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Calculation of electromagnetic parameter based on interpolation algorithm

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ABSTRACT

Wave-absorbing material is an important functional material of electromagnetic protection. The wave-absorbing characteristics depend on the electromagnetic parameter of mixed media. In order to accurately predict the electromagnetic parameter of mixed media and facilitate the design of wave-absorbing material, based on the electromagnetic parameters of spherical and flaky carbonyl iron mixture of paraffin base, this paper studied two different interpolation methods: Lagrange interpolation and Hermite interpolation of electromagnetic parameters. The results showed that Hermite interpolation is more accurate than the Lagrange interpolation, and the reflectance calculated with the electromagnetic parameter obtained by interpolation is consistent with that obtained through experiment on the whole.

1. Introduction

With the rapid development of the electronics industry, radio communication, etc., electromagnetic radiation not only causes serious harm to the commonly used electronic systems such as communication and computer, but also poses a threat to human health [1–9]. As an important functional material of electromagnetic protection, the wave-absorbing material is essential to achieve the incidence, loss and absorption of electromagnetic waves, which can effectively prevent the secondary scattering of electromagnetic waves and has become a research hotspot [4–8]. In the practical applications of wave-absorbing materials, due to their different working frequencies, loss values, environmental characteristics (temperature and humidity, space and mechanical strength) etc. [1,7–9], the optimal monomer or combination needs to be selected from electromagnetic wave absorbing particles that are reported to have different forms and properties and additional structural optimization is required [10–15]. In order to design the desired material quickly and accurately and reduce blindness in investment and experiment, it is necessary to study the calculation and design methods of wave-absorbing materials. Studies have shown that for monolayer wave-absorbing materials, accurate obtaining of the equivalent electromagnetic parameter of the mixed media (complex permittivity (ε) and complex permeability (μ)) is of great importance to predict the electromagnetic properties [15].

2. Experimental section

2.1. Build Lagrange interpolation method model and define parameters

Lagrange interpolation method is to achieve the interpolation of univariate function. Given that there are $n+1$ mutually exclusive real numbers, $x_0, x_1, x_2,\ldots, x_n$, whose corresponding function values are $y_0, y_1, y_2,\ldots, y_n$, the odd function of interpolation is taken as follows:

$$l_k(x) = \prod_{\substack{j=0 \\ j\neq k}}^{n} \frac{x - x_j}{x_k - x_j} \quad (k = 0, \ 1, \ \ldots, \ n) \tag{1}$$

Obviously, $l_k(x)$ has the following properties:

$$l_k(x_i) = \begin{cases} 1, & (i = k) \\ 0, & (i \neq k) \end{cases} \tag{2}$$

Then the interpolation function can be written as follows:

$$p(x) = \sum_{k=0}^{n} l_k(x) y_k \tag{3}$$

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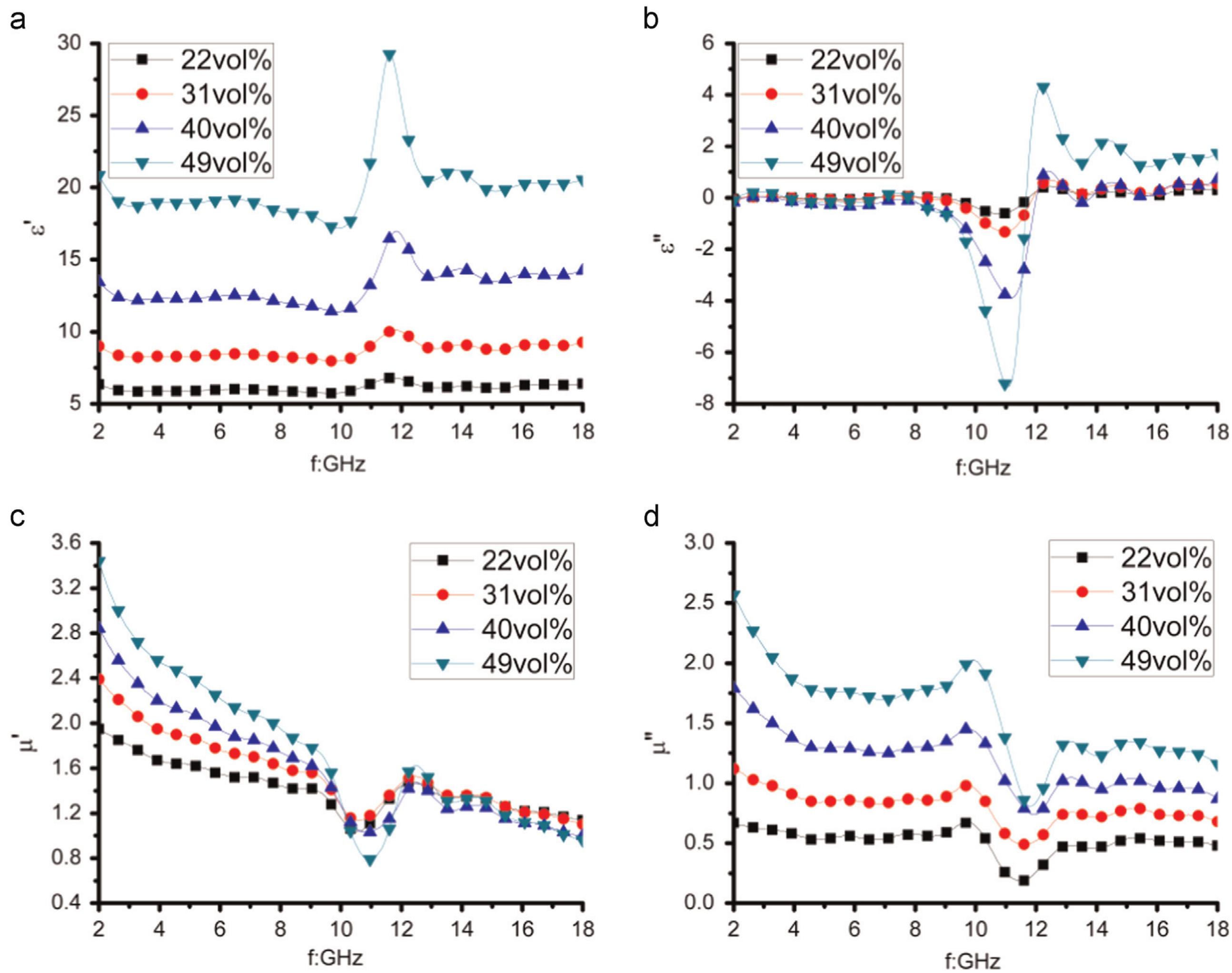

Fig. 1. Electromagnetic parameters of mixtures with different volume fractions of CIP. (a) Real part of permittivity, (b) imaginary part of permittivity, (c) real part of permeability, and (d) imaginary part of permeability.

When the above formula is used for the interpolation calculation of electromagnetic parameter, y_k is the complex electromagnetic parameter, and $l_k(x)$ is a polynomial of the volume fraction of the absorbent.

2.2. Build Hermite interpolation method model and define parameters

Given that the function values of $n+1$ mutually exclusive points $x_0, x_1, x_2, \ldots, x_n$ are $y_0, y_1, y_2, \ldots, y_n$, and the derivative values of $m+1$ points in the $n+1$ ones are $y_{i0}, y_{i1} \ldots y_{im}$, then the polynomial

$$H(x) = \sum_{k=0}^{m+n+1} a_k x_k \tag{4}$$

satisfies

$$\begin{cases} H(x_i) = y_i & (i = 0,\ 1,\ \ldots,\ n) \\ H'(x_{i_k}) = y'_{i_k} & (k = 0,\ 1,\ \ldots,\ m) \end{cases} \tag{5}$$

The pivotal of Hermite method used for the interpolation of the electromagnetic parameter is to solve the derivative of the electromagnetic parameter for individual volume fraction. LLL hybrid theory describes the relationship between the electromagnetic parameter of the mixture and that of each constituent, as follows:

$$\begin{cases} \varepsilon_{eff}^{1/3} = p\varepsilon_i^{1/3} + (1-p)\varepsilon_h^{1/3} \\ \mu_{eff}^{1/3} = p\mu_i^{1/3} + (1-p)\mu_h^{1/3} \end{cases} \tag{6}$$

where ε is the permittivity, μ is the permeability, i is the additive, h is the substrate, and p is the volume fraction of the additive. Based on the above formula, the derivative of the electromagnetic parameter for the volume fraction can be obtained as follows:

$$\begin{cases} \dfrac{d\varepsilon_{eff}}{dp} = \dfrac{3\varepsilon_{eff}^{2/3}(\varepsilon_{eff}^{1/3} - \varepsilon_0^{1/3})}{p} \\ \dfrac{d\mu_{eff}}{dp} = \dfrac{3\mu_{eff}^{2/3}(\mu_{eff}^{1/3} - \mu_0^{1/3})}{p} \end{cases} \tag{7}$$

2.3. Experimental

A vector network analyzer was used to measure the EM-wave parameters of the samples in the frequency range of 2–18 GHz. The cylindrical toroidal measurement samples were composed of the isotropic spherical carbonyl iron powder (CIP), anisotropic flaky carbonyl iron powder (FCIP) and bio-flaky particles [14]. To the mixtures containing CIP, the volume fractions of the samples for interpolation calculation were 22%, 31%, 40% and 49%. To the mixtures containing FCIP, the volume fractions of the samples for