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# Microwave absorbing properties of composites filled with glass-coated $Fe_{69}Co_{10}Si_8B_{13}$ amorphous microwire

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ABSTRACT

The electromagnetic parameters and microwave absorbing properties of paraffin and polymer composites filled with glass-coated $Fe_{69}Co_{10}Si_8B_{13}$ amorphous microwire (GCFAW) were investigated. The results show that the microwire filling ratio and annealing temperature have no obvious influence on the complex permeability, while they exhibit significant effect on the complex permittivity. The complex permittivity increases remarkably with the increase of microwire filling ratio, and decreases sharply with increasing the annealing temperature. With the increase of microwire filling ratio and absorber thickness, the minimum reflection loss decreases firstly and then increases, and shifts towards lower frequency region. For the paraffin composite with GCFAW filling ratio of 15% and thickness of 1.4 mm, the minimum reflection loss is −28.5 dB and the frequency bandwidth less than −10 dB is 2.9 GHz. When the microwire filling ratio and the thickness of paraffin composite are invariant, the frequency of minimum reflection loss shifts towards higher region with increasing the annealing temperature. The change trend of measured reflection loss of polymer composite is consistent with that of calculation reflection loss of paraffin composite, but the minimum reflection loss increases a little and shifts towards lower frequency. As the microwire filling ratio is 15%, the reflection loss of polymer composite exhibits two extreme values.



## 1. Introduction

The interest in microwave absorbing properties of composites filled with fibers is inspired recently due to the unique properties compared with the composites packed with powders [1,2]. The glass-coated amorphous microwires have superior electromagnetic and mechanical properties [3–6] and are beneficial to form good interface with resin because the surface tension of glass is much higher than that of resin. Therefore, the glass-coated microwires have excellent application prospect as structural radar absorbing materials.

Microwave absorbing composite with wider frequency range of microwave absorption, lower density, higher strength and thinner thickness, is the main pursuing goal for satisfying the application requirements. Therefore, it is necessary to investigate the dependence of the microwave properties, i.e., electromagnetic parameters or reflection loss, on the preparation parameters such as absorber thickness, microwire filling ratio and microwire arrangement orientation.

In the present work, taking the glass-coated $Fe_{69}Co_{10}Si_8B_{13}$ amorphous microwire as an example, the electromagnetic parameters and microwave absorbing properties of paraffin and polymer composites filled with GCFAW are investigated.

## 2. Experimental

The GCFAW with glass-coating thickness between 6 and 7 $\mu$m and core radius between 5 and 6 $\mu$m were prepared by the Taylor–Ulitovsky technique [7].

The GCFAW samples were annealed at 450 °C and 530 °C for 20 min in tube resistance furnace with heating rate 10 °C/min, and then cooled in air. The as-cast or annealed GCFAW were cut into 1–1.5 mm length (short-cut GCFAW).

The paraffin composite was prepared by dispersing the short-cut GCFAW randomly in paraffin, and then mould formed as the cylindrical toroidal sample with inner diameter of 3 mm, outer diameter of 7 mm and height of 3.5 mm. The electromagnetic parameters (complex permeability $\mu$ and complex permittivity $\varepsilon$) of paraffin composite were measured by the vector network analyzer.

The polymer composite prepared by bonding short-cut GCFAW with polyamine dissolved by alcohol was coated on the 180 mm × 180 mm standard aluminum plat, and then cured for 48 h. The polymer composite plates are shown in Fig. 1(a) and the

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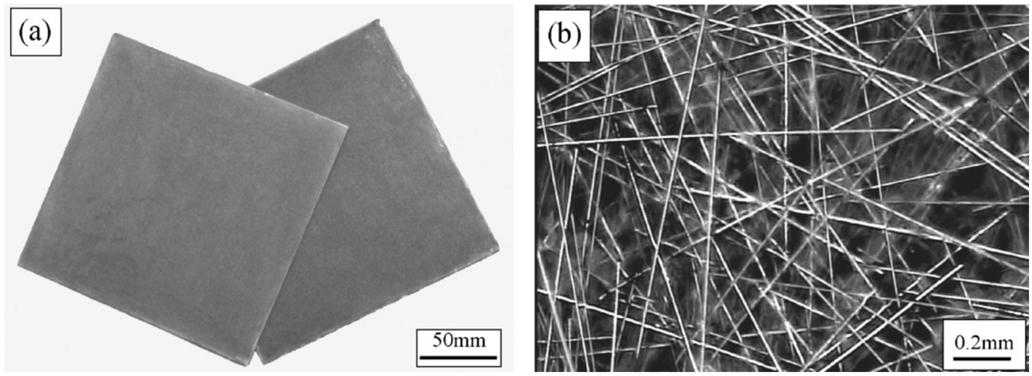


**Fig. 1.** Morphology of polymer composite plate sample (a) and arrangement of the short-cut microwires in it (b).

microwire arrangement in the composite is displayed in Fig. 1(b). The reflection loss of polymer based sample was measured by the naval research laboratory (NRL) arch method.

The microwave properties of materials were evaluated by the reflection loss, and which can be calculated based on complex permeability and complex permittivity. According to the transmission line theory [8], for a single layer absorbing material backed by a perfect conductor, the input impedance ($Z_{in}$) at the air–material interface is given by

$$Z_{in} = Z_0\sqrt{\frac{\mu}{\varepsilon}}\tanh\left\{i\left(\frac{2\pi fd}{c}\right)\sqrt{\mu\varepsilon}\right\} \tag{1}$$

where $\mu$ is the complex permeability ($\mu = \mu' - i\mu''$), $\varepsilon$ is the complex permittivity ($\varepsilon = \varepsilon' - i\varepsilon''$), $f$ is the frequency, $d$ is the absorber thickness, $Z_0$ is the impedance of free space, and $c$ is the velocity of electromagnetic waves in free space.

The reflection loss of normal incident electromagnetic wave at the absorber surface is given by

$$R = 20\ \lg\left|\frac{Z_{in} - Z_0}{Z_{in} + Z_0}\right| \tag{2}$$

where lg is the decimal logarithm.

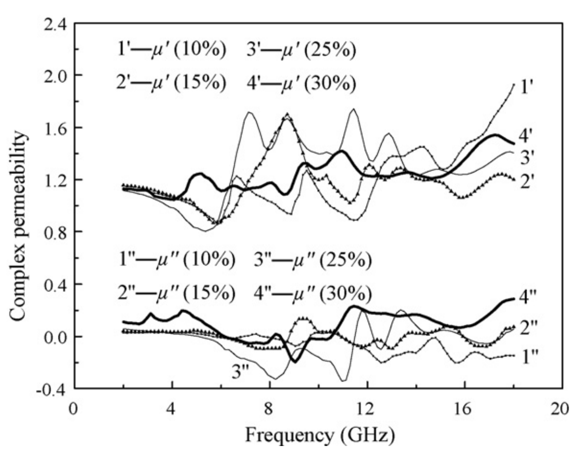


**Fig. 2.** Complex permeability curves of paraffin composite with GCFAM filling ratios of 10%, 15%, 25% and 30%.

## 3. Electromagnetic parameters and calculation reflection loss

### *3.1. Influences of microwire filling ratio and absorber thickness on electromagnetic parameters*

Fig. 2 shows the dependence of the complex permeability of paraffin composite on GCFAW filling ratio, represented by mass percentage of 10%, 15%, 25% and 30%. As observed, the influence of the GCFAW filling ratio on the complex permeability is not obvious, and only the imaginary part increasing slightly with the filling ratio increasing. As the GCFAW filling ratio increasing, the distance among microwires decreases and the electromagnetic coupling of microwave reinforces [9], which lead to the increase of imaginary part.

Fig. 3 displays the dependence of the complex permittivity of paraffin composite on GCFAW filling ratio (10%, 15%, 25% and 30%). It shows that the GCFAW filling ratio has a significant effect on the complex permittivity, i.e., the real part and the imaginary part increase drastically with the increase of filling ratio. As the filling ratio increases, the distance among the microwires decreases and the percolation threshold of composite falls, which means the absorber conductivity enhanced. Therefore, the complex permittivity of absorber increases.

Figs. 2 and 3 also indicate that the measured permeability of the samples is uncertainty. The most probably, the magnetic properties of the microwire are too low-frequency to be detected above 2 GHz. Therefore, the absorbing performance under the conditions of the paper is mainly due to dielectric properties only.

### *3.2. Influences of microwire filling ratio and thickness of paraffin composite on reflection loss*

According to the electromagnetic parameters, the reflection loss of paraffin composite plate can be calculated by the formula (2). When the plate thickness is 1.5 mm, the dependence of the calculated reflection loss of paraffin composite plate on GCFAW filling ratio is illustrated in Fig. 4. As shown, with increasing the filling ratio, the minimum reflection loss decreases firstly and then increases, and the frequency bandwidth less than −10 dB exhibits reverse change tendency, i.e., it increases firstly and then decreases. In addition, the frequency position of minimum loss shifts towards lower frequency.

When the microwire filling ratio is much lower (such as 10%), or much higher (such as 30%), the calculation reflection losses of paraffin composite plates is larger, which means the complex permittivity of the composite cannot meet the impendence matching requirements appropriately. As the microwire filling ratio is 15%, the electromagnetic parameters of composite are suited. Compared