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Copper fiber reinforced needle-coke/carbon composite for pantograph slide and its current-carrying wear performance

Meng Li, Boyong Ren, Wei Wu, Ke Jiang, Jiamin Zhang, Enze Xu, Junwu Liu, Honghai Zhong, Guoqing Tong and Yang Jiang

School of Materials Science and Engineering, and Engineering Research Center of High-Performance Copper Alloy Materials and Processing of Ministry of Education, Hefei University of Technology, Hefei 230009, People’s Republic of China

E-mail: apjiang@hfut.edu.cn

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Abstract

Copper fiber reinforced needle-coke/carbon (CF-NC/C) composites with different copper fiber contents have been successfully developed for urban rail pantograph slide block. The mechanical properties of needle coke samples containing 0 wt%, 4 wt%, 8 wt%, 12 wt% and 16 wt% were examined separately. It is found that the presence of needle coke with high aspect ratio, strength and electrical conductivity can greatly improves the physical properties of the pure carbon matrix. Therefore, we have obtained a novel carbon matrix composite. It is also revealed that the optimized CF-NC/C with 5 wt% copper fibers (CF-NC/C-5) composite has outstanding mechanical properties, current-carrying friction/ wear properties. The density, resistivity, and impact strength of the CF-NC/C-5 composite are 1.8788 g cm\(^{-3}\), 35.18 \(\mu\Omega\) m, 0.16 J cm\(^{-2}\), respectively. In current-carrying friction wear tests (0 A, 5 A, 10 A and 15 A), the CF-NC/C-5 shows an optimum friction wear performance. To avoid agglomeration of copper fibers, the copper fibers are added innovatively during the rolling process and uniformly distributed in the carbon matrix under the tangential force of rolling, which exhibits an improved effect on reinforcing the NC/C composites. Our results greatly advance the development of the needle-coke/carbon composite, which makes the new CF-NC/C composite an ideal candidate for sliding plate material with excellent properties.

1. Introduction

With the rapid development of modern rail transit, pantograph sliders as power transmission have received more and more attentions [1, 2]. As current collectors in high-speed railway train, the pantograph is acted as the contact slider and equipped on the top of the trains, which is regarded as the electric power transmission device of the train [3]. The performance of pantograph is the critical issue to the stable and safe operation of the train [4]. During the rapid running process of high-speed railroads, the pantograph sliders and copper wires not only suffer from the contacting friction and wear, but are also accompany with the generation of the arc ablation. Therefore, the regular maintenance and replacement are expected to perform in order to keep their high operational performance. However, comparing with the transmission copper wire, it is widely accepted wisdom to replace the sliders because of their low-cost of raw materials and effectiveness of replacement-cost [5]. On high-speed railroads, the former material and performance are mainly concerned topics. Recently, the carbon/carbon (C/C) composites drawn tremendous attentions [6], because of its excellent self-lubrication and electrical conductivity, which makes the C/C composites be widely applied in pantograph slider. To obtain the high quality of C/C composites, chemical vapor deposition (CVD) was proposed to reduce the porosity and improve the density of composites. For example, Wang et al [7] prepared the carbon fiber-reinforced copper/carbon composites for new carbon-based pantograph slider. Ma et al [8] designed aluminum/sintered-carbon (Al/SC) composites by impregnating aluminum alloy into porous carbon matrix to form Al\(_{4}\)C\(_{3}\) during the infiltration process. The maximum compressive strength of 304.28 MPa is obtained with an aluminum alloy...
incorporation ratio of 26.92 vol%. Moreover, a similar method was carried out by Li et al\cite{9} to realize the uniform distribution of copper in the pores of sintered carbon, which significantly improved the holistic mechanical properties, resulting in a compressive strength of 159.81 MPa. Additionally, Qin et al\cite{10} investigated the effect of carbon fiber content on the mechanical properties and current-carrying friction wear of C/C composites by using the addition of high-strength and short-cut carbon fibers. The excellent physical properties with compressive stability of 184.05 MPa was obtained followed by 4 wt% carbon fiber incorporation.

However, the heavy impact energy with a high temperature, and the appearance of violent arc action between the pantograph slider and the copper wire accelerate the failure of the C/C composite material during the high speed running of the train\cite{11, 12}. Therefore, how to improve the strength, electrical conductivity, and wear resistance of C/C composites is a challenge topic to realize the stable and safe operation of the high-speed train. Many efforts have been devoted to improve the mechanical properties and electrical conductivity of carbon-based slider materials\cite{13}. For example, Kang et al\cite{14} proposed to take the petroleum as an additive to obtain the needle coke from coal pitch by electric field refining method\cite{15, 16}. In addition, copper fibers made from electrolytic copper show all the features of metallic copper, such as softness, good abrasion resistance, and excellent thermal conductivity\cite{17}, which can effectively protect the high-speed railway copper wire\cite{18}. Bagwell, R. and coworkers\cite{19} found that the short copper fiber is a kind of multifunctional material that can not only improve the flexural strength and impact toughness of thermosetting polymer matrix, but also significantly enhance the conductivity of composites.

In this work, aiming to improve the physical properties of pantograph slider to provide stable and security conditions for urban rail transit trains traveling at a high speed, we proposed to use high-strength needle coke to improve the electrical conductivity and strength of the pantograph carbon slide matrix. The effect of needle coke on carbon matrix was investigated by adding different content of needle coke into pure carbon matrix following by evaluating the mechanical properties, current carrying friction and wear experiments of NC/C composite with different needle coke contents. Afterwards, the NC/C composite was reinforced with copper fibers to achieve a metal-reinforced composite pantograph slide. Copper fibers were well immersed and uniformly distributed in the sintered carbon matrix after sintering at 1250 °C. In addition, the mechanisms related to current conduction, fracture failure, and tribology were analyzed, and the main factors affecting the comprehensive performance of CF-NC/C composites were elucidated. This method not only provides a facile way to fabricate the pantograph, but also avoids the complicated process of metal melting and high-pressure infiltration, which effectively solves the problem of the high cost of impregnated metallic carbon slider\cite{20}. Therefore, the preparation method of copper fiber reinforced composite pantograph slider offered in this paper is simplified and effective, which shows the capability of improving the preparation process of traditional impregnated metal pantograph slider.

2. Experiments

2.1. Materials

Needle coke (Jinmei Carbon Material Technology Co of Anhui, China) are prepared from petroleum coke with a size of 100–500 μm in size. Copper fiber (Xinsheng Friction Material of Shandong Linyi, China) made by the drawing process has a diameter of 0.08–0.15 mm, and a length of 1–3 mm. As an incomplete combustion product of organic matter, carbon black with 325 mesh has a chain-like structure, surface characteristics of particles, and strong dispersion. As the central part of C/C composites, pitch coke (Jinmei Carbon Material Technology Co of Anhui, China) with 80–325 mesh is crucial to the mechanical strength and wear resistance of the sintered carbon matrix.
2.2. Preparation process
Pitch coke, carbon black, needle coke, pitch, and flake graphite were used to prepare carbon matrix materials. The preparation technology process is shown in figure 1. To make them evenly mixed, the powders were added into the V-mixer sequentially from coarse to fine. The temperature of the twin-screw kneader was controlled at 140–160 °C for 60–80 min. As shown in figure 1, similar mesophase microspheres were formed, and the raw material powder was uniformly covered with bitumen. Then, the obtained NC/C composites paste were put into a roll mill at a temperature of 140–160 °C. In this step, copper fibers were continuously added into it. Finally, the flake passing through the rolling mill was preheated to 140 °C and moved into a hot-pressing die at 190 °C and 30 MPa pressure for pressing. As a result, the pure carbon matrix was obtained. The composites contented needle coke with 4 wt%, 8 wt%, 12 wt%, and 16 wt% were abbreviated as NC/C-4, NC/C-8, NC/C-12, and NC/C-16 composite, respectively. Based on the NC/C-8 composite, the copper fiber reinforced needle-coke/carbon (CF-NC/C) composite were obtained. Copper fiber contents of 5 wt%, 10 wt% and 15 wt% named as CF-NC/C-5, CF-NC/C-10, CF-NC/C-15 composite, respectively.

2.3. Test procedures
Using the CMT4304 universal material testing machine, the Flexural strength (ASTM D7972-14(2020)) and compressive strength (ASTM C695-21) of 64 mm × 10 mm × 10 mm and 10 mm × 10 mm × 10 mm specimens were tested, respectively. The density of samples, which were machined and polished, was measured by an electronic solid densitometer (MH-3005A). For the sample size of 50 mm × 10 mm × 10 mm, the impact testing machine (XJJ-5) was used for measurement and calculation. Shore A durometer (LX-D) was used to detect the hardness value. The hardness and resistivity of the samples were tested six times to achieve the average value. Using the voltammetry, we measured the voltage and current between two points of the specimen, calculated by the resistivity formula:

\[ \rho = \frac{US}{IL} \]  

Where, \( \rho \), U, I, S, and L represents the resistivity, voltage drop (mV), current intensity (A), cross-sectional area (mm²), and length (mm), respectively.
2.4. Measurement of current-carrying friction and wear

In the current-carrying friction and wear experiment, the speed was controlled at 170 r min$^{-1}$, the load was 10 N, the time was 30 min, the current was 0 A, 5 A, 10 A, and 15 A. Then the friction coefficient was calculated by monitoring the data changes, and the wear quantity was recorded by an electronic scale (FC1004G). The coefficient of friction can be expressed by the following formula:

$$ P = \frac{T \cdot n}{9550} $$

(2)

$$ \mu = \frac{P_1 - P_0}{N \cdot F \cdot \nu} $$

(3)

Where, $T$, $n$, $\mu$, $P_1$, $P_0$, $N$, $F$, and $\nu$ represents the torque (N m), speed (r/min), friction coefficient, load power (W), no-load power (W), number of sample, load (N), and sliding speed (m/s), respectively. The speed of the friction testing machine was 1.16 m s$^{-1}$. The loading force was 10 N, then the sample connected with the copper wire through the conductive adhesive, and the current was 0 A, 5 A, 10 A, and 15 A, respectively, for 30 min. The friction coefficient was calculated through the formula and the wear rate is calculated through the mass change before and after the friction.

X-ray diffractometer (XRD) (D/max2550VB), energy dispersive spectrometer (EDS), scanning electron microscope (SEM) (SU8020), and 3d laser measuring microscope was used to study the fracture morphology, microstructure, friction surface and wear mechanism of the samples, respectively.

Table 1. Physical and mechanical properties of the composites.

| Sample          | Density (g cm$^{-3}$) | Electrical resistivity ($\mu\Omega$ m) | Hardness (HD) | Compressive strength (MPa) | Flexure strength (MPa) | Impact strength (J cm$^{-2}$) |
|-----------------|-----------------------|--------------------------------------|---------------|---------------------------|------------------------|-----------------------------|
| Pure carbon     | 1.6838                | 43.493                               | 74.75         | 60.5                      | 22.03                  | 0.11                        |
| NC/C-1          | 1.665                 | 41.12                                | 76.3          | 70.14                     | 24.49                  | 0.11                        |
| NC/C-8          | 1.6882                | 40.64                                | 75.75         | 71.53                     | 26.49                  | 0.13                        |
| NC/C-12         | 1.6722                | 41.3                                 | 74.35         | 72.01                     | 25.88                  | 0.12                        |
| NC/C-16         | 1.6538                | 38.92                                | 74.25         | 70.84                     | 25.44                  | 0.12                        |
| CF-C/C-5        | 1.8788                | 35.18                                | 75.75         | 56.68                     | 28.34                  | 0.16                        |
| CF-C/C-10       | 1.9695                | 22.39                                | 74.35         | 54.6                      | 25.3                   | 0.15                        |
| CF-C/C-15       | 2.0445                | 19.09                                | 74.25         | 52.4                      | 25.13                  | 0.14                        |

Figure 3. Top-view SEM images of the friction surfaces of NC/C-8 composite at (a) 5 A, (b) 10 A, and (c) 15 A, respectively, (d) EDS of the friction surface of NC/C-8 composite at 15 A.
3. Results and discussion

3.1. Mechanical and electrical properties
As shown in Table 1, the NC/C composites show better mechanical properties than the pure carbon matrix. Figure 2 shows the density and current-carrying wear performance of the NC/C composites. The density of the sample decreases after sintered (Figure 2(a)), which can be explained by the fact that the needle coke tends to release the gas in the lamellar structure during the high-temperature sintering process, resulting in the volume expansion [21]. As the increase of the needle coke, the decease behavior of density becomes more pronounced, yielding a smallest density of the NC/C-16 composites. Furthermore, NC/C composites show a little bit enhancement in the physical properties following an increased content of needle coke. In combination with the current-carrying friction performance in figures 2(b)–(c), it is found that the NC/C-8 composite show outstanding physical properties with a low friction coefficient and wear rate at different currents. Besides, with current in a cyclic variation, gradual increase of the friction coefficient of the NC/C-8 composite is observed (Figure 2(d)), which indicates that the elevated friction coefficient and repeated formation of lubrication film [22]. Figures 3(a)–(c) are the surface morphologies images of the NC/C-8 composite samples under different current. As the current increases from 5 A to 15 A, the needle coke is gradually exposed to the friction surface and comes off. The EDS result in Figure 3(d) shows that the sample is composed mainly of carbon. The presence of oxygen elements indicates oxidative wear with current ablation during current-carrying friction. In addition, the absence of copper elements can be explained by the fact that the material on the copper ring between the tribological subsets does not transition to the sintering carbon substrate, and the lubricating film is dominated by the carbon film [23]. It means that with the gradual wear of the carbon matrix, the high-strength needle coke is the major part of the friction and takes on a larger frictional shear load, signifying that the needle coke can increase the strength of the sintered carbon matrix.

To further understand the role of the copper fibers in the carbon matrix, 5 wt%, 10 wt%, and 15 wt% of copper fibers were added into the NC/C-8 composites, respectively. As shown in Table 1, with the increase of copper fiber content, the resistivity of CF-NC/C composites decreases from 35.18 μΩ·m to 19.09 μΩ·m, which is superior to the pure carbon matrix (42.493 μΩ·m). The corresponding impact strength is improved from 0.13 J cm⁻² to 0.16 J cm⁻², which indicates that the copper fiber can effectively enhance the electrical conductivity and impact strength of the NC/C-8 composites. After sintering at a high temperature of 1250 °C, Figure 4 indicates that the copper fibers basically maintain their previous shape and still have good mechanical properties, reinforced matrix and formed sintered neck [19, 20]. Therefore, the CF-NC/C composite has superior electrical conductivity and impact resistance. However, it shows no discernible increase in the compressive strength of CF-NC/C following an increase of copper fiber content. Whereas the wetting angle between copper and carbon, even at 1000 °C, copper and graphite still exist a wetting angle of 140° as shown in...
Figure 4, the copper fibers are only mechanically bonded to the carbon matrix [24]. Thus, there is a sidewall spacer between the copper fibers and the carbon matrix, where cracks are most likely to occur and expand during compression [25]. Moreover, it is found that if the content of copper fiber is reasonably controlled (about 5 wt%), the influence of copper fibers on compressive strength will be minimized. Meanwhile, the conductivity, impact toughness and flexure strength will be improved to a certain extent.

Figure 5 shows the fracture of the composite material after flexural impact. The fracture surface of pure carbon matrix shows flat and smooth morphology in figure 5(a), which indicates that the fracture mode of the pure carbon matrix is close to the brittle fracture, and the impact strength is inferior. It is well known that the carbon-based materials are the brittle materials, coupled with the action of cracks and pores in the matrix, which makes the cracks expand perpendicular to the surface of the sample, leading to a smooth fracture [26–28]. The impact strength of the pure carbon matrix is 0.11 J cm$^{-2}$ as seen in table 1, which demonstrates the higher brittleness of the pure carbon matrix. Figure 5(b) shows the fracture of the NC/C-8 composite. Different from the fracture of the pure carbon matrix, the needle coke is pulled out after the impact test [29], which is ascribed to the fact that the direction of the 30–60 mesh needle coke becomes perpendicular to the direction of pressure after molding (which also happens to be the direction of the force in the impact test). The high-strength needle coke embedded in the carbon matrix not only suffers from most of the impact energy, but also acts as a dowel. As a result, the compressive strength and flexural strength of the NC/C composite show superior performance in comparison with those of the pure carbon matrix, and the addition of needle coke can significantly improve the properties of the composite.

Figures 5(c)–(f) shows the fracture morphologies of the composites containing 5 wt%, 10 wt%, and 15 wt% copper fibers. From the SEM images, it is found that the pores of the fracture are gradually noticeable with the increase of copper fiber content. In figures 5(e), (f), cracks and pores are observed because of the incompatibility of copper and carbon. This incompatibility can be explained by the fact that there is a wall gap on the contact
Therefore, the crack propagation is prone to occur at the contact surface, resulting in the performance degradation. However, in figures 4 and 5, it is evident from the morphology of the carbon matrix attached to the surface of carbon fibers that part of the molten copper joined the carbon matrix after sintering as seen in figure 7. On the basis of the above analysis, the reasonable content of copper fiber addition is expected to improve the performance of NC/C-8 composite. For example, the sample shows the highest impact resistance of 0.16 J cm$^{-2}$ and improved performance of resistivity and flexural strength after incorporating 5 wt% content of copper fibers. In general, both needle coke and copper fiber can improve the physical properties of the pure carbon matrix.

3.2. Current-carrying wear performance
3.2.1. Tribological behavior and wear mechanism
The tribological behavior was investigated by controlling the current of a homemade friction machine (0 A, 5 A, 10 A, and 15 A) at a speed of 170 r/min for 30 min. The corresponding friction coefficient results were recorded in figure 6. Figure 6(a) shows the current-carrying process of the different samples under the current of 5 A. The NC/C-8 composite shows the highest coefficient of friction because the high-strength needle coke is involved in the abrasive wear, destroying the lubricant film formed by the sintered carbon. The needle coke in figure 3(a)–(c) and 7(b) show a high roughness with an uneven height distribution, which can explain why the friction coefficient of the needle coke matrix is the highest at the same current condition.

As the case of the copper fiber existing in the carbon matrix, the copper fibers take on the role of the main friction component. The surface temperature of the copper fibers gradually increases under severe frictional wear, which facilitates the copper fibers softening. As a results, the softened and flowing copper fibers can participate in replacing part of the ablated binder and penetrate the carbon matrix. On the basis of above procedure, a stable metal (Cu) lubrication film is formed after frictional wear, which can improve the friction and wear properties of CF-NC/C composites [32]. Thus, the copper fiber carbon matrix show a low average friction coefficient as seen in figure 6(c). The smooth surface of the pure carbon sample (in figure 7(a)) after the friction test indicates that the formation of a stable lubrication film (Carbon) and friction coefficient. In addition, the friction coefficient curve of the carbon matrix containing copper fibers (figure 6(a)) shows a volatility behavior, which reflects that the lubrication and friction layers are alternately created.

![Figure 6. Current-carrying friction and wear experiments: (a) the curve of the coefficient of friction with time under 5 A current, (b) the variation of the friction coefficient of CF-NC/C-5 composite under different currents, (c) the average friction coefficient of different composites under different currents, (d) the wear rate of different composites under different currents.](image-url)
Figure 6(b) shows friction coefficient of the CF-NC/C-5 composites under different currents. The variation trend of the friction coefficient is the same as that in figure 6(a) and figure 2(d), which increases gradually with the extension of time. It is worth noting that the friction coefficient shows a fluctuate curve at the beginning, which is ascribed to the unevenness of the composite surface causing abrasive wear and many plow grooves, resulting in large fluctuations in the friction curve. As the friction time extending, the temperature of sample gradually increases, resulting in the acceleration of shedding of abrasive particles. This shedding of abrasive particles process facilitates the formation of the lubricant film, which improve the surface smooth, leading to relative stable friction coefficient [33]. However, the joule heat is generated under continuous thermal stress and arc treatment in the composite material, which causes the appearance of different chip shapes as seen in figures 7(c)–(e). The existence of these chip shapes act as 'third-body' hard abrasive particles on the dual surface, resulting in a lot of furrow morphology [34]. The complex 'third body' abrasive grains are subjected to frictional shear stresses at the higher temperature frictional pair surfaces, which results in fatigue wear of the friction surface under periodic force. Therefore, it shows large fluctuations in the friction coefficient after 1500 s (s). The relationship between the abrasion loss of the sample and the variation of the current is shown in figure 6(d), in which the abrasion loss of the same sample increases as the increase of the current. The reason is as follows: when the current increases, the Joule heat and arc heat on the friction surface of the composite material are increased simultaneously. The arc generated by the current-carrying friction produces hard 'third-body' abrasive particles on the material surface, which are forced off by the shearing and splashing action of the arc. As a result, current-carrying friction produces hard 'third-body' abrasive particles on the material surface, which are compelled to remove from the high-temperature, softened friction surface by frictional shear and arc splash, exacerbating abrasive wear and fatigue wear.

Figures 7(a)–(e) show the friction surfaces of different composites at 5 A current. The friction surface of pure carbon is much smoother than others. The friction-reinforced matrix of the NC/C-8 is dominated by needle
coke, and the reinforcing materials of the CF-NC/C composites are dominated by copper fibers and needle coke. In figures 7(c)–(e), the copper fiber cross-section underwent a large plastic deformation after the friction experiment, indicating that the copper fiber assumed more shear friction and possessed a reinforcing effect. In figure 7(c), the copper fibers underwent volume creep after high-temperature sintering. The XRD of the CF-NC/C-5 and NC/C-8 composite are showed in figure 7(f). In addition, the copper fiber cross-section in figure 8 are plastically deformed by frictional shear forces, and softened metallic copper is infiltrated into the porous carbon matrix. After the friction and wear experiment with current-carrying, the surface of copper fiber with good plasticity is deformed with the friction direction under the frictional shear force. In figure 8(b), the oxygen element is evenly distributed, which indicates that the CF-NC/C-5 composite material is oxidized under arc action after current-carrying friction and wear [35].

3.2.2. Wear surface
Figure 9(a) is the CF-NC/C-5 composite material without wear test, and the surface of the copper fiber is covered with the NC/C-8 composite material. By comparing figures 9(a)–(f), it is found that only the unworn surface height of the copper fiber is consistent with the characteristics of the carbon matrix. This indicates that the carbon matrix adhered to the surface around the copper fibers has been shed after the friction and wear tests in wear surface with current, confirming that the CF-NC/C wear phase is dominated by the copper fibers. However, as seen in figures 9(b)–(f), the pre-existing wear is mainly on the carbon substrate under the action of frictional shear. Thus, there is a shedding of sintered carbon particles, which makes the friction curve more fluctuate. Then, the specific content of copper fibers can reduce both the coefficient of friction and the abrasion loss because the later period is primarily worn on the copper fibers, and the surface of the copper fibers is deformed [36]. In addition, the distortion degree of the copper fiber surface, arc ablation craters, and grooves in figures 9(b)–(f) progressively increased as the current increased to 0 A, 5 A, 10 A, and 15 A, respectively.

Moreover, as shown in figures 7(a), (b), (c), and (e), only the unworn surface is homogeneous in color, while the rest are the bright white area, which suggests that this area is smoother. In the current-carrying friction and wear experiments, the uneven friction surface is in a different order of contact with the friction pair. Under the action of shear friction and high temperature, the shape of the first contact has been worn and deformed, gradually flat and smooth showing bright white. The surface of the unstressed part is rough and grayish. Yet, the part that first contacts the friction surface turns into abrasive wear and then pits. In this way, the composite surface is gradually worn and destroyed, the abrasion loss of concretes is increasing.

Figure 8. (a) Top view SEM images of CF-NC/C-5 composite. (b)–(d) EDS mappings of oxygen, carbon, copper in CF-NC/C-5 composites.
Then, the wear mechanism is analyzed according to the 3D laser measurement microscope figures 10(a)–(d). In contrast, figure 10(a) mainly occurs adhesive wear, which is caused by shear action at the joint of the friction surface. As the current increases, the temperature of the composite friction surface rises, the abrasive particles in the carbon-based part are rapidly depleted, and the exposed copper fibers increasingly become the main body of electric and oxidative wear [19], as shown in figure 10(b). Figures 10(b)–(d) current-carrying friction in the relative motion of the friction pair generates an electric arc. The arc is essentially a gas discharge phenomenon. In the process of current-carrying friction, the surface of the friction pair is rough and the relative motion is fast. At that moment, there is a point discharge between the contact surfaces and generates a large amount of energy, producing the effect of an electric arc [37]. For adhesive wear with weak bonding, shearing usually occurs at the interface itself, while for solid adhesion, shearing occurs some distance inside the softer metal and aggravates the wear [38]. With the addition of electric current, figures 10(b)–(d), the plastic deformation of the copper fiber section becomes more obvious, and the surrounding carbon matrix falls off more seriously. Arc ablation caused by the arc effect is the main form of electrical wear. Electrical wear always exacerbates mechanical and oxidative wear simultaneously [36, 39]. Besides, the friction surface of the copper fiber reacts with the gaseous medium to produce an oxide film on the surface, which is brushed by the action of abrasive particles. Then the newly exposed surface is oxidized again, and repeatedly. Eventually, the copper fibers lost their original shape and gradually formed a friction layer in a specific area. This indicates that the copper fibers take up most of the shear forces and serve to strengthen the carbon matrix during the last stages of the wear experiment.

4. Conclusions

Needle coke has excellent electrical conductivity, strength, and high graphitization. The uniform distribution and directional consistency of needle coke can effective improve the mechanical properties of the domestic
carbon matrix. Copper fibers after being rolled, hot-pressed, and sintered can be welded together with the carbon matrix to serve as a reinforcement. When the needle coke contenting is 8 wt%, the NC/C-8 composite has excellent mechanical properties with the density, resistivity, and impact strength of 1.6882 g cm\(^{-3}\), 40.63 \(\mu\Omega\)·m, and 0.13 J cm\(^{-2}\), respectively. Based on the NC/C-8 carbon matrix, the CF-NC/C-5 exhibits the champion performance by adding 5 wt% copper fiber with the highest impact strength of 0.16 J cm\(^{-2}\), the flexural strength of 28.34 MPa, the average friction coefficient, and the lowest wear rate, respectively. Our results demonstrate that the new CF-NC/C composite can be acted as an ideal candidate for sliding plate material with excellent properties.

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**Data availability statement**

All data that support the findings of this study are included within the article (and any supplementary files).

**ORCID iDs**

Yang Jiang [https://orcid.org/0000-0002-5364-1421](https://orcid.org/0000-0002-5364-1421)

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