Friction and Wear Properties of Copper/Carbon/RB Ceramics Composite under Electrical Current

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Friction and wear properties of the copper/carbon/RB ceramics (Cu/C/RBC) composite were investigated under electrical current with and without arc-discharge. The weight fraction and the mean diameter of RB ceramics powder were 5 wt% and 4.9 μm , respectively, in the Cu/C/RBC composite. Friction tests were conducted with the block-on-ring friction apparatus. The Cu/C/RBC and the copper/carbon (Cu/C) composite, the conventional pantograph slider material of a railway current collector, were used as block specimens. Under electrical current without arc-discharge, the Cu/C/RBC composite showed 98% reduction in the specific wear rate of the block specimen, 23% reduction in that of the ring specimen, and 75% reduction in the friction coefficient over the conventional Cu/C composite. Under electrical current with arc-discharge, the Cu/C/RBC composite showed the wear resistance to arc-discharge equivalent to the conventional Cu/C composite.

Keywords: arc-discharge, electrical current, composite, friction, pantograph slider, RB ceramics, wear

1. Introduction

Pantograph sliders of a railway current collector require several characteristics such as low electrical resistivity, high strength, high wear resistance and low aggression to contact wires. Recently, reduction in maintenance costs of a pantograph system has been also desirable. Thus, a pantograph slider material requires higher wear resistance and lower aggression than the conventional pantograph slider material, the copper/carbon (Cu/C) composite¹⁾.

In our previous work, the copper/carbon/RB ceramics (Cu/C/RBC) composites were developed²⁾. RB ceramics are hard porous carbon materials made from rice bran as a main constituent³⁻⁶⁾. RB means the acronyms of rice bran. On the basis of pin-on-disk friction tests under non-electrical current, the Cu/C/RBC composites showed tribological properties superior to the Cu/C composite. Especially, the Cu/C/RBC composite showed the highest wear resistance, low aggression, and a low friction coefficient when the weight fraction and the particle diameter of RB ceramics powder were 5 wt% and 4.9 μm , respectively²⁾.

A pantograph slider's actual working condition

implies sliding against a contact wire under electrical current. Hence, the Cu/C/RBC composite required a clarification of friction and wear properties of under electrical current to be applied actual pantograph sliders.

On the basis of the background described above, the friction and wear properties of the Cu/C/RBC composite ($\alpha = 5$ wt%, $d_m = 4.9$ μm) under electrical current with arc-discharge and without arc-discharge were investigated.

2. Experimental procedure

2.1. Sample preparation

Figure 1 shows a schematic diagram of the preparation process of the Cu/C/RBC composite block specimen. The Cu/C/RBC composite was prepared by forming a compound of copper, carbon, and RB ceramics powders into a block shape. Then, the formed block was sintered in an inert gas. The conventional pantograph slider material, the Cu/C composite, was also prepared as a comparison. Each composite was cut into the block shape (25 mm $\times$ 60 mm $\times$ 10 mm), and then their test surfaces were finished by grinding. The surface roughness R_a of the Cu/C/RBC and the Cu/C composite were 1.6 and 1.8 μm , respectively. Table 1 shows composition ratios and mechanical, electrical properties of each composite. The Cu/C/RBC

Fig. 1 Schematic diagram of preparation process of Cu/C/RBC composite

composite satisfied the bending strength requirement of 70 MPa and the electrical resistivity requirement of $3 \mu\Omega\cdot\text{m}$. Figure 2 shows optical microscope images of the buffed surfaces of each composite.

2.2. Experimental apparatus

Figure 3 shows the block-on-ring friction apparatus used under electrical current. Block specimens were the Cu/C and the Cu/C/RBC composites. A ring specimen as a simulated contact wire was an oxygen-free copper ring of $5 \text{ mm} \times 45 \text{ mm}$ rectangular cross-section with a chamfered edge. The ring specimen set on the periphery of a rotation disk with a diameter of 1000 mm. Normal load was applied with a spring attached on the block specimen. Contact points between the block specimen and the ring specimen reciprocated with sinusoidal amplitude of 50 mm on the block specimen.

2.3. Experimental condition

Table 2 shows the experimental condition. The normal load W was 49 N (the corresponding apparent contact pressure P was 0.39 MPa). The sliding velocity v was 27.8 m/s. The voltage of power supply E was DC 100 V. The direction of electrical current was from a ring specimen to a block specimen. Friction tests were conducted under electrical current with and arc-discharge at the ambient temperature of 12 ± 2 degrees C and the relative humidity of 54 ± 12 %RH.

Under electrical current without arc-discharge, an electrical current of 100 A was applied. A surface of a ring specimen was treated with 60 grid sandpapers and thereby the surface roughness of the ring specimen R_{max} was 12 μm .

Under electrical current with arc-discharge, large surface roughness of a ring specimen promoted occurrence of contact breaks. The test surface of a ring specimen was treated by the following process. The surface of the ring specimen was treated with 60 grid sandpapers. Then, the polished surface was slid on a copper-based sintered metal alloy at the sliding velocity of 6.9 m/s under the electrical current of 100 A for 10 minutes. Consequently, the range of the surface roughness of the ring specimen R_{max} was from 15 to 60 μm . After that, the treated ring specimen was slid on the Cu/C and the Cu/C/RBC composites under the electrical current range from 100 to 400 A for 10 minutes. This abrasion process of the ring specimen and the friction tests were repeated for three times for each set of friction tests.

Specific wear rates of the block specimens were calculated based on a weight loss measured with the

Table 1 Composition ratios and mechanical, electrical properties of each composite

Composite materials		Cu/C (conventional)	Cu/C/RBC
Mean diameter of RBC powder d_m , μm			4.9
Weight fraction, wt. %	RBC powder α	0	5
	Carbon powder β	40	35
	Copper powder γ	60	
Density ρ , g/cm^3		3.5	3.6
Electric resistivity R , $\mu\Omega\cdot\text{m}$		1.2	2.0
Bending strength σ_B , MPa		108	106
Shore hardness HS		86	76

(a) Cu/C composite

(b) Cu/C/RBC composite

Fig. 2 Optical microscope images of buffed surface of each composite

Fig. 3 Schematic diagram of block-on-ring friction apparatus used under electrical current

Table 2 Experimental condition

Test condition	Without arc-discharge, With arc-discharge
Block specimens	Cu/C composite, Cu/C/RBC composite
Ring specimen	Oxygen-free copper
Normal load W , N	49
Sliding velocity v , m/s	27.8
Sliding time T , min	30
Voltage of power supply E , V	100 (DC)
Electrical current I , A	Without arc-discharge : 100
	With arc-discharge : 100, 200, 300, 400

electronic balance. Specific wear rates of the ring specimens were calculated based on a wear depth measured with the laser type surface profilometer.

3. Experimental results and discussion

3.1. Friction and wear properties under electrical current without arc-discharge

Figure 4 shows the relationship between friction coefficients and the number of repeat passages for each composite under electrical current without arc-discharge. The friction coefficient of the Cu/C composite increased to around 0.25 at the initial stage of friction, and then gradually decreased with the number of repeat passages. The friction coefficient of the Cu/C/RBC composite very slightly increased up to around 0.08 at the initial stage of friction, and then gradually decreased with the number of repeat passages.

Figure 5 shows optical images of each block specimen after testing under electrical current without arc-discharge. The worn area of the Cu/C/RBC composite was significantly smaller than those of the Cu/C composite.

Figure 6 shows the comprehensive tribological properties of each composite under electrical current without arc-discharge. The Cu/C/RBC composite showed the tribological properties significantly superior to the Cu/C composite. The Cu/C/RBC composite showed 98% reduction in the specific wear rate of the block specimen, 23% reduction in that of the ring specimen, and 75% reduction in the friction coefficient over the conventional Cu/C composite.

Figure 7 shows scanning electron microscope (SEM) images of the worn surfaces of each block specimen after testing under electrical current without arc-discharge. Plastic flows of the copper parts possibly caused by severe adhesion were observed on the worn surface of the Cu/C composite. On the other hand, smoother surfaces and smaller areas of the copper parts were observed on the worn surface of the Cu/C/RBC composite.

In the Cu/C composite, severe adhesion of copper/copper caused high specific wear rate greater than 10^{-7} mm²/N. Additionally, expansion of real contact areas due to high wear produced the increase of friction coefficients at the initial stage of friction in Fig. 4. On the other hand in the Cu/C/RBC composite, severe adhesion of copper/copper hardly occurred. This

non-occurrence prevented expansion of the copper areas. Thus, the friction coefficients took lower and more stable values regardless of the number of repeat passages.

Fig. 4 Relationship between friction coefficient and number of repeat passages

(a) Cu/C composite (b) Cu/C/RBC composite
Fig. 5 Optical images of each block specimen after testing without arc-discharge

Fig. 6 Comprehensive tribological properties of each composite without arc-discharge

(a) Cu/C composite

(b) Cu/C/RBC composite

Fig. 7 SEM images of worn surface of each block specimen after testing without arc-discharge

3.2. Wear properties under electrical current with arc-discharge.

The specific wear rate of a slider material tends to increase with the arc-discharge rate I_A expressed by the following equation⁷⁾:

$$I_A = \frac{p}{100} \times I \quad (1)$$

where, p is average contact break ratio, I is electrical current. Handa and Kubo⁷⁾ evaluated the wear resistance to arc-discharge by the slope of the approximate line between the specific wear rate of the block specimen and the arc-discharge rate ws/I_A .

Figure 8 shows the relationship between specific wear rates of block specimens and arc-discharge rates. The specific wear rates of both composites linearly increased with the arc-discharge rate. Besides, the slopes of the approximated line for each composite was equal ($ws/I_A = 1.8 \times 10^{-8} \text{ mm}^2\text{-s}/(\text{N}\cdot\text{C})$), which indicates that the Cu/C/RBC composite showed the wear resistance to arc-discharge equivalent to the Cu/C composite.

Figure 9 shows SEM images of the worn surfaces of each block specimen after testing under electrical current with arc-discharge. Wear particles of copper disappeared from the surfaces of both composites.

It can be considered that the dissipation of copper particles is caused by a high temperature over the melting point of copper.

On the basis of the experimental results, it can be concluded that the Cu/C/RBC composite has the tribological properties under electrical current without arc-discharge superior to the Cu/C composite.

4. Conclusions

- (1) The Cu/C/RBC composite ($\alpha = 5 \text{ wt}\%$, $d_m = 4.9 \mu\text{m}$) showed 98% reduction of in the specific wear rate of the block specimen, 23% in that of the ring specimen, and 75% in the friction coefficient over the conventional Cu/C composite under electrical current without arc-discharge.
- (2) The wear resistance to arc-discharge of the Cu/C/RBC composite was equivalent to that of the conventional Cu/C composite.

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Fig. 8 Relationship between specific wear rate of block specimen and arc-discharge rate

(a) Cu/C composite (b) Cu/C/RBC composite

Fig. 9 SEM images of worn surface of each block specimen after testing with arc-discharge

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