EFFECT OF DIELECTRIC PROPERTIES DUE TO THE CHANGE OF DIELECTRIC AS A RESULT OF ELEVATORY TEMPERATURE

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Abstract

In this paper, both the permittivity and the microwave transmittance properties of organosilicon-matrix composites under different temperature have been studied. In order to investigate the reason for the changing of dielectric property, both TGA and high-temperature dielectric spectrum measurement have been carried out. A theoretical model of radome, with a temperature gradient distribution, has been built to analyze the dependence of microwave transmittance property on temperature. Based on the experimental results, we can optimize the effective operating temperature of this kind of organosilicone-matrix composites.

1 Introduction

In order to solve the modern fighting requirement，the speed of all kinds of aircrafts need to be improved unceasingly. When the aircraft flies at speeds in air, the surface temperature will increase sharply due to friction. Therefore, the stiffness and high temperature performance of aircraft should meet higher stands. The electrical properties of aircraft are also affected by the temperature changing. It will be of great significance in researching the influence of temperature increase on permittivity of radome, which is important to ensure normal operation of the airborne Radio Systems.

Aircrafts which fly at high temperature are not only require stiffness, heat-resisting, and thermal insulation， but also require good qualities of dielectric. There existing two kinds of materials：ceramic microwave-transmitting materials and polymer matrix composites [1]. The ceramic microwave-transmitting materials are widely used in high-temperature, narrow-band and regular-shaped radome, such as missile radome. As for the wide-band, complicated-shaped and low temperature radome, polymer matrix composites are appropriate. The surface temperature of materials increase sharply when the aircraft flies at speeds, which makes temperature gradient exist along the thickness direction and flight direction. Accordingly, permittivity ε and loss tangent tgδ of different part of radome will be inconsistent because of the temperature gradient [2]. Internal relevant scientific and research institutes have been studied the electric properties of materials with different temperature to meet the design requirements [3], but there is few research on the variation of dielectric properties with the temperature changing.

High-temperature organosilicone-matrix composites stand out in the requirement of modern wide-band radar and complicated-shaped radome. Organosilicone-matrix composites are widely used in wave-transparent material field in Russia [4], which is presently a new research area in China. Accordingly, this paper will focus on the relationship between the temperature and dielectric properties of organosilicone-matrix composites, and then further analysis the microwave-transmitting property of radome.

2 Experiment

A very important performance for the design of radome was complex permittivity of materials, including permittivity and loss tangent. All measurements of organosilicone-matrix composites were carried out by using the high Q cavity method for high temperature measuring system [5] under the temperature from room temperature to 550 ℃ in the frequency range from 6 GHz to 18 GHz.
The samples were put into testing chamber, heated the testing chamber until the temperature around samples to a certain level， and then measured the value of Q. The phase constant of testing chamber which was placed sample would be increased due to that the permittivity of the sample was greater than 1. The resonant frequency must go down under definite length factor of resonant cavity. At the same time, the value of natural quality factor of the testing chamber would be decreased because of additional dielectric loss carried by medium. The complex permittivity was obtained by counting the resonance frequency and the natural quality factor after the sample putting into testing chamber.3 General Style Preferences

3 Results and Discussion

3.1 The influence of temperature on the properties of materials

The temperature dependence of permittivity and loss tangent at 9.7 GHz for organosilicone-matrix composites are shown in Fig. 1. It is clearly indicates that the permittivity and loss tangent spectra of the composites increases with the temperature increasing under 400 ℃ while their value decline sharply above 400 ℃.

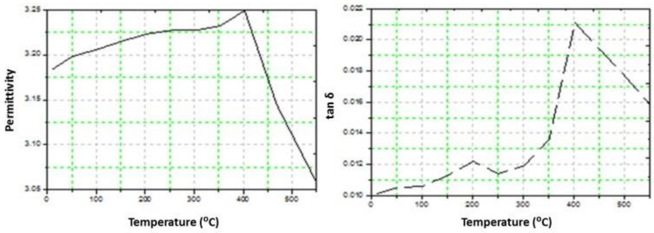

Fig. 1 The permittivity and loss tangent pattern of composites

Fig. 2 shows temperature dependence of TGA curves with different treatment processes. As shown in the figure, the thermal weightlessness of organosilicone-matrix composites is obvious at 350 ℃, and the thermal weightlessness increase with the temperature increasing which indicating that the properties of materials begin to change. The thermal weightlessness of materials in air is mainly caused by the degradation of main chain. As for organosilicone-matrix composites, decomposition reaction occurred with the temperature increasing and the molecular chains are rupturing and restructuring. The damage of matrix/fiber causes fibers fail, and the fibers will be broken while bearing loads. Meanwhile, small-molecule gases are produced in the pyrolysing of resin, which makes material defected by increasing voidage, and its tensile strength is decreased accordingly. The permittivity of composites decreases sharply at the same time.

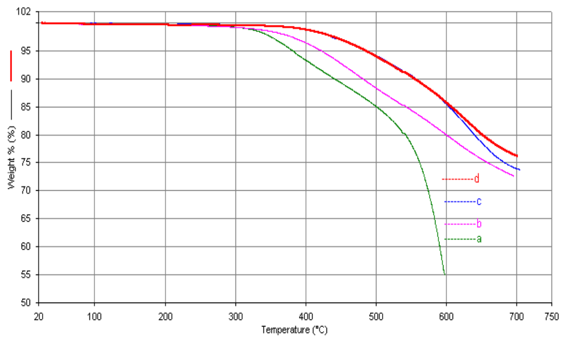

Fig. 2 TGA curves of composites with different treatment processes

Above all, the performance of materials are stable when the temperature under 350 ℃, and the values of permittivity and loss tangent are increase slowly. The materials begin to take place decomposition reaction between 350 ℃to 400 ℃, and the values of loss tangent increase from 0.013 to 0.021 drastically which due to the vibration and crash of molecule; When temperature further heightens, defections are showed up because that the decomposition leads to the increasing voidage. For air is lossless material, as a result, the permittivity of organosilicone-matrix composites decreases rapidly.

3.2 The influence of permittivity on the wave-transmitting properties for radome

When the hostile heating-load bearing performance remains a certain value, the thickness of wave-transmitting medium is decided by electric. The theory electrical thickness of half-wave radome is shown in formula (1):

$$d = N\frac{\lambda}{2\sqrt{\varepsilon - \sin^2\theta}} \qquad (1)$$

Where λ is the wavelength of radar, ε is the permittivity of radome, θ is effective incidence angle of radar beam, N is positive integer (1，2，3).

We can see from Fig. 2, the permittivity of microwave-transmitting materials is considerable difference between room temperature and high temperature, and electrical thickness is related to permittivity. Under the same wall thickness, the variation of permittivity can have great impact on electrical property of radome, and can't even work. Under this situation, materials can be divided into several layers on the basis of computational accuracy and performance data of materials. Each layer is correspond to different ε and tgδ under different temperatures, and the ε and tgδ of each layer can be actually measured. The more layers with different temperatures are divided, the higher calculation precision it is. The wave-transmitting character of uniformly heated materials can be obtained by normalizing the wave-transmitting material with temperature gradient through the formula of transmission coefficient of multilayer walls. Effective theory and empirical formula can be found after experimental and flying modification, and it is important to electrical design of high speed aircraft and research of material.

The plane wave transmission characteristics of multilayered plane are about thickness, permittivity, loss tangent, angle of incidence, polarized state known by the electromagnetic transmission theory[6]. If media plate can be regarded as impedance transmission by equivalent transmission theory, multiple layers media plate can be equivalent to combination of impedance transmission lines. So the transmission coefficient of plate can be solved by transmission matrix formula which can be expressed as:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix}\begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix}\cdots\cdots\begin{bmatrix} A_n & B_n \\ C_n & D_n \end{bmatrix} \qquad (2)$$

Where,

$$\begin{cases} A_i = D_i = chjv_i d_i \\ B_i = Z_{ci} shjv_i d_i \\ C_i = shjv_i d_i / Z_{ci} \end{cases}$$

$$Z_{Ci} = \begin{cases} Z_{ci}^{\parallel} = Z_0\sqrt{\varepsilon_{ir} - \sin^2\theta_0} / \varepsilon_{ir} \\ Z_{ci}^{\perp} = Z_0 / \sqrt{\varepsilon_{ir} - \sin^2\theta_0} \end{cases}$$

$$v_i d_i = 2\pi d_i\sqrt{\varepsilon_{ir} - \sin^2\theta_0}$$

ε_{ir} ——permittivity of the i layer dielectric plate;

d_i ——thickness of the i layer dielectric plate;

So the transmission coefficient as follows:

$$T = 2/(A + B' + C' + D) \qquad (3)$$

Where,

$B' = B / Z_{C0}$ $\qquad C' = Z_{C0}C$

Simulation model is a radome which works in X-band and 10 mm thickness. When the temperature of outside surface heated from 23 ℃ to 500 ℃, temperature gradient in thickness direction of radome wall is obtained by using thermal analysis software (Ansys) set up the corresponding simulation model for linear discrete. To improve the calculation accuracy, the thickness is dispersed into 10 layers, and then calculating its transmission characteristics by setting up corresponding mathematical model. While setting up mathematic model of radome to calculate its transmission property, radome wall is approximate to infinitely large platform. According to equivalent circuit principles and four-port network transmission methods, wall layer with different permittivity can be realized by cascade formula of linear algebra. The simulations of temperature dependence transmission property for radome are shown in Fig.4.

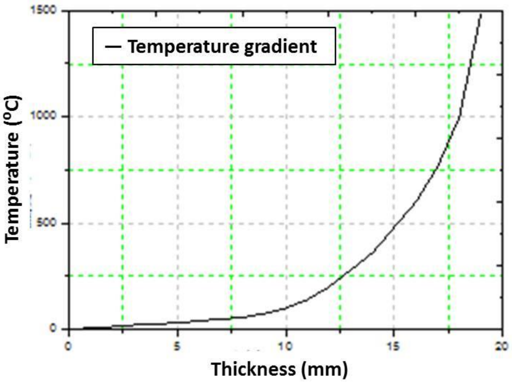

Fig. 3 Thickness dependence of temperature gradient for materials

In Fig.4, when the temperature of radome under 350 ℃, transmission property is relatively stable and decline slowly with the temperature rising; While the temperature above 350 ℃, decomposition reaction of material and acute shaking of molecule making the permittivity and loss tangent increase sharply which dramatically limits its wave transmission performance. Wave transmission performance is down to the lowest point (decline about 5%) when the temperature is 400 ℃; Further increasing temperature, decomposition reaction of materials results in the void content increasing and defects appear, eventually, the permittivity and loss tangent is reduced and the transmission ratio is increased. But the radome can not meet the requirement of using due to that the mechanical properties were decreased seriously. As a result, this material can be used above 400 ℃.

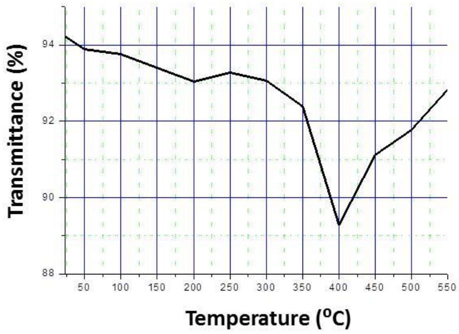

Fig. 4 Effects of temperature on wave-trasmitting properties for radome

The simulations above are based on ideal model, but there not only existing temperature gradient but also existing distortion on the heated surface of radome when under high temperature, which makes situation more complicated. So the final influence shall be as per the results of electric property testing about radome.

4 Conclusions

This paper can get the following main conclusions after testing and simulation:

(1) Before the decomposition reaction occurred, the permittivity of organosilicone-matrix composites is stable and increases slowly with the temperature increasing; when the degradation of main chain begins, the dielectrical property decline rapidly and the increasing of voidage makes the permittivity of composites decreases sharply at the same time.

(2) Setting up mathematical model under high-temperature to evaluate the wave-transmitting properties of radome, based on temperature gradient in thickness direction of radome wall. When the temperature increases to 350 ℃, wave transmission performance suffers dramatically performance degradation due to the permittivity increases sharply, and it is down to the lowest point at 400 ℃. Above 400 ℃, the transmission ratio is increased because of the increasing of void content.

(3) In this paper, the effective service temperature of radome which is made of organosilicone-matrix composites is defined. It

can offer some valuable guidances to engineering application.

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