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Dielectric and microwave absorption properties of CB doped SiO_{2f}/PI double-layer composites

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A B S T R A C T

Carbon black (CB) with contents of 5.5 wt% and 15 wt% filled quartz glass fiber reinforced polyimide (SiO_{2f}/PI) composite were designed and prepared. A double-layer absorbing material was designed using the two composites materials as a matching layer and an absorption layer, respectively. The microwave absorption property of single-layer and double-layer composites is calculated according to transmission line theory. The results show that the microwave absorbing property of double-layer composite is better than that of single-layer at the same thickness. When the 5.5 wt%CB doped SiO_{2f}/PI composite is used as the matching layer with a thickness of 0.7 mm and 15 wt%CB doped SiO_{2f}/PI composite is used as the absorption layer with a thickness of 0.9 mm, the RL (reflection loss) of the composite reaches a minimum value of −46.18 dB at 16.07 GHz. Meanwhile, the bandwidth of RL ≤ −5 dB is 5.87 GHz and the bandwidth of RL ≤ −10 dB is 3.95 GHz.

1. Introduction

In recent years, electromagnetic wave is widely used in the field of military applications. The use of advanced detection equipment has increased the requirement for radar absorbing performance [1–3]. Fortunately, the structural absorbing composite material has waves absorbing and load-bearing characteristics. Polymer composites as the main structural absorbing composite material have the advantage of light weight and easy preparation, in addition, its absorbing properties can be adjusted by adding dielectric or magnetic fillers [4,5]. Doping conductive absorbers such as carbon black(CB) [6–9], carbon nanotubes [10–12], and graphene [13–15] into insulated polymer matrix can generate polymer composites with excellent electrical conductivity, and the composites have wide applications in absorbing materials and anti-static materials [16,17]. CB is one of the common fillers due to its superior features such as high electrical conductivity, chemical stability and low cost [7]. The core-shell structure PANI/CB composites with different CB content (5–30 wt%) were synthesized by in situ polymerization method. When the content of CB was 20–30 wt%, the composites exhibited good performance in the wide range of 2–40 GHz [8]. Liu [18] added complex absorbents composed of carbonyl-iron power(CIP) and CB to epoxy resin, and found that the bandwidth of reflectivity below −4 dB can be enhanced by increasing CB content, and the bandwidth reached 10.1 GHz with the CB content of 25 wt%. Wan [19] studied the microwave absorption properties of CB doped SiC fiber/aluminum phosphate matrix composites. Found that the absorption properties of single-layer composites with the thickness of 2.8–3.2 mm could be improved by adding 4%CB and 5–15% Al_2O_3. Liu [6] compared the effects of nano-sized CB and nano-sized silicon carbide(SiC) mixture absorbers with a single nano-sized CB absorbent on the microwave absorption properties of composites, and found that the composites could achieve better absorbing performance only with the addition of nano-sized SiC with a certain thickness. These results show that the single-layer microwave absorbing performance can only be improved by higher CB content with relatively large thickness or auxiliary addition of other absorbents.

The ideal absorbing material generally meets two basic principles: impedance matching and attenuation. When electromagnetic waves come to the surface of the material, reflection, absorption and transmission occur. The impedance of the surface material should match the impedance of the free space to reduce the reflection of the electromagnetic waves. Once the electromagnetic enters the material, the incident waves can be rapidly attenuated through the materials and reduce the transmission [5,20,21]. However, most materials cannot satisfy the two basic principles at the same time. Therefore, composite material with two or more layers satisfied these two basic principles can obtain better microwave absorption performance even when the thickness was small [22,23]. In this paper, we used different contents of CB as the absorbent to design and prepare two kinds of single-layer composites, and calculated their microwave absorbing properties according to transmission line theory. Then, we introduced computer-aid and calculated the absorbing properties of double-layer composite

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materials by using the two composites materials as the matching layer and absorber layer, respectively. The microwave absorbing properties of the single-layer and double-layer composites were analyzed and discussed.

2. Experimental

2.1. Materials

The quartz glass fabric in this experiment was supplied by Hubei feilihua quartz glass Co. Ltd, China, with the areal density of 200 g/m^2. The bismaleimide precursor for synthesis polyimide powder was purchased from Wuhan zhisheng science & technology Co. Ltd, China, with the martin heat resistance temperature of 260 °C. The acetylene CB with a diameter of 30–40 nm was provided by Shandong chengda Co. Ltd, China.

2.2. Experimental preparation

The quartz glass fabrics were cut into proper size beforehand. A resin solution with a solid content of 45 wt% was obtained by dissolving the polyimide resin powder into N, N-dimethylformamide solution. Then, the above-prepared resin solution was mixed with 5.5 wt%CB, ball milling for 24 h. Brushed a certain amount of as-prepared resin solution on fiber cloths, and stacked up six layers one by one. Next, put them in vacuum oven for 2 h at room temperature, to get ride of the air between the fiber bundles and promote the penetration of resin into fabric. Then, set the temperature of vacuum over to 85 °C for 12 h to ensure the complete evaporation of solvent. The dried fabrics were then hot-pressed in a die at 230 °C for 1 h with a pressure of 3 MPa. It should be noticed that when the temperature reached 100 °C, the pressure was applied until the end of curing process. In addition, 15 wt% CB doped six layers fiber cloth reinforced polyimide composite was fabricated by the same preparation process and method.

2.3. Characterization

The properties of the obtained composites were measured by scanning electron microscope (SEM Tescan Vega3 SBH, Brno, Czech Republic) and the network analyzer (Agilent technologies E8362B). The cross section morphology of the composites was observed by SEM. And the complex permittivity of X and Ku bands were measured using wave guide method by the network analyzer. The sample sizes are 22.86^l mm * 10.16^w mm * 1^t mm and 15.89^l mm * 7.89^w mm * 1^t mm, respectively. Finally, the reflectivity of the composite was calculated based on the transmission line theory.

3. Results and discussion

3.1. The morphology of the CB doped SiO_{2f}/PI composites

Fig. 1 shows the morphology of 5.5 wt% and 15 wt% CB doped SiO_{2f}/PI composites. It can be seen from the cross section that the resin is better immersed in the fiber bundles. Resin stacking between the two layers of fiber reinforcement can be seen both in Fig. 1(a) and (b). The small window in the Fig. 1 is the local magnification of the resin between the fiber bundles. The CB content in Fig. 1(a) is less than that in Fig. 1(b), but they are both uniformly distributed in the matrix.

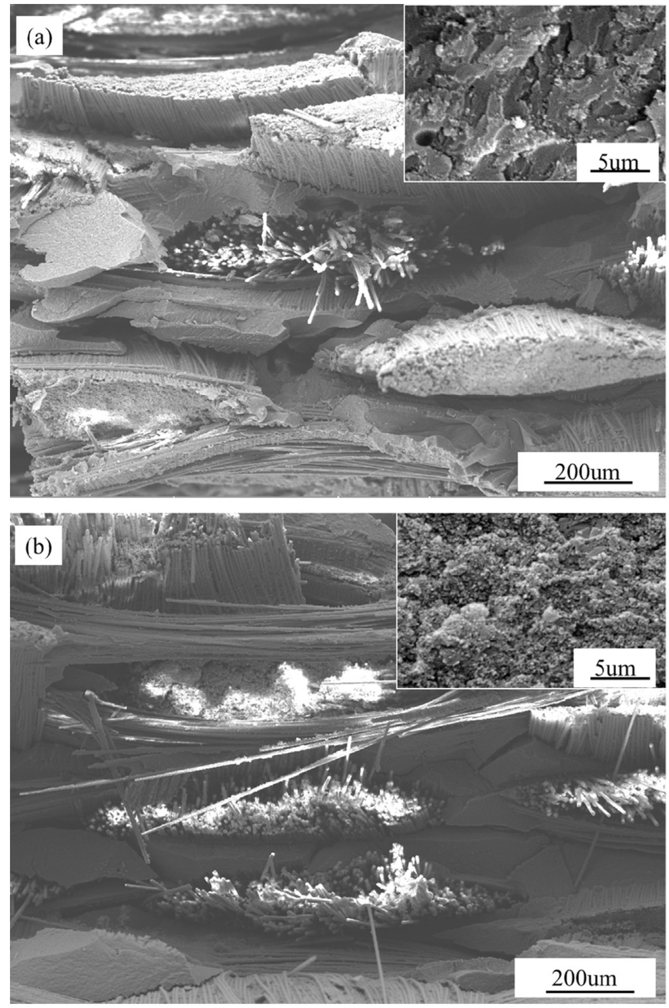

Fig. 1. The morphology of CB doped SiO_{2f}/PI composites. (a): 5.5 wt% CB doped SiO_{2f}/PI (b):15 wt% CB doped SiO_{2f}/PI.

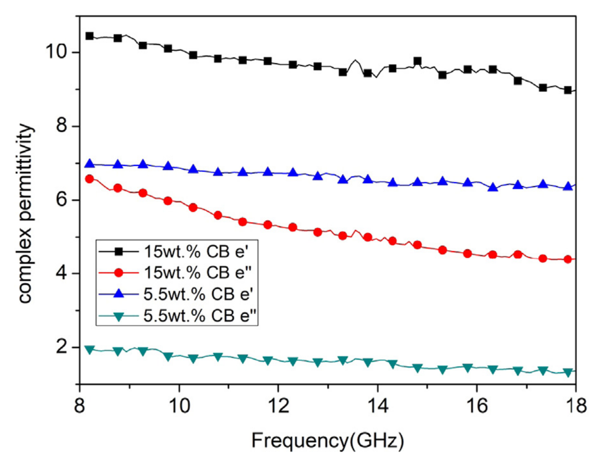

Fig. 2. Real part and imaginary part of complex permittivity of CB doped SiO_{2f}/PI composites.

3.2. Dielectric and microwave absorption properties of single-layer composites

3.2.1. Dielectric property of 5.5 wt% and 15 wt% CB doped SiO_{2f}/PI composites

Fig. 2 shows the dielectric properties of two contents of CB doped SiO_{2f}/PI composites in the frequency range of 8.2–18 GHz. Since the absorbent of CB has no magnetic property, we only discuss the dielectric properties of the composites. The complex permittivity can be expressed by $\varepsilon = \varepsilon' - j\varepsilon''$. ε' represents the ability of material to store electrons, that is polarization ability. And ε'' means the ability of material to transform electromagnetic energy into other energies, owing to changes from various directions in the material and various relaxation