

Study of the Equivalent Thermal Conductivity of Composites Reinforced by Nanopaper

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Abstract: The finite element software FLUENT is used to analyze the equivalent thermal conductivity of composites reinforced by pulse bending nanopaper during the heating process. When the thermal conductivity of the two materials is similar, the equivalent thermal conductivity of the system can be approximately solved by means of the linear average method. The maximum and minimum temperature of the end face of the nanocomposites along three different directions is 400 K and 300 K respectively. The temperature distribution of other surface is calculated under the adiabatic condition. It can be seen that the temperature section is gradually decrease from the end face of high temperature to the end face of low temperature.

1. Introduction

Due to the quasi-one-dimensional nature and extraordinary topology of CNTs, CNTs have been extensively studied for their excellent electrical, chemical, thermal and mechanical properties [1-4]. Theoretically, the thermal conductivity of the composites filled with 1wt% CNT could be more than ten times larger than that of the corresponding untreated polymer, depending on CNT length and interfacial thermal resistance [5]. Nanopaper was developed to infiltrate a preformed nanotube network or nanotube mat [6]. The singlewalled CNTs (SWCNTs) can form dense networks in nanopapers and composites reinforced by nanopaper, so a high thermal conductivity could be achieved [7]. The finite element software FLUENT is used to analyze the equivalent thermal conductivity of composites reinforced by pulse bending nanopaper during the heating process.

2. Numerical model

The heating model of composites reinforced by pulse bending nanopaper is shown in Figure 1.

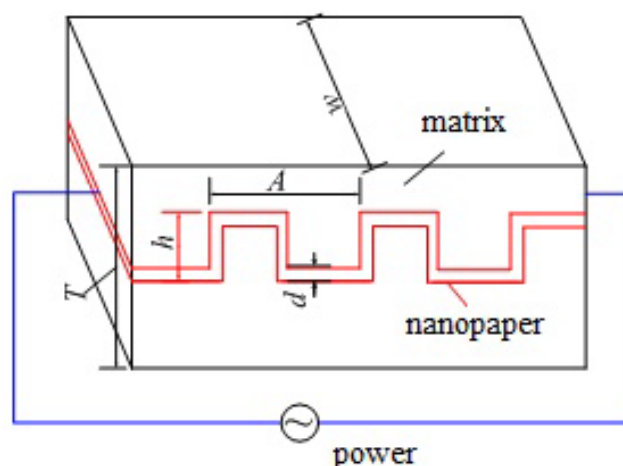


Fig. 1. Sketch diagram of heating experimental device

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 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 36 mm, 5 mm, and 10 mm respectively. The thickness of the nanopaper is 0.4 mm. The bending height (h) and bending period (A) of the sinusoidal and pulse bending nanopaper are 6 mm and 12 mm.

3. Calculation Condition

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

The thermal conductivity of nanopaper is 1.5 W/(m·K). The equivalent thermal conductivity is calculated by the linear average method, the expression is as shown in formula (1).

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

As shown in formula (1), p is the volume share of the heating plate in the submerged heating device. For pulse bending nanopaper, the volume share of heating plate is 0.1493. For flat nanopaper, the volume share of heating plate is 0.07983.

4. Results and discussion

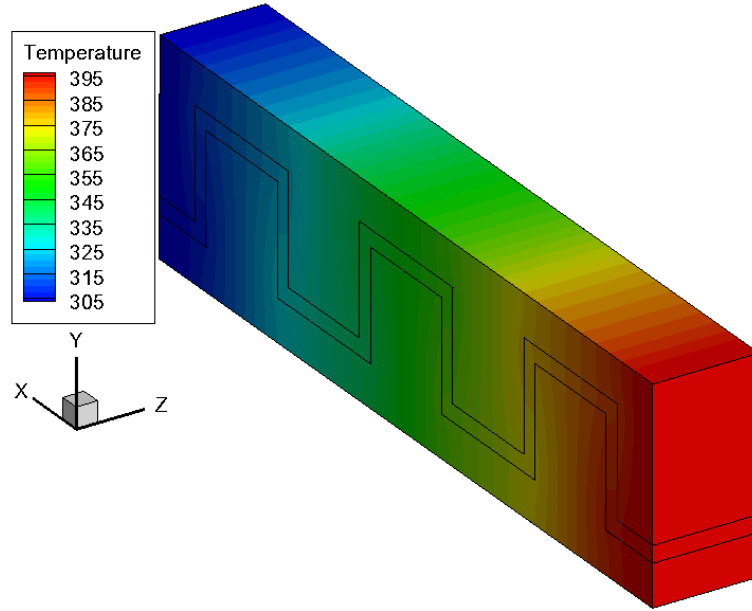
Table 1 shows the equivalent thermal conductivity of the polymer composites reinforced by pulse bending nanopaper. When the thermal conductivity of insulators is 0.8 W/(m·K) and the thermal conductivity of nanoscale paper is 1.5 W/(m·K), the maximum error between the calculated thermal conductivity and the linear average is 2.8%.

Table 1 The equivalent thermal conductivity of the polymer composites reinforced by pulse bending nanopaper

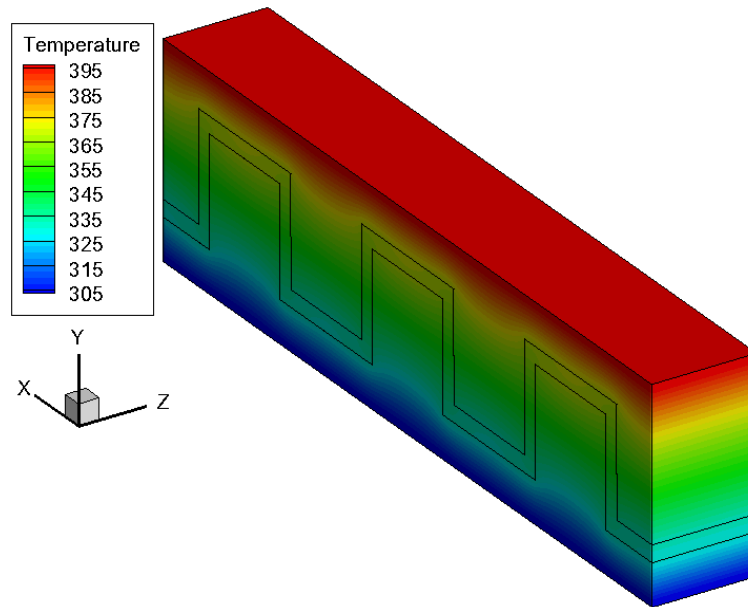
The thermal conductivity of matrix	Thermal conductivity of X direction	Thermal conductivity of Y direction	Thermal conductivity of Z direction	Linear mean value
0.02	0.09026	0.039	0.25084	0.24096
0.05	0.12643	0.0885	0.27616	0.26649
0.1	0.18384	0.1587	0.31836	0.30902
0.2	0.29353	0.2793	0.40276	0.39409
0.4	0.49886	0.4922	0.57156	0.56423
0.6	0.6928	0.6899	0.74036	0.73437
0.8	0.88079	0.8791	0.90917	0.90451
1.0	1.06298	1.0622	1.07797	1.07465
1.2	1.23944	1.2404	1.24675	1.24479
1.5	1.49785	1.4998	1.49993	1.50000

As shown in Table 1, the maximum error increases with the decrease of the thermal conductivity of the insulators, when the thermal conductivity of the insulator is equal to that of the insulator. Table 1 shows when the thermal conductivity of insulators is 0.02 W/(m·K), only the equivalent thermal conductivity in the direction of Z is close to the linear average, the error between the two is 4.1%. And the error between the equivalent thermal conductivity and the linear average in the direction of X and Y is 62.5% and 93.8% respectively. It's can be concluded that when the thermal conductivity of the two materials is similar, the equivalent thermal conductivity of the system can be approximately solved by means of the linear average method.

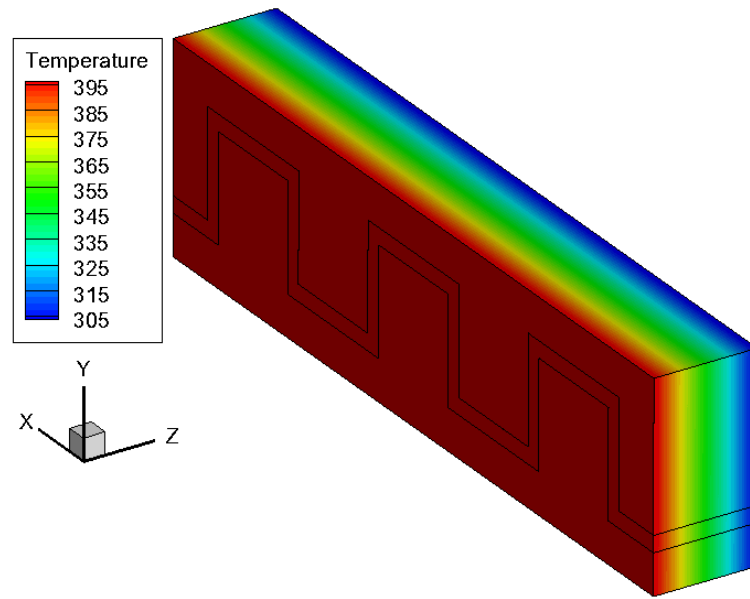
As shown in Figure 2, the maximum and minimum temperature of the end face of the nanocomposites along three different directions is 400 K and 300 K respectively when the thermal conductivity of the nanopaper is $1.5 \text{ W/(m}\cdot\text{K)}$ and the thermal conductivity of the polymer matrix is $0.8 \text{ W/(m}\cdot\text{K)}$. The temperature distribution of other surface is calculated under the adiabatic condition. As shown in Figure 2, it can be seen that the temperature section is gradually decrease from the end face of high temperature to the end face of low temperature.



(a) X direction



(b) Y direction



(a) Z direction

Fig. 2. Temperature field distribution cloud map of composites reinforced by pulse bending nanopaper

5. Summary

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

When the thermal conductivity of the two materials is similar, the equivalent thermal conductivity of the system can be approximately solved by means of the linear average method.

The maximum and minimum temperature of the end face of the nanocomposites along three different directions is 400 K and 300 K respectively. The temperature distribution of other surface is calculated under the adiabatic condition. It can be seen that the temperature is gradually decrease from the end face of high temperature to the end face of low temperature.

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