Carbon Fiber/Phenolic Composites with High Thermal Conductivity Reinforced by a Three-Dimensional Carbon Fiber Felt Network Structure

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ABSTRACT: The formation of highly thermally conductive composites with a three-dimensional (3D) oriented structure has become an important means to solve the heat dissipation problem of electronic components. In this paper, a carbon fiber (CF) felt with a 3D network structure was constructed through the airflow netting forming technology and needle punching. The carbon fiber/phenolic composites were then fabricated by CF felt and phenolic resin through vacuum impregnation and compression molding. The effects of CF felt content and porosity on the thermal conductivity of carbon fiber/phenolic composites were investigated. The enhancement of carbon skeleton content promotes the conduction of heat inside the composites, and the decrease of porosity also significantly improves the thermal conductivity of the composites. The results indicate that the composites exhibit a maximum in-plane thermal conductivity of 1.3 W/mK, which is about 650% that of pure phenolic resin, showing that the construction of 3D thermal network structure is conducive to the reinforcement of thermal conductivity of composites. The method can provide a certain theoretical basis for constructing a thermally conductive composite with a three-dimensional structure.

INTRODUCTION

Polymer composites are widely used in aerospace, automotive, construction, electronic components, and other fields due to their excellent mechanical properties and corrosion resistance. However, low thermal conductivity limits their applications; they must be modified to obtain high thermal conductivity. Therefore, the preparation of high thermal conductivity polymer composites has become an urgent problem. Generally speaking, polymers are mixed with thermally conductive fillers to improve the thermal conductivity of polymer materials, such as metal filler (Ag, Cu, Au), ceramic filler (MgO, Al₂O₃, BN, AlN, SiC, SiO₂), and carbon material (carbon fiber, carbon black, graphene, single-wall/multi-wall, graphite). However, ceramic fillers and metal fillers generally have high density, and it is difficult to achieve high thermal conductivity with low filler content. Meanwhile, high content of fillers will increase the viscosity of the system, making processing difficult and affecting the mechanical properties of the composites. In addition, the dispersion of the filling phase and the interfacial adhesion between the components of the composites are also important factors that determine the thermal conductivity. Hence, a high thermal conductivity path needs to be formed between the fillers to acquire high thermal conductivity. It has become a research hotspot that constructing a network structure improves thermal conductivity at this stage.

The thermal conductivity of enhanced polymer composites mainly depends on the inherent properties and microstructure of the polymer matrix and fillers. Carbon fiber has received widespread attention because of its high strength, light weight, excellent thermal stability, and high aspect ratio. Carbon fiber-based materials show ultrahigh thermal conductivity. Therefore, carbon fiber is considered to be an ideal filler for enhancing thermal conductivity. To receive high thermal conductivity, it is important to build a three-dimensional thermal conductivity network to allow the filler to percolate in the polymer matrix, thereby increasing the thermal conductivity path. Three-dimensional network preparation methods include freeze-drying method, electrostatic flocking method, electrophoretic deposition method, self-assembly, and so on. Ma et al. freeze the carbon fiber...
solution vertically through the freeze-drying method, assemble it into a through-plane skeleton, and then infiltrate the epoxy resin to prepare a 3D carbon fiber/epoxy composite thermal interface material with enhanced thermal conductivity (2.84 W/mK, 13.0 vol % CF). Uetani et al. used the electrostatic flocking method to immerse the rubber matrix in a set of vertically arranged high-density carbon fibers to produce a thermal interface management material with a high thermal conductivity (23.3 W/mK, 13.2 wt %). The preparation method of the three-dimensional network structure indicates that the polymer composites with high thermal conductivity can be prepared through the orientation of the high thermal conductivity filler.

In this work, the 3D CF felt network structure was constructed by air flow-needle punching technology. Moreover, the carbon fiber/phenolic composites were prepared by compressing the carbon fiber felt impregnated with phenolic resin into different proportions through lamination method. This paper studies the effect of 3D CF felt network on the thermal conductivity of composites and discusses the influence of porosity on thermal conductivity. The method can effectively solve the disadvantage of low polymer crystallinity, leading to low thermal conductivity, and provides some suggestions for the preparation of high thermal conductivity composites.

## RESULTS AND DISCUSSION

### Morphology of Carbon Fiber/Phenolic Composites

During the preparation process, the carbon fibers had a certain orientation through airflow technology and needle punching. Initially, the dispersed carbon fibers formed an interwoven carbon fiber mat in the X−Y plane under the action of airflow. The carbon fibers overlapped each other and were basically distributed in the X−Y plane, forming a loose structure. Then, a small amount of carbon fibers originally located on the X−Y axis changed their original orientation through the needling process. Afterward, some of the carbon fibers in the X−Y plane were aligned along the Z direction. These vertically oriented fibers improved the integrity of carbon fiber mat and combined with carbon fibers in the X−Y plane to form a three-dimensional network structure. CF felt with a 3D network structure was impregnated in phenolic resin to prepare carbon fiber/phenolic composites. The 3D carbon fiber network provided richer thermal conduction paths for carbon fiber/phenolic composites. The thermal conductivity of composites was optimized from the horizontal and vertical directions. Therefore, it is necessary to observe the arrangement and distribution of carbon fibers in the carbon fiber/phenolic composites and the bonding between the matrix and the CF felt from the in-plane and through-plane directions.

Figure 1 presents the SEM images of the carbon fiber/phenolic composites. As can be seen from Figure 1a,b, the composites exhibit a distinctly aligned layered structure. The orientation of the CF felt remained unchanged in the composites, suggesting that the impregnation process did not significantly alter the microstructure. In addition, as the number of CF felt layers increased, the microstructure of the carbon fiber/phenolic composites changed significantly. The reduction of the distance between carbon fibers in different planes can further increase the contact area between the filler and the matrix, which has a significant impact on the thermal conductivity in the through-plane direction. According to Figure 1c,d, we can see that the carbon fibers are basically in the X−Y plane and have high orientation. The carbon fiber filaments overlap each other and are more closely combined with the carbon fibers in the parallel direction at the junction of different fibers, under the curing action of phenolic resin. The carbon fiber cluster circled by the red circle in the picture is formed by bonding carbon fibers under the action of phenolic resin during the impregnation process. The carbon fibers of the same layer are bonded together, which is beneficial to enhance the strength of the carbon fiber layer. These agglomeration points will reduce the scattering phenomenon that occurs in the heat transfer process and further increase the in-plane thermal conductivity of the composites. It can be seen from Figure 1 that during the compression confinement process, the distances between carbon fibers in different layers are continuously reduced, thereby reducing the interface thermal resistance and promoting the conduction of heat in the composites. In addition, under the curing action of the phenolic resin, the carbon fibers are more tightly bonded at the junctions of different fibers. The tight interfacial structure facilitates phonon transfer, which further improves the thermal conductivity of the composites. Moreover, the carbon fiber felt with a 3D network structure can form a high thermal conductivity path, which is conducive to the conduction of heat inside the composites. This indicates that the airflow-needle punching-laminating method is a feasible method for preparing high thermal conductivity composites with a three-dimensional network structure.

### Porosity of the Carbon Fiber/Phenolic Composites

In the process of compression molding, the overall shape of the composites prepared in this experiment is regular and all surfaces are flat. The geometry and mass of the composites were measured by vernier calipers and balances, respectively, and the bulk density was obtained. The bulk density of composites ranges from 0.32 g/cm\(^3\) (8 L) to 0.94 g/cm\(^3\) (28 L), as presented in Figure 2a. It can be concluded from Figure 2a that the bulk densities of the composites are all less than the sum of the densities of carbon fiber and phenolic resin. Combined with the SEM images, it shows that there are still pores in the composites. Therefore, it is essential to discuss the influence of the porosity on the thermal conductivity.

The level of porosity reflects the degree of densification of the material. Porosity is an important factor that affects the...
The bulk density, actual density, and porosity of the sample are calculated according to the following formulas, respectively. The results are reflected in Table 1 and Figure 2.

\[
\rho_0 = \frac{m}{v} \quad (1)
\]

\[
\rho = \frac{m_1 \rho_2}{m_1 + m_2 - m_3} \quad (2)
\]

\[
P = \left(1 - \frac{\rho_0}{\rho}\right) \times 100\% \quad (3)
\]

Table 1. Porosity of Carbon Fiber/Phenolic Composites

| layers (L) | bulk density (g/cm\(^3\)) | actual density (g/cm\(^3\)) | porosity (%) |
|------------|-----------------------------|-----------------------------|--------------|
| 8          | 0.32                        | 1.61                        | 80           |
| 12         | 0.42                        | 1.60                        | 74           |
| 16         | 0.56                        | 1.68                        | 67           |
| 20         | 0.65                        | 1.64                        | 60           |
| 24         | 0.80                        | 1.76                        | 55           |
| 28         | 0.94                        | 1.66                        | 43           |

Here, \(\rho_0\) is the bulk density, \(m\) is the geometric mass, and \(v\) is the geometric volume; \(\rho\) is the actual density of the sample, \(m_1\) is the mass of the sample material, \(m_2\) is the total mass of (gravity bottle + anhydrous ethanol), \(m_3\) is the total mass of (gravity bottle + anhydrous ethanol + sample material), \(\rho_2\) is the density of anhydrous ethanol at 25 °C; \(P\) is the porosity of the sample.

As the compression ratio increases, the bulk density of the composites increases continuously, while the actual density of the material itself remains basically unchanged. Consequently, the calculated porosity shows a decreasing trend, as presented in Figure 2b. With the increase of the number of compressed layers, the bulk density of the composites rises, resulting in an enhancement in the carbon fiber content per unit volume. The three-dimensional carbon fiber network inside the composites is denser, which enriches the heat conduction path and is beneficial to improve the thermal conductivity of the composites. Moreover, the growth in bulk density also reduces the distance between carbon fibers, resulting in a shorter conduction path, thereby increasing the thermal conductivity of the composites. Furthermore, because air is a poor conductor of heat, the presence of a large number of pores.
can negatively affect the thermal conductivity of the composites. The increase in bulk density leads to a decrease in composite porosity. The reduction of the air ratio inside the composites makes the contact thermal resistance between carbon fibers smaller, resulting in an upward trend in the thermal conductivity of the composites with the decrease in porosity. Therefore, the thermal conductivity of composites shows a decreasing trend with the increase of porosity.

### Thermal Conductivity of Carbon Fiber/Phenolic Composites

Generally, polymers are often used as substrates for composite molding due to their light density, easy processing, and stable chemical properties. However, polymer materials are poor conductors of heat, and their thermal conductivity is difficult to reach 0.5 W/mK, which makes them greatly limited in the field of electronics and electricity. In this study, we impregnated different layers of CF felt with a 3D network structure in phenolic resin to prepare carbon fiber/phenolic resin composites under specific process conditions and investigated the effect of carbon fiber content on the thermal conductivity of composites. The thermal conductivity of composites was tested by a hot disk thermal constant analyzer.

**Figure 3a** displays the thermal conductivity of carbon fiber/phenolic composites. It can be seen from **Figure 3a** that the thermal conductivity of composites shows an upward trend in different directions, as the number of CF felt layers increases. The through-plane thermal conductivities of the composites are 0.21 W/mK (8 L), 0.26 W/mK (12 L), 0.39 W/mK (16 L), 0.48 W/mK (20 L), 0.65 W/mK (24 L), and 0.78 W/mK (28 L), respectively. The maximum thermal conductivity of the composites in the through plane is 0.78 W/mK (28 L), which is about 350% that of the pure phenolic resin matrix. The reasons for the significant improvement of the composites in the through plane are as follows: (1) With the increase of the number of compressed layers, the content of carbon fiber in the composites increases, and the thermal conduction path formed by the carbon network increases accordingly, which has a positive impact on the thermal conductivity of composites. (2) The distance between the carbon fibers on different planes is shortened during the compression process, and the thermal resistance between the interfaces is reduced, which promotes the propagation of heat in the through plane. This also improves the thermal conductivity of the composites. The in-plane thermal conductivities of the composites are 0.43 W/mK (8 L), 0.58 W/mK (12 L), 0.89 W/mK (16 L), 1.0 W/mK (20 L), 1.1 W/mK (24 L), and 1.3 W/mK (28 L), respectively, as shown in **Figure 3a**. The apparent increase in the in-plane thermal conductivity of the composites is attributed to the following: (1) Carbon fibers are used as fillers for thermally conductive composites due to their high thermal conductivity. In the process of air flow netting and needle punching, carbon fibers are mainly distributed in the X–Y plane. The conduction in the in-plane direction of the composites is mainly conducted along the axial direction of the carbon fibers, which optimized the original thermal conduction path of the matrix, resulting in an improvement of thermal conductivity. (2) In the in-plane direction, phonons mainly propagate in the carbon network. With the increase of the number of compressed layers, the in-plane carbon network becomes denser and the thermal conduction path increases, which improves the thermal conductivity of the composite. (3) During the impregnation process, some bond points were formed between the phenolic resin and the carbon fibers. These bond points connect different carbon fibers, allowing heat to transfer between adjacent carbon fibers, widening the thermal conduction path, and causing an enhancement in the in-plane thermal conductivity of the composites. In conclusion, the improved thermal conductivity of the composites is attributed to the inherently high thermal conductivity of carbon fibers. Besides, the increase of carbon fiber content and contact area during the compression process also resulted in the improvement of the thermal conductivity of the composites.

**Figure 3b** indicates that the thermal conductivity of carbon fiber/phenolic composites increased by multiples. The growth multiples of the in-plane and through-plane directions are both greater than 100%; that is, the thermal conductivity in both directions is higher than that of the matrix itself, which confirms that the three-dimensional carbon framework effectively promotes the thermal conductivity in both directions. Comparing **Figure 3a** and **Figure 3b**, it can be seen that with the increase of the number of compressed layers, the thermal conductivity of the composites increases significantly in two directions. However, the in-plane thermal conductivities of the composites are significantly higher than the through-plane thermal conductivities, and the in-plane growth multiple is much higher than that in the through-plane direction. When the number of carbon fiber layers is 28, the thermal conductivity of the carbon fiber/phenolic composites is 650% that of pure resin (in the in-plane direction) and about

### Table 2. Data of the Thermal Conductivity from Previous Research

| method                                      | materials           | filler content (wt %) | thermal conductivity (W/mK) | references |
|---------------------------------------------|---------------------|-----------------------|-----------------------------|------------|
| dip coating, high temperature thermal reduction vacuum, and in situ perfusion | CF/rGO/PAI          | 4.25                  | 0.53                         | 56         |
| vacuum impregnation                         | CF/PW               | 8.8                   | 0.77                         | 57         |
| solution blending                           | CF/PDMS             | 20                    | 2.73                         | 58         |
| freeze-drying                               | CF-MXenes/epoxy     | 30.2                  | 9.68                         | 47         |
| magnetic field driving                      | CF/PDMS             | 20                    | 1.51                         | 59         |
| vacuum impregnation                         | CF/PW               | 12.8                  | 1.73                         | 60         |
| blending and curing                         | CF/Al2O3/epoxy      | 80.4                  | 3.84                         | 17         |
| electroless plating method                  | CF-Ca/SR            | 4                     | 1.99                         | 61         |
| electropolating and melt-mixing             | CF-Ni/PEEK          | 40                    | 0.59                         | 62         |
| freeze-drying technique                     | graphene/carbon fiber/PDMS | 2                    | 1.569                        | 63         |
| fused filament fabrication (FFF) technology | CF/PLA              | 30                    | 0.212 ± 0.001 (90 °C)        | 64         |
| vacuum impregnation and compression molding | CF/phenolic         | 50                    | 1.3                          | This work  |

This work
achieved by electroless plating, generally obtain higher thermal conductivity, which can be enhancing the thermal contact resistance due to the crystal orientation in the production process. In the in-plane direction, the heat is mainly conducted along the fiber axis. Compared with the vertical direction, it is easier to form a denser heat conduction path, which is conducive to the spread of heat in the $X$–$Y$ direction. (2) The interlayer distance of composites is much larger than the distance between fibers in the horizontal direction, resulting in high heat transfer efficiency in the in-plane direction. Therefore, the thermal conductivity of the composites is highly anisotropic. (3) During the impregnation process, the bonding point formed between the carbon fiber and the phenolic resin in the plane increases the thermal conduction path, which promotes the conduction of heat between adjacent carbon fibers and effectively improves the in-plane thermal conductivity. This shows that the carbon fiber/phenolic composites prepared by the method has good thermal conductivity, which can provide a certain technical method for the preparation of high thermal conductivity composites.

Table 2 summarizes the data of the thermal conductivity from previous research. Seen from Table 2, the thermal conductivities of the composites ranges from 0.53 to 9.68 W/mK, but they are all larger than the thermal conductivity of the polymer matrix itself, indicating that the inherent high thermal conductivity of carbon fiber has a positive effect on the thermal conductivity of composites. The composites made by combining carbon fibers with other polymer matrix can generally obtain higher thermal conductivity, which can be achieved by electroless plating, electroplating, blending, dipping, freeze-drying, 3D printing, and other methods. In recent years, researchers have carried out oriented research on carbon fibers through a series of techniques, including freeze-drying and 3D printing, and so forth. More importantly, the unidirectional thermal conductivity of composites can be acquired through the carbon fiber orientation research. Guo et al. used freeze-drying method to prepare three-dimensional carbon fiber (CF)-MXene foam and compounded with epoxy resin to form CF-M/epoxy composites. The oriented CFs was used as the main heat transfer path in the through-plane direction. MXenes acted as bridges between in-plane CFs, forming the main heat conduction paths in the in-plane direction. Due to the synergistic effect of carbon fibers and MXenes, the thermal conductivity of the composites increased to 9.68 W/mK when the mass fraction of the hybrid filler was 30.2 wt %. This shows that the orientation of carbon fibers in a certain direction can achieve high thermal conductivity in a single direction efficiently. However, it must be synergistic with other fillers to enhance thermal conductivity in other directions. In this paper, CF felt with a three-dimensional interconnected network was constructed as thermally conductive filler, which has a significant effect on improving the thermal conductivity of composites. The synthesized composites gained higher thermal conductivity in the in-plane direction, and all directions in the $X$–$Y$ plane had the same thermal conductivity (1.3 W/mK). In addition, the advantages of this paper are that it can be prepared on a large scale and can prepare large samples. The disordered state of carbon fibers in composites is one reason that affects the overall thermal conductivity. In addition, due to the existence of pores, the thermal conductivity is lower than some of the above-mentioned thermal conductivities, and it still needs to be optimized. Next, we can further reinforce thermal conductivity by reducing porosity, and we have the potential to continue this research.

**Thermal Management Performance of the Carbon Fiber/Phenolic Composites.** In order to study the thermal management capability of the carbon fiber/phenolic composites, pure phenolic resin, composites 8 L, and composites 16 L were placed on the same heat source platform. The surface temperature of different samples was characterized and analyzed with an infrared thermal imager.

**Figure 4**. (a) Thermal image of carbon fiber/phenolic composites; (b) surface temperature–time curve of carbon fiber/phenolic composites.
surface temperature–time curve of carbon fiber/phenolic composites. The variation range of pure phenolic resin is relatively gentle, and the temperature change curve of composites 16 L increases greatly within the same heating time. As shown in Figure 4b, when the heating time was 40 s, the surface temperatures of phenolic resin, composites 8 L, and composites 16 L were 57, 87, and 101 °C, respectively. The reason for the different thermal management performance of the three samples is that the good crystalline structure of carbon fiber can optimize the crystal regularity of the composites and provide more abundant heat conduction paths for the composites. In addition, the introduction of the lamination method makes the carbon network more complex and promotes the heat conduction, so that the thermal management performance of carbon fiber/phenolic composites with high compression ratio is higher than that of low compression ratio composites.

The heat transfer of the carbon fiber/phenolic composites is mainly carried out through the carbon fiber skeleton with high thermal conductivity, but there will still be a part of the heat transfer through the phenolic resin itself. In this paper, carbon fibers with a three-dimensional network structure were constructed, and the thermal conductivity in different directions is anisotropic, so it is necessary to study the heat transfer mechanism in different directions. To further demonstrate the thermal management properties of carbon fiber/phenolic composites, the heat conduction mechanism in the composites is illustrated in Figure 5. As presented in Figure 5a, the heat conduction in the X–Y direction is mainly carried out through the axial direction of carbon fibers. The reasons for the improved in-plane thermal conductivity are as follows: (1) Most of the carbon fibers in the composites are distributed in the X–Y plane. Due to the fiber orientation, the thermal conductivity of the fiber in the axial direction is higher than that in the non-axial thermal conductivity. (2) The bonding points between the carbon fiber and the phenolic resin widen the thermal conduction path, which further improves the thermal conductivity of the composites. (3) During the...
compression process, the content of carbon fibers per unit volume rises, and the contact probability between fibers in the plane increases, resulting in a further enhancement in thermal conductivity. As shown in Figure 5b, the conduction in the Z direction mainly happens by the interlayer conduction through the carbon fibers in each layer. The conduction path becomes longer, and the heat transfer efficiency decreases. In addition, the contact probability of carbon fibers between layers is lower, higher than the through-plane direction. The heat transfer in the Z direction is directly conducted along the fibers or bonding and the interfacial thermal resistance increases. Comparing Figure 5a and Figure 5b, the heat conduction in the X–Y direction is mainly through the interlayer conduction through the carbon fibers in each layer, the conduction path is longer, and the interface thermal resistance increases. This is the reason why the thermal conductivity of the composites in the in-plane direction is higher than the through-plane direction.

■ EXPERIMENTAL SECTION

Materials. The carbon fiber SYT45 with a length of 120 mm was purchased from China Zhongfu Shenying Carbon Fiber Co., Ltd, China. It has high tensile strength with a diameter of about 7 microns and a density of about 1.79 g/cm³. Phenolic resin PF-5408 was supplied by Jinan Shengquan Resin Co., Ltd., with a solid content of 65 wt %, a free phenol of 9.5–11.8 wt %, and a moisture content of 2.5–4.0 wt %. Its viscosity is about 40 mPa s (25 °C), which is reddish-brown at room temperature. The thermal conductivity and density of phenolic resin is about 0.2 W/mK and 1.1 g/cm³, respectively. The 88% ethanol used in this study was provided by Sigma-Aldrich (US).

Preparation of Carbon Fiber/Phenolic Composites. The carbon fiber/phenolic composites were prepared by the method of air flow netting—needle punching—liquid impregnation—compression molding. The process diagram of the preparation of carbon fiber/phenolic composites is shown in Figure 6a. The main preparation steps are as follows: First, the carbon fiber filaments (length 120 mm) were placed in a mesh container, and a high-pressure airflow was introduced into the container. The carbon fibers moved under the action of air flow, and then most of the carbon fibers fell at a horizontal angle. The carbon fibers overlapped each other and were all distributed in the X–Y plane. When the carbon fibers were stacked to a certain height, a relatively loose carbon fiber felt is formed. At this time, carbon fibers had low stability and were not easy to shape. Second, needle punching method was introduced in order to improve the overall stability of materials. The CF felt was pierced by metal needles to change the orientation distribution of the fibers in the plane. Subsequently, the carbon fibers originally distributed in the X–Y plane tended to be distributed in the Z direction under the action of vertically aligned needle array. The carbon fibers in the vertical direction connected carbon fibers in different planes, which strengthened the stability of the CF felt and made it more integrated through needle punching. The density of the CF felt was about 0.04 g/cm³ and the thickness was about 0.01 m. In this manner, a CF felt with a 3D network was constructed by air flow netting and needle-punching. Third, the carbon fiber/phenolic composites were prepared by liquid impregnation and compression curing. The CF felt was immersed in a mixed solution of phenolic ethanol (mass ratio is 1:1), with the assistance of vacuum conditions. After infiltrating completely, the sample was placed in an oven and heated at 80 °C to remove the alcohol. Finally, different layers of CF felts were stacked and placed in the hot press at 175 °C for 5 h under a pressure of 20 MPa. By this lamination method, the different layers of carbon fiber/phenolic composites were obtained. The physical picture of composites is reflected in Figure 6b.

Characterization. The quality of carbon fiber/phenolic composites was measured with a digital analytical balance (FA1106) from Guangzhou Biaogeda Laboratory Instrument Co., Ltd. The digital vernier caliper (SHAHE) of Ningbo Kecheng Instrument Co., Ltd was adapted to estimate the volume of composites. The microstructure of composites was observed and analyzed with a field-emitting scanning electron microscope produced by Shanghai Jianhu Instrument Equipment Co., Ltd. The samples were quenched and ultrasonically treated, and the surface was clean and free of impurities. In addition, the surface was gold-coated to make the image clearer before scanning. The density of the samples was examined by using the Archimedes alcohol displacement method. The porosity of composites was calculated by: \( P = (1 - \rho/\rho_0) \times 100\% \), where \( \rho_0 \) is the bulk density and \( \rho \) is the actual density. The thermal conductivity of different layers of composites from both the in-plane and through-plane direction was tested by a hot disk thermal constant analyzer (TPS500, Hot Disk, Sweden). In our study, we define the fiber direction as the in-plane direction and perpendicular to the fiber direction as the through-plane direction. In order to study the thermal management performance of the composites, an infrared thermal imager (Fluke Ti-400, USA) was used to collect IR images and record the surface temperature of composites under the heat source.

■ CONCLUSIONS

In this paper, CF felt with three-dimensional structure was compounded with phenolic resin under specific process conditions. High thermal conductivity carbon fiber composites were prepared by changing the content of carbon network. The introduction of the lamination method allows more carbon fibers to overlap each other, reducing the interface thermal resistance of the composites and promoting the transmission of energy between the carbon fiber and the phenolic matrix, thereby increasing the thermal conductivity of the composites. The results show that the in-plane thermal conductivity of the composites can reach up to 1.3 W/mK (28 L), which is about 650% that of pure phenolic resin. At the same time, the composites also have excellent thermal management properties. Therefore, this method can provide certain methods and suggestions for the preparation of high thermal conductivity composites. In addition, the thermal conductivity of the composites in the Z direction needs to be improved. Next, we can continue to build a three-dimensional thermal conductivity network structure for in-depth research and strive to prepare isotropic thermal conductivity composites with high thermal conductivity in all directions.

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