Study on the Characteristics of Electrothermal Corrosion Trace of Aluminium-Brass Connector

Dazhi E
Shenyang Fire Research Institute, Shenyang, China
E-mail: raul9055@163.com

Abstract. In this paper, both thermal corrosion trace and electrothermal corrosion trace of aluminium-brass connectors are prepared by conducting simulation experiments under different heating temperatures and overload current conditions. The test samples are analyzed and described by metallographic analysis method, and the corresponding characteristic patterns are summarized, which provides the technical basis for the identification of the melting traces in the fire.

1. Introduction
Fire investigation is the responsibility of the public fire protection institutions in accordance with Fire Law of People's Republic of China, is a kind of systematic, rigorous and scientific work. A scientific, accurate conclusion on the cause of the fire is supported by a lot of evidences, which must have no relationship with each other, but supported by each other to be a complete “chain of evidence”. Therefore, identification the material evidences of the fire scene accurately is a process of forming "chain of evidence" with independent evidences, which is the core and technical guarantee in the determination of the cause of the fire. It is an important component of investigation on electrical fire to accurately extract the electrical fire evidence and identify it, and even determine whether the cause of the fire is correct or not. For material evidence identification technology of electrical fire, in the persistent efforts of the researchers in our country, the application of macro analysis, metallographic analysis, morphology and composition analysis and other technical methods, have basically solved qualitative and semi-quantitative evaluation problem of the material evidence of electrical fire. However, there are some identification problems of special traces have not been resolved, such as identification problem of melting trace for electrical connector. Due to the connection of the plug-in often employs the different metals such as aluminium conductor connected to brass connectors, while the contact resistance and the membrane resistance between different metallic materials are both high, in the course of long-term use or overload use, it tends to form metal melting trace on the connecting point [1-3]; On the other hand, when the different metals are subjected to thermal effect, the diffusion free energy of the materials can be reduced, which often results in the interfusion of the conductor and the connector below the melting point of either metal. As lack of related research, it is a technical problem to identify and distinguish between the thermal corrosion trace and electrothermal corrosion trace of electrical connector, which brings the trouble to determine the cause of the fire in some special circumstance. Therefore, we need to carry out the related research, in order to solve the problem of existing methods and correspond to the requirements of fire investigation.
2. Simulation test and sample preparation

For studying the effect of thermal corrosion and electrothermal corrosion on electrical component under the circumstance of high temperature of fire and electrical failure, in this paper, solid aluminium conductor (2.5) and brass connector (10 A) are selected as the main research object which are common material evidences in fire.

![Figure 1. Appearance of connector at the heating temperature of 500 ℃](image1)

![Figure 2. Appearance of connector at the heating temperature of 600 ℃](image2)

2.1. Heating test of connector

To simulate the lean oxygen environment in actual fire scene, place connectors at high temperature and vacuum resistance furnace (rate of temperature rising with 800 ℃/hour) for heating, setting up test temperature at 400 ℃, 500 ℃, 600 ℃, 700 ℃ and 800 ℃, respectively. When reaching the required test temperature, keep the temperature stable for 30 minutes, then cooling the sample with the furnace naturally(cooling rate is 200℃/hour). After the tests, the samples are analyzed accordingly.

The appearance of the connector after the test is as follows:

1) At the heating temperature of 400℃ and 500℃, the connector has no significant change, as shown in Figure 1.

2) At the heating temperature of 600℃, the connector has no significant change, on which the connected solid aluminium conductor is slightly fused, as shown in Figure 2.

![Figure 3. Appearance of connector at the heating temperature of 700 ℃](image3)

![Figure 4. Appearance of connector at the heating temperature of 800 ℃](image4)

3) At the heating temperature of 700℃, the connector appears slight deformation, solid aluminium conductor and brass connector are melt slightly, as shown in Figure 3.

4) At the heating temperature of 800℃, the deformation of connector is serious, solid aluminum conductor and brass connector are mutually melt together, as shown in Figure 4.

2.2. Overcurrent test of connector

Connectors are joined up with electrical load under the condition of AC220V. The overcurrent experiments are carried out at the rated current of 2.0le, 3.0le, 4.0le and 5.0le (20-group tests are
conducted for each overcurrent condition), the connection mode is shown as Figure 5. During the test, the temperature parameters near the connectors are recorded by infrared thermal imager and thermocouples, then after the test, the test samples are analyzed accordingly.

![Figure 5. Overcurrent test of connector](image1)

![Figure 6. Overcurrent test of connector at 3.0Ie](image2)

The detailed phenomena of tests are as follows:

1. At the rated current of 2.0Ie, the temperature at contact point is going up slowly. And the equilibrium temperature is usually achieved in 2-3 minutes, which is to maintain under 110℃. There is no obvious change on both the connector and the insulation of conductor.

2. At the rated current of 3.0Ie, the temperature at contact point is rising fast. And the equilibrium temperature is usually achieved in about 2 minutes, which is to maintain at 200℃. It appears a slight thermal decomposition on the insulation layer of conductor, as shown in Figure 6.

![Figure 7. Overcurrent test of connector at 4.0Ie](image3)

![Figure 8. Overcurrent test of connector at 5.0Ie](image4)

![Figure 9. Overcurrent trace of connector at 4.0Ie](image5)

![Figure 10. Overcurrent trace of connector at 5.0Ie](image6)
(3) At the rated current of 4.0Ie, the temperature at contact point is rising rapidly. It appears a significant thermal expansion on the insulation layer of conductor and a large amount of smoke are produced, as shown in Figure 7.

(4) At the rated current of 5.0Ie, the temperature at contact point is rising rapidly, some samples have the phenomenon of melting and arcing, and flame combustion is observed, as shown in Figure 8. After the tests, the connectors are removed for macroscopic examination, some of which appear discoloration, and some of which have the situations of breakdown or melting traces, as shown in Figure 9 and Figure 10

3. Sample analysis and pattern summary
By means of metallographic analysis, composition analysis and other technical methods, the samples prepared by simulation tests are analyzed and the corresponding characteristic patterns are summarized.

3.1. Heating sample of connector
The boundary between the aluminium conductor and the brass connector is obvious, which are the multi-layer structure (the two layers). The original body of aluminium conductor is characterized by large columnar crystals or isometric crystals, while the original body of brass connector appears obvious annealing. The higher the temperature, the greater the thickness of the diffusion layer. Metallographic photos are shown in Figure 11.

![Metallographic structures of heating sample of solid aluminium-brass connector 100X](image1.png)

(a)  (b)

Figure 11. Metallographic structures of heating sample of solid aluminium-brass connector 100X

According to composition analysis, there are two main elements of copper and aluminium in the diffusion layer, and there are also obvious differences in the contents of two elements in the diffusion layer, that is, the content of copper element near the original body of brass connector is obviously higher.

3.2. Overcurrent sample of connector
It presents a layered structure on the metallographic structure, but only one of which is transition layer. The side of solid aluminium presents tiny columnar crystals and acicular crystals with obvious direction [4, 5]. The side of brass connector possesses certain heat-affected zone, as shown in Figure 12.
### Figure 12. Metallographic structures of overcurrent sample of solid aluminium-brass connector 100X

#### 3.3. Comparative analysis of sample characteristics

The comparison of the characteristics of the above sample structures can be seen:

1. There is a certain mutual melting phenomenon while either electrothermal corrosion or thermal corrosion is having effect on the electrical component with different types of materials.
2. The electrothermal corrosion traces formed by the arc discharge are similar to the traces formed by traditional ground fault.
3. At the heating temperature of 600°C, although aluminum conductor has contracted with brass connector, there is not thermal corrosion happened.
4. Although it presents a layered structure on both electrothermal corrosion and thermal corrosion, there are obvious differences in the number and morphology of the diffusion layer, which can be considered as an important condition for deciding trace type.

#### 4. Conclusions

In this paper, both thermal corrosion trace and electrothermal corrosion trace of aluminium-brass connectors are prepared, testing phenomenon and the macroscopic characteristics of test samples are described. On the basis of metallographic analysis and composition analysis, characteristic patterns of traces are summarized, which will provide the technical support for the identification of the melting traces in the fire.

#### 5. References

[1] Ministry of Public Security Fire Station 2013 *China Fire Service 2013* (Beijing: International Culture Press)
[2] Ministry of Public Security Fire Station 2014 *China Fire Service 2014* (Beijing: International Culture Press)
[3] Ministry of Public Security Fire Station 2015 *China Fire Service 2015* (Beijing: International Culture Press)
[4] Jinzhuan Zhang and Hao Jiang 2008 *J. Fire Safety Science*. 17(1) 63-66
[5] Shanjun Mo, Wenjing Peng, Dong Liang and Yutao Long 2012. *J. Journal of Safety Science and Technology*. 8(1) 63-70