ATF Fire Research Laboratory Technical Bulletin

ATF Fire Research Laboratory
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Visual Characteristics of Fire Melting on Copper Conductors

Abstract

The purpose of this Technical Bulletin is to provide the Fire Investigation Community with an understanding of some of the major technical problems that we believe are contained in *Forensic Investigation Techniques for Inspecting Electrical Conductors Involved in Fire* (Document No.: 239052, Award Number: 2010-DN-BX-K246), a report released after the completion of a research project that was funded by The National Institute of Justice (NIJ). We take issue with: the study's methodology; the interpretation of results; and, what we believe to be, the incorrect conclusion that fire investigators cannot visually differentiate between fire and arc melting when examining conductors.

Statement of Issue

Forensic Investigation Techniques for Inspecting Electrical Conductors Involved in Fire (Document No.: 239052, Award Number: 2010-DN-BX-K246) is a report released after the completion of a research project that was funded by NIJ. The same study was also the basis for a thesis project at the University of Maryland. In the past, NIJ has funded a number of projects that have advanced the science of fire investigation. However, in this case, the conclusions presented in the aforementioned study are misleading due to the study's methodologies and the analysis of the damage to test conductors.

According to the authors:

> *The main objective of this research was to determine, experimentally, if distinguishing characteristics exist between energized and non-energized wires subjected to various types of fire exposures.*
> (Page 12)

Of prime interest to the fire investigation community is the study's principle conclusion:

> *The research findings clearly show that the sole use of visual characteristics to establish the energized state of a wire can lead to erroneous conclusions.*
> (Page 98)

This conclusion itself is problematic based on the study's experimental methodology and the method of data analysis.

The study was presented as "preliminary results" at the 2010 International Symposium on Fire Investigation Science and Technology (ISFI) and several student presentations since then. The study will also be presented at the 2012 ISFI. Accordingly, the paper has / will appear in the Proceedings of both ISFI conferences. ISFI is not a peer reviewed conference and does not have a peer review committee. There is no technical analysis or review of any paper prior to presentation at the conference. ATF personnel present at the 2010 presentation publically argued against the premise of the study at the time of the presentation.

Based on public statements, the authors of both the thesis and the NIJ project are pursuing both peer-reviewed and non-peer reviewed journals and conferences to publish and present these results in the upcoming months.

In both articles and presentations, they are presenting their conclusions as scientific fact.

Analysis of Issue

Since the conductors used in the study were primarily manufactured for residential applications, the test environments should have been consistent with what would normally be expected in a residential compartment fire.

The test methodology exposed conductors to four different environments (Test Exposures):

1. A Bernzomatic Max Power Propylene Torch (Page 30) – this is not a reasonable representation of a residential compartment fire.
2. A radiant tunnel apparatus exposed conductors to: approximately 125 kW/m^2; 1050-1100 ˚C; until melting or electrical failure. (Page 31) This is not consistent with a residential compartment fire.
3. A 2/5-scaled compartment that exposed conductors to a fire that developed from incipient stage to fully-developed stage. (Page 33) In order to increase the temperature within this compartment, oxygen was forcibly delivered by a doorway blower. (Page 35) This is not consistent with a residential compartment fire – it is more consistent with a small furnace.
4. A full-scale compartment that exposed conductors to a fire that developed from incipient stage to fully-developed stage. (Page 36) This exposure is consistent with a residential compartment fire.

As stated above, Test Exposures 1, 2 and 3 were not consistent with what would realistically be expected in a residential compartment fire for the following reasons:

- Test exposures 1, 2, and 3 impinged the test conductors in a highly localized area, which is a hallmark of damage resulting from electrical failure and not typical of residential compartment fires.
- Work performed by J. B. Fang of NIST demonstrates that temperatures in residential post-flashover compartment fires do not routinely reach temperatures capable of melting copper conductors (NBSIR 80-2120l, NBSIR 80-2134).
- The fact that a compartment fire attained a temperature of 1082˚C, the melting point of copper according to NFPA 921-11 Table 6.2.8.2, does not guarantee that the conductor will melt. The heat transfer from the gases of the fire to the copper conductor also needs time to allow the melting to take place.
- The combination of the highly localized exposure combined with the higher than anticipated temperatures creates a heat transfer rate to the conductors that is greater than expected in a normal residential compartment fire.

The study did not address any conductors that would normally be used in commercial applications.

The observed data from the de-energized, full-scale compartment tests support the assertion that Test Exposures 1, 2, and 3 were unrealistic:

> *The production of beads on non-energized wires in the full-scale compartment was minimal. The lack of bead production occurred because on average, the compartment did not exceed 950˚C. Beads were formed on non-energized wires in all scenarios except the full-scale testing and 12-gauge radiant tunnel testing.* (Pages 90 – 91)

In other words, the primary observation of the study did not occur when conductors were placed in a full-scale compartment test. This was the one test environment that was most consistent with actual residential compartment fire conditions. Furthermore, the study did not attempt to correlate this observation with any real-world scenario.

The study's analysis of globules (incorrectly referred to as beads) failed to identify visible evidence of thermal melting that is clearly present in the photographs. This mostly included the visual effects of gravity and blistering.

Testing also utilized energized conductors. Based on the report's photographs, all of the remnants of the energized tests had results that visibly met the current NFPA 921 descriptions of an arc bead without the use of special instrumentation such as a scanning electron microscope. This fact was not emphasized in any of the data analysis.

Concern over the appropriate identification of damaged conductors is not a new topic within the realm of fire investigation. The NFPA 921 Technical Committee recently commissioned a Task Group to examine the topic of arcing as it is used within NFPA 921. ATF personnel actively participated in this Task Group.

Recommendations

NFPA 921 currently has several guidelines that describe the different types of conductor damage that can be encountered during a post-fire analysis. NFPA 921 states that "These guidelines are not absolute, and many times the physical evidence will be ambiguous and will not allow a definite conclusion." (NFPA 921-2011 8.10.1) Accordingly, if there is any confusion whether or not damage to a conductor is thermal or electrical, the investigator should not assume it is electrical. This point has been emphasized by ATF for a long time.

ATF also warns about making determinations based solely on conductors that are smaller than AWG #14 and encourages the use of larger conductors when arc mapping or analyzing damage to a building's electrical system to aid in determining an area of origin.

Any overall conclusions regarding a fire scene that includes analysis from arc melted conductors should never be made without considering all of the evidence from the scene that includes, but is not limited to, witness statements, burn patterns, and fire dynamics. In other words, the conclusions from damage to the electrical system should be consistent with the other evidence collected and observed during scene processing.

Practice and training are the best ways to become proficient in identifying the difference between fire and arc melting.

A proposal to the aforementioned NFPA 921 Task Group was made by Dr. Vytenis Babrauskas that effectively improved the existing definition of arc melting. Based on this proposal, the physical descriptions of arc melting that can be readily identified by an investigator in the field, and do not require special instrumentation such as a scanning electron microscope, include:

- Sharp line of demarcation between damaged and undamaged area
- Round smooth shape
- Localized point of contact
- Identifiable corresponding area of damage on opposing conductors
- Copper drawing lines visible outside the damaged area
- Localized round depressions
- Small beads and divots over a small area

The same proposal by Dr. Babrauskas included physical descriptions associated with melting by fire. The physical descriptions of melting by fire that can be readily identified by an investigator in the field, and do not require special instrumentation such as a scanning electron microscope, include:

- Extended area of damage without a sharp line of demarcation from undamaged material
- Visible effects of gravity in the artifact
- Blistering on the surface
- Gradual necking of the conductor
- Non-localized loss of integrity of individual strands on stranded conductors (NOTE: This characteristic was not included in Dr. Babrauskas' proposal but is included here since it is part of the ATF training curriculum.)

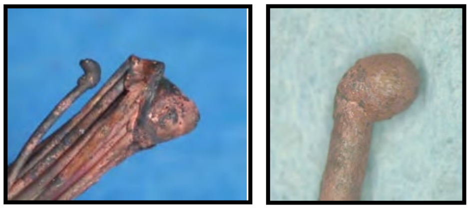
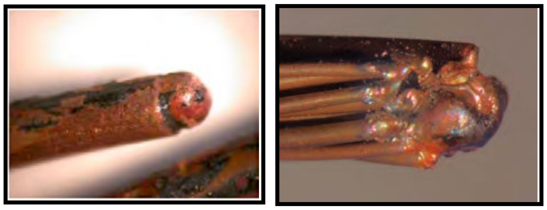
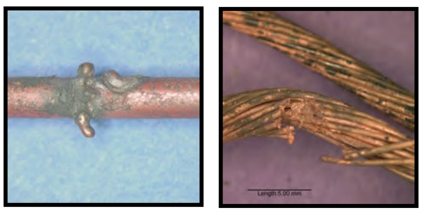
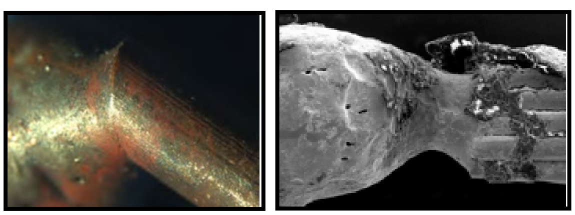
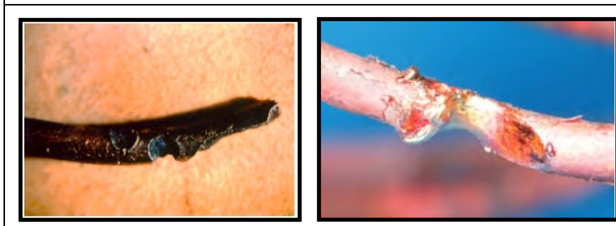
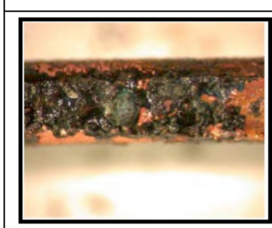
Examples of damaged conductors are shown in Tables 1 and 2 at the end of this bulletin. These definitions have been included in the current ATF training programs and have been distributed to all ATF Certified Fire Investigators.

The First Draft Report for NFPA 921-2014 includes information based on Dr. Babrauskas' proposals as shown above.

Magnification and some minor cleaning using a dry brush or an ultrasonic bath may be necessary to detect fine features including the demarcation between the melted and un-melted regions on a conductor.

It should be noted that an investigator does not need to observe all or more than one of the above described physical characteristics of damaged conductors in order to classify the type of damage.

It is highly recommended that investigators familiarize themselves with the damage descriptions as shown above and in Tables 1 and 2 when attempting to describe conductors impacted by fire.

Table 1 Characteristics of Arc Beads	
	Sharp Line of Demarcation between damaged and undamaged area (Photos by Kevin Lewis / E. C. BUC)
	Round Smooth Shape (Photos by Nick Cary / Kevin Lewis)
	Localized Point of Contact (Photos by Kevin Lewis / E.C. Buc)
	Identifiable Corresponding Area of Damage on Opposing Conductor (Photo by Kevin Lewis)
	Copper Drawing Lines Visible Outside the Damaged Area (Photos by Kevin Lewis)
	Localized Round Depressions (Photos by David Reiter / Kevin Lewis)
	Small Beads and Divots Over a Small Area (Photo by Nick Carey)

Photos and descriptions courtesy of Dr. Vytenis Babrauskas.

Table 2
Characteristics of Melt Globules

 	Extended Area of Damage Without a Sharp Line of Demarcation from Undamaged Material (Photos by Yasuki Hagimoto / E. C. Buc)
	Visible Effects of Gravity in the Artifact (Photo by Stephen Andrews)
 	Blisters on the Surface (Photos by E. C. Buc)
	Gradual Necking of the Conductor (Photo by Jeremy Neagle)
	Non-Localized Loss of Integrity of Individual Strands on a Stranded Conductor (Photo by Michael Keller) (NOTE: This characteristic was not included in Dr. Babrauskas' proposal but is included here since it is part of the ATF training curriculum.)

Photos and descriptions courtesy of Dr. Vytenis Babrauskas.