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Electromagnetic interference shielding properties of carbon fiber cloth based composites with different layer orientation

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ABSTRACT

Carbon fiber cloth/epoxy resin composites with different layer orientation angles were prepared to evaluate electromagnetic shielding properties in the X band. The results showed that the electrical conductivity, dielectric constant and shielding effectiveness of composites decreased with increase in layer angle. Absorbed power had the maximum value (0.577) at 49.60° with sample thickness 4.00 mm. After using carbonyl iron powder as the radio wave absorber, both conductivity and shielding effectiveness improved when layer angle was beyond 10.06°. Reflected power decreased while absorbed power increased with increase in layer angle and their variation rates decreased. Structure and function integrated shielding products made of these composites can be used to get the highest shielding effectiveness or highest absorbed power with designed layer angles.

1. Introduction

Carbon fiber and its products are widely used in structural materials due to its excellent mechanical properties [1–4]. However, it cannot be ignored that carbon fiber is also a conductor [5–8]. The use of carbon fiber in shielding products can reduce electromagnetic institution and radio wave pollution [9–12]. Structure and function integrated research for carbon fiber based composites is meaningful. The distribution and orientation of carbon fibers in composites will significantly affect the electrical conductivity and shielding effectiveness (SE) of composites [13–16], which needs further study.

In this paper, carbon fiber cloth (CFC)/epoxy resin (EP) composites were prepared and made into samples with different fiber cloth layer orientation to evaluate the electromagnetic shielding properties. Layer angle (angle between CFC layer and sample surface) was tested to evaluate the orientation of CFC layer. Schematic diagram of CFC/EP composite with layer angle (θ) was showed in Fig. 1(a) and layer angle can be measured by digital microscope image analysis showed in Fig. 1(b). Carbonyl iron powder (CIP) with high absorption loss was used as radio wave absorber to improve absorbed power [17]. Digital microscope was used to observe the cross section structures of composites. Variations of electrical conductivity (σ), dielectric constant [real part (ε') and imaginary part (ε'')], magnetic permeability [real part (μ') and imaginary part (μ'')], SE and power constituent parts [reflected power (P_R), absorbed power (P_A) and transmitted power (P_T)] with increase in layer angle were studied.

2. Experimental

CFC (T300-6k, 300 $g \cdot m^{-2}$, Aosheng Hi-Tech co., LTD, Jiangsu, China)/EP (CYD-128, epoxide group content: 0.0051 mol/g, Baling Petrochemical co., LTD, Hunan, China) composites were prepared by vacuum bag molding. The mixed resin system were EP and modified amine (active hydrogen content: 0.0213 mol/g, prepared by our laboratory) with mass ratio 100:24. The composites were cured in the air for 24 h and posted cured at 80 °C for 4 h. The composites were cut into samples with the size $22.86 \times 10.16 \times 4.00 \pm 0.02$ mm to fit the sample holder for the X band. For samples with CIP (diameter: 2.5–3.5 μm, mass content $\geq$ 99.5%, Xingrongyuan Technology co., LTD, Beijing, China), the mass ratio of EP, modified amine and CIP is 100: 24:125. CIP–CFC/EP composites suffered the same molding and curing process. Another group of samples were prepared independently to evaluate the repeatability. The structure of CFC layers and the distribution of CIP were observed by digital microscope (Gaosuo Digital Technology co., LTD, Shenzhen, China). The layer angle was measured by image analysis and the test method was showed in Fig. 1(b). The σ of composites were tested through 4 probe resistance tester (RTS-8, 4 Probes Tech. co., LTD, Guangzhou, China) on the top surface (Parallel to X axis in X–Y plane). The SE, ε' and

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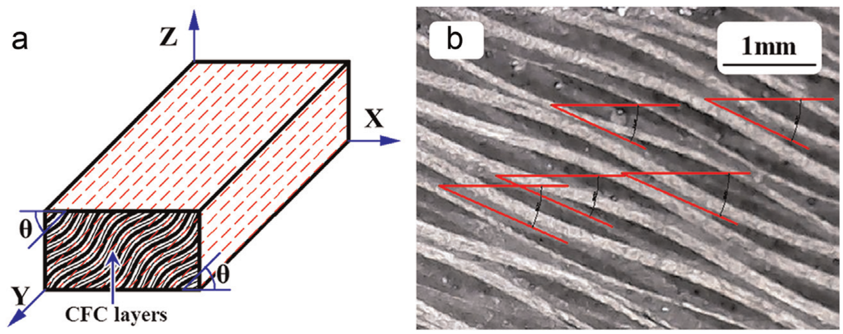

Fig. 1. (a) Schematic diagram of CFC based composite with layer (θ) and (b) layer angle measurement by digital microscope through image analysis.

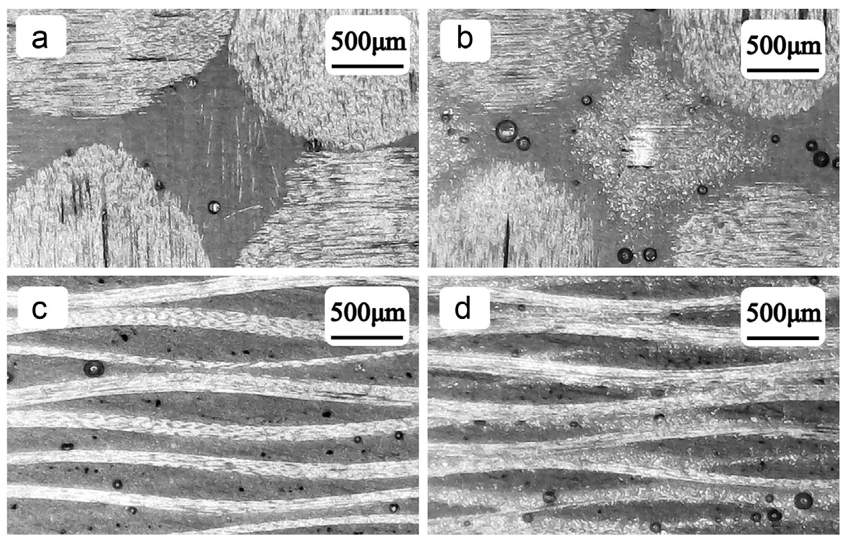

Fig. 2. Front surface and cross section structures of (a) and (c): CFC/EP composite, (b) and (d): CFC-CIP/EP composite.

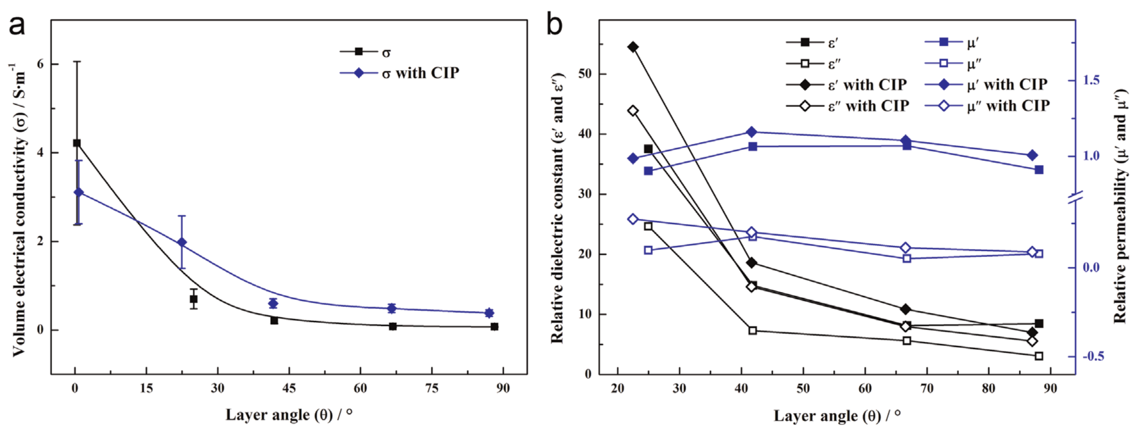

Fig. 3. Variations of (a) electrical conductivities and (b) relative dielectric constant and relative permeability of CFC/EP and CIP–CFC/EP composites with increase in layer angle.

ε'', μ' and μ'' were measured through vector network analyzer (Agilent N5247A) with waveguide for the X band. Since SE, ε' and ε'', μ' and μ'' were also impacted by frequency, the measured values in the X band were calculated into average values to study the independent effect of layer angle.

3. Results and discussion

Fig. 2(a) shows the clearances in carbon fiber warps and wefts. Fig. 2(b) shows that carbon fiber bundles were covered with resin matrix with low CIP content and CIP with high content covers around the top of next CFC layer. Fig. 2(c) and (d) shows that after adding CIP, the clearances between layers decrease and the layers connect together closer.

Since mixed resin contain CIP was brush onto CFC layers to prepared prepregs, and the density of CIP is much bigger than mixed resin. The filtration effect from the CFC layers and the settlement of CIP will lead to high CIP content on top and low content in bottom for a CFC layer. CIP with high content covers on the surface will reduce the amount of resin infiltrating into the CFC which leads to decrease of clearances between carbon fiber layers.