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Sliding electrical contact behavior of brass fiber brush against coin-silver and Au plating

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ABSTRACT

Sliding electrical contact behavior of the brass fiber brush with 23% packing fraction was investigated as sliding against coin-silver and Au plating under vacuum and air conditions. The friction coefficient, contact resistance and electrical noise of the brushes were analyzed. The microstructure and worn surfaces of the brass fiber brush and counter discs were observed to discover the involved wear mechanisms. The friction coefficients in vacuum are much higher than those in air. The contact resistances and electrical noises of the brush against both discs in vacuum are extremely low. The contact resistance against coin-silver quickly increases as the sliding condition varies from vacuum to air, which is much higher than that against Au plating. Sliding speed has an insignificant effect on the contact resistance and electrical noise of fiber brush. Formation of oxide film and loose oxide particles on the worn surfaces of fibers and the coin-silver disc leads to the increase of contact resistance and electrical noise. The transfer of gold from Au plating to worn surfaces of brass fibers is used to prevent the oxidation of fibers and keep the contact resistance and electrical noise in a relatively low level. The multi-contact mechanism of brass fiber brush has been also discussed.

1. Introduction

Metal fiber brush is a new kind of sliding electrical contact material that can effectively transfer electrical power or signals from a stationary part to a moving part [1]. Generally, metal fiber brush is composed by many metal fibers aligned along the length direction. According to the working surface of the metal fibers, metal fiber brushes can be divided into two kinds: lateral contact type and end contact type. The lateral contact type brush uses the lateral surface of metal fibers as the working contact surface [2,3], while the end contact type applies end surface of metal fibers as the working contact surface [4–6]. Regardless of contact type, both brushes are designed to provide more contact spots, so the brush can sustain stable and reliable contact with the slip ring surface and transport electrical current. In fact, each metal fiber could be treated as a small independent brush. When lots of metal fibers work together under elastic contact instead of plastic contact, the real contact area of the brush would be much higher than traditional monolithic brushes under the same load. Therefore, comparing to traditional monolithic brushes, metal fiber brushes with the multi-contact structure are expected to have the following performances: 1) high current carrying capacity, 2) low electrical noise, 3) long service life, 4) high sliding velocity, 5) less heat generation, 6) less wear debris and 7) compact structure [7–9].

In fact, the earliest use of electrical brush, applied in generator, was formed by a bundle of copper wires in eighteenth-century. However, it was soon replaced by graphite and metal-graphite brushes, because the wires brush wore quickly and caused heavy wear of counter surface. After then, monolithic brushes were wildly used and multi-contact brushes almost disappeared. Recently, with the improvement of electric generators and slip-rings, the shortcoming of monolithic brushes becomes more and more obvious. The main drawback of monolithic brushes is their low number of contact spots, which influence the contact resistance, electrical noise, current density and other related performances. Then, multi-contact fiber brushes are again back to the focus of researchers [10–13]. Kuhlmamm-Wilsdorf [1,8] carefully analyzed the reasons for failure of the copper wire brush, and found that big wire diameter and high wire packing fraction are the main two reasons attributed to the failure. Hence, fine metal fibers (often below 100 μm) with good elasticity are suggested to be used in brushes. Aligned multiwalled carbon nanotubes were even prepared for electrical brushes [9]. Low packing fraction of fibers would offer much open space for the elastic bending of fibers. Thus, fibers can work independently to keep contact with the changing topography of a sliding surface. In order to provide a low

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contact resistance, metal fiber brushes generally work under direct metal-to-metal contact without lubricating supplied by oil or solid lubricant. Hence, the selection of appropriate work environment and counterface materials is very important for lightening the adhesive wear or oxidation wear. Humid carbon dioxide was applied as a protective environment to the copper fiber brush-copper ring slip-ring systems [14,15]. The wear mechanisms of the brass fiber brush were found to be strongly depended on the counterface materials under dry sliding condition [16]. Owing to the high performance as sliding electrical contacts, metal fiber brushes are expected to be applied in solar array drive mechanism of spacecraft, de-icing systems of helicopter, hydro-electric generator, wind power, submarine motor generator and so on. Therefore, investigation on the sliding electrical contact behavior of metal fiber brush both in vacuum and in atmospheric environments is essential.

In this paper, the sliding electrical contact behavior of the brass fiber brush with packing fraction of 23% was investigated as sliding against coin-silver and Au plating discs under vacuum and air conditions. The friction coefficient and contact resistance of the brass fiber brush were recorded in function of sliding distance. The electrical noises were calculated from the variation of contact resistance. The microstructure and worn surfaces of the brass fiber brush and the mating discs were carefully observed. The effects of mating discs and environments on the sliding electrical behaviors of brass fiber brush were investigated. The multi-contact mechanism of brass fiber brush was also briefly discussed.

2. Experimental

2.1. Materials

The metal fiber brush as shown in Fig. 1 was prepared by a filling and dissolving method. Brass (Cu20Zn) fibers owing excellent elasticity, electrical conductivity, anti-wear and anti-corrosion properties were used as the raw material. The diameter of brass fibers is 50 μm. During preparation, the brass fibers were firstly uniformly mixed with Al fibers, and then they were pressed into a block. Afterwards, one end of the compressed block was immersed into sodium hydroxide solution to dissolve away the Al fibers, exposing an array of brass fibers. The residual Al fibers in another end of the brush squeeze the brass fibers to avoid falling off. The brass fibers are homogeneously separated by the filled aluminum fibers in the brush. The detailed preparation procedure can be reached in our previous paper [16]. A brass fiber brush with the packing fraction of 23% was prepared and tested in this paper. The free length of the brass fibers in the brush is about 20 mm. There are about 11,500 brass fibers in one square centimeter at the end cross-section of the brush.

The coin-silver with the composition of Ag-10wt%Cu was applied as one counter disc, which had a hardness of 130 HV. The Au plating disc prepared by the electroplating method was also used as the mating surface of the brass fiber brush. The cross section of the Au plating is shown in Fig. 2a. An about 10 μm cobalt gold (0.2 wt% Co) layer was plated on a 20 μm nickel layer, and the substrate of the coating is pure copper. The micro-hardness of the Au plating and the nickel plating are 185 and 551 HV, respectively. The intermediate nickel plating can provide a hard substrate to the Au plating, and can also prevent the diffusion of copper atoms from the substrate into the Au plating. Fig. 2b reveals the original top-view surface of Au plating. The surface of coin-silver disc was polished by 1000 mesh SiC paper before tests, and the surface of Au plating was of the original electroplating morphology. The average roughness (Ra) values of the coin-silver and Au plating were about 0.16 and 0.12 μm respectively.

2.2. Friction and wear tests

Sliding electrical contact tests were performed using a self-made vacuum tribometer. Fig. 3 shows the test apparatus and electrical circuit applied for the sliding electrical contact tests. The brass fiber brush was sliding on the surface of coin-silver or Au plating disc with electrical current. A negative brush and an auxiliary brush were sliding on the side of disc. A constant current flowed from the positive of DC supply to the test brush, the mated disc, and then through the negative brush and a constant resistance back to the supply. The contact area of the brush was 72 mm^2. The normal contact load of the brush was chose to be 2 N and the sliding speeds were selected to be 100 rpm (0.265 m/s). Sliding speeds of 10, 20, 50, 75 and 100 rpm were used to investigate the effect of sliding speed on the electrical noise. The diameter of disc wear track was 50 mm. The brush was first tested in the high vacuum condition with a pressure of 10^{-5} Pa for

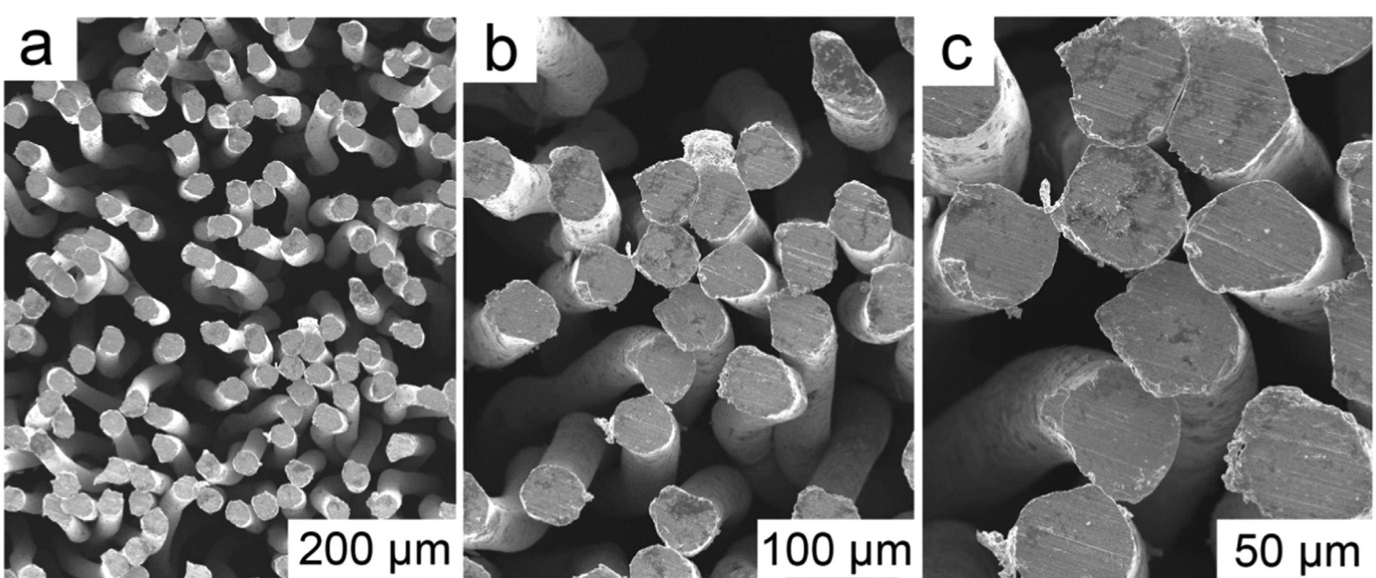

Fig. 1. SEM micrographs of brass fiber brush with 23% packing fraction in different magnifications.