Three-dimensional Imaging of Subsurface Defect in CFRP using Photoacoustic Microscopy

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Abstract

Photoacoustic (PA) imaging utilizes an ultrasonic wave generated by optical excitations with a short-pulse laser. A pulsed laser illuminates the target zone, then a rapid thermo-elastic expansion generates broadband high-frequency ultrasonic waves. In this study, the depth and size of subsurface flaws in a carbon fiber reinforced plastic laminate were evaluated using the PA microscope. From the PA imaging, the location and shape of the artificial delaminations in a cross-ply laminate can be clearly reconstructed as a three-dimensional image.

1. Introduction

Carbon fibers and matrices form thin sheets (plies), which are then bonded to form a carbon fiber reinforced plastic (CFRP) laminate. During the fabrication and manufacturing processes, flaws such as concealed cuts, lack of roving, delamination, and resin-starved layers might be found. When the flaws are in shallow position, to detect the flaws is sometimes challenging because the trailing signal from the surface is not discriminated from the flaw signal. In this study, we developed a photoacoustic microscope (PAM) for the evaluation of subsurface flaws. In the PAM, a laser illuminates the target zone, then a PA wave is generated in CFRP. The PA wave is detected by an immersion ultrasound transducer. The laser excitation and ultrasonic detection are focused, and both the foci are configured to maximize the intensity (1). Here, imaging of artificial delaminations embedded in a cross-ply laminate was tested.

2. Photoacoustic microscopy (PAM)

The PAM system for CFRP inspection is illustrated in Figure 1(a). Laser generation is driven by a compact Q-switched Nd:YAG laser operating at approximately 0.6-mJ pulse energies and at a 100-Hz pulse repetition rate (Nano L90-100, Litron). The laser emits 4-ns pulse at the wavelength of 532 nm. The laser emission is controlled by an external trigger signal outputted from a scanner controller. The light at the fiber output end is collimated and reshaped using an axicon lens to form a ring pattern. The ring-shaped light is then focused onto the target using a reflecting prism. The generated PA waves are detected by a focused ultrasound transducer (50MHz, V214-BB-RM, Olympus) located at the center of the prism (see Figure 1(b)). In our apparatus, the focus of the laser excitation and ultrasonic detection are set to the same distance to maximize the intensity of the generated PA wave. Two-dimensional (2D) raster scanning (x and y directions) is implemented by translating the microscope unit.
Figure 1. (a) Flow diagram of PAM system and (b) photograph of reflecting prism in microscope

3. Result of PA imaging

Figure 2(a) shows a CFRP specimen with artificial delaminations (5mm x 20mm) which are located at the different depth. The translation of microscope unit is performed along a zig-zag path to acquire a complete 3D data set that characterizes delaminations. It is assumed that the PA wave is generated mainly from the surface of the CFRP laminate. The transit time of the first received signal is related with the location of the CFRP surface. The delamination depth $z$ is calculated based on the flight time of the PA wave between the surface and delamination. The wave velocity in the $z$ direction is approx. 3.0 km/s. The scanning in $x$ and $y$ directions is performed at a pitch of 50 μm. Figure 2(b) and (c) shows the 3D image and cross-sectional view of the specimen, respectively. The color indicates the signal amplitude over a threshold in the $z$ direction. The PAM image showed the accurate location and size of delaminations. It was also found that the pattern on the delamination reflected the fiber orientation in each ply.

Figure 2. (a) Cross-ply CFRP specimen [(0°/90°)4s] with artificial delamination, (b) the 3D image, and (c) the cross-sectional view of specimen

References: