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Arc erosion behavior of Ag/Ni electrical contact materials

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ABSTRACT

Ag/Ni electrical contact materials tend to be weld together under high current and/or high temperature, which was a key problem to restrict the usage of Ag/Ni electric contact materials. Arc erosion characteristics of Ag/12Ni electrical contact material after 50,000 operations under direct current 19 V, 20 A and resistive load conditions were investigated. The result indicated that the probability distribution and change trend of arc energy and arc time during 50,000 operations were similar and the relationship between arc time and arc energy followed exponential function. On the one hand, "Crater" type erosion pit, island-like melted silver, pore, crack and coral-like structure spitting were observed on erosion surface of Ag/Ni contact materials. On the other hand, distribution of Ag and Ni element on molten pool of movable contact was different from that of stationary contact. For movable contact, element Ni mainly distributed on melted pool root, whereas element Ag mainly distributed inside of melted pool. For stationary contact, however, element Ni and Ag distributed layer by layer. Furthermore, arc erosion of stationary contact is more serious than that of movable contact.

1. Introduction

Electrical contacts have found a variety of applications due to their high conductivity, low contact resistance and good arc erosion resistance [1–4]. For example, Ag/Ni electrical contact materials are used for household applications, contactors, miniature circuit breakers and automobile relays due to their low and stable contact resistance, excellent machinability, high resistance of electrical loss and non-toxcity [5]. However, Ag/Ni electrical contact materials tend to be weld together under high current and/or high temperature. As a result, a large number of researchers have focused on arc erosion properties of Ag/Ni electrical contact materials in order to improve their welding resistance. For example, Yoshida and coauthors clarified the influence of voltage on arc characteristics [6], arc duration [7] and electrode mass change [8] of Ag/Ni contacts for electromagnetic contactors. Morin et al. [9] found that Ag/Ni electrical contact materials had high local materials transfer under lamp and resistive loads at 14VDC and current range from 10 to 70 A. Kawakami et al. [10] discussed that the possibilities of lifetime predictions in terms of cathode losses and arc energy with the data of Ag/Ni contacts for electromagnetic contactor. Doublet et al. [11] investigated the arc erosion, welding tendency and welding forces of Ag/Ni electrical contact materials under resistive load at current range from 10 to 90 A. Luo et al. [12] investigated the arc erosion characteristics of Ag/Ni electrical contact materials fabricated by mechanical alloying. Liu et al. [13] found that the welding resistance of Ag/10Ni was relatively bad under high arc energy. Li found [14] that the arc erosion resistance of Ag/10Ni electrical contact materials fabricated by chemical coating method was better than that fabricated by powder metallurgy method. Huang et al. [15] indicated that Ag/10Ni electrical contact materials fabricated by chemical co-deposition method had strong welding resistance. Yan et al. [16] suggested that the addition of brittle materials could improve the electrical performance of Ag/Ni contact. Chen et al. [17] indicated that RE (rare earth) could improve the electrical performance of Ag/Ni contact. Li et al. [18] found that Ag/Ni contact had serious material transfer. They indicated that the improvement of material transfer between Ag/Ni contact not only considers material intrinsic nature but also matching among them. Tan et al. [19] studied the arcing mechanism and electric corrosion patterns of Ag/10Ni contact under low voltage and direct current after single breaking operation. Their results indicated that the arc erosion spot area is a linear function of load current. Li et al. [20] investigated the arc erosion of Ag/Ni contact at 50 Hz and 400 Hz. They found that the welding resistance of Ag/10Ni contact was better at 400 Hz while the arc erosion resistance was better at 50 Hz. Li et al. [21] analyzed the arc energy, arc time and welding force of Ag/Ni contact. They indicated that the arc time of Ag/10Ni contact fabricated by chemical co-deposition method was longer with higher arc energy. Zheng and coauthor [22] studied the arc erosion morphology and formation mechanism of Ag/Ni contact. Eight distinct types of surface morphologies were observed after arc erosion.

However, little information is available on element distribution and formation mechanism of molten pool of Ag/Ni contact after arc erosion in literature. Information on element distribution and formation

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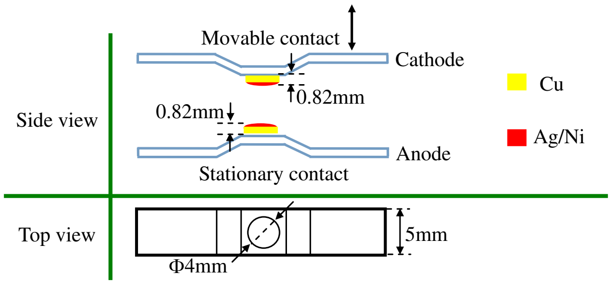

Fig. 1. CAD drawing of contacts.

mechanism of molten pool is helpful to improve the welding resistance and electrical performance of Ag/Ni contact. The aim of this work is therefore to investigate arc erosion behavior of Ag/12Ni contact and discuss relationship between electrical contact physical phenomena and formation mechanism of molten pool.

2. Experimental procedures

2.1. Tested contacts

The form of contacts is shown in Fig. 1. The movable and stationary contacts have a curved surface. Ag/12Ni (Ag: 88 wt.%; Ni: 12 wt.%) contact material fabricated by powder metallurgy technology is selected as a contact material, which manufacture technology flow diagram is represented in Fig. 2 and properties are represented in the Table 1.

2.2. Experimental apparatus

Apparatus used in this experiment are shown in Fig. 3. The system consists of measuring and test equipment such as industrial PC, signal collecting, measuring and protection device, contact motion simulator and steady flow test power system. The data of arc energy, arc time and welding force can be collected used by this apparatus. Three contact samples were tested in this article considering the repeatability of experimental results.

2.3. Experimental conditions

The experimental conditions are shown in Table 2. The load current was set at DC 19 V 20 A, and current-carrying time was about 0.3 s. The arc energy, the arc time and the welding force were measured during the operation under the above conditions. In this paper, the mass losses were measured using an electrical scale. By using the scale, mass changes of more than 0.1 mg can be measured with accuracy. The microstructure was characterized by both an optical microscope (POLYVAR-MET) and a scanning electron microscope (Sirion200) equipped with an energy dispersive energy diffraction spectroscope (Gensis60). The element map analysis and composition quantitative analysis were used by electron probe micro-analyzer (JXA-8230).

Table 1
Properties of Ag/12Ni materials fabricated by powder metallurgy technology.

Density (g/cm^3)	10.36
Electrical contact resistance (μ Ω · cm)	1.92
Strength of extension (MPa)	312
Elongation after fracture (%)	19
Hardness (Hv0.3)	83

3. Results

3.1. Electrical contact physical phenomena

Electrical contact physical phenomena, such as arc energy, arc time, welding force, etc., will change due to the changing of contact surface microstructure and composition under arc erosion. An average every 100 operations of arc energy, arc time and welding force of Ag/12Ni electrical contact materials during 50,000 operations is represented in Fig. 4. Change trend of arc time and arc energy during 50,000 operations is similar, which is different from welding force. When operation numbers are less than 8000, arc time and arc energy increase with the increase of operation numbers. But they decrease when the operation numbers increase from 8000 to 15,000, and then they basically keep stable when operation numbers increase from 15,000 to 50,000. As well as arc time and arc energy, when operation numbers are less than 8000, welding force increases with the increasing of operation numbers. Welding force decreases when the operation numbers increase from 8000 to 10,000. It basically keeps stable when operation numbers increase from 10,000 to 30,000. But it first increases and then decreases when the operations increase from 30,000 to 40,000, and then it basically keeps stable when the operation numbers increase from 40,000 to 50,000. Consequently, electrical contact physical phenomena (arc time, arc energy and welding force) every operation change under the action of arc erosion.

Mass of movable and stationary contact will change under the action of arc erosion due to evaporation and splash erosion. In addition, material transfer occurs between movable and stationary contact during arc operation and also will result in their mass change. In this experiment, mass on movable and stationary contact decreases (movable contact mass loss: 2.7 mg; stationary contact mass loss: 4 mg) after 50,000 operations. Mass loss of stationary contact is larger than that of movable contact, which indicates that arc erosion of stationary contact is more serious than that of movable contact.

3.2. Erosion morphology of Ag/Ni contact materials

3.2.1. Macro-morphology

Macro-morphology of Ag/12Ni contact material after 50,000 operations under the above conditions is represented in Fig. 5, where surface morphology of movable and stationary contact is changed due to the arc erosion. On the one hand, serious deformation has been observed on both movable and stationary contact surface due to action of arc erosion and contact force. On the other hand, splash erosion also has been observed on both movable and stationary contact surface (see red circle in Fig. 5a and b). Furthermore, arc erosion on stationary contact surface is more serious than that on movable contact surface, which is consistent with the result of mass loss in the above.

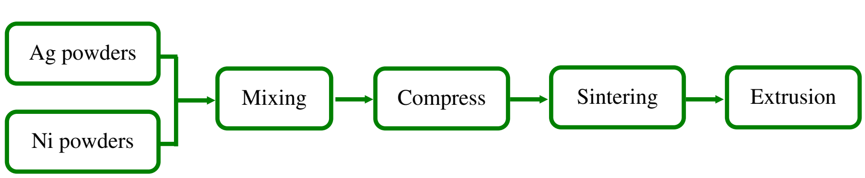

Fig. 2. Flow diagram of manufacture technology of Ag/12Ni electrical contact material.