Loose electrical connections at screw terminals can create an increase in resistance, which promotes development of oxide layer(s) on the affected metals and localized heating. While the oxides are conductive (meaning the circuit will still “work”) its resistance is higher than that of the original metals involved (NFPA 921, 2014)[1]. The nature of the heating results in a locally high “watt density” and creates a potentially competent ignition source for proximal fuels (DeHaan, J., Icove, D., 2012)[2].

Recent literature, including works by Benfer and Gottuk (2013)[3], Korinek and Lopez (2013) [4] and Shea (2006)[5], provide detailed explanation of the chemical and physical processes of oxidation (copper I and copper II oxides) and corrosion associated with high resistance or “glowing” electrical connections. It is the visible effects of such localized high resistance heating on the receptacle terminals, and the persistence of these effects in a post-flashover fire environment, that are the subject of this paper.

**INTRODUCTION**

In this research, glowing connections were created on multiple electrical receptacles to produce heat effects on only one line side terminal connection of each receptacle. The purpose of this experiment was not to determine how heat effects manifest themselves on the terminals of electrical receptacles and associated conductors. The focus of this study was to determine whether or not the known effects persist beyond flashover at a visually perceptible level. This information is of importance to the fire investigator in the field. The reader should note that this work is considered preliminary. Potential variables were minimized, such as having conductors terminated on all screw connections and having multiple receptacles with varying loads on the same circuit. Further testing is required to evaluate the significance of such variables. Nonetheless the results of this testing are notable.

The “heat damaged” test receptacles were installed in metal junction boxes and exposed to a room and contents fire that transitioned through flashover. The compartment was not instrumented. The point of origin and fuel load arrangement was selected to expose the receptacles to varying levels and duration of heat intensity. The post-flashover persistence of the effects of a glowing connection was subsequently visually evaluated. The intent was to provide fire investigators a resource for the preliminary field evaluation of electrical receptacles as a potential ignition source.
Visual Effects of a High Resistance Connection

The effects of an overheated or glowing receptacle connection have been cataloged (Benfer and Gottuk 2013), (Korinek et.al. 2013). These effects include discoloration, oxidation (copper I and II) and corrosion of metallic receptacle components. Plastic components display melt, char and loss of mass. These effects are highly localized. This research has also shown that a radial pattern around the threaded hole into which the terminal screw is affixed at the high resistance connection is consistently generated. These effects are visually recognizable as changes in color and texture of the metallic surfaces. The effects were also compared to the neutral terminal where the electrical connection had been “properly” made. Pre-fire images of the neutral terminals are not included. The post-fire images clearly illustrate the absence of localized thermal effects on the neutral terminals, particularly when contrasted with the line side terminals.

Experimental Conditions

On March 7, 2014 four electrical receptacles were installed in the Eastern Kentucky University (EKU), Fire and Safety Engineering Technology Program’s burn facility at the EKU campus in Richmond, Kentucky. These receptacles had previously been connected to an electrical supply in such a manner to cause a glowing connection on a single, line side, terminal screw connection. A load of 8.2 amperes was applied to each receptacle for a period of time sufficient to attain a similar degree of thermal effect.

The burn compartment measured seventeen feet (5.18m) by fifteen feet (4.57m) with a ceiling height of eight feet (2.43m). Interior walls and the ceiling were lined with gypsum wallboard. The personnel door, measuring 39” (.99m) x 7’2” (2.18m), was open during the fire and was the lone vent in the room. The room layout is shown in figure 1. The red star indicates the area of fire origin.

continued on page 22
The compartment fire was ignited by application of an open flame to the bedding material on the west side of the bed near the head (see the yellow arrow in figure 3). The fire was allowed to burn for as long as possible beyond flashover without causing the wallboard to fail (appx. 3 minutes). Figure 4 provides a view, through the doorway, of the interior fire conditions shortly before the fire was extinguished.

As expected, the plastic components of the receptacles were damaged to varying degrees in the fire. There was no melt damage to the metallic components of any of the test receptacles. Receptacle SW (figure 5) was immediately adjacent to the origin of the fire. It was the most severely damaged in terms of loss of mass of the plastic housing. The metallic components were no longer secure in the plastic body. The face of receptacle SE (figure 6) was severely charred, however the rear of the receptacle body and conductive elements remained intact. Receptacle NW (figure 7) was in a condition similar to receptacle SE. Receptacle NE (figure 8) was the least severely damaged.
Laboratory Inspection

The receptacles were removed from the junction boxes for laboratory inspection to determine if the previously documented heat effects imparted by the glowing connections persisted. The receptacles were visually examined and photographically documented in the "as recovered" condition. Each of the conductive elements was subsequently subjected to an ultrasonic bath in distilled water. Side by side comparisons of the pre and post-fire conditions of the line and neutral terminals follow.

The glowing connection on receptacle NW caused discoloration of the terminal screw and melt/char of the adjacent plastic material of the receptacle face and body. The conductor was discolored adjacent to the terminal screw. The insulation on the supply conductor was missing within inches of the connection. The adjacent line side terminal and screw were unaffected. The arrow in figure 9 indicates the effects of the high resistance connection.
There was significant loss of mass to the face of the receptacle. The loss of mass was greater at the top end of the room-facing side of the receptacle than the bottom. The rear portion of the body displayed a lesser degree of thermal effects and retained its shape. The Mylar UPC label on the rear of the body was still intact. The terminals were still firmly embedded in the plastic body. Receptacle NW was closest to the doorway and was subject to increased fire intensity due to ventilation effects.

Nonetheless, a distinct difference in the visual appearance of the terminals was evident. The left side terminal in figure 10 was where the glowing connection had been made. A change in the color and texture of the terminal face where the glowing connection had been made exists. A radial pattern of significant oxidation surrounding the hole for the terminal screw is also apparent. The stamped “dimples” (visible on the adjacent terminal face) are mostly gone.

The neutral terminal (shown in figure 11) by comparison, showed minimal changes in the color and texture of the terminal. Heat effects were evident around the perimeter of the terminal screw while mechanical deformation of the neutral terminal was evident where the conductor was in firm contact (under the terminal screw). This area sustained no visible heat effects. It appeared that a properly terminated connection acted to protect the terminal face. This effect was noted on all of the test receptacles.
Due to the glowing connection, receptacle NE sustained discoloration of the terminal screw and melt/char of the adjacent plastic material of the receptacle face and body to a slightly greater degree than receptacle NW. The insulation on the supply conductor was also missing within a few inches of the connection. The conductor was discolored adjacent to the terminal screw as shown in figure 12.

Figure 13 shows the post-fire condition of the line side terminal of receptacle NE. The thermal effects on the receptacle face and body were similar to that of receptacle NW however greater heat effects were apparent on the terminal face. There was nonetheless, a distinct difference in visual appearance between the two line side terminal faces. The left face, where the glowing connection had been, showed a greater degree of oxidation and an overall darker color than the adjacent face. A radial pattern around the threaded hole for the terminal screw was also evident. There was also a loss of the smooth surface and the “dimples” on the left (glowing) side. Figure 14 depicts the neutral terminal.

continued on page 26
Receptacle SE showed the largest area of melt/char to the plastic body as a result of the high resistance connection. The line side terminal face and screw were discolored. The insulation on the supply conductor was also missing within a few inches of the connection. The conductor was discolored adjacent to the terminal screw. The adjacent terminal and screw were unaffected by the heat. These effects are shown in figure 15.

The plastic face of receptacle SE and a large portion of the body were consumed in the fire. The terminals were still affixed to the remaining plastic. There was no melt damage to the terminals. Both line side terminals were discolored but there was a distinct difference in the visual appearance of these adjacent terminals. There was a greater degree of oxidation as well as a radial pattern where the glowing connection had been. The dimples were virtually nonexistent there as well. The insulation on the supply conductor was also missing within a few inches of the connection. The conductor was discolored adjacent to the terminal screw.

The neutral terminal also showed heat effects. These effects were least severe where the neutral conductor had been connected as shown in figure 17.

Receptacle SW sustained the least amount of thermal effect from the glowing connection. A slight discoloration of the screw head and terminal were evident. Insulation on the supply conductor adjacent to the terminal screw was softened and distorted but not consumed. The conductor showed minor discoloration adjacent to the terminal screw. There was distortion of the receptacle body but no charring of the adjacent plastic.

Post-fire there was little of the receptacle body remaining. The receptacle ground strap and terminals had separated from the plastic body. Consequently there was discoloration of both of the terminals. Some of the pre-stamped “dimples” had been obliterated on the non-glowing terminal but those were along the outer edge. The area beneath the terminal screw was not as severely damaged.

There remained a visually greater degree of oxidation and texture changes to the terminal where the glowing connection had been. There were also the radial patterns visible on all the other receptacles.

The neutral terminals (figure 20) were also significantly heat affected but visually distinguishable from the effects at the glowing connection.
Conclusions

Characteristics of the existence of a pre-fire glowing connection include a generally darker color of the terminal, a rougher surface due to oxidation and corrosion, and a radial pattern around the terminal screw hole. Additional research is needed to evaluate the persistence of the heat effects from a glowing connection under different wiring and circuit configurations.

Based on the results of this study it is expected that the physical effects of a pre-fire high resistance “glowing” connection will be visually apparent post-fire. This finding is consistent with the studies previously cited herein.

Thus, when a fire investigator encounters an electrical receptacle within the area of fire origin, the receptacle should be subjected to a close but non-destructive field inspection for any of the “forensic markers” of an overheated connection (Korinek et. al. 2013).

When such evidence is present, it is recommended the investigator consult a forensic electrical engineer. The investigator is cautioned to avoid spoliation of evidence. Other parties, such as the receptacle manufacturer and installer, may have a legal interest in the cause of the fire under investigation. Notice to the interested parties may be required prior to removal or destructive inspection of the receptacle (NFPA 921, 2014).

References