ELECTROMAGNETIC SHIELDING PROPERTY OF CFRP COMPOSITE LAMINATES

Q.Q. Ni[1]*, M. Inoue[1], L. Zhang[1]
[1] Department of Functional Machinery & Mechanics, Shinshu University, Ueda, Japan
Corresponding author(niqq@shinshu-u.ac.jp)

Keywords: *EMI SE, CFRP, Laminates, Conductivity, Electromagnetic wave*

1 Introduction

In the high-speed communication, the higher frequency range from the microwave to the millimeter wave is expected. Many electronic instruments with the higher frequency, such as satellite communication, automobile collision prevention radar, and millimeter wave wireless LAN and so on, have been developed and applied. The electromagnetic waves produced from electronic instruments have an adverse effect on the performance to other equipments. This is called as electromagnetic interference (EMI). EMI may cause malfunction to medical apparatus, industry robots or even cause harm to human body and become one of public nuisances. Therefore, the development of EMI shielding materials is receiving increasing attention briskly.

EMI shielding refers to the reflection and/or adsorption of electromagnetic radiation by a material, which thereby acts as a shield against the penetration of the radiation through it. Recently, polymer composites are extensively employed in EMI shielding [1]-[4] due to their superior molding, more dependable lightweight and respected adsorption property of EMI wave. For these composites, the EMI shielding effectiveness increases with increasing contents of the fillers and their aspect ratio. The continuous carbon fiber reinforced composites (CFRP) is an important EMI material for its high conductivity and excellent mechanical property. Here, we investigated the EMI property of CFRP laminates and proposed a new nondestructive evaluation (NDE) to predict the anisotropic behavior in CFRP.

2 Preparation of materials and EMI SE measurement

The CFRP laminates were fabricated from the carbon fiber prepreg (E6026-12S, Japan Graphite Fiber Co., Ltd.) by a heat press machine with 2 MPa, 130 ºC for 1.5 hour. The laminate number varied from 2 to 6, which marked as 2CFRP00, 4CFRP00 and 6CFRP00 with the thickness of 0.23, 0.46, 0.69 mm, respectively.

The electromagnetic interference property of materials was evaluated by the parameter, EMI SE (electromagnetic interference shielding effectiveness), the ratio of induced wave to transmitted one as follows,

$$\begin{aligned} SE &= 10\log(P_i / P_o) \\ &= 20\log(E_i / E_o) \end{aligned} \quad (1)$$

where, P_i and P_o are the power, and E_i and E_o are the energy of induced and transmitted electric field, respectively. EMI SE is evaluated by a measurement system (Fig. 1) with dielectric lens and vector network (VNA, Anritsu Co., Ltd.). The frequency range of the EMI SE system is 1 to 18 GHz with a line scanning vibration of electrical field wave. The measurement of SE is conducted at each 15 degree between the electrical field direction and carbon fiber direction.

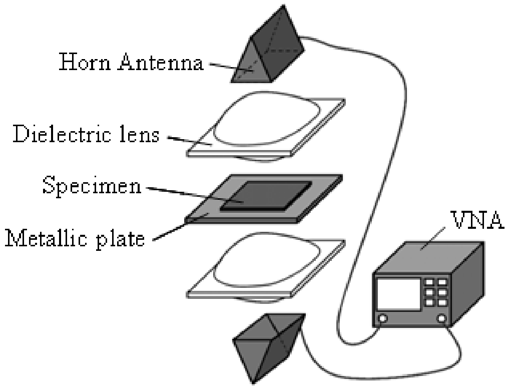

Fig. 1. The schematic of EMI SE measurement.

The electrical conductivity is measured by four-probe method. The measurement system is shown in Fig. 2, and a constant current was passed with a direct current (DC) voltage source (EX-375L2 EXTENDED RANGE DC POWER SUPPLY) through two outer electrodes and an output voltage was measured across the inner electrodes with the voltmeter (R8240 DIGITAL ELECTROMETER). The specimen of two layer laminates of CFRP was cut to be 10mm width and 80 mm length and the measurement is conducted at each 15 degree interval to carbon fiber direction.

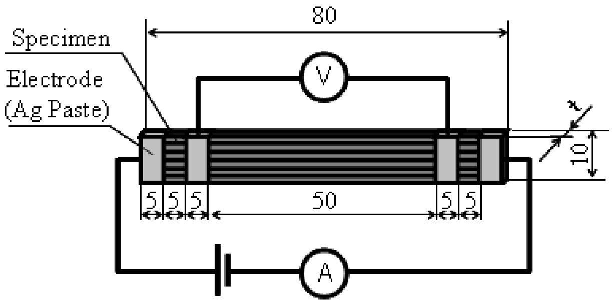

Fig. 2. Specimen used for measurement of the lectrical conductivity by four-probe method.

3 EMI SE approach

The mechanism of electromagnetic EMI SE may be considered three parts according to their propagation characteristics.

$$SE = SE_R + SE_A + SE_{MR} \qquad (2)$$

SE_R , SE_A and SE_{MR} correspond to the reflection, adsorption and multi-reflections, respectively. They may have following formula for calculation [5].

$$SE_R = 20\log\frac{|k+1|^2}{4|k|} \qquad (3)$$

$$SE_A = 8.686\frac{t}{\delta} \qquad (4)$$

$$SE_{MR} = 20\log\left|1-\frac{(k-1)^2}{(k+1)^2}e^{-2\gamma t}\right| \qquad (5)$$

where k is the ratio of impedance in air and in a material, t is the thickness of material, δ is surface deepness with the relation of δ=1/α, and is an attenuation constant, γ is the propagation parameter, $\gamma=\alpha+j\beta$, β is a phase constant.

4 Fiber direction dependency of electrical conductivity

The electrical conductivity for unidirectional CFRP laminates is shown in Fig. 3. A big difference of electrical conductivity with three orders at 0 degree and 90 degree direction is confirmed due to carbon fibers. The reduction of electrical conductivity is especially rapid from 0 degree to 30 degree.

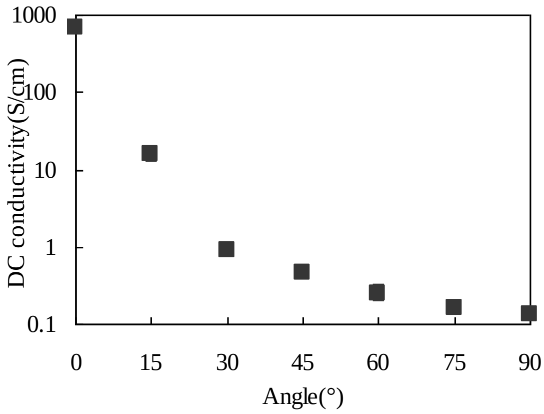

Fig. 3. Fiber direction dependency of electrical conductivity in unidirectional CFRP.

5 EMI SE of CFRP laminates

The EMI measurement system used is in a line scanning of electromagnetic wave and thus we can utilize this particular function to evaluate the anisotropic EMI SE in a material.

Figure 4 shows the SE results for the unidirectional laminates at 45 degree (marked as CFRP45) and 90 degree (marked as CFRP90) between the scanning direction and fiber direction. Firstly, the SE value increased almost linearly with the thickness of the specimens, CFRP45 with 2, 4, and 6 layers. Comparing with the specimens 2CFRP45 and 2CFRP90, we can find SE in 2CFRP45 is about 6 dB higher than that in 2CFRP90 due to the change of the scanning direction to carbon fiber direction. This is related to the electrical conductivity as shown in Fig. 2, in which the electrical conductivity in 45 degree direction was much higher than that in 90 degree direction. Using Eqs. (3)-(5) and the electrical conductivity as measured in Fig. 2, the SE values could be predicted as shown in Fig. 5. The experimental and theoretical results agree well although there is some difference for the thinner laminates.

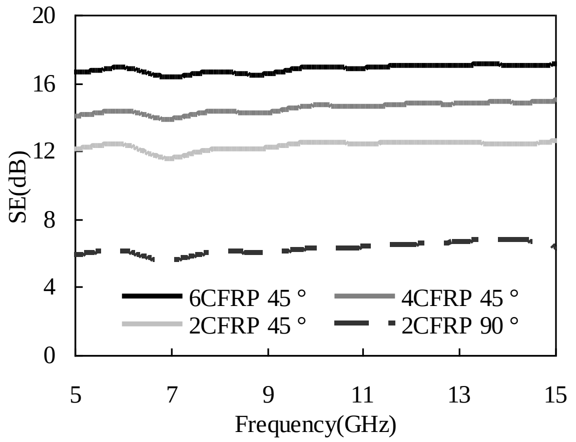

Fig. 4. Measurement results of SE for unidirectional CFRP in different scanning direction.

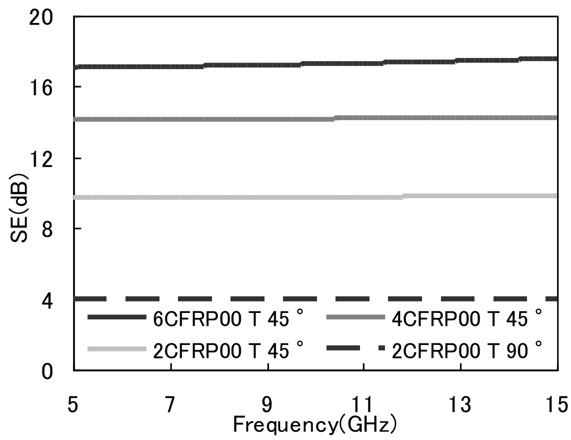

Fig. 5. Theoretical results of SE for unidirectional CFRP in the range of 5~15 GHz.

6 Fiber direction dependency of EMI SE

The fiber direction dependency of EMI SE in unidirectional laminates is shown in Fig.6. The SE values are symmetrical with 90 degree. Thus observing the region from 0 to 90 degree, the SE values obviously depend on the angle between electromagnetic wave direction and carbon fiber direction. When the carbon fiber is in the same direction of electromagnetic wave vibration, the SE value obtained the largest one, while at the angle of 90 degree, it is smallest. The SE values vary smoothly with the angle change. This change seems like the curve of the electrical conductivity shown in Fig. 2. Furthermore, when the number of lamina increased the SE values at all of angles increased. It is reported that the reflection effect of electromagnetic waves is related to the motion of electrons, which is contributed by the interaction of the electromagnetic wave propagation in the materials [6]. Thus, the electrical conductivity of CFRP at any electromagnetic wave direction is related to the easiness of electron motion, and then will have a direct relation to the EMI SE values. The lowest SE value at 90 degree is attributed to that electron motion is disturbed due to the epoxy resin surrounded carbon fibers. The largest SE values at 0 degree is attributed to easy electron motion due to the carbon fiber along the electromagnetic wave direction. The SE values at the angle of 0 degree are more than 40dB, which means 99.99% shielding effect. However, the values may be much higher in the practical case due to measurement limit of the dynamic range in our system.

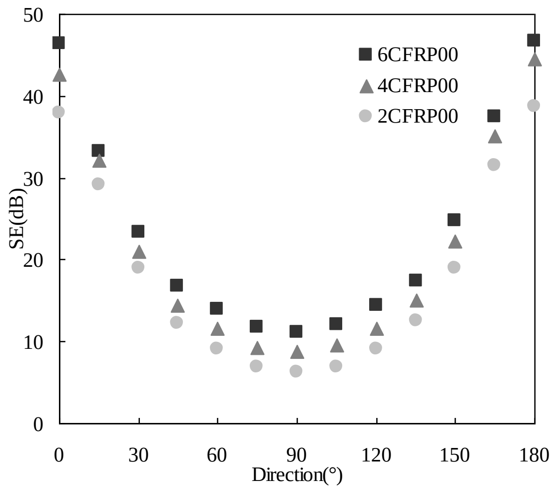

Fig. 6. Fiber direction dependence of SE for unidirectional CFRP.

From Fig. 4 and Fig. 6, we found that the value of SE in 45 degree is almost two times of that in 90 degree, and it increased with the laminate number. The other data also support this fiber direction dependence of EMI SE due to the anisotropic electric conductivity of CFRP. On the other hand, the SE value is calculated by S parameters in VNA (vector network analyzer). To make clear of this fiber direction dependence of EMI SE, the S_{ij} parameters of vector network analyzer is used.

$$SE = -10\log T = -10\log |S_{21}|^2 \qquad (6)$$

where, T is the transmittance rate, S_{21} is the parameter in scanning direction. According to the measurement of S_{21} parameter, it is found that the direction dependence of $|S_{21}|$ can be represented by sin curve.

$$|S_{21}| = A\sin\left(2\theta - \frac{\pi}{2}\right) + B \qquad 0 \le \theta \le \pi \qquad (7)$$

where, θ (rad) is the angle between the electromagnetic wave direction and fiber direction. A and B are amplitude and $|S_{21}|$ value at 45 degree, respectively. The value of the amplitude A can be determined by the difference of $|S_{21}|$ values at 45 degree and 0 degree. Using Eqs. (6) and (7), the EMI SE for different fiber direction can be derived as follows.

$$SE = -20\log\left(A\sin\left(2\theta - \frac{\pi}{2}\right) + B\right) \qquad 0 \le \theta \le \pi \ (8)$$

where, A is the amplitude, and B corresponds S_{12} at 45 degree fiber direction.

Based on Eqs (3), (4), (5) and (7) and the measured electric conductivity at 0 and 45 degree fiber direction, the EMI SE for unidirectional CFRP could be predicted. Figure 7 shows both experimental and predicted results and a very good agreement between them is confirmed.

7 Conclusions

The EMI property of CFRP laminates is measured and an obvious carbon fiber direction dependency is found. Using the S parameters in the vector network analyzer a sin curve prediction is proposed. That is, a new NDE technology based on the EMI SE measurement was proposed to evaluate the SE anisotropic characteristics in CFRP composites.

Acknowledgment

This research was partly supported by the Program for Fostering Regional Innovation in Nagano, granted by MEXT, Japan.

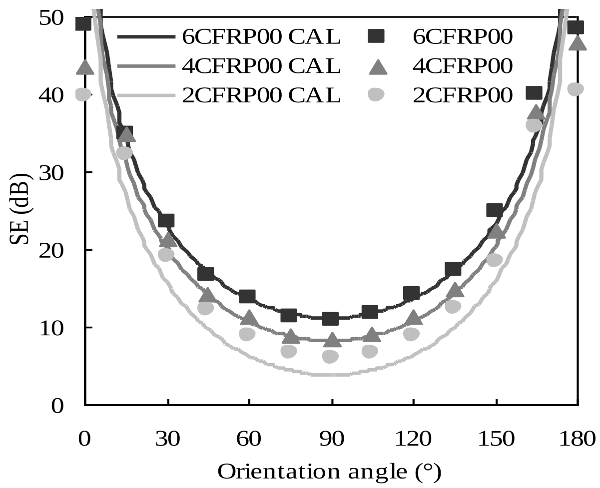

Fig. 7. Comparison of theoretical and experimental results for fiber direction dependence of EMI SE in CFRP unidirectional materials at the frequency of 8 GHz.

References

1) M. Inoue, T. Hashidume, T. Natsuki, Q.Q. Ni, Electromagnetic Interference Shielding Property of composite sheet, JCCM-1, Vol.1, 87-89 (2010).

2) C.S. Zhang, Q.Q. Ni, S.S. Fu, K. Kurashiki, Electromagnetic interference shielding effect of nanocomposites with carbon nanotube and shape memory polymer, *Composite Science and Technology*, Vol.67, 2973-2980, 2007.

3) Das NC, Chaki Tk, Khastgir D, Chakraborty A. Electromagnetic interference shielding effectiveness of ethylene vinyl acetate based conductive composites containing carbon fillers. J Appl Polym Sci 2001;80:1601-1608.

4) Chou K-S, Huang K-C, Shih Z-H. Effect of mixing process on electromagnetic interference shielding effectiveness of nickel/acrylonitrile-butadiene-styrene composites. J Appl Polym Sci 2005;97:128-135.

5) Richard B. Schulz, V. C. Plantz, D. R. Brush. Shielding Theory and Practice, IEEE Transactions On Electromagnetic Compatibility, Vol.30, No.3 (1988).

6) Mohammed H. AL-Saleh, Uttandaraman Sundaraj, Electromagnetic interference shielding mechanisms of CNT/polymer composites, CARBON, 49, 1738-1746 (2009).