Ultrasound-excited active thermography inspection of CFRP: relationship between detectable delamination conditions and propagating waves

by M. Ishikawa*, M. Koyama**, R. Fukui***, H. Nishino*

* *Tokushima University, Tokushima, Japan*
** *Meisei University, Tokyo, Japan*
*** *KJTD Co., Ltd., Osaka, Japan*

Abstract

This study focuses on non-destructive testing using ultrasound-excited active thermography method and examines its application to the detection of delaminations in CFRP laminates. Experimental and numerical results showed that distinct large heat generations occurred at delamination tips, and that the cause of the heat generation is not frictional heat between the delamination surfaces, but viscoelastic heating caused by the concentration of stress and strain near the delamination tips.

1. Introduction

Ultrasound-excited active thermography method is an effective nondestructive technique for detecting closed defects (cracks or defective bonds, etc.), and it is also applicable for inspections of delaminations in carbon fiber reinforced plastic (CFRP) laminates. Detectable delamination conditions (or detectable opening width of the delamination) should depend on the excited ultrasounds; frictional heat between the delaminated layers is expected to be generated when the ultrasonic amplitude is smaller than the opening width. In this study, the conditions under which delaminations are detected and the causes of heat generation were examined through experiments on CFRP specimen with an artificial delamination.

2. Experiments

2.1. Experimental setup

Figure 1(a) shows the experimental setup. A 28-kHz ultrasound was excited in a CFRP specimen using an ultrasonic vibrator (HW-D250H-28, Nippon Avionics Co., Ltd.). The specimen was an 8-ply laminate measuring 150 mm × 20 mm × 2 mm and had a single-layer delamination between the center plies (thus, defect depth from the surface was approximately 1 mm). Experiments were performed under two different ultrasonic excitation conditions; the total amplitude of the excited ultrasound was varied as approximately 20 and 40 μm. The surface temperature during the vibration was monitored using an infrared thermography (A615, FLIR). After the thermographic measurement, the specimen was cut and the opening width of the delamination was measure using a microscope (VHX-7000, Keyence Corporation). Figure 1(b) shows an example of observed cross-sectional image of the specimen.

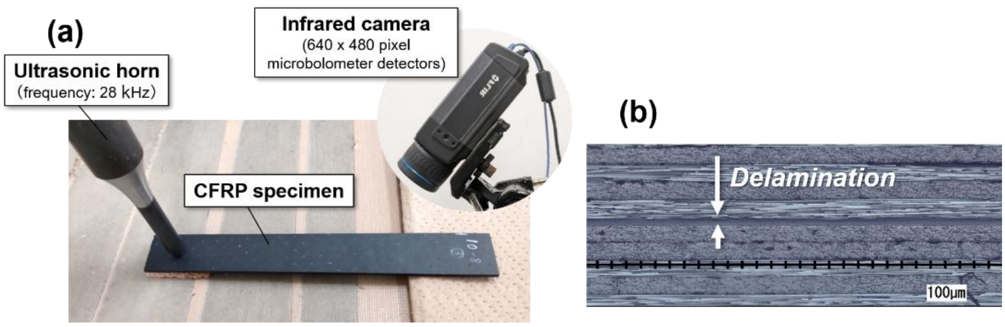

Figure 1. (a) Experimental setup, (b) Cross-sectional microscopic image of CFRP specimen.

2.2. Experimental results

Figure 2(a) and 2(b) show thermal images observed when the total amplitude of the excited ultrasound was 20 and 40 μm, respectively, and figure 2(c) shows the profile of temperature increase along dashed lines in figure 2(a) and 2(b). In figure 2(c), the microscopically measured delamination opening widths are also plotted. These figures indicate that two distinct high-temperature regions, those should be caused by the delamination, were observed in the thermal image, and the high-temperature regions were observed when the opening width was less than approximately

40 µm. When comparing the results for different excitation amplitudes, although the temperature values for the 40-µm condition were higher than those for the 20-µm condition, the position of the high-temperature regions was the same regardless of the amplitude. This implies that the cause of the distinct high-temperature regions may not be the frictional heat generated by contact between the delamination surfaces.

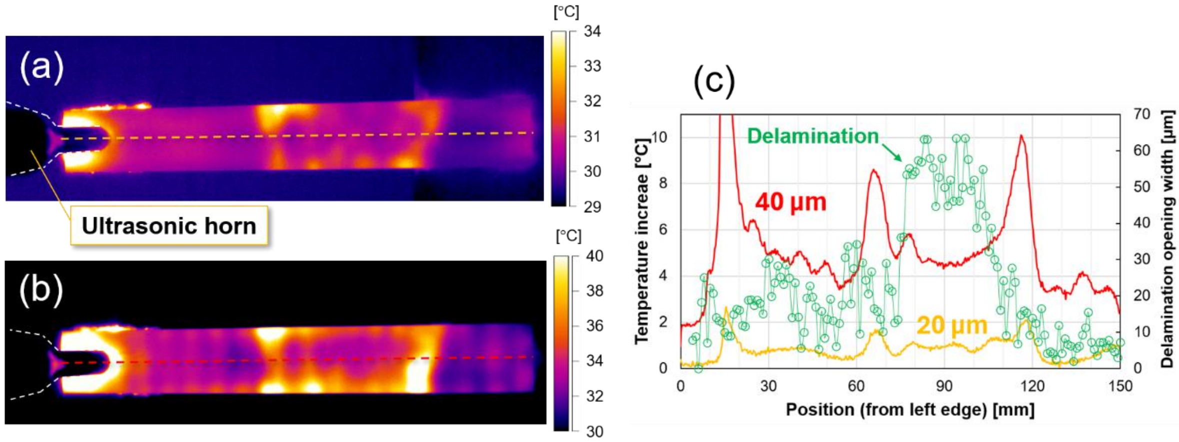

Figure 2. Thermal images observed when total amplitude of excited ultrasound was (a) 20 µm and (b) 40 µm, and (c) comparison of temperature profiles along dashed lines shown in (a) and (b) with the opening width of delamination measured by microscopic cross-sectional observations.

3. Discussions though numerical simulations

To investigate the cause of heat generations around a delamination, two-dimensional numerical calculation simulating the experimental conditions were performed. In the calculations, an 8-ply CFRP laminate with a delamination (tapered-slit with a maximum opening width of 50 µm) was modelled; the model was vibrated by applying a 28-kHz cyclic forced displacement with a total amplitude of 20 µm to the surface. The strain energy in the model was calculated and then the heat generation (rate of temperature increase) caused by viscoelastic heating [1] was estimated assuming a loss factor of the model of 0.015. The calculation results shows that the maximum temperature increase occurred at the tips of the delamination; the maximum temperature increase rate was approximately 1°C/s, which almost agreed with the experimental results. These results indicated that the distinct high-temperature regions observed in the experiments were caused by the viscoelastic heat generation near the delamination tips.

4. Conclusions

Nondestructive testing of delaminations in CFRP laminates using ultrasound-excited active thermography method was examined. Experimental and numerical results indicated that the local high-temperature regions observed near a delamination should not be caused by frictional heat generation, but by viscoelastic heat generation at the tips of the delamination. In this study, an interlaminar delamination propagating in the in-plane direction was examined. However, when inspecting transverse cracks in the thickness direction, the effect of frictional heat generation should be greater because the dominant ultrasonic waves propagating in plate-shaped objects during testing are Lamb waves that vibrate in thickness direction [2]. Furthermore, heat generations cause by standing waves (which are also caused by viscoelastic heating) could be observed in the thermal images. Therefore, analyzing and interpreting the obtained thermal images is essential for accurately assessing the condition of the defect.

Acknowledgments

This work was supported by JSPS KAKENHI Grant Number JP24K07930**.**

References

[1] J. Renshaw, J. C. Chen, S. D. Holland, R. B. Thompson, «The sources of heat generation in vibrothermography,» NDT & E International, vol. 44, n. 8, pp. 736-739, 2011.

[2] M. Ishikawa, R. Maeda, H. Nishino, M. Koyama, R. Fukui, «Waves causing undesired heat pattern detected via ultrasound-excited active thermography,» Infrared Physics & Technology, vol. 145, 105652, 2025.