Analysis of Microstructure Characteristics of Overload Trace of Copper Conductor

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Abstract. Metallographic method is the most commonly used technique in electrical fire physical evidence identification. Firstly, the overload test samples of electrical lines were prepared in the simulated test chamber by using the simulation test method. Then, the macroscopic analysis and metallographic analysis were carried out on the overload melting marks of copper wires prepared in the early stage with the use of advanced instruments such as metallographic microscope and video microscope. The transition zone between the melt site and the substrate is not obvious, and there are many protruding weld marks of different sizes along the surface of the copper wire, and the wire diameter of the wire has obvious thickness change. The characteristic of metallographic structure is that the outer layer is eutectic, the inner layer is dendrite or dendrite coexists with eutectic, the size of the equiaxed crystal of the adjacent wire melting mark is obviously different, and some of them have more holes along the axis.

1. Introduction
With the development of technology and the improvement of people's living standards, household equipment is gradually developing towards the trend of electrification, and fires caused by electrical equipment are also increasing year by year. Among them, the number of electrical fires accounted for more than 30% of the total number of fires, has been in the top of all kinds of fires in the country. According to data from China fire statistics yearbook published by the fire bureau of the ministry of public security, there were 130,000 fires nationwide in 2008. It had 30,000 electrical fires and 40,000 electrical fires, accounting for 30.1% [1]. In electrical fires, electrical line faults account for the vast majority, and fires caused by electrical lines account for more than 60% [2]. Therefore, the investigation of electrical fire is particularly important. To find out the cause of electrical fire, it is necessary to conduct property analysis of the electrical line debris in the fire, especially the identification of the overload melt mark. An overload is when the power or current of an electrical device or conductor exceeds its rating. the case of overload, the main aspects of contradiction the is electricity problems, need to think about the maximum bearing capacity of the circuit of current, if the current exceeds the safety current value of the wire, wire overload phenomenon will occur. Generally, the overload time should not be too long, otherwise, it is easy to burn out the electrical appliances or circuits, thus causing a fire. There are many reasons for the overload of electrical lines. First, the section of the electrical line is too small. The electrical circuit is too thin, which leads to the long term overload of the circuit, the insulation drop, and the short-circuit fire has become the main cause of electrical fire. At present, the electrical circuit capacity of most buildings designed before the 1990s is generally difficult to bear the increase of current residential electricity load, so it causes frequent tripping for the light, and it even caused fires. Secondly, the non-linear load of harmonic generation in
household appliances increases. With more and more practical household appliances such as microwave ovens, the harm of harmonics to electrical circuits is becoming more and more obvious. The current will increase with the increase of the harmonic content of the harmonic source electrical equipment, so that the wire is in a serious state of overload, resulting in fire.

2. Preparation of Overloading Melt Mark Samples

Connect the two ends of the copper wire to the positive and negative poles of the ac 220V power supply respectively, and then start the test when the power is connected, until the wire fuses, or the test stops when the power is on for more than 2 minutes.

2.1. Sample Preparation at 2Ie

First, adjust the experimental current to 2Ie and turn off the power. Then remove the insulation layer at both ends of 1mm2 single copper wire and connect them to the positive and negative poles of the power supply. Switch on the power and the experiment begins. The experiment time was 1min.

2.2 Sample Preparation at 4Ie

First, adjust the experimental current to 4Ie and turn off the power. The following steps are the same as above.

2.3 Sample Preparation at 6Ie

First, adjust the experimental current to 6Ie and turn off the power. Experiment until the wire is blown.

2.4 Sample Analysis Methods

Firstly, the sample was analyzed macroscopically. The instruments of the method is video microscope, see figure 1. The magnification of the microscope should be more than 30 times. This kind of microscope has a large depth of field and can adjust the focal length as needed to reach the position to be observed.

And then micro analysis. The method of use is metallography method. The instruments used include pre-grinding machine, polishing machine and metalloscope. The model of the metalloscope is OLYMPUS PMG3, see figure 2.

For microscopic analysis, samples are prepared first. The parts with melting marks and corrosion pits were extracted and removed. Longitudinal and transverse sections should be cut. The cross section is the microstructure of the weld mark and the longitudinal section is the microstructure of the transition zone between the weld and the conductor. Metallographic samples are prepared after inlaying, pregrinding, polishing and etching. The sample etchant is usually ferric chloride alcohol solution.
3. Experimental Results and Analysis

Under the normal condition of power on, the copper conductor has obvious directional structure which is a fibrous structure elongated along the direction of deformation.

3.1 Feature and Analysis of Melt Mark at 2Ie Current

The temperature of the wire rises slowly as the current on the line passes through 2Ie. When the heating temperature is close to the recrystallization temperature of copper, the microstructure of copper wire begins to change. The original fibrous structure gradually changed to equiaxed grain, but due to insufficient energy, the grain boundary did not change much, so the metallographic structure was still dominated by fibrous structure, as shown in figure 3.

3.2 Feature and Analysis of Melt Mark at 4Ie Current

When 4Ie current flows through the wire, the temperature of the wire rises rapidly. The characteristics of the insulating layer are obvious. The inner layer of the incomplete carbonization insulating layer is more serious than that of the outer layer. Due to the overheating of the whole line and the melted surface layer flow, Make the wire diameter uneven thickness changes, the formation of a small cavity scar distributed on the surface of the wire. The weld marks formed are round, pointed, etc., as shown in figure 4; There is no obvious transition zone between the conductor matrix and the melt mark, as shown in figure 5. The copper wire near the bead and under the weld mark of multiple strands of flexible wire, which is hard to separate. When the heating temperature is close to or above the melting point, the microstructure of copper conductor changes significantly. The original equiaxed grains were no longer obvious, but the primary Cu$_2$O, dendritic crystal and Cu+$\text{Cu}_2$O eutectic appeared. If there is no recrystallization along the length of the wire at a certain location, or if there is recrystallization at a certain location with the occurrence of excessive melting, it can be inferred that it is caused by the high temperature of the flame [3-4]. Under the condition of 4Ie current, it takes a long time for the wire to fuse. Therefore, some of the metallographic structures formed at this time are similar to those formed by the burn mark, as shown in figure 6.
3.3 Feature and Analysis of Melt Mark at 6Ie Current

3.3.1 Organization Character. The outer layer of melt mark of single conductor is eutectic, and the inner layer is dendrites or dendrite coexisting with eutectic, as shown in figure 7. Part has more holes along the axial direction, as shown in figure 8. These phenomena indicate that under overload, the wire melted or partially melted and then resolidified. In this case, the temperature of the wire is higher than the melting point of copper, that is, more than 1065°C.

3.3.2 Origin Analysis. At the melting temperature of metals, there is a leap change in the solubility of gases, that is, at the same temperature; the solubility of metals in solid state is nearly 20 times smaller than that in liquid state [5]. This sharp change is associated with the release of latent heat as the metal solidifies from a liquid into a solid. During solidification, due to the decrease of gas solubility, the gas precipitates out, and the precipitated gas is trapped in the microstructure before it has time to overflow from the liquid level, and exists in the microstructure in the form of stomata.

4. Conclusion
Although the experimental results show that the characteristics of the overload melt mark is obvious, however, the eutectic microstructure was found in both the burn and overload scars, It's just the odds are different. The actual application needs to be combined with specific environmental conditions to analyze, in order to ensure the accuracy of the identification results.

5. Reference
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