3P2-11

Interfacial stiffness evaluation based on resonance characteristics of weak bonds due to adherend contamination

被着体汚染に起因する弱接着部の共振特性に基づく界面剛性評価

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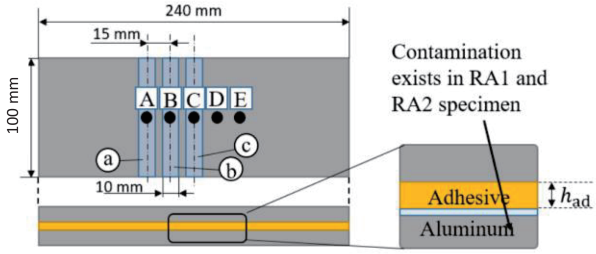
1. Introduction

C-scan is an ultrasonic detection method that is widely used for the nondestructive evaluation (NDE) of adhesive joints because it is capable of detecting voids, dis-bonds, and porosity in an adhesive layer. The C-scan device relies on a pulse-echo method, whereby the height of an echo returned from an adhesive joint is measured1). However, it has been challenging to detect weak bonds that are caused by the local sub-standard strength of the adhesive. A recent study2) revealed that contamination on the faces to be bonded with the adhesive affects the frequency spectra. The same study suggested various means of detecting such contaminations, but these methods continue to present difficulties.

The present study addresses the effects of contaminated adhesives on the interfacial stiffness. The interfacial stiffness was evaluated by combining experimental measurement based on the ultrasonic reflection method and theoretical analysis. In addition, the mode I fracture toughness of the interface between the adhesive and the adherend was measured by conducting the double-cantilever beam (DCB) tests.

2. Experimental measurements

The experiments were conducted on three specimens: a properly bonded specimen (PB) and two specimens (RA1 and RA2) with a release agent between the adhesive and adherend. The RA2 specimen was treated with a greater amount of release agent than the RA1 specimen. The specimens were created by bonding aluminum-alloy (A2024) plates with an FM300-2 film adhesive (121 °C curing epoxy-resin, Cytec), as shown in **Fig. 1**. The size of the aluminum-alloy plates and the adhesives was 240 mm × 100 mm. The nominal thicknesses of the aluminum-alloy plates and the adhesives were 2.0 and 0.2 mm, respectively.



Contamination exists in RA1 and RA2 specimen

Fig. 1 Dimensions of specimens.

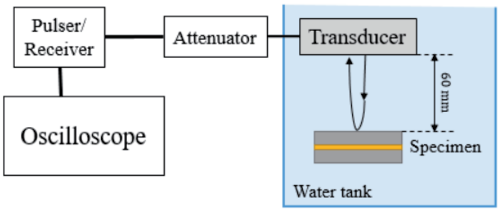


Fig. 2 Schematic of experimental setup.

The ultrasonic reflection method was combined with the immersion technique to measure the waveforms being reflected from the specimens, as shown in **Fig. 2**. The sinusoidal burst waves were normally incident on the specimens. The frequency of the incident wave was set in the range of 1 to 12 MHz, in steps of 0.1 MHz, with measurements being taken at each frequency step. For each specimen, reflected waveforms were measured at five points, A-E, as shown in Fig. 1. The waveforms that were measured by using a stainless-steel reflector were used as the reference waveforms. Fast Fourier transform (FFT) was performed to calculate the amplitude spectra of the measured waveforms. The reflection coefficient of the specimen was obtained by the ratio of amplitude spectra of the specimen to that of the reflector. The solid line in **Fig. 3** indicates

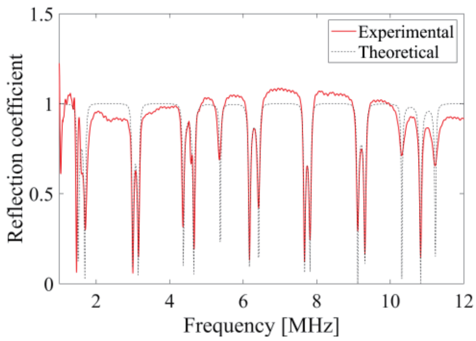


Fig. 3 Reflection coefficient of PB specimen (solid line) and theoretically calculated reflection coefficient for estimated parameter (dashed line).

the reflection coefficient of the PB specimen measured at point C. The reflection coefficient of each specimen showed multiple notches, which are caused by through-thickness resonance.

3. Theoretical analyses and determination of interfacial stiffnesses

The adhesive joint was modeled as a double-interface model[3)]. In this model interfaces between the adhesive and the adherend are expressed as the spring-type interface which is characterized by interfacial stiffness. The thickness of the adherend was set to 2.055 mm. The mass density of adherend, adhesive, and water was set to $2.77 \times 10^3\ \mathrm{kg/m^3}$, $1.24 \times 10^3\ \mathrm{kg/m^3}$, and $1.00 \times 10^3\ \mathrm{kg/m^3}$, respectively. The wave velocity of the adherend, adhesive and water were set to $6.35\ \mathrm{km/s}$, $2.54\ \mathrm{km/s}$, and $1.45\ \mathrm{km/s}$, respectively. The reflection coefficients were calculated based on the stiffness matrix method[4)]. The calculated reflection coefficient curves exhibited notches similar to the experimental results shown in Fig. 3 (dashed line). Some of these notches proved to be sensitive to the variations in the two interfacial stiffnesses and the thickness of the adhesive layer. Thus, the optimal values of those three values could be identified, minimizing the error between the experimentally and theoretically obtained notch frequencies.

4. Results and discussion

The interfacial stiffness of RA1 specimen was estimated to be approximately 24% of that of PB specimen, while that of RA2 specimen was almost the same as that of RA1 specimen, as shown in **Fig. 4** (blue bars). The error indicators on the bars in Fig. 4 show the standard deviation of the estimated values at five measurement points. These results indicate that the contamination of the release agent in the adhesive interface dramatically affects the resonance characteristics of adhesive joints and can be detected by identifying the interfacial stiffness with the proposed method. However, the interfacial stiffness may be less sensitive to the degree of contamination when the contamination level exceeds a certain level.

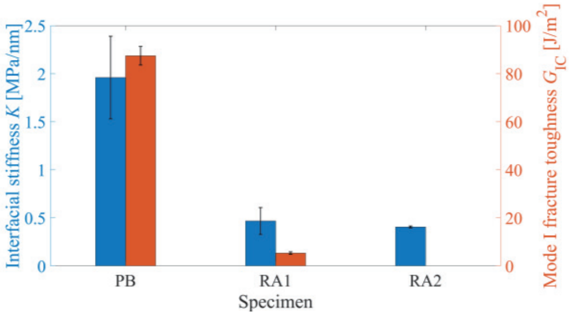


Fig. 4 Estimated values of interfacial stiffness (blue bars) and measured values of mode I fracture toughness (red bars).

After the ultrasonic measurement, three coupon specimens (a-c) were cut from each specimen as shown in Fig. 1. The fracture toughness of the coupon specimen was evaluated by conducting DCB tests. The fracture toughness of the contaminated interface of the RA1 specimen was only 6% of that of the properly bonded interface of the PB specimen, as shown in Fig. 4 (red bars). The fracture toughness of contaminated interface of the RA2 specimen could not be obtained because all coupon specimens cut from RA2 specimen were broken during machining. These results suggest that reduction in the mode I fracture toughness induced by adherend contamination can be detected by evaluating the interfacial stiffness, based on the proposed method.

5. Conclusions

In the present study, the interfacial stiffness between the adhesive and adherend of adhesive joints contaminated with a release agent, was evaluated. These evaluations were carried out on the adhesive joints of aluminum alloys. The results suggest that the contaminations of release agents can be detected by identifying interfacial stiffness, using the method proposed in this paper. In addition, the results of the DCB tests suggest a reduction in the mode I fracture toughness, induced by adherend contamination, can be detected by evaluating the interfacial stiffness using the proposed method. On the other hand, the interfacial stiffness may be less sensitive to the degree of contamination when the contamination level exceeds a certain limit.

Acknowledgments

This study was supported by the R&D Institute of Metals and Composites for Future Industries (RIMCOF) as part of the projects commissioned by the New Energy and Industrial Technology Development Organization (NEDO) of Japan. The authors would like to thank Mitsubishi Heavy Industries, Ltd. for providing the bonded specimens.

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