2E3-1

Noncontact measurement of liquid viscosity in a soft container using free vibration after acoustic irradiation

音波照射後の自由振動を用いた軟性容器内の液体粘度の非接触計測

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1. Introduction

As a conventional non-contact viscosity measurement method, a method using sound waves or ultrasonic vibrations has been studied. However, since these are methods for measuring the vibration state of the liquid level, it is necessary to open the upper surface of the container to measure the liquid level. Therefore, there is a problem that the measurement cannot be performed when the content liquid is sealed in the actual container. Further, it is extremely difficult to detect the so-called flat sour putrefaction, in which only the viscosity changes without gas generation, because the shape does not change. Therefore, conventionally, there is a problem that measurement cannot be performed by non-destructive non-contact.

On the other hand, the noncontact acoustic inspection method [1-8)] that we are studying in our laboratory has been developed mainly as a non-destructive inspection method for defect exploration of concrete structures. In this method, vibration energy is applied to an object using sound wave irradiation and vibration, and the vibration velocity is measured by a laser Doppler vibrometer (LDV). This method is applicable not only to concrete but also to various objects. For example, it is possible to perform vibration and measurement on a paper container or a resin container in a completely non-contact manner. Furthermore, when the viscosity of the contents filled in the flexible container, changes, it can be predicted that the vibration damping due to the constant vibration energy given by the sonic excitation also changes. Therefore, by using this method, there is a possibility that the viscosity change can be estimated from the vibration of the flexible container and the vibration behavior of the content liquid without destroying the container itself from the difference in the attenuation of the vibration velocity waveform. Therefore, this time, by applying this method to the container itself containing liquids with different viscosities, it was examined whether the viscosity can be actually measured from the vibration behavior of the side wall of the container.

2.Viscosity measurement principle using noncontact acoustic inspection method

In the case of a change in the viscosity of the contents in the flexible container, it can be predicted that a difference will appear in the attenuation waveform at resonance depending on the magnitude of the viscosity. For the sake of simplicity, we assumed that the pressing force in the acoustic irradiation excitation was almost constant, and conducted a study using the static model of Voigt, which is the basic model of the viscoelastic body (see Fig. 1). Eq. (1) shows the time change of strain γ (t) when a constant pressing force S_0 is applied.

$$\gamma(t) = \frac{S_0}{G}\left(1 - e^{\frac{Gt}{\eta}}\right) \quad \cdots (1)$$

Here, G and η represent elastic modulus and viscosity, respectively. From Eq. (1), it can be seen that the strain γ in the static free vibration region exhibits an exponential damping characteristic that is inversely proportional to the magnitude of the viscosity η. That is, it is predicted that when the viscosity η is large, the given constant strain γ is rapidly attenuated, and conversely, when the viscosity η is small, the given constant strain γ is slowly attenuated.

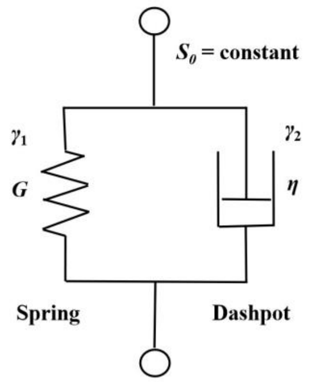

Fig.1. Voigt viscoelastic model (static model).

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3. Viscosity measurement experiment

Figure 2 shows the experimental setup using a commercially available PS (polystyrene) container ($100 \times 100 \times 60$ mm^3, average wall thickness 250 µm, full filling 500 g). Since most of the commercially available beverage containers have a wall thickness of 1 mm or less, the relationship between the contents viscosity was investigated from the vibration energy value of the side wall of the container using a commercially available PS container.

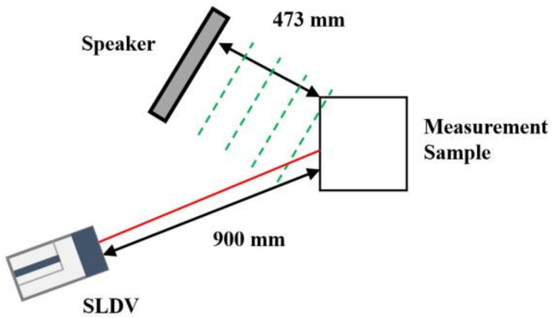

Fig.2. Experimental setup of viscosity measurement using acoustic irradiation induced vibration and LDV.

One to two hours before the experiment, distilled water was set aside to about 10 liters to stabilize the liquid temperature. Glue (sodium carboxymethyl cellulose) was mixed with distilled water and stirred to obtain contents having different viscosities.

Since the specific gravity of the glue is almost the same as that of distilled water, the experiment was conducted with weight control. The capacity of the contents was 400 ± 0.02 g, and the temperature of the contents was 24.5 ± 0.1 ° C, and the measurement conditions were kept almost constant. The viscosity was measured using a viscosity measuring device (Model: DV-I Prime, Brookfield Viscometer) immediately after the vibration velocity measurement. As the sound wave for excitation, a single tone burst wave with a frequency range of 100 to 1200 Hz, a pulse duration of 20 ms, and an interval time of 200 ms was used. In this measurement, as shown in Eq. (2), the free vibration energy elimination frequency (FE_{res} (m / s) ^{2}: Free vibration energy investigated frequency) at the resonance frequency was calculated.

$$FE_{res}(m/s)^2 = \int_{t_1}^{t_2} |V(t)|^2 \, dt \qquad \cdots (2)$$

This time, t_1 is set to 25 msec and t_2 is set to 150 msec according to the transmitted waveform.

Figure 3 shows the change in the free vibration energy value as the calculation result of Eq. (2) at the resonance frequency of 325 Hz when the content viscosity is changed. From the figure, an exponential inverse proportional relationship can be seen between the content viscosity and the free vibration energy value at the resonance frequency, showing a tendency similar to that of Eq. (1) obtained from the Voigt stationary model.

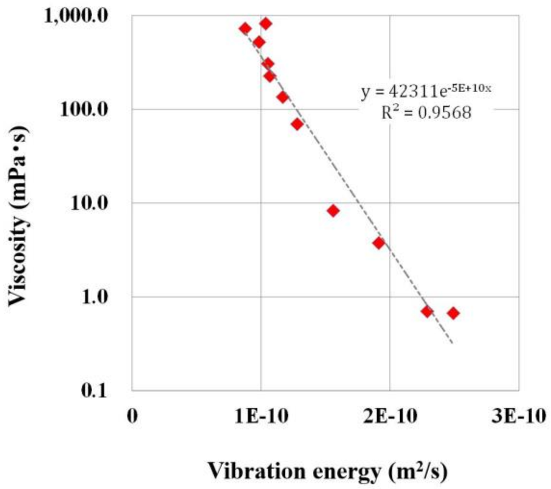

Fig.3. Relationship between viscosity and vibration energy.

4. Conclusion

From the experimental results, it was clarified that the change in the vibration energy value according to the viscosity of the contents can be measured when the measurement conditions such as the temperature of the contents liquid and the weight of the liquid are constant. This result indicates that the change in viscosity of the contents of the container may be detected from the outside of the container in a non-contact and non-destructive manner.

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