Optimized Analysis of Composites Reinforced by Buckypaper on Thermal Properties

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Abstract. FLUENT was used to analyze how the shapes of buckypaper and the thermal conductivity of the polymer matrix affects the temperature distribution of composites reinforced by the flat, sinusoidal and pulse bending buckypaper when the composite materials is heated. The larger the thermal conductivity of the polymer is, the lower the maximum and average temperature are. As the minimum temperature is increased, the distribution of the temperature is more uniform. Meanwhile, the increased thermal conductivity of the polymer matrix leads to more uniform temperature distribution and increased lowest temperature. The obtained temperature distribution maps shows that high temperature region appear in the vicinity of the buckypaper.

1. Introduction

CNTs have other advantages beneficial for practical applications, including low thermal expansion coefficient, high chemical stability, and corrosion resistance to many severe environments. As a result, CNTs were frequently mixed with polymers to enhance their thermal conducting performance [1,2]. However, manufacturing CNT-reinforced composites with uniform tube dispersion and large CNT loading is a great challenge since the CNTs have a strong tendency to form bundles or ropes and rapidly increase the viscosity during processing [3]. CNT buckypaper, the membrane materials composed of CNT network, are self-supporting networks of entangled CNT assemblies arranged in a random fashion and held together by van der Waals interactions at the tube-tube junctions [4,5].

Previous research on the properties of buckypaper and buckypaper/polymer composites has mostly been concentrated on their mechanical properties and conductive properties. In this work, the thermal responses of the polymer composites reinforced by flat, sinusoidal and bent buckypaper were systematically studied and the heating mechanisms of multiple-field coupling were identified.

2. Numerical model

The finite element software FLUENT was used to analysis the thermal property of composites reinforced by the flat, sinusoidal and pulse bending buckypaper during the heating process. The heating model of the polymer composite reinforced by the buckypaper is shown in Figure 1. As shown in Figure 1, the length (L), width (w), and the thickness (T) of the heating model of the polymer composite reinforced by the flat, sinusoidal and pulse bending buckypaper are 600 mm, 50 mm, and 100 mm respectively. The thicknesses (d) of the flat, sinusoidal and pulse bending buckypaper are 10 mm. The bending height (h) and bending period (A) of the the bent buckypaper are 60 mm and 120 mm.

The objective of this research is to analyze the effect of the bending shapes of buckypaper and the thermal conductivity of the polymer matrix on the temperature distribution of composites reinforced by the flat, sinusoidal and pulse bending buckypaper when the composite materials is heated using a finite element software FLUENT.

Comparative analysis was carried out for the following aspects:
(1) the shapes of buckypaper reinforcement: flat, sinusoidal and pulse bending;

(2) the thermal conductivities of the polymer matrix: 0.02 W/(m•K), 0.05 W/(m•K), 0.10 W/(m•K), 0.20 W/(m•K).
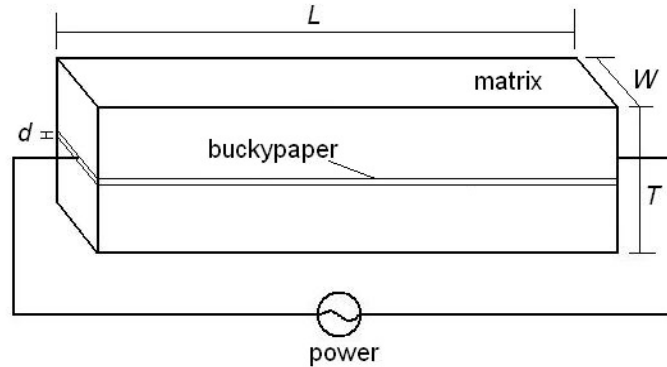

Fig. 1. Sketch diagram of heating experimental device

3. Calculation Condition

The natural convection heat transfer coefficient was set to be 10 W/(m²•K). The ambient temperature was set to be 300 K. The thermal conductivity of buckypaper was set to be 1.0 W/(m•K). The specific heat capacity of buckypaper and the polymer matrix was set to be 1000 J/(kg•K) and 1300 J/(kg•K). The thermal conductivity of the polymer matrix was set to be 0.1 W/(m•K). The density of buckypaper and the polymer matrix was set to be 500 kg/m³ and 1000 kg/m³.

Figure 2 shows the geometry model of the polymer composites reinforced by flat buckypaper.
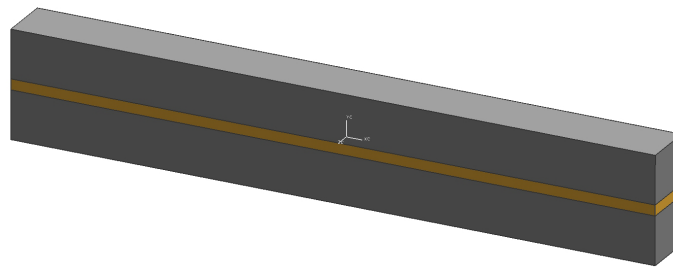

Fig. 2. Model of the polymer composites reinforced by flat buckypaper

The inner heat source of the buckypaper with sinusoidal heating sheets can be obtained by formula (1).

$$\Phi_{sin} = \frac{25\text{W}}{\left(0.01 \times 0.05 \times 0.161226\right)\text{m}^3 \times 5} = 62024.7\,\text{W/m}^3 \tag{1}$$

The inner heat source of the buckypaper with flat heating sheets can be obtained by formula (2).

$$\Phi_{flat} = \frac{25\text{W}}{\left(0.01 \times 0.05 \times 0.12\right)\text{m}^3 \times 5} = 83333.3\,\text{W/m}^3 \tag{2}$$

The inner heat source of the buckypaper with pulse bending heating sheets can be obtained by formula (3).

$$\Phi_{pulse} = \frac{25\text{W}}{\left(0.01 \times 0.05 \times 0.22\right)\text{m}^3 \times 5} = 45454.5\,\text{W/m}^3 \tag{3}$$

4. Results and discussion

The typical temperature of the polymer composites reinforced by different shape buckypaper with different thermal conductivity along the section z=0 are listed in Table 1 to Table 3. Table 1 to Table

3 shows that the maximum and average temperature of the polymer composites are decreased as the thermal conductivity of polymer matrix is increased from 0.02 to 0.20 W/(m•K), whereas the minimum temperature show an increasing trend.

Table 1 Typical temperature of composite reinforced by pulse bending buckypaper with different thermal conductivity along the section z=0

Temperature /K	Thermal conductivity/ W/(m•K)			
	0.02	0.05	0.1	0.2
T_{max}	372.87	352.34	339.99	330.90
T_{min}	300.39	301.09	302.16	303.74
T_{ave}	345.36	333.72	326.79	321.76

Table 2 Typical temperature of composite reinforced by sinusoidal buckypaper with different thermal conductivity along the section z=0

Temperature /K	Thermal conductivity/ W/(m•K)			
	0.02	0.05	0.1	0.2
T_{max}	397.41	368.38	350.65	337.42
T_{min}	300.20	300.63	301.41	302.83
T_{ave}	348.50	335.83	328.23	322.63

Table 3 Typical temperature of composite reinforced by flat buckypaper with different thermal conductivity along the section z=0

Temperature /K	Thermal conductivity/ W/(m•K)			
	0.02	0.05	0.1	0.2
T_{max}	428.97	389.43	365.10	346.65
T_{min}	300.22	300.69	301.56	303.09
T_{ave}	352.95	338.88	330.40	324.07

The temperature distribution of the polymer composites reinforced by pulse bending buckypaper at the stable states along the section z=0 were calculated. The obtained temperature distribution maps are shown in Figures 3. Figures 3 shows that high temperature region appear in the vicinity of the buckypaper.
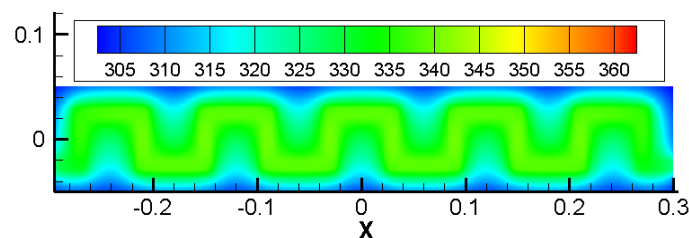

Fig. 3. Temperature distribution maps of composites reinforced by pulse bending buckypaper along the section z=0

The heating rate and the time for the composites reinforced by the sinusoidal buckypaper reaching a steady state were calculated by the finite element software FLUENT. The relationship of the average temperature as a function of time in a transient state along the section z=0 was also analyzed and the results are shown in Figure 4.

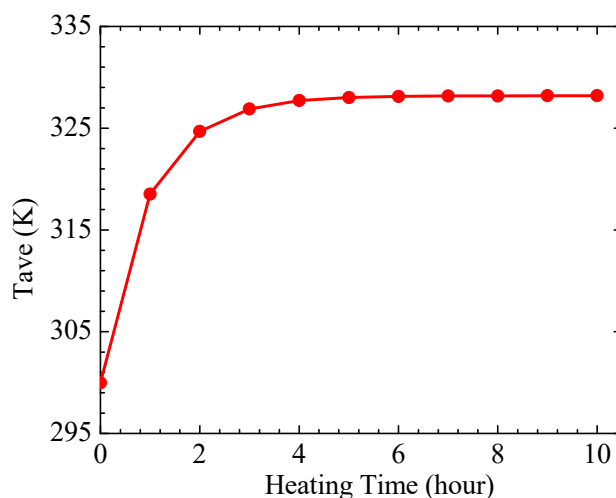Fig. 4. Temperature distribution maps of composites reinforced by sinusoidal buckypaper along the section z=0

5. Summary

FLUENT was used to analyze how the shapes of buckypaper and the thermal conductivity of the polymer matrix affects the temperature distribution of composites reinforced by the flat, sinusoidal and pulse bending buckypaper when the composite materials is heated.

The larger the thermal conductivity of the polymer is, the lower the maximum and average temperature are. As the minimum temperature is increased, the distribution of the temperature is more uniform. Meanwhile, the increased thermal conductivity of the polymer matrix leads to more uniform temperature distribution and increased lowest temperature.

The obtained temperature distribution maps shows that high temperature region appear in the vicinity of the buckypaper.

Acknowledgement

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