DETECTION OF IMPACT DAMAGE IN CARBON FIBER-REINFORCED(CFRP) BY EDDY CURRENT NON-DESTRUCTIVE TESTING

K.Koyama[1*], H.Hoshikawa[1]

[1]*College of Industrial Technology,Nihon University/1-2-1Izumicho,Narashino,Chiba 275-8575 JAPAN*
**e-mail：koyama.kiyoshi@nihon-u.ac.jp*

Keywords: Eddy Current Testing, CFRP, Impact Damage, Ultrasonic testing, X-ray testing

Abstract

Presentation paper describes the use of eddy current testing (ECT) method for the inspection and detection of impact damage in carbon fiber-reinforced plastics (CFRP). Inspection of impact damage in CFRP by ECT method was investigated. Scanning experiments were carried out using eddy current theta probe, which is developed by the authors, at test frequency of 1MHz. CFRP samples of 3.0mm in thickness with artificial impact damage were used. As a result, it has been confirmed that eddy current theta probe can be detected the impact damage, that produced the energy of 0.25J, with high signal-to-noise ratio rather than conventional eddy current probe.

1 Introduction

This paper reports the results of the detection of flaws in CFRP by ECT, a non-destructive testing method using electromagnetic induction.

Composite materials present the combined advantage of high strength, high fatigue resistance and very low weight. They are used to a great extent in the aerospace industry. However, fiber-reinforced composite materials can show poor resistance to impact. In order to maintain the high level of quality and safety required by the aerospace industry, the use of Non-destructive Evaluation (NDE) techniques is a major factor in the quality assessment for these new materials.

An external impact causes delamination of CFRP, resulting in reduced mechanical properties. Non-destructive testing is performed to detect flaws. Ultrasonic testing, which requires a contact medium, is used as a non-destructive testing method for CFRP. ECT method is a non-destructive testing method where electric induction is used, and has advantages in the inspection of CFRP that are not available with other testing methods[1]-[6]. In this method, change of electric current in a test material by a test coil, where an alternating current is applied, are monitored as change of impedance of the test coil or another detecting coil. Distinctive feature of this method is an ability of fast and contact-free inspection of flaws that affect local electric conductivity of the sample. This method is widely used for detecting cracks and corrosion in metals, or checking their electric conductivity.

Because carbon fiber in CFRP has electric conductivity, ECT method has a potential to inspect the flaws. However, electric conductivity of CFRP is much smaller than that of metals. Moreover, from the view of the eddy current probe, CFRP to be checked looks as a inhomogeneous conductive materials where conductive fibers are bundled and laid up, and

this is completely different situation comparing with metal samples that are homogeneous. Therefore there are several problems to be solved for applying ECT method to CFRP such as proper selection of test frequency, shape of probe, or signal processing.
The authors developed an ECT probe that takes into account the anisotropic conductivity of CFRP, and reported that the probe can detect artificial flaws with a high signal-to-noise ratio[7]. In this study, we artificially introduced simulated flaws into the specimens by applying an impact, performed flaw detection, and examined the correlation between the impact force and the detection signal. We also examined correlations with the results of ultrasonic testing and observation of the cloth section of the damage zone.

2 Application of the electromagnetic induction non-destructive method to CFRP

CFRP contains carbon and is electrically conductive. Its conductivity is 10^4 to 10^6 less than that of metals. This conductivity value is measurements by the material manufacturer. ECT can be applied to CFRP because of its conductivity. Figure 1 shows the probe[8] (called a theta probe) used in ECT of CFRP. The theta probe consists of a circular exciting coil and a rectangular vertical detecting coil. The exciting coil generates an eddy current in the specimen by electromagnetic induction. The detecting coil detects the magnetic flux produced by the eddy current induced by a flaw, and generates a signal.
The principle of the detection of flaws in cloth CFRP is described below. CFRP is conductive in the xy-direction in the plane of the CF sheet. If there is no flaw in the specimen, the eddy current flows through the winding of the exciting coil. The sum of the magnetic flux crossing the detecting coil is zero, and no voltage is induced in the detecting coil; that is, no signal is generated without a flaw. If there is an interlaminar flaw, as shown in Figure 2, the eddy current is prevented by the flaw from flowing, and the flow of the eddy current around the flaw changes, generating a signal in the detecting coil. As shown in Figure 2, the current flows in the detecting coil in one direction when the detecting coil is placed above the flaw, and in the opposite direction when it is placed below the flaw. The polarity of the signal detected changes accordingly.

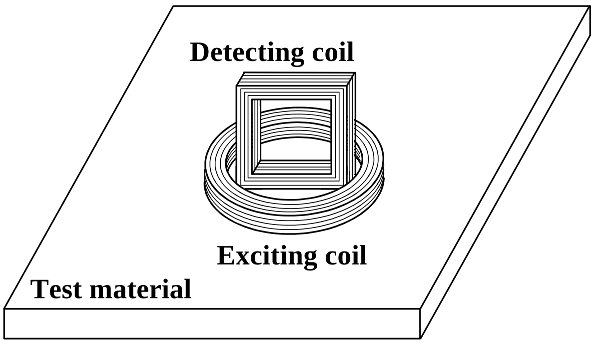


Figure 1. Structure of eddy current theta probe

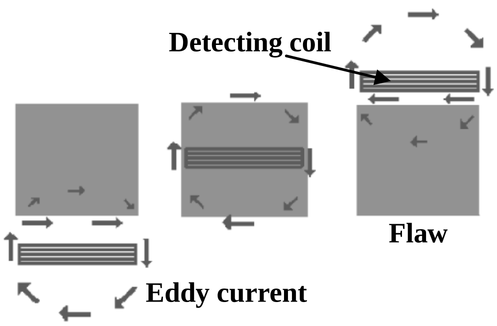


Figure 2. Eddy current flow with flaw in CFRP

3 Experimental method

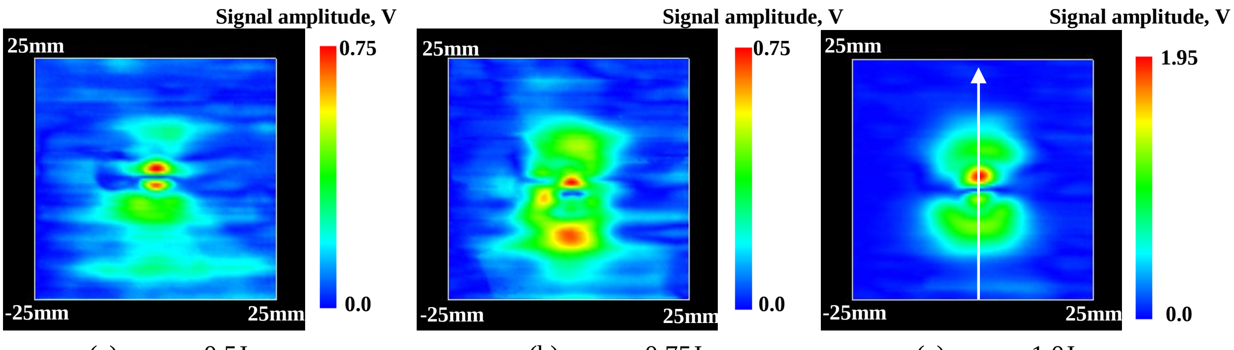
The specimens used were a 3 mm thick, cloth CFRP plate laminated with layers of 0.2 mm thick, woven CF sheets; and a 3 mm thick, quasi-isotropic CFRP plate [45/0/-45/90]2s laminated with 0.2 mm thick, unidirectional fiber CF sheets. Artificial impact damages were introduced by dropping a 1 kg steel ball, from different heights, onto a 3 mm drill bit placed on the CFRP specimen. The drop heights used were 0.25, 0.5, 0.75, 1.0, 1.5, and 2.0 m, which correspond to impact energy of 0.25, 0.5, 0.75, 1.0, 1.5, 2.0 J. The exciting coil of the theta probe used was 9 mm in outer diameter, with a winding cross-section of 1 mm^2. The detecting coil was 7 mm wide and 7 mm high, with a winding cross-section of 1 mm^2. The theta probe was two-dimensionally scanned without contact at a constant distance (0.5 mm) from the CFRP specimen. The scan range was ±25 mm in the x- and y-directions, and the scan interval was 0.5 mm. The intensity of the eddy current induced in the specimen is determined by the product of the test frequency and the electromagnetic characteristic of the specimen. The test frequency was set to 1 MHz, taking into account the conductivity of the CFRP.

4 Experimental result

4.1 Results of the detection of flaws in the cloth CFRP

Figure 3 shows images of the detection signal of each impact damage in the cloth CFRP specimen. In ECT, a sine wave alternating current is applied, and thereby, the complex voltage of the in-phase component having the same phase as the exciting current and the 90-degree phase-advanced quadrature components is obtained. The amplitude of the detection signal is shown in the figure. The probe has been shown to have the capability to detect impact damage corresponding to an impact energy of up to 0.25 J with a high signal-to-noise ratio.

The signal in the y-direction (shown by the arrow in Figure 3) passing through the maximum point of the signal amplitude is shown in Figure 4 of the complex voltage plane. The signal amplitude and the signal phase were obtained from the figure. Figure 5 shows the change in the signal amplitude and the signal phase with impact energy changes. Though the signal amplitude is nearly the same for 0.5 and 0.75 J, the display area of the signal is larger for 0.75 J than for 0.5, as shown in Figure 3. The signal phase varies with impact energy.



(a) energy 0.5J (b) energy 0.75J (c) energy 1.0J

Figure 3. Image display of ECT flaw signal amplitude for cloth CFRP

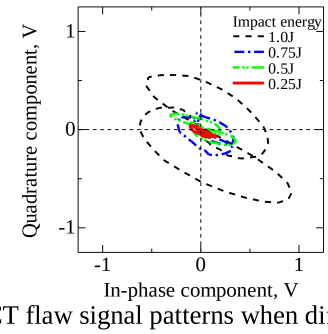
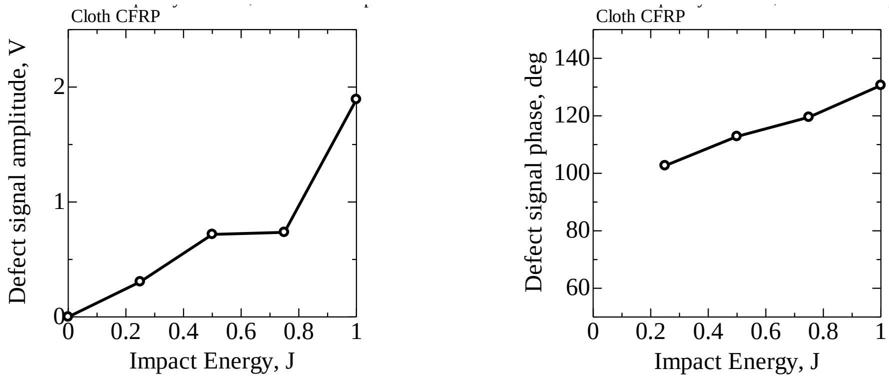


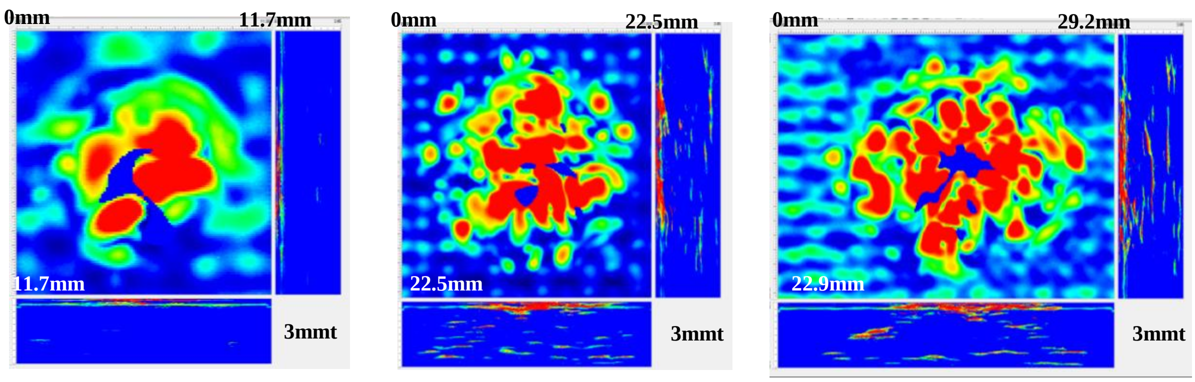
Figure 4. ECT flaw signal patterns when different impact energy



(a) impact damage signal amplitude (b) impact damage signal phase

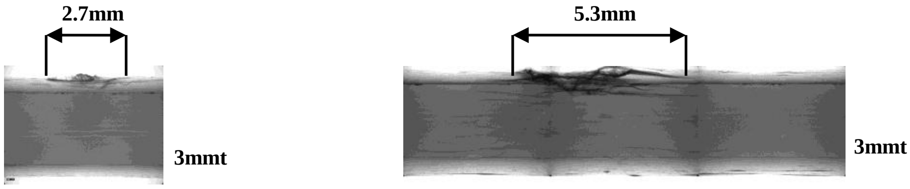
Figure 5. Detection signal amplitude and phase vs. impact energy

Ultrasonic testing and X-ray observation of the cross-section of the damage zone were performed to evaluate the detection signal in ECT in detail. Figure 6 shows display images of the detection signal in ultrasonic testing (UT). The immersion/reflection technique was employed, using a 5 MHz probe. The probe was two-dimensionally scanned at 0.1 mm intervals. The display area of the signal increases with increasing impact energy, and shows a good agreement between ECT and UT. Signals were observed near the surface for 0.25 and 0.5 J, and across the thickness of the specimen for 0.75 and 1.0 J. Figure 7 shows X-ray images of the cross-section of the damage zone. The damage becomes larger in the thickness direction with increasing impact energy. Since the signal phase varies with impact energy, there probably is a correlation between the phase of the detection signal in ECT and the development of damage in the thickness direction.

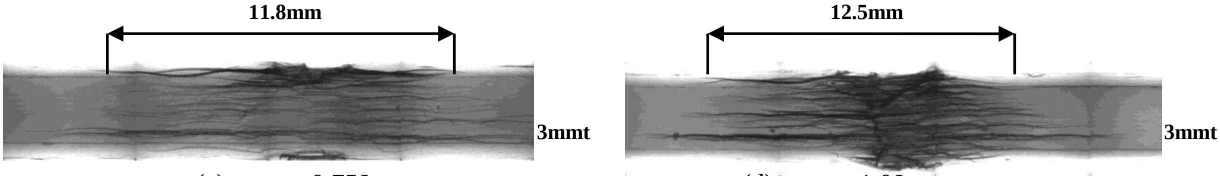


(a) energy 0.5J (b) energy 0.75J (c) energy 1.0J

Figure 6. Image display of UT signal with different impact energy



(a) energy 0.25J (b) energy 0.5J

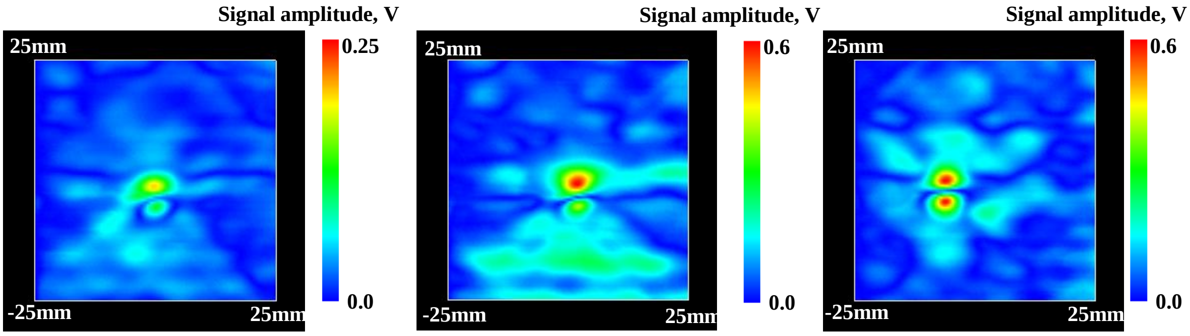


(c) energy 0.75J (d) energy 1.0J

Figure 6. Image display of UT signal with different impact energy

4.2 Results of the detection of flaws in the quasi-isotropic CFRP specimen

Figure 8 shows display images of the signal amplitude of each impact damage in the quasi-isotropic specimen. Under the test conditions used, impact damages in the specimens subjected to an impact energy of less than 1.0 J were difficult to detect due to a low signal-to-noise ratio. Those in the specimens subjected to an impact energy of 1.0 J or more were detected with a high signal-to-noise ratio. Ultrasonic testing and X-ray observation of the cross-section of the damage zone will be performed later.



(a) energy 1.0J (b) energy 1.5J (c) energy 2.0J

Figure 8. Image display of ECT flaw signal amplitude for quasi-isotropic CFRP

5 Conclusion

We performed a test to detect artificially introduced, simulated impact damages with the eddy current theta probe, and examined the correlation between the impact force and the detection signal. We also examined correlations with the results of ultrasonic testing and X-ray observation of the damage zone. No correlation was found between the amplitude of the detection signal and the impact force. The phase of the detection signal varied with the impact force. This suggests that there is a correlation with the damage development in the thickness direction of CFRP. More data will be collected and analyzed in detail.

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