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Cross sectional acoustic impedance imaging of multi layered coating by wide-band ultrasound
広帯域超音波による多層塗膜の
音響インピーダンス断層イメージング

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1. Introduction

A coating layer normally consists of multiple layers of paint, where each layer has a thickness of up to several tens of micrometers. It is mainly used to protect the substrate (base layer) from rust and dirt. Monitoring the condition of the coating film with respect to layer uniformity and separation state is important in the production and maintenance processes. Most condition monitoring is done by destructive testing methods, where the coating cross-section is exposed and observed optically. If this can be observed nondestructively, the inspection efficiency will be improved.

An attempt has been made to perform the time-domain measurement using THz light in order to observe the internal structure of multilayer coatings, however, the path difference between the pump light and the probe light is changed by mechanical scanning to obtain the sequential correlation, which requires large equipment and high cost (1).

On the other hand, ultrasonic waves are relatively easy to measure in the time domain due to their slow propagation speed. In addition, the hardware required for observation is quite simple and does not require a high cost. Therefore, by taking advantage of this feature, ultrasonic inspection is considered to be suitable for observation of multi-layer structures such as coating film.

2. Sample and experimental method

Fig. 1 shows the illustration of the sample used in the experiment. As many as four-layer of coating film with various thicknesses (A: 16 µm, B: 40 µm, C: 68 µm, D: 59 µm) that are made from acrylic paint mixed with different pigments are laminated on the top of an ABS (Acrylonitrile Butadiene Styrene) substrate.

During the measurement, water is used as a coupling medium between the transducer and the object. A focused transducer with center frequency of approximately 80 MHz and aperture diameter of 2.4 mm scans through 2 mm along the horizontal direction with a scanning accuracy of 10 µm on 2 mm, and single cross-sectional view that consists of 200 x 250 points (x-and t-resolution) is obtained.

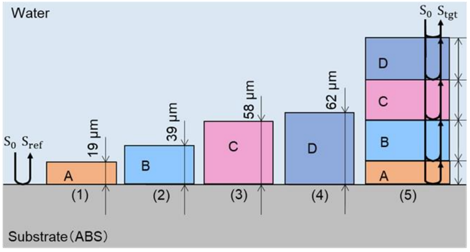

Fig.1 Schematic diagram of the specimen.

For the calculation, two types of signals are used, as shown in **Fig. 2**. The first is the target signal (S_{tgt}), namely, the signal that comes back from the interface between each two adjacent layers. The second is the reference signal (S_{ref}), namely, the signal that comes only from the interface between the ABS (substrate) and water.

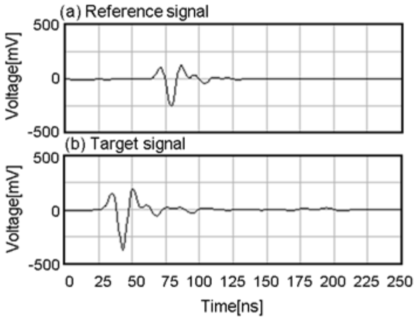

Fig.2 Waveforms as acquired.

The reflection coefficient that comes back from the object is then reconstructed by deconvoluting the target signal by the reference signal in time and frequency (dual) domain **(Fig.3(a))**. Each calculated reflection coefficient depending on the scanning point is then converted into the distribution of acoustic impedance by using algorithm similar to Time Domain Reflectometry (TDR), and the cross-sectional acoustic impedance distribution was obtained **(Fig3(b)(c))** (2).

In order to verify the validity of the measurement results for the multilayer film, monolayer samples made of the same material as each layer (Fig. 1(1)~(4)) were prepared and the same measurements were performed. In addition, the film thickness of each single layer sample was measured after exposing its cross section. The sound velocity for each coating was calculated according to the propagation time in the coating and the film thickness measured as mentioned above **(Table 1)**.

Table 1 Sound velocity of each individual coating calculated by using thickness and traveling time

	Film thickness [μm]	Traveling time in coating film / sampling [ns]	Speed of sound [m/s]
Coating A	19	12.51	3040
Coating B	39	28.94	2700
Coating C	58	49.89	2330
Coating D	62	56.31	2210

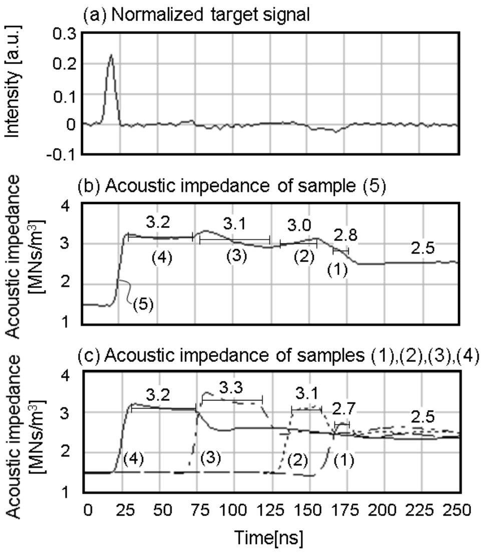

Fig 3. Deconvoluted signal and its acoustic impedance interpretation.

3. Results and Discussion

Fig. 3(b) shows the acoustic impedance distribution of the four-layer coating calculated from the normalized reflection coefficient.

In contrast, the acoustic impedance distribution calculated by coating one layer of each on the substrate and performing the same measurement is shown in **Fig. 3(c).** The coating films used in both of the above measurements were applied on a substrate with the same physical properties.

The acoustic impedance of the individually measured coating layers is in good agreement with that of each corresponding layer in the four-layer sample. Regardless of the composition of the coating, the estimated acoustic impedance of the substrate is around 2.5 MNs/m3 . The acoustic impedance of the substrate calculated from the sound velocity and density was 2.46 MNs/m3, which was in good agreement with the estimated value.

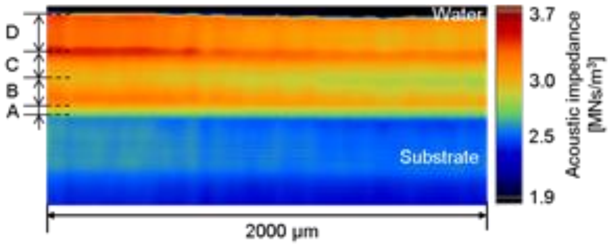

Fig.4 Cross-sectional acoustic impedance image of sample (5).

Fig. 4 shows an acoustic impedance tomogram. Water, substrate and four layers of coatings (A-D) are shown. The interfaces between substrate and A, A and B, C and D, D and water are clearly visible.

The interface between B and C is unrecognizable. The sound velocities of coatings A and D, calculated from the known thickness and traveling time, were 2960 m/s and 2340 m/s, which were in agreement with the results in Table 1. The difference between the acoustic impedance values of B and C is about 0.2 based on the measurement results of the single layer samples. Therefore, the interface between these two coatings is not clearly displayed. As a result, we were able to draw an acoustic impedance tomogram of the multilayer coating based on the reflection waveform.

4. Conclusion

Acoustic impedance tomography imaging of multilayer coating films was performed by using ultrasonic microscopy. The acoustic impedance of each layer obtained by using the multi-layer sample was consistent with that obtained using a single layer sample made of the material of the corresponding layer. Since the measured sound velocity of each coating layer differ by about 20%, this much of correction is necessary to represent the same scale as real space in the acoustic impedance image. As a future prospect, we believe that these observations can be used to evaluate the unevenness of the coating.

References

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