Extended Abstracts of the 2017 International Conference on Solid State Devices and Materials, Sendai, 2017, pp375-376

H-2-06

Evaluation of Electrical Conductivity of CFRP by Surface Potential Distribution

Kazuya Kikunaga[1] and Nao Terasaki[1]

[1] National Institute of Advanced Industrial Science and Technology
807-1 Shuku-machi, Tosu, Saga 841-0052, Japan
Phone: +81-942-81-3662 E-mail: k-kikunaga@aist.go.jp

Abstract

A new method for the evaluation of electrical conductivity in a structural material like CFRP using static electricity is proposed. After the CFRP was charged by a corona discharge, its surface potential distribution was measured by scanning a vibrating linear array sensor along the object surface over a short time period. A correlation between the weave pattern of the CFRP and the surface potential distribution was observed. This result indicates that the electrical conductivity of a material, in which an insulator and a conductor are mixed, can be evaluated.

1. Introduction

Carbon fiber reinforced plastic (CFRP) is an excellent structural material having low thermal expansion, high heat dissipation, lightweight, high voltage endurance, and high strength. CFRP is used for various purposes such as a structural material of multilayer printed circuit boards, semiconductor wafer transfer robot elements, and aircrafts. The electrical conductivity of CFRP is lower than that of the metallic materials by about $10^4 \sim 10^5$ and is anisotropic. Therefore, the influence of static electricity is a concern in the printed wiring boards or the robot elements that include CFRP. In an aircraft composed of CFRP, metal foils or meshes are affixed to the surface of the structural members to ensure a conductive path for lightning strike current, in order to prevent the damage associated with the resistance heating due to lightning strikes [1]. However, since the impulse current associated with thunder and electrostatic discharge generates leakage currents and induced currents, it may lead to damage due to the flow of the electric current into the CFRP and induce the interlayer peeling of the CFRP. Therefore, studies on damage to CFRP laminates by lightning protection tests using impulse current have been actively carried out [2-4]. Hence, in order to improve the reliability of multilayer printed circuit boards and semiconductor wafer transport robot elements that include CFRP, it is important to evaluate the electrical conduction characteristics of CFRP under an assumption that electrostatic discharge occurs.

Electrical properties of CFRP can be evaluated using four-probe method [5], eddy current method using electromagnetic induction [6-8], electrical resistance tomography mapping [9], and electric current analysis [10, 11]. However, it is difficult to evaluate the distribution of electrical conduction in CFRP with an impulse current such as an electrostatic discharge using these methods as the surface of the CFRP is insulated, and both insulating and conducting regions partially exist in the CFRP. Therefore, it is necessary to develop a new nondestructive technology to evaluate the distribution of electrical conduction in CFRP.

We have focused on charging the CFRP by a corona discharge and measuring the changes in the surface potential of the charged CFRP, as a means of observing the distribution of electrical conduction in CFRP. Since the charge would be flowing through a highly conductive part, it may be possible to measure the flow of electricity into the CFRP if the two-dimensional distribution of the surface potential with a high resolution can be observed over a short duration. Up to now, the surface potential measurement technologies using targeted electrostatic fields include static induction type, vibrating reed induction type fieldmeters, and chopper stabilized instruments, and the surface potential measurement technologies using induced electric fields make use of ultrasound waves [12]. For a high spatial resolution, it is necessary to narrow the sensing area and scan point by point over the whole surface when these techniques are used to measure the surface potential distributions on an object surface [13]. Therefore, it is difficult to measure the surface potential distribution over a short duration using these techniques. A new system has been developed for measuring the surface potential distribution with a high resolution over a short duration by scanning an object along a vibrating linear array sensor [14]. In this study, we evaluated the electrical conductivity of CFRP by measuring the change in the surface potential distribution in CFRP with time, after charging the CFRP by corona discharge.

2. Experimental method

The experimental setup for the surface potential distribution measurement is shown in Figure 1. The system consists of a linear array sensor, a vibration generator, a multichannel lock-in amplifier, and an automatic positioning stage. The linear array sensor comprises of 30 parallel individual flat-plate electrodes (size: 0.7 mm × 0.7 mm) placed at 1 mm intervals with a vibrating sensor substrate in this system. The array sensor was connected to the vibration generator, which was vibrated in the frequency range 0.01–1 kHz, and the amplitude range was 0.01–1 mm. Each of the linear array sensors was connected to the multichannel lock-in amplifier. The AC voltage and the phase detected by the individual sensors were simultaneously measured through the individual lock-in amplifier. Twill weave pattern of the CFRP plates (area: 25 mm × 30 mm, thick: 1 mm) were used as the samples. The widths of weave pattern were (i) 4 mm and (ii) 2 mm. The samples were installed in parallel at a distance of 0.1–2 mm from and facing the linear array sensor. The samples were fixed to the automatic positioning stage and were moved by a scan speed in the range of 1–20 mm/s. The samples were brought in contact with the needle of the corona discharge (output voltage -50 kV, maximum output current 20 μA) and were charged. After that, the surface potential distribution of CFRP was measured.

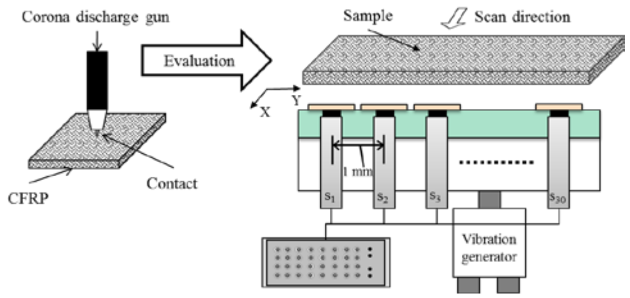

Fig. 1 Experimental setup for the surface potential distribution measurement.

3. Results and discussion

The surface potential distribution of the CFRPs was evaluated using the system shown in Figure 1 after they were charged with the corona discharge for 5 s. The time dependence of the surface potential distribution was then observed. The linear array sensor was vibrated at a frequency of 200 Hz and an amplitude of 0.25 mm. It was placed in parallel at a distance of 0.5 mm from the sample. The sample was scanned in the X-axis direction at a speed of 10 mm/s. The signals detected in each sensor were measured through the multi-channel lock-in amplifier at an interval of 1 mm. The surface potential distribution of the sample was visualized in an area of 25 mm × 30 mm by combining the information of the surface potentials from each position. Here, the surface potential was calibrated using the detected voltage from the sensor and the electrical polarity. The measurement time of the surface potential distribution at each position was 3 s.

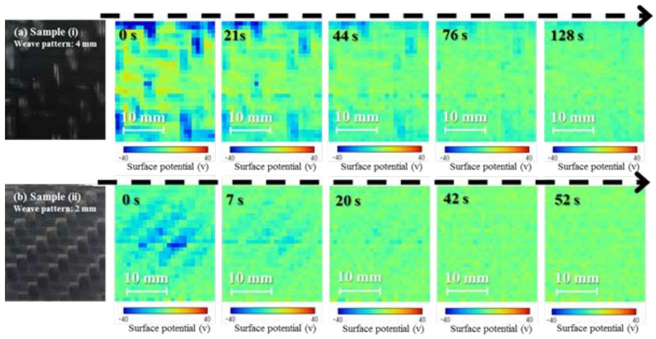

Fig. 2 Change in the surface potential distribution of (a) Sample (i) and (b) Sample (ii) after the CFRPs were charged by the corona discharge.

Figure 2(a) shows the change in the surface potential distribution of Sample (i) from immediately after charging (0 s) to 128 s. Figure 2(b) shows the change in the surface potential distribution of Sample (ii) from immediately after charging (0 s) to 52 s. Red and the blue on the scale indicate strong positive and negative charges. It can be seen that both charged and non-charged locations coexist on the surface of Samples (i) and (ii) immediately after charging. It can also be observed that all the charges on the surface disappear after about 2 min. The decrease in the charge of the CFRPs is caused by the natural discharge into air.

These results indicate that there is a partial existence of a conducting and an insulating region. It is also found that the surface potential distribution of the charged CFRP reflects its weave pattern. The position with a high surface potential was generally consistent with the position where carbon was close to the surface layer. From this result, it is presumed that the charge flows into the CFRP by the corona discharge and the electricity flows through the highly conductive carbon. It is for the first time that the conductivity in CFRP is visualized.

4. Conclusions

In this study, a new method to evaluate the electrical conductivity distribution of CFRP nondestructively was established by measuring the surface potential distribution over a short duration after charging the CFRP by a corona discharge. The surface potential distribution at a spatial resolution of 1 mm was measured with a measurement area of 25 mm × 30 mm and measurement time of 3 s by scanning the object surface along the vibrating linear array sensor. The surface potential distribution of the charged CFRP was successfully visualized using the developed system. The surface potential distribution of the charged CFRP also reflects the weave pattern of the CFRP and it is presumed that the flow of the electricity into the CFRP is through carbon.

References

[1] M. Gagné and D. Therriault: Progress in Aerospace Sciences, 64 (2014) 1.
[2] P. Feraboli and M. Miller: Composites: Part A, 40 (2009) 954.
[3] T. Ogasawara, Y. Hirono and A. Yoshimura: Composites: Part A, 41 (2010) 973.
[4] G. Abdelal and A. Murphy: Composite Structures, 109 (2014) 268.
[5] M. Yamashita: Jpn. J. Appl. Phys., 26 (1987) 1550.
[6] A.R Valleau：Materials Evaluation, 48 (1990) 230.
[7] M. Goeje and K. Wapenaar：COMPOSITES, 23 (1992) 147.
[8] X.E.Gros and W.Lowden：INSIGHT, 37 (1995) 290.
[9] A. Baltopoulos, N. Polydorides, L, Pambaguian, A. Vavouliotis, and V. Kostopoulos: Journal of Composite Materials, 47 (2013) 3285.
[10] A. Todoroki: Journal of the Japan Society for Aeronautical and Space Sciences, 59 (2011) 132.
[11] A. Todoroki, Y. Shimazu and Y. Misutani: Journal of Solid Mechanics and Materials Engineering, 6 (2012) 1042.
[12] K. Kikunaga, H. Yamashita, Y. Fujii and K. Nonaka: Jpn. J. Appl. Phys., 52 (2013) 05DB16-1.
[13] K. Kikunaga, T. Hoshi, H. Yamashita, M. Egashira and K. Nonaka: J. Electrostat., 73 (2015) 6.
[14] K. Kikunaga and N. Terasaki: ECS Trans., 75 (2017) 33.