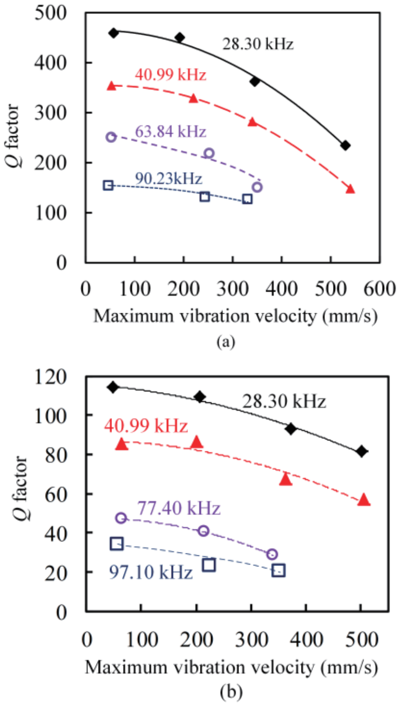

Fig. 3 Measurement results of Q factors for (a) the PPS-based and (b) PEEK-based vibrating bars as a function of the maximum vibration velocity at different driving frequencies.

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