Effect of SnO\textsubscript{2} content on properties and microstructure of Ag/SnO\textsubscript{2} electric contact materials

J B Wang\textsuperscript{1,4}, H H Qiu\textsuperscript{2}, F Si\textsuperscript{1}, Y B You\textsuperscript{1}, S T Liu\textsuperscript{1} and N H Matsumoto\textsuperscript{3}

\textsuperscript{1}School of Materials Science & Engineering, Xi’an Polytechnic University, Xi’an, Shaanxi, 710048, China
\textsuperscript{2}Mitsubishi Electric (China) Co., Ltd, 200336, China
\textsuperscript{3}Mitsubishi Electric Corporation Advanced Technology R&D Center, Japan

Email: wangjunbo@xpu.edu.cn

Abstract. In order to explore the effects of SnO\textsubscript{2} content on the properties and microstructure of Ag/SnO\textsubscript{2} electric contact materials with low silver content. A series of Ag/SnO\textsubscript{2} electric contact materials with different SnO\textsubscript{2} content were prepared and their arc erosion properties and physical properties were tested. The results show that with the decrease of Ag content, the hardness of Ag/SnO\textsubscript{2} contact materials increases, and the conductivity and density decrease. When the Ag content is 88%, Ag and SnO\textsubscript{2} enrichment zones are formed on the surface of the Ag/SnO\textsubscript{2} contact material after arc erosion test. When the silver content is less than 82%, the surface microstructure of the Ag/SnO\textsubscript{2} contact material after arc erosion is uniform, and no obvious Ag and SnO\textsubscript{2} enrichment zones were formed, but cracks and pores increased.

1. Introduction

Ag/SnO\textsubscript{2} electric contact materials has excellent arc erosion resistance as a substitute for Ag/CdO contact materials, at the same time, a large number of Ag/SnO\textsubscript{2} electric contact materials are used in the field of low voltage electrical appliances due to its non-toxicity and environmental protection [1-5]. However, in order to ensure good conductivity, Ag content in Ag/SnO\textsubscript{2} electric contact materials is generally higher, which results in high cost of Ag/SnO\textsubscript{2} electric contact materials. In order to reduce the cost, many researchers use various methods to prepare low-silver Ag/SnO\textsubscript{2} electric contact materials and carried out performance tests [6-7]. However, little research has been done on the performance changes of Ag/SnO\textsubscript{2} electric contact materials with multiple concentration gradients at low Ag content. Moreover, the reduction of Ag content has a decisive effect on the performance of Ag/SnO\textsubscript{2} electric contact materials. Therefore, the systematic study of the influence of Ag content on the properties of Ag/SnO\textsubscript{2} electric contact materials has very important application value.

In this paper, a series of Ag/SnO\textsubscript{2} electric contact materials with different silver content were prepared by powder metallurgy process. The physical properties and arc erosion resistance of contact materials with different silver content were tested. The effects of silver content reduction on the properties of contact materials were analyzed by observing the surface micro-morphology and element distribution of Ag/SnO\textsubscript{2} electric contact materials with different silver content after arc erosion test.
2. Experimental methods

2.1. Processing method of Ag/ SnO\textsubscript{2} contact materials
Ethanol, ammonia, SnCl\textsubscript{4}•5H\textsubscript{2}O were used to compound the pure SnO\textsubscript{2} powder by chemical co-precipitation method. Then, the pure SnO\textsubscript{2} (12wt.%, 18wt.%, 24wt.%, 30wt.%) and Ag powders were mixed and high-energy ball milled for 2h respectively. The ratio of ball to material is 10:1. In order to release the milling stress, the ball-milled Ag/SnO\textsubscript{2} composite powders were annealed at the temperature of 573K for 2h. The Ag/SnO\textsubscript{2} composite powder is pressed under 200MPa, and sintered at 1123K for 5h, then re-pressed under 800MPa.

2.2. Physical performance testing
A Vickers micro-hardness tester (MH-3, Shangguang Instrument Factory) was used to test the hardness. Density measurements of the samples were implemented by using Archimedes method. The conductivity of the samples was tested by an Eddy Current Nondestructive Conductivity Instrument.

2.3. Arc erosion test
The samples were fitted into brass holder for test. The contact force applied to the closed contact is 2N. Each sample was tested (make and break 1000 operations) under the current in DC of 10A.

2.4. Phase structure and microstructure test
The composition and microstructure of samples after fusion welding were detected by scanning electron microscope (SEM) and energy dispersive spectrometer (EDS).

3. Results and discussion

3.1. Effect of SnO\textsubscript{2} content on the microstructure of Ag/SnO\textsubscript{2} contact material

![Figure 1. SEM images of Ag/SnO\textsubscript{2} contact materials with different Ag contents: (a) 88%, (b) 82%, (c) 76%, (d) 70%](image-url)
Figure 1 shows the microstructure and morphology of Ag/ SnO$_2$ contact materials with different SnO$_2$ contents. The light area is silver matrix and the dark area is SnO$_2$. From figure 1(b) and 1(c), we can see the SnO$_2$ oxide particles are distributed in the Ag matrix, and no obvious pores, cracks or other defects are found. This is because in the process of high-energy ball grinding, Ag and SnO$_2$ particles can be repeatedly extruded, cold welded, broken and fully mixed under the action of mechanical forces such as extrusion, impact, shear and friction. High energy will make the SnO$_2$ particles with high hardness penetrate into the silver matrix with low hardness, so that each component forms a coating, and finally forms the Ag/SnO$_2$ contact material with uniform distribution of components [8].

By comparing figure 1 (a) ~ (d), it can be found that with the increase of SnO$_2$ content, for the Ag/SnO$_2$ contact material containing 82 and 76% silver contents, SnO$_2$ particles are evenly distributed in the silver matrix. However, when the silver content is 88% and 70%, an agglomeration obviously exists in the Ag/SnO$_2$ contact material. Therefore, the uniformity of mixed powder of contact materials needs to be further improved.

3.2 Physical properties
The results of physical performance test are shown in figure 2. It can be seen that density and electrical conductivity of the samples are decrease as the Ag content goes down, while hardness of the samples increase with the decrease of the Ag content. This is because the uniform distribution of SnO$_2$ particles increases the chance of contact between SnO$_2$ particles and Ag matrix, therefore promoting the growth and formation of sintered neck. In addition, nano-sized SnO$_2$ particles possess a large surface energy, it is conducive to sintering and forming a more compact AgSnO$_2$ contact material. With the increase of SnO$_2$ content, fine SnO$_2$ particles are easy to agglomerate, which reduces the chance of contact between SnO$_2$ particles and Ag matrix. The agglomerated hard SnO$_2$ particles will have a cleavage effect on Ag matrix, thus reducing the density of contact materials. At the same time, density and conductivity of SnO$_2$ particles are much lower than Ag matrix, which result in the decrease of density and conductivity of Ag/SnO$_2$ contact materials with the decrease of Ag content. And the increase of hardness is because of the increase of harder SnO$_2$ reinforcing particles [6].

![Figure 2](image1.png)

**Figure 2.** Physical properties of Ag/SnO$_2$ contact materials with different Ag contents: (a) conductivity, (b) density, (c) hardness

3.3 Morphology changes of Ag/SnO$_2$ contact materials after arc erosion
The SEM images of Ag/SnO$_2$ contact materials after arc erosion are shown in figure 3. The results show that the surface of Ag/SnO$_2$ contact materials with 88% Ag content after arc erosion test is rough. Moreover, micro cracks appear in the depressed area. With the decrease of Ag content, the obvious bumps and depression areas of the Ag/SnO$_2$ contact materials are decrease after arc erosion, but when the Ag content below 82%, more cracks and pores appear on the surface with the decrease of Ag content.
Figure 3. SEM images of Ag/SnO$_2$ contact materials with different Ag content after arc erosion test: 
(a) 88%, (b) 82%, (c) 76%, (d) 70%

Generally, it is believed that arc erosion usually occurs in components with low-escape power [9]. Since the escape work of Ag and SnO$_2$ are 4.70 eV and 3.54 eV [10], SnO$_2$ is more likely to be eroded first. For Ag-SnO$_2$ contact materials, the first arc is easy to occur in the weak breakdown phase SnO$_2$. When the cathode spots go out, the secondary arc is more likely to occur in SnO$_2$ around the primary arc area. The arc jumps from the extinguished arc root to the new weak breakdown phase to reignite the arc, forming the arc root on the SnO$_2$ particles. The area of weak breakdown phase increases with the increase of SnO$_2$ content. With the repeated erosion, the arc is continuously extinguished and generated, and a large amount of arc heat is generated. Under the electromagnetic force and friction force, Ag is vaporized in the gas phase and splashed in the liquid state, and the repeated liquid-solid transformation leads to the uneven surface of the material and forming deeper corrosion pits. At the same time, rapid heat and cold make cracks appear.

In addition, when Ag content was 88%, SnO$_2$ content was low, SnO$_2$ particles dispersed well in Ag matrix and have a large contact area with liquid Ag, which increases the viscosity of silver melting pool and thus reduces Ag splashing [11]. Therefore, under the action of multiple arcs, the ablation degree of material surface is small and surface defects are few. With the decrease of Ag content, high SnO$_2$ content resulted in serious agglomeration of SnO$_2$ particles. Under the repeated action of the arc, a single arc is easy to gather into a larger arc, which makes the mobility of the arc worse and easy to stay in a certain position for a long time. As a result, the ablation of the material surface is serious and there are many holes and cracks.

In order to find another reason of microstructure changes of Ag/SnO$_2$ contact materials with different silver content, EDS was used to test the surface element distribution of Ag/SnO$_2$ contact materials with different silver content after arc erosion, and the results were shown in Figures 4-7. The result shows that, after arc erosion test, the surface of Ag/SnO$_2$ contact materials with Ag content shows obvious element separation, the solidification of liquid silver mainly causes the formation of bumps, and the SnO$_2$-enrich area mainly exist in depressed areas. However, when the Ag content below 82%, the
The elements distribution of Ag/SnO$_2$ contact materials is uniformly, and there is no obvious single element aggregation.

**Figure 4.** Elemental mapping results of Ag/SnO$_2$ contact materials with 88% Ag content after arc erosion test

**Figure 5.** Elemental mapping results of Ag/SnO$_2$ contact materials with 82% Ag content after arc erosion test
Figure 6. Elemental mapping results of Ag/SnO$_2$ contact materials with 76% Ag content after arc erosion test

Figure 7. Elemental mapping results of Ag/SnO$_2$ contact materials with 70% Ag content after arc erosion test

4. Conclusion

1) The hardness of Ag/SnO$_2$ contact material increases with the increase of SnO$_2$ content, while the density and electrical conductivity decrease.

2) As the content of SnO$_2$ increases, the arc erosion area on the surface of Ag/SnO$_2$ contact material decreases, the corrosion pit deepens and the ablation degree increases.
3) After arc erosion test, Ag and SnO$_2$ enrichment zones were formed on the surface of the Ag/SnO$_2$ contact material with a 88% silver content. If the silver content is less than 82%, the surface microstructure of the Ag/SnO$_2$ contact material is uniform, and there are not obvious Ag and SnO$_2$ enrichment zones, but the number of cracks and pores is increased.

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