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Case Report

Visual and oxide analysis for identification of electrical fire scene

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ABSTRACT

Three aluminum wires with different melted mark, which were found inside a burned distribution board from the electrical fire debris in rural areas of Northeast China were characterized to determine the cause of fire. By visual and microstructure/metallographic analysis, one melted bead shows typical morphology (microstructure/characteristics) as a result of overheating or electric short circuit (ESC) arc beads which was identified as the most possible ignition source. The macro-/micro-structure of the metallic wire, the chemical composition of the beads surface and the state of the polymer insulating sheath combining the tension state of the electric wire provided solid evidence on the exposure temperature and time of each aluminum wire. Consequently, the fire source was identified. Therefore, the characterization on the macro-/micro-structure and chemical composition of metallic surface with scientific technique is greatly helpful in determining heating process of metallic parts and subsequently the cause of fire.

1. Introduction

With the rapid development of China's national economy, fire is becoming a major threat to life and property in urban and rural areas. Although electrical fire is one of the primary causes of most building fires in rural areas of China [1], to identify the fire cause is usually challenging due to the complex situation in fire scenes. In legal disputes, the rigorous proof and scientific way to found the fire source are always required. Study on the fire investigation requires different techniques, and the integrity and traceability of material evidence in fire scene are also necessary. Comparing with combustible material commonly used in residual, commercial and industrial constructions, metallic material is more easily preserved at the fire scene, which might record the fire temperature changes and the direction of the fire spread. Usually, extreme heat can cause metallic conductor melted, then a short circuit can create an appearance of arc beading. Therefore, during the investigation of an electrical fire, the “arc beads” is one evidence for fire investigators, which are melted marks found at a fire scene caused by a short circuit [2–4]. Nonetheless, it is very difficult to distinguish the fire-causing (the primary molten mark) from fire-resulting (the secondary molten mark) arc beads. There has been no sufficient scientific evidence regarding fire-causing arc beads available for such investigations so far [5,6]. In this study, visual and complementary surface analysis of the aluminum lead melting trace in terms of their microstructure/composition changes have been employed to investigate their dependence on the electrical fire cause.

2. Materials and methods

The material tested in this study is aluminum core wire which is widely used as electrical wire. The surface morphologies, microstructures, and phase constituents of the oxide scales formed on the wire were examined by Leica M125 optical microscopy (OM), a Philips XL-30 scanning electron microscope (SEM) equipped with energy-dispersive spectroscopy probe (EDS).

3. Fire scene observation

The examined countryside house fire occurred at 4 am on January 15th, 2015 in Mudanjiang, China. The fire report from fire personnel and witnesses pinpointed the fire started at the distribution board outside the building and quickly engulfed the structure. The fire caused neither dead nor wounded but damaged property at an estimated loss of ¥800,000. Fig. 1 shows the damaged building after the fire. The distribution board outside the building was damaged significantly. Three wires leading to different households named No. 1, No. 2 and No. 3, respectively, were found in the fire scene. Fig. 2 shows the electrical wires with and without bead that were found leading to the distribution

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Fig. 1. The rare brick-concrete composite structure houses after the fire. The distribution board and electric meter box were outside the building and damaged in the fire.

board. The bead would occur when the electrical wire was melted at high temperature and then solidified in the following cooling process. This temperature-dependent metallographic structure alteration may offer information about the exposure temperature. In other word, the establishment of accurate correlation between the fire characteristics and the thermal patterns in fire scenes is helpful for fire investigation [7,8].

4. Tracing the fire ignition

The fire damaged and undamaged wires near the contact of the burned distribution board were cut into specimens and are shown in Fig. 2. From the macroscopic observation on No.1 wire as shown in Fig. 2a, it can be seen that the wire was fused, only a small area was affected by heat and the outside sheath was only slightly hardened except pyrolyzation close to the melting point. For No. 2 wire shown in Fig. 2b, it is apparent that the metallic wire was fused and the length of wire heated was much longer than that of No. 1 wire. Additionally, the No. 2 aluminum wire was covered by an oxide scale that is readily cracked and spalled into large flakes (friable to the touch). The insulting polymer layer was completely decomposed around melting point and the left was curled and charred. Fig. 3 shows the melted mark at the ends of No. 1 and No. 2 wires. The No. 3 wire is undamaged, and shown as a comparison.

The macroscopic observation on the melting end of No. 1 wire shown in Fig. 3a indicates a sudden reduction of aluminum wire cross section, which implies the wire was broken in a short time considering the tension state of working electric wire and the excellent ductility of aluminum. The microstructure analysis with SEM and EDS reveals the chemical composition of the melting point consist of major Al and minor O and Cl, as shown in Fig. 3e. The macroscopic observation and microstructure of No. 2 wire are shown in Fig. 3b and d. Compared to No. 1 wire in Fig. 3a and c, longer part suffered high temperature exposure, aluminum wire gradually thinned and the melting point has higher amount O and Cl, as shown in Fig. 3f. All these evidence supported a longer exposure of No. 2 wire at high temperature.

In order to properly identify the origin and cause of the fires, the fire investigators need to collect all the related trace evidences and perform comprehensive scientific analysis. At most fire scenes, electric short circuit (ESC) arc beads can be found, which may provide useful information on the cause and development of the fire. Various physical or chemical methods have been proposed for identifying these electric short circuit beads to be either the cause of a fire (primary arc beads) or one caused by the flames (secondary arc beads) [9,10]. The morphologies of melting beads are dependent on the exposure temperatures and periods of time. Electric arcing can produce local temperatures in excess of 6000 °C (10,832 °F) in a short time and cause the splattering of melted

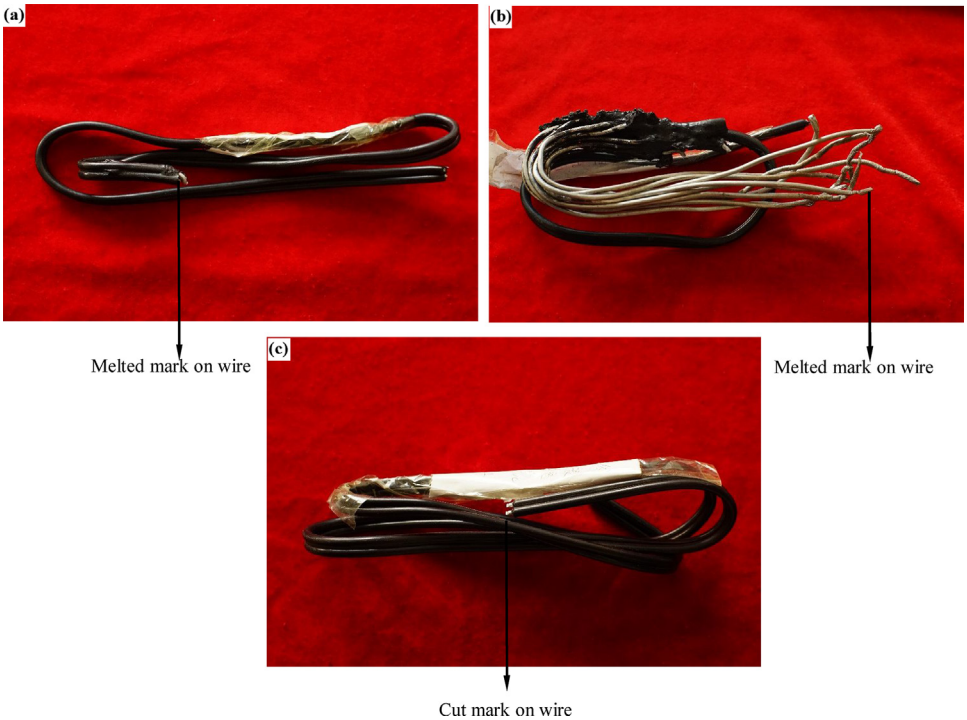

Fig. 2. View of wire with and without melted mark at the end (arrow indicates), (a) No. 1, (b) No. 2 and (c) No. 3, the melted mark was used for further metallographic examinations.

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