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Electromagnetic shielding properties of carbon fiber felt–glass fiber felt based multilayer composites with different layer angle

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ABSTRACT

Carbon fiber felt–glass fiber felt/epoxy resin multilayer composites with different layer angle were prepared to evaluate electromagnetic shielding properties in the X band. Comparison of composites with or without adding carbonyl iron powder was made in electric properties and shielding properties. Carbon fiber felt–glass fiber felt/epoxy resin multilayer composite can get a high shielding effectiveness (76.3 dB) at a suitable thickness (4.00 mm) when layer angle is close to 0°. Shielding effectiveness decreases rapidly with increase in layer angle and power constituent parts have different variations. Variations in dielectric constant and magnetic permittivity were found after adding carbonyl iron powder. Use of carbonyl iron powder can improve shielding effectiveness and absorbed power when layer angle is beyond 35°. Carbonyl iron powder-carbon fiber felt–glass fiber felt/epoxy resin composite can get high absorbed power (62.6%) when layer angle is about 45°.

1. Introduction

Electromagnetic pollution has become increasingly serious due to increasing use of electronic products. Electronic components have to face interference around and human beings have to face health problems [1–3]. Multilayer composites with high Shielding effectiveness (SE) and absorption loss (AL) have become research focus, especially sandwich structural materials with absorbing medium between layers [4–6]. The total reflection loss (RL) for n conducting layers stacked together is equal to the reflection contribution of one layer. Multilayer composites with alternating conductive layers and insulating layers can improve SE. After adding radio wave absorber, multi-reflection can enhance absorption loss by adding absorption path [7–9]. However, if incident wave is not perpendicular to functional layers, radio wave can transmit through insulating layers easily. Suppose function layers have included angles with sample surface, SE and power constituent parts will change remarkably, which needs further study.

Carbon fiber felts (CFFs) with good electric conductivity and good mechanical properties and glass fiber felts (GFFs) with good insulation properties were used as conductive layers and insulating layers, respectively. In this paper, CFF–GFF/epoxy resin (EP) composite was prepared and made into samples with different layer angle to evaluate variations of SE and power constituent parts of incident wave power (P_I): reflected power (P_R), absorbed power (P_A) and transmitted power (P_T) with increase in layer angle. Carbonyl iron powder (CIP) with good absorption loss was used to improve absorption power [10], and comparison was made between composites with or without CIP. Fig. 1(a) shows angle between functional layers and sample surface named layer angle (θ). In order to study the independent effect of layer angle, measured values of electric parameters and shielding parameters from 8.2 GHz to 12.4 GHz were calculated into average values.

2. Experimental

The CFF–GFF/EP composites were prepared by vacuum bag molding. The mass ratio of EP (CYD-128, epoxide group content: 0.0051 mol/g, Baling Petrochemical co., LTD, Hunan, China), modified amine curing agent (active hydrogen content: 0.0213 mol/g, prepared by our laboratory) was 100: 24. The CFFs (fiber length: 6 mm, fiber diameter: 6–7 μm, areal density: 28 ± 3 g/m^2, Aoda Composite co., LTD, Shandong, China) and GFFs (EST30M-1000, fiber diameter: 11 ± 1 μm, areal density: 30 ± 3 g/m^2, Chongqing Polycomp International co., LTD, Chongqing, China) were infiltrated by mixed resin to prepare prepregs. The composites were cured at room temperature (about 25 °C) at 0.1 MPa for 24 h and post cured at 80 °C for 4 h. The CIP–CFF–GFF/EP composites were prepared and cured at the same progress. The mass ratio of EP, modified amine curing agent and CIP (diameter: 2.5–3.5 μm, mass content ≥ 99.5%, Xingrongyuan Technology co., LTD, Beijing, China) was 100: 24: 125.

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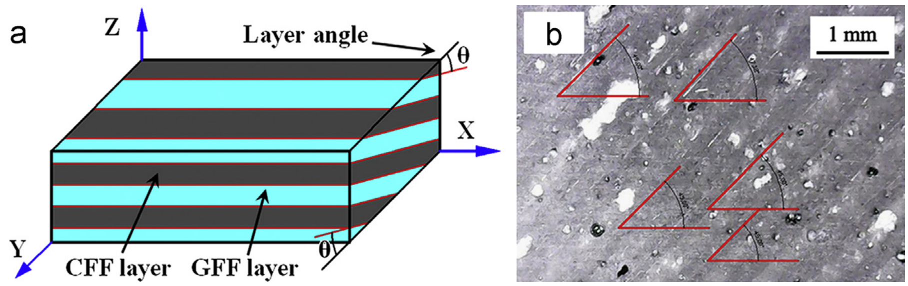

Fig. 1. (a) Sample with layer angle (θ), (b) measurement of layer angle through image analysis.

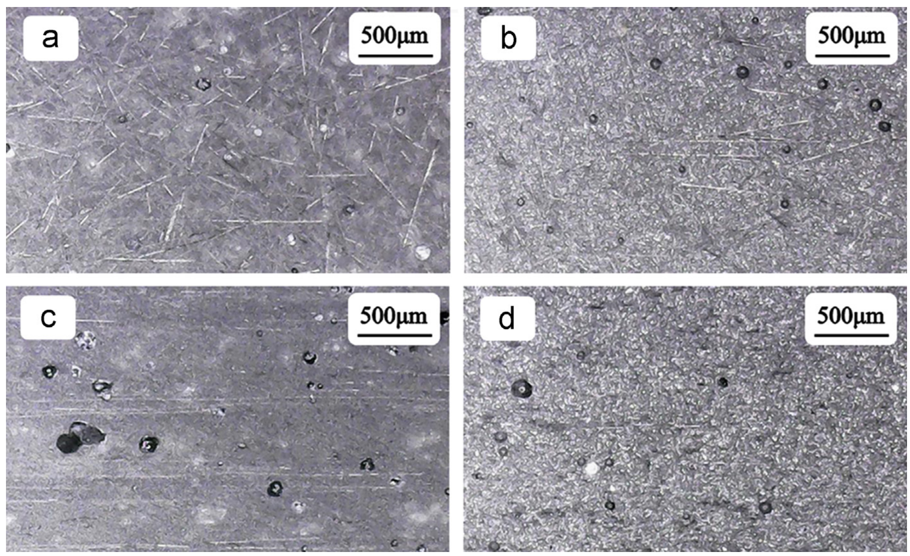

Fig. 2. Digital microscopic analysis of sample surface [X–Y plane in Fig. 1(a)]. (a) and (c) CFF–GFF/EP with layer angle 1.52° and 88.15°. (b) and (d) CIP–CFF–GFF/EP with layer angle 1.25° and 87.75°.

The composites were made into samples in designed layer angle at designed size ($22.86 \times 10.16 \times 4.00 \pm 0.02$ mm) to fit the sample holder whose inner dimensions were 22.86 mm × 10.16 mm. Another group of samples were prepared independently to evaluate the repeatability. The schematic diagram of sample with layer angle (θ) was shown in Fig. 1(a). Digital microscope (Gaosuo Digital Technology co., LTD, Shenzhen, China) analysis was made on the top surface [Parallel to X–Y plane in Fig. 1(a)] of the sample. The layer angle was measured through image analysis on two sides [parallel to Y–Z plane in Fig. 1(a)] of the sample. Fig. 1(b) shows the measurement of layer angle. The layer angle between fiber layers and sample surface were measured 5 times each side and got the average value. The dielectric constant, magnetic permeability, shielding effectiveness and power constituent parts were calculated by scattering parameters (S_{11}, S_{12}, S_{21} and S_{22}) measured through the vector network analyzer (Agilent N5247A) and wave guides for the X band.

3. Results and discussion

Fig. 2(a) shows the network structure of fiber felts. Fig. 2(b) shows that network structure suffers effect by CIP but it still exists. Fig. 2(c) shows the multilayer structure of CFF–GFF/EP composite. Glass fibers with larger diameter can be found and divide CFFs into independent layers. Fig. 2(d) shows that independent GFF layers are not obvious. Fig. 2(b) and (d) also shows that CIP spreads uniform in composites, obvious reunion phenomenon was not found. Use of CIP will affect the network structure of CFF layers and leads to decrease in conductivity of CFF layers. Use of CIP may also affect the network structure of GFF layers and leads to decrease in resistance of GFF layers between CFF layers.

Fig. 3(a) shows that the real part and imaginary part of relative dielectric constant (ε' and ε'') of CFF–GFF/EP composite decrease with increase in layer angle. The maximum value of $\varepsilon''/\varepsilon'$ appears at about 45°. After adding CIP, ε' increases rapidly. With increase in layer angle, insulating GFF layers exposed and destroyed the conductive plane perpendicular to the incident wave. This structural factor leads to decrease in ε' and ε'' of CFF–GFF/EP composite. Use of CIP weaken the insulating effect of GFF layers and improve the transfer ability of electron from one CFF layer to another. This factor leads to increase in ε'. Fig. 3(b) shows that the real part and imaginary part of relative permeability (μ' and μ'') of CFF–GFF/EP composite is close to non-magnetic materials (μ' is close to 1 and μ'' is close to 0). After adding CIP, Both μ' and μ'' increase. Both μ' and μ'' of CIP–CFF–GFF/EP composite increase first and then decrease with increase in layer angle. The maximum value of μ''/μ' appears at about 45°. High magnetic loss will lead to high P_A at about 45°.

Fig. 4(a) shows variation of SE of CFF–GFF/EP and CIP–CFF–GFF/EP composites with increase in layer angle. Both curves decrease with increase in layer angle. SE is equal to S_{21} and can be calculated as 10log (P_I/P_T). SE of composite with CIP is lower when layer angle is below 21.5° and higher when beyond 21.5°. Fig. 2(b) shows variation of power constituent parts of CFF–GFF/EP and CIP–CFF–GFF/EP composites with increase in layer angle. When P_I was treated as 1, power constituent parts can be calculated as $P_R = 10^{-|S_{11}|/10}$, $P_T = 10^{-|S_{21}|/10}$ and $P_A = 1 - P_R - P_T$. For CFF–GFF/EP composite, P_R falls down fast and P_A rises up quickly with layer angle increase from 0° to 22.5°. P_R continues to decrease and P_A decreases slightly with layer angle increase to 45°. After that, P_R increases slightly and then