Investigation on Fusion Bridge of Au Electrical Contacts Material under Different Voltage

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Abstract. The fusion bridge phenomenon caused by Au contacts was investigated with the high speed video-electrical contact testing system built by ourselves. The microscopic topography of Au contacts surface was observed after the survey of fusion bridge size. The results in this paper revealed some novel phenomena and rules. The size of fusion bridges which generated during electrical contact process of Au contacts is micron scale when the load is DC 10 A (6 V to 15 V); The shape of fusion bridges has three types which are the cylindrical, dumbbell and frustum; With the increase of the voltage, the size of the diameter exhibit the characteristic of S type, and the change in length also has such a rule; the molten bridge behaviour can erode the Au contact surface and present the erosion surface with the characteristics of the molten pool, spray particles and convex hill, the droplet spray is the main form of the loss of Au contact material in the process of electrical contact.

1. Introduction

Electrical contact issues have received more and more attention due to their wide application in switching and conducting [1, 2]. Au was widely used in the fields of electrical, electronic, aviation and aerospace with the superior ductility and conductivity, the contact resistance of Au is low and stable and the oxidation resistance is strong [3]. In the microsecond time interval, the fusion bridge is produced in the breaking gap of contacts within micron scale [4-7]. The limit of contacting life and materials transfer can be attributed to the generation of fusion bridges [8-11]. The development of computer technology and numerical simulation technology provides an effective theoretical analysis means for the study of electrical contact phenomena. However, the research on the numerical simulation of Fusion Bridge and the establishment of related models are mostly based on the simplification and neglect of the shape and other factors from the formation to the disconnection process because of the lack of sufficient evidence about the evolution of fusion bridges and other related experimental [12-14]. Therefore, the research on the behaviour of the molten bridge is of great significance [15]. Observing fusion bridges directly, many difficulties will arise because of fusion bridges’ dimension (millimetre to micron size) and duration time (millisecond to microsecond interval) is too small [16].

To explore the fusion bridges phenomenon of Au contacts generated in dynamic processing, we built a high speed video-electrical contact testing system. With the Scanning Electron Microscope, the microstructure of contacts surface was studied after the electrical contact testing to further explore the fusion bridges’ evolution behaviour.
2. Experimental
The appearance of Au contact object studied in the experimental was cylindrical with the diameter of 2.0 mm. The contact surface was the bottom of the cylinder. The contact surface of the upper contact was processed into cambered by grinding and polishing while the contact surface of the lower contact is processed into plane. Experiments were carried out at DC 10 A (6 V, 8 V, 10 V, 12 V, 14 V, respectively). Thereinto, the anode contact was the upper one while the cathode contact was the lower one.

The high speed video-electrical contact testing system was mainly composed of four parts: the illuminant equipment, the testing machine of electrical contact, the system of scanning and the computer, illustrated in Fig.1. The adjustment of illuminant equipment and scanning system device were performed before the starting of experimental. Next, installed the video to high-speed mode, and opened the testing machine of electrical contact for experimental research. In the mode of break only and the DC load, the Au contacts were studied by the testing machine of electrical contact. The experimental parameters involved were breaking speed ($v = 20.0 \text{ mm}\cdot\text{s}^{-1}$) and contact force ($f = 0.50 \text{ N}$). The image capture rate of the high-speed video was 480 fps ($n = 480 \text{ fps}$) in this study, and the resolution of the captured picture was $224 \times 160$. The computer received video data from the high-speed video. The data was analysed by EDIUS6.0 software to select meaningful and representative images. Taking the diameter (2.0 mm) of the lower contact as the scale, the size of both the length and diameter of fusion bridges were measured with the Digimizer software. At last, the SEM was used to study the microscopic morphology of Au contacts surface after the testing of electrical contact.

3. Results and Discussion
3.1. High Speed Video Research on Fusion Bridges
The dynamic process trajectory of fusion bridges behaviour is illustrated in Fig.2 under the load of DC 10 A and 6 V. The time interval between each tow pictures is 2.08 ms. The breaking action of the anode shown in Fig.2a has begun, but the Au contact pairs are still not completely separated. As the breaking action of the anode contact continues, a fusion bridge appears between the gaps as shown in Fig.2b. The shape of the fusion bridge can be observed to be dumbbell when the picture is enlarged. The shape of the fusion bridge can be observed to be dumbbell when the picture is enlarged. With the increasing separation of the anode, the fusion bridge disappears so that the Au contact pairs are completely broken. Based on the cathode diameter value of 2.0 mm in Fig.2a, the contact area of Au contact pairs before disconnection is $600.406 \text{ μm}$ in diameter. In above method, the fusion bridge can be $81.093 \text{ μm}$ in diameter and $66.989 \text{ μm}$ in length as illustrated in Fig.2b.
The behaviour characteristics of fusion bridges under the load of DC 10 A and 8 V are similar to that under DC 10 A and 6 V, as shown in Fig.3. It can be seen from Fig.3b that the shape of the fusion bridge looks like a dumbbell. The contact area of Au contact pairs in Fig.3a has a diameter of 445.358 μm. The size fusion bridge occurred in Fig.3b can be 68.460 μm in diameter and 63.194 μm in length.

Under the condition of DC 10 A and 10 V, there is a cylindrical fusion bridge in the gap of Au contact pairs as illustrated in Fig.4b. The contact area of Au contact pairs in Fig.4a has a diameter of 632.860 μm. The size fusion bridge occurred in Fig.4b can be 267.245 μm in diameter and 59.161 μm in length. The contact area of Au contact pairs in Fig.4a has a diameter of 632.860 μm.

Figure 5b illustrates that the fusion bridge of frustum appearance in the gap of Au contact pairs under the load of DC 10 A and 12 V. With the continue breaking of the cathode, the fusion bridge is broken and then falling back to the surface of cathode. A small residual melt can be observed in Fig.5c which is retained on the surface of the cathode. The size fusion bridge occurred in Fig.5b can be 477.876 μm in diameter and 106.195 μm in length.
Figure 5. The dynamic process trajectory of fusion bridges under the load of DC 10 A, 12 V

Figure 6 shows the dynamic process trajectory of the fusion bridge under the load of DC 10 A and 14 V which are similar to that under DC 10 A and 12 V. A fusion bridge can be seen in Fig.6b which looks like a dumbbell appearance. The size fusion bridge occurred in Fig.6b can be 493.927 μm in diameter and 133.603 μm in length.

Under the load of DC 10 A and 15 V, the dynamic process trajectory characteristics of fusion bridge are similar to that under DC 10 A and 12 V, as shown in Fig.7. A fusion bridge can be seen in Fig.7b which looks like a frustum appearance. The size fusion bridge occurred in Fig.7b can be 347.242 μm in diameter and 121.186 μm in length.

Figure 6. The dynamic process trajectory of fusion bridges under the load of DC 10 A, 14 V

3.2. SEM Morphology on Au Contacts Surface
The microscopic topography of the Au anode surface after the testing of electrical contact is illustrated in Fig.8. An approximately circular erosion area is seen on the surface of Au contact pairs as shown in Fig.8a, which is formed by lots of overlapping fusion pools. The diameter of the erosion area is between 910 μm and 974 μm, which is consistent with the contact area diameter of the high speed video-electrical contact testing experiments. The typical fusion pool morphology is illustrated in Fig.8b. The fusion pool is seen like a circular shape and the size is about 50 μm which belongs to the same order of magnitude as the fusion bridge diameter of high speed video-electrical contact experiments. The surface of the molten pool is relatively flat and a small amount of spray particles can be observed in the vicinity of the molten pool edge.

Figure 7. The dynamic process trajectory of fusion bridges under the load of DC 10 A, 15 V
Figure 9 gives the microscopic topography of the Au cathode surface after the testing of electrical contact. The basic features of the erosion area of the contact surface can be observed from Fig.9a, including the shape of the circular, which consists of a number of molten spot and convex hills. The morphology characteristics of the convex hill are shown in Fig.9b. After the broken of molten bridge, the convex hill may be formed by the solidification of the melt down to the contact surface. There are a lot of molten spot and splash particles around the convex hill.

3.3. Discussion on the Experimental Results

The results of high speed video data on fusion bridges show that the duration time of the molten bridge from the appearance to the fracture is no more than 2.08 ms when the contact voltage is less than 10 V. While the contact voltage is higher than 10 V, the duration time of molten bridge will be between 2.08 ms and 4.16 ms. The size of fusion bridges formed during electrical contact of Au contact pairs is varied from 68.460 μm to 493.927 μm in diameter, and 59.161 μm and 133.603 μm in length. The existing report also gives the results that the size of precious fusion bridges is micron grade, which is similar to the results in this paper [17]. The size of fusion bridges is much smaller in diameter than that of the contact area. This result fully demonstrates that the total area of all conductive spots is only a small fraction of the area of the contact area. H Ishida reported the consistent research conclusion with our results [18]. It can be found from the experimental that the appearance of fusion bridges has three types which are the cylindrical, dumbbell and frustum. The results in this paper also prove the conclusion from P M Davidson that the appearance of fusion bridges has three types such as pier, cylindrical and dumbbell [19].

Figure 8. SEM morphology of Au anode contact surface

Figure 9. SEM morphology of Au cathode contact surface
Figure 10 illustrates the rules of diameter and length of fusion bridges versus the load of voltage. Under the condition that the voltage is less than 8 V, the diameter of fusion bridges is nearly not affected by the voltage change. When the voltage is more than 8 V, the diameter increases rapidly with the increase of voltage. When the voltage is up to 12 V, the diameter stops increasing and shows a decreasing trend. When the voltage is lower than 10 V, the length of fusion bridges decreases because of the voltage increase. After the voltage is greater than 10 V, the length increases sharply with the increase of voltage. When the load of voltage reaches to 14 V, the fusion bridges length decreases with the voltage increase. Taken as a whole, both the length and diameter of fusion bridges have the growth characteristics of the S type with the voltage increase. The total tendency of experimental results and data analysis give in this research shows difference from the conclusion from H Ishida [20] on Pd contact pairs under low current. The main reason for the emergence of these different phenomena may be that the properties of these two materials are different. With the increase of voltage, the value of both the diameter and length increase while the diameter has a larger growth gradient. Therefore, fusion bridges will show the characteristics of stub type. When the voltage is less than 8 V, the Au contacts are not easy to generate fusion bridges during the electrical contact process.

The behaviour of electrical contact can affect the microscopic topography on the surface of Au contact pairs. Both the surface characterization of Au contacts in the paper of W B Ren [21-23] under the (5 V, 15 V and 25 V)/1 A load and our research conclusions in this paper have a high degree of consistency. During the electrical contact behaviour, fusion bridges will make the contacts surface to form an erosion surface with characteristics of fusion pool, spray particles and convex hill. The shape of fusion pool is circular indicates that the shape of fusion bridge observed in experimental has three types which are the cylindrical, dumbbell and frustum are correct. A large number of spray particles exist on contacts surface shows clearly that the droplet spray is the main form of the loss of Au contact material in the process of electrical contact.

4. Conclusion

The experimental results are summarized as following: under the condition of DC 10 A (6 V to 15 V), the shape of fusion bridges has three types which are the cylindrical, dumbbell and frustum. The dimension of fusion bridges which generate during electrical contact process of Au contacts is micron grade. The diameter and length of fusion bridges both illustrate the growth characteristics of the S type with the voltage increase. The duration time of voltage increase from the appearance to the fracture is no more than 2.08 ms when the contact voltage is less than 10 V. While the contact voltage is higher than 10V, the duration time of fusion bridges will be between 2.08 ms and 4.16 ms. when the voltage is less than 8 V; the Au contacts are not easy to generate fusion bridges during the electrical contact process. The fusion bridges behaviour can erode the Au contact surface and present the erosion surface with the characteristics of the fusion pool, spray particles and the convex hill, the droplet spray is the main form of the loss of Au contact material in the process of electrical contact.
As discussed above, various experimental which are still vague are remained, one is the build of theory to reveal fusion bridges phenomena and the other is the lack of accurate experimental data. Those things are our future works.

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