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The Analysis of the Equivalent Thermal Conductivity of Nanopaper Enabled Polymer Composite Materials

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Abstract. The finite element software FLUENT is used to analyze the equivalent thermal conductivity and the thermal balance of composites reinforced by line, sinusoidal and pulse bending nanopaper during the heating process. The equivalent thermal conductivity does not change linearly with the increase of thermal conductivity of insulators. The smaller the thermal conductivity of insulators, the more the equivalent thermal conductivity deviates from the linear average value. The more the equivalent thermal conductivity deviates from the linear average, the equivalent thermal conductivity of the system can be approximately solved by means of the linear average method when the thermal conductivity of the insulators is close to 0.6. The proportion of convective heat loss is very small under the condition of three different shape of heating sheets. The proportion of convective heat loss of pulse bending heating sheets s the largest, and the line shape is the smallest.

1. Introduction

Carbon nanotubes (CNTs) have excellent electrical and thermal properties [1-4]. CNTs have been used as reinforcement materials or functional agents in high performance structural and multifunctional nanocomposites [5-10]. However, it's exceptionally difficult for CNTs to disperse effectively in a resin matrix for more than 10 wt.% as the nanoscale dimensions and surface areas of CNTs is extra-large [11]. While as, nanopaper is made of a preformed nanotube network or nanotube mat which exhibit a better thermal conducting performance. Gonnet et al [11] indicated that nanotube alignment has a measurable influence on the thermal conductivities of both buckypaper and nanocomposites, and the thermal conductivities were found to increase linearly with temperature for both buckypapers and composites.

The finite element software FLUENT is used to analyze the equivalent thermal conductivity and the thermal balance of composites reinforced by different shape nanopaper during the heating process.

2. Numerical model

The heating model of the polymer composite reinforced by the nanopaper is shown in Figure 1. As shown in Figure 1, the heating model of the polymer composite reinforced by pulse bending nanopaper is established to analyze the equivalent thermal conductivity and the thermal balance of nanopaper reinforced composite.

The length (L), width (w), and the thickness (T) of the heating model of the polymer composite reinforced by line, sinusoidal and pulse bending nanopaper are 600 mm, 50 mm, and 100 mm respectively. The thicknesses of the nanopaper are 10 mm. The bending height (h) and bending period (A) of the sinusoidal and pulse bending nanopaper are 60 mm and 120 mm.

In Figure 1, heating the nanopaper is driven by a power source, and the cube region is the polymer matrix which is heated by the nanopaper. The temperature of the polymer matrix is increased due to the electro-heating of the nanopaper. The heating powers are 25 W.

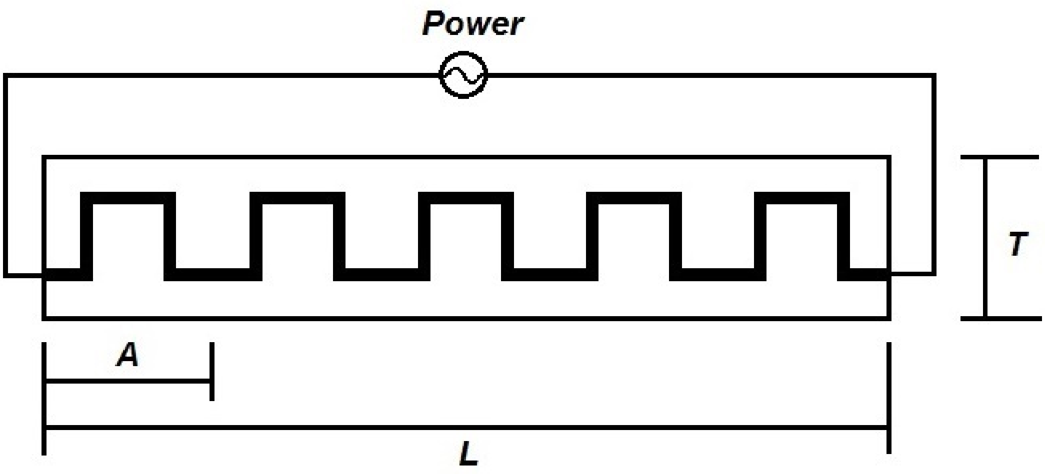

Fig. 1. Sketch diagram of heating experimental device

3. Calculation Condition

When the whole system is regarded as an apparent homogeneous medium, the effective thermal conductivity (ETC) varies with the thermal conductivity of the insulator.

The thermal conductivity of buckypaper was set to be 1.0 W/(m•K). The thermal conductivity of the polymer matrix was set to be 0.1 W/(m•K). The temperature of the end face at a given high and low temperature is 400K and 300K, respectively.

4. Results and discussion

Figure 2 shows the change of equivalent thermal conductivity with the thermal conductivity of insulators of composites reinforced by the pulse bending nanopaper. The total heat flow through the system is solved. The apparent equivalent thermal conductivity is obtained by introducing Fourier law into homogeneous medium.

As shown in Figure 2, the black line is the equivalent thermal conductivity obtained by calculating the heat flux, and the red line is the thermal conductivity obtained by using the linear average.

As shown in formula (1).

$$\lambda_{\text{eff}} = p\lambda_{\text{heater}} + (1-p)\lambda_{\text{insulator}} \tag{1}$$

As shown in formula (1), p is the volume share of the heating plate in the submerged heating device.

As shown in Figures 2, the equivalent thermal conductivity does not change linearly with the increase of thermal conductivity of insulators. The smaller the thermal conductivity of insulators, the more the equivalent thermal conductivity deviates from the linear average value.

The more the equivalent thermal conductivity deviates from the linear average, the equivalent thermal conductivity of the system can be approximately solved by means of the linear average method when the thermal conductivity of the insulators is close to $\lambda_{\text{insulator}} > 0.6$.

Figure 3 shows the change of equivalent thermal conductivity with the thermal conductivity of insulators of composites reinforced by the line nanopaper. The total heat flow through the system is solved. The apparent equivalent thermal conductivity is obtained by introducing Fourier law into homogeneous medium. As shown in Figure 3, the black line is the equivalent thermal conductivity obtained by calculating the heat flux, and the red line is the thermal conductivity obtained by using the linear average.

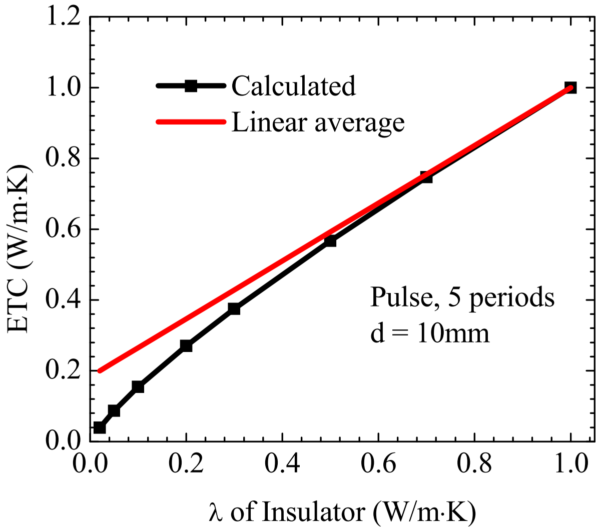

Fig. 2. The change of equivalent thermal conductivity with the thermal conductivity of insulators of composites reinforced by pulse bending nanopaper

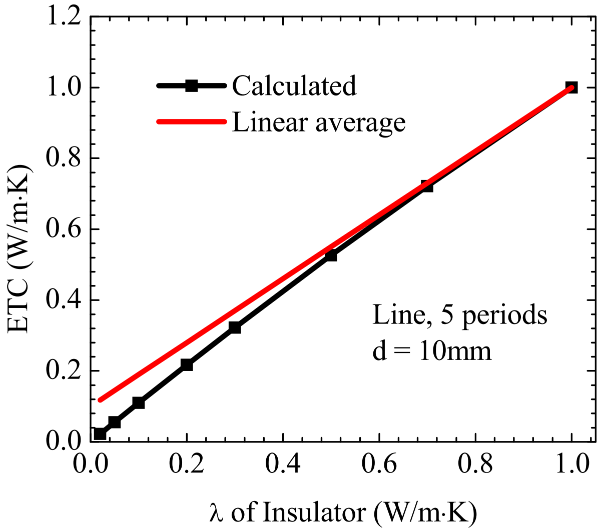

Fig. 3. The change of equivalent thermal conductivity with the thermal conductivity of insulators of composites reinforced by line nanopaper

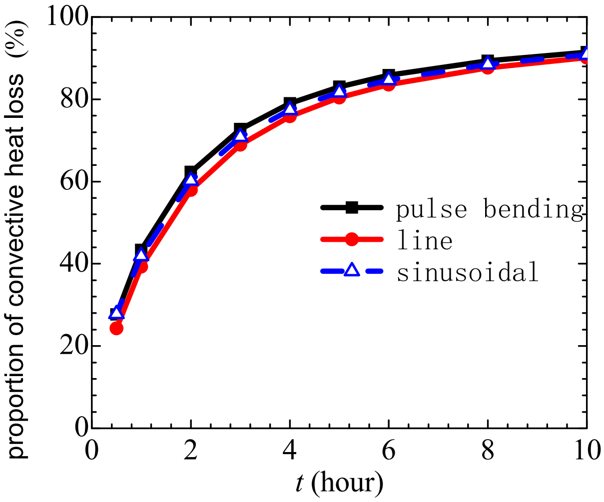

Fig. 4. The change in the proportion of convective heat loss with time of composites reinforced by line, sinusoidal and pulse bending nanopaper

Figure 4 shows the change in the proportion of convective heat loss with time of composites reinforced by line, sinusoidal and pulse bending nanopaper. As shown in Figures 4, the ratio of the total loss of heat to the total heating energy consumed by the convection heat dissipation on the external surface is compared with time.

Figure 4 shows that the proportion of convective heat loss is very small under the condition of three different shape of heating sheets. The proportion of convective heat loss of pulse bending heating sheets s the largest, and the line shape is the smallest.

5. Summary

The finite element software FLUENT is used to analyze the equivalent thermal conductivity and the thermal balance of composites reinforced by line, sinusoidal and pulse bending nanopaper during the heating process.

The equivalent thermal conductivity does not change linearly with the increase of thermal conductivity of insulators. The smaller the thermal conductivity of insulators, the more the equivalent thermal conductivity deviates from the linear average value. The more the equivalent thermal conductivity deviates from the linear average, the equivalent thermal conductivity of the system can be approximately solved by means of the linear average method when the thermal conductivity of the insulators is close to 0.6.

The proportion of convective heat loss is very small under the condition of three different shape of heating sheets. The proportion of convective heat loss of pulse bending heating sheets s the largest, and the line shape is the smallest.

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