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Arc erosive characteristics of a carbon strip sliding against a copper contact wire in a high-speed electrified railway

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ABSTRACT

Experimental studies on arc erosive characteristics of a carbon strip rubbing against a copper contact wire were carried out on a ring-on-block electrical sliding tester. The test result shows that the intensity of arc discharge has a significant influence on friction and wear performance. These arc erosive characteristics are characterized by two special traces. SEM examination shows that arc erosion and oxidative wear caused by arc discharge are the main wear mechanisms. This indicates that the off-line arc discharge of the contact couple should be suppressed to the maximum extent to extend the service life of the pantograph strip in high-speed electrified railways.

1. Introduction

In recent years, the operation speed of high-speed trains has reached 250–350 km/h. The driving power of the trains has reached 8000–10000 kW. This energy is transmitted to the running train through the pantograph strip which rubs against the contact wire. The pantograph strip/contact wire system is used under such a poor condition that the wear of the pantograph strip and contact wire materials is severe. In China, most of the pantograph strips of electrified railway locomotives are imported from foreign countries. The wear life of imported pantograph strips is very short, only about $8–10 \times 10^4$ km/piece. The Beijing–Shanghai high-speed railway line also experiences severe wear of the pantograph strip. This severe wear involves high maintenance costs. For this reason, it is very important to study friction and wear behavior of the pantograph strip rubbing against the contact wires in high-speed electrified railway lines. Several investigations have been performed to study the anti-wear properties of pantograph strips and contact wire materials, particularly the friction and wear behavior of electric contact materials. Their ultimate aim was to reduce the wear levels of pantograph–catenary systems and consequently reduce the life cycle costs [1–4]. Lubrication is an effective mean of reducing friction and decreasing wear. Several studies have also focused on the effects of oxidative films at the electrical contact interfaces [4–8]. The effects of lubrication on wear of electrical sliding contact materials were also studied. Several mechanisms of electrical sliding wear including abrasive wear, adhesive wear, oxidation wear and arc erosive wear have been reported [3,9–14]. However, less effort has been made to study the effects of arc discharge on the friction and wear behavior of electric contact materials in the high-speed electrified railways. The authors' experience suggests that experimental testing of electrical contact materials may lead to excessive wear of strip materials due to severe arc discharge.

In present work, a large-scale tester was developed and used to study the effect of arc discharge on the friction and wear behavior of a carbon strip rubbing against a copper contact wire. This paper presents some test results. The mechanism of arc erosion proposed here is based on observations and analysis of the worn scars on the carbon strip and the copper contact wire.

2. Test equipment and procedures

2.1. Test apparatus

The test machine has been described in detail in previous works [14–16]. Here, the couple consisting of a carbon strip and a copper contact wire is particularly introduced. As shown in Fig. 1, the rotational disc is driven by a variable-frequency 58 kW motor. The sliding velocity of the rotational disc with respect to the collector strip varies from 0–400 km/h to simulate the sliding speed of pantograph strip of electrified railways in the longitudinal direction. The collector strip frame oscillates at an amplitude of 60 mm and at a frequency of 0.3–3 Hz in the vertical direction to partially simulate staggering of the contact wires of electrified railways on the

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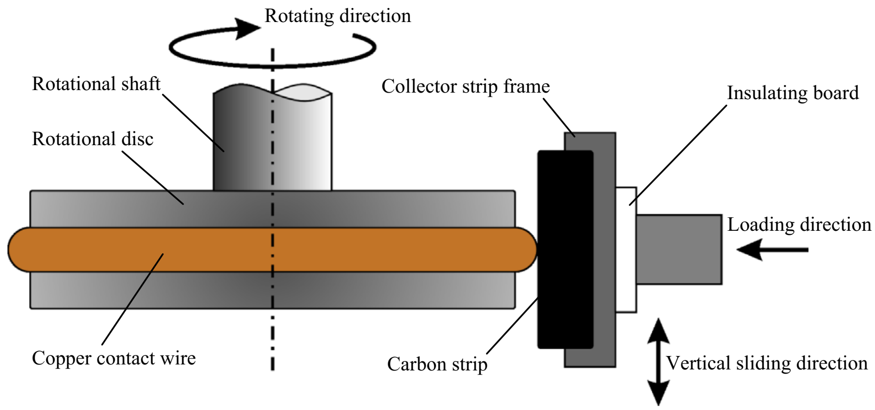

Fig. 1. Schematic of the carbon strip/copper contact wire couple.

horizontal plane. The collector strip frame is driven by an electric servo actuator to provide a steady normal force F_n between the collector strip and the contact wire. The normal force varies from 10 to 300 N. The force sensor is placed on the collector strip frame. The friction force F_t between the collector strip and the contact wire is measured by the force sensor. The friction coefficient μ is calculated based on the following formula: $\mu = F_t / F_n$.

2.2. Test materials

Here, the pure carbon strip and copper contact wire, which have been widely used in high-speed railways, were chosen as test materials. The pure carbon strip was formed into a rectangular-shaped block of 135 mm × 34 mm × 25 mm. The copper contact wire was bent into a circular ring with a diameter of 1100 mm and embedded into an annular groove of the rotational disc without joint. The chemical compositions of the pure carbon strip and pure copper contact wire were introduced in a previous study [14].

2.3. Test parameters and test procedures

The test parameters were set as follows. An electric current I of 0, 180, 200, 220 and 240 A was applied. The tangential speed of the rotational disc v was set to 150, 160, and 170 km/h. The normal force F_n was set to 30, 60, 90, 120, and 150 N. The sliding distance of the contact wire relative to the collector strip S was set to 150 km. For the vertical reciprocating movement of the pure carbon strip, the frequency and sliding stroke were set to $f = 1$ Hz and $A = 55$ mm, respectively. An electronic balance with an accuracy of 0.1 mg was used to measure the wear volume of the pure carbon collector strip. A digital camera was used to take pictures of the worn scars. A scanning electron microscope (SEM) was used to observe the morphology of the worn scars. The profile of worn surfaces was measured with an Ambios XP-2 profiler. The friction force, sliding speed, and normal load of the contact couple were recorded automatically using a data acquisition system. To create a good contact condition, the strip sample was rubbed against the contact wire at a low speed of about 20 km/h without electric current for 10 min. Before testing, pure carbon strips and copper contact wires were polished by abrasive papers with grain 1000. Their surface roughness was approximately $R_a = 1.6$ μm.

3. Results and discussion

3.1. Friction coefficient

Previous studies have indicated that the intensity of arc discharge is determined by the intensity of electric current. The more intense the electric current, the more intense the arc discharge [14,16–19].

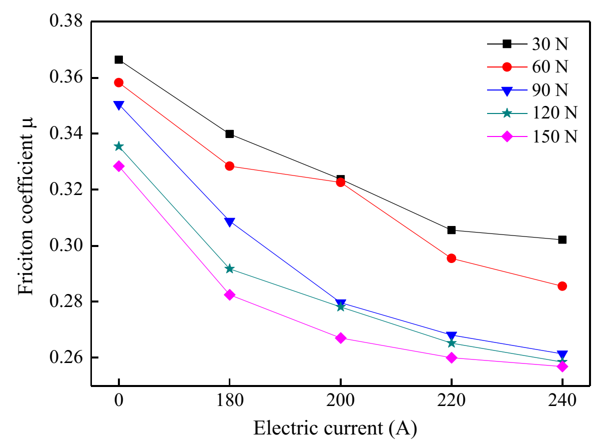

Fig. 2. Variation of friction coefficient with electric current.

Fig. 2 shows that the friction coefficient varies from 0.330 to 0.370 in the absence of arc discharge. However, the friction coefficient decreases significantly and fluctuates between 0.257 and 0.339 in the presence of arc discharge. Results also show that the friction coefficient in the absence of arc discharge is much greater than that in the presence of arc discharge under the same conditions. The friction coefficient decreases as the intensity of arc discharge increases. When arc discharge occurs in the electric sliding process, arc heat and frictional heat easily cause material oxidation and produce an oxidative layer at the interface. The oxidative layer acts as a lubrication, decreasing the friction coefficient [9,20–24]. In addition, the carbon particles of carbon strip may form a good lubrication film, which may also reduce the friction coefficient. In the absence of arc discharge, the frictional heat may be too slight to oxidize the contact materials. In this case, the lubrication film does not form easily at the interface. In this way, the friction coefficient increases in the absence of arc discharge.

3.2. Wear rate of pure carbon strip

Fig. 3 shows the variation in the wear rate of the carbon strip with and without electric current. In the absence of arc discharge, the wear rate is the lowest, about 0.00096 g/km. In the presence of arc discharge, the wear rate is very high, generally no less than 0.00259 g/km. As shown in Fig. 3, the wear rate of pure carbon strip increases in a near- linear fashion as the intensity of the arc discharge increases. And the fitting curve is expressed with the pink line as shown in Fig. 3. When the electric current is 240 A, the intensity of arc discharge is the strongest. The wear rate of carbon