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ONTARIO HYDRO
RESEARCH DIVISION REPORT

To Mr. F.J. Simpson
Director of Research

METALLURGICAL ANALYSIS OF FAILED CO/ALR DEVICES

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Two CO/ALR duplex receptacles which failed prematurely and resulted in overheated connections were submitted to the Research Division for examination. Metallurgical study of the failed receptacles revealed a great deal of arcing damage on both the screws and baseplates. Indentations on the wires in one case indicated that the screws had been tightened but screw looseness could have contributed to the other failure. The precise failure mechanisms could not be determined.

INTRODUCTION

Two CO/ALR receptacles which failed in residential use resulting in overheating were forwarded by the Utilization Section of the Electrical Research Department to the Metallurgy Section for an evaluation of the damage. These investigations included stereoscopic examination, scanning electron microscope study and a limited amount of metallography.

METALLURGICAL STUDIES

1. Visual Examinations

The two receptacles were identified as follows:

A - Leviton CO/ALR
B - Eagle CO/ALR

Initial examination of receptacle A before disassembly (aluminum wires had been removed and were not included in the investigation) revealed several interesting details. The break-off tab on the live side had been broken but the broken ends had been molten at some point, indicating that an arc had taken place between the two live lines. There were white deposits on the plastic surrounding the terminal and on the baseplate material itself and green deposit on one of the live screws. The terminals were not held rigidly

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within the plastic and could easily be moved by about one millimetre.

Stereoscopic examination after disassembly revealed that there had been arcing between the live screw and the baseplate in the threaded portion of the baseplate. Terminals were identified by number: live side 1, 2; neutral side 3,4. Large melted areas were observed on the baseplate rear screw 1 and smaller areas near screw 3. There was also arcing damage under the head of screw 2.

A similar visual examination of receptacle B showed a basically similar pattern of damage although more severe. On the live side there was arcing damage on the underside of the screw heads and the baseplate. On the neutral side one terminal exhibited arcing damage to the baseplate and the screw threads but the other showed almost no damage.

Since the wires for this receptacle were included, an attempt was made to estimate torques used on the wires by comparing mechanical damage observed on the wires with damage created on wires connected to similar receptacles with known torques. A successful comparison was obtained for one wire from the live side and one from the neutral side. The wire from the live side exhibited severe arcing damage but in addition, an impression of the baseplate was clearly visible (Figure 1). This impression corresponded well with the impression created using a 0.56 N.m torque on the screw (Figure 2). The areas where the screw touched the wire were damaged by arcing but showed that the screw was touching in two places. The wire from the neutral side exhibited mechanical damage on the screw side which corresponded to a 0.33 N.m torque.

Scanning Electron Microscope Study

Receptacle A

Both the screw and the baseplate of terminal 1 were examined in detail . The plating material was identified as indium. This was confirmed by optical spectroscopy (the indium and tin lines of the X-ray energy dispersive spectrum overlap and are not easily distinguished).

Two areas of the baseplate were photographed and analysed, these are shown as Figures 3 and 4. Particles on the surfaces were also analysed. Most contained aluminum, some had copper, zinc, silicon and calcium. Analysis of general surface areas revealed that there were often zinc concentrations on the surface which were significantly higher than would be expected for the normal brass composition. In the area shown in Figure 4, the surface appears cracked. High concentrations of indium, chlorine and zinc were found in this area.

The underside of the screw of terminal 1 of the receptacle was also examined. A typical area where arcing was observed is shown in Figure 5. X-ray analysis showed high concentrations of aluminum,zinc and copper. No other elements were detected. Again, the zinc level was significantly higher than the copper in the overall surface analysis.

Receptacle B

Generally, the most damaged areas were not examined because the stereoscopic examination had already shown the arcing damage. In order to try to determine the cause of the failure other areas of contact which had not yet progressed to the arcing stage were examined.

Two different areas under terminal 3 were examined. An area where the indium-tin plating (found by optical spectroscopy) was deformed can be seen in Figure 6. X-ray analysis of the overall surface in this area showed that the plating was indium or tin but also that zinc, copper, sulphur, chlorine and aluminum were also present in significant quantities. Analysis of particles on the surface indicated very high concentrations of aluminum and chlorine. A similar analysis of the surface of one of the pyramidal depressions in the surface showed an increased ratio of zinc to copper. Other particles found on the surface where the wire had been showed little aluminum but large amounts of chlorine and zinc.

Areas removed from the points of contact of the aluminum wire also showed large quantities of particles (Figure 7).

Under terminal 4, surface analysis of a darkened area where contact of the aluminum wire had been, indicated high levels of the same elements as before except that the copper was not present. The peak heights for aluminum and zinc were almost equal. Some irregular particles on the surface were mostly aluminum.

The surface of the least damaged aluminum wire was also examined in the area where it had made contact with the baseplate. There was some buildup of corrosion-like damage. An x-ray analysis of this area revealed only low concentrations of indium and chlorine.

Metallography

Sections of two screw heads from receptacle A were examined metallographically. Screw 1 exhibited melted areas near the surface and most of the deformed screw head showed varying degrees of recrystallization. Screw 3 which had been plated showed dezincification at the surface where there had been contact with the aluminum wire (as shown in Figure 8) but no recrystallization in the section examined.

The thickness of the indium plating on the A receptacle baseplate was estimated to be 5.4 µm. The plating material was a single phase.

Metallographic examination of the baseplate and wires of the B receptacle was also performed. The plating material on this receptacle was found to consist of two phases, Figure 9. Spot EDAX analyses across the plating layer indicated that the ratio of copper to zinc increased moving away from the brass interface. The surface of the plating was found to be porous. Two sections of wire were examined. Figure 10 shows the cross-section of a blackened area where contact was made with the baseplate. Again, the EDAX system was used to identify the principal constituents of the phase at edge of the wire. These were found to be aluminum

Figure 9: Two phase structure of plating material x 600 mag

Figure 10: Cross section of aluminum wire at contact point x 500 mag

Figure 11: Cross section of wire showing corrosion damage x 500 mag

and copper. A second section through a corroded area showed the damage of Figure 11.

DISCUSSION

The object of this work was to characterize the damage which occurred in two failed CO/ALR receptacles with a view to determining the causes of failure. Since CO/ALR devices have performed very well in laboratory current cycling tests and these devices were the only field failures known, it was hoped that the cause of the failure could be traced. Unfortunately, no obvious cause of failure could be determined.

Two possibilities were considered:

1) that screws were insufficiently tightened or were tightened on to poorly trimmed insulation,

2) the mechanisms of failure similar to those seen in non-CO/ALR devices were operative. These mechanisms are not at all well understood but characteristics of such failures have been previously documented.

It is apparent that for receptacle B, the first possibility can be ruled out since mechanical marks on the wires indicated that the screws had been tightened. Arcing damage was found adjacent to an impression of the baseplate in the wire.

The situation for receptacle A is less clear since the wires were not supplied. The mechanical damage of the baseplates was slight and in this case it seems possible that the screws were tightened insufficiently. In addition, the looseness of the baseplate in the molded plastic (apparently due to the fact that the receptacle was split for two circuits) could have contributed to the failure by allowing motion of the baseplate each time a plug was inserted or removed. Aluminum wired connections are very sensitive to such small motions. The arcing across the break-off tab area is probably a result of breakdown of the plastic material due to an already overheating connection. Initially, the arcing damage in the screw thread between screw and baseplate was taken to the evidence of a loose connection, but it is evident that the arcing damage between the wire and screw or between wire and baseplate would be sufficient to reduce any pressure present in the connection before such arcing.

The dezincification of the screw head at the contact point in receptacle A is similar to that observed in non-CO/ALR device failures/1/. Also the recrystallization of screw head and baseplate materials has been observed in non-CO/ALR failures.

The high concentrations of zinc observed on the baseplate are puzzling. Observations of zinc redeposition near contacts between aluminum and brass have been previously observed/2/ but as far as known, not in cases where the brass is plated. There are several possible explanations:

1) the zinc condensed in these areas after being vaporized in areas where arcing occurred,

2) the zinc diffused through the plating material at a high rate when the baseplate overheated due to the failing connection,

3) zinc diffuses through the plating material at normal temperature of operation of the baseplate.

The spot analysis of the plating of receptacle B indicated that there was no zinc concentration profile consistent with diffusion through the plating. Therefore explanation (1) seems most probable.

CONCLUSIONS AND RECOMMENDATIONS

1) Receptacle A could have failed because of screw looseness. Motion of the baseplate of the split receptacle probably accelerated the failure.

2) Screws on receptacle B which exhibited screw arcing damage had been tightened to about 0.56 N.m torque.

3) The behaviour of zinc in the contact requires additional study.

4) Many of the features observed in these failures (dezincification, recrystallization, intermetallic compounds) are similar to those observed in non-CO/ALR receptacle failures.

5) Plating quality on receptacle B was poor in that the surface was extremely rough and porous. The effect of plating quality on connection life should be investigated.

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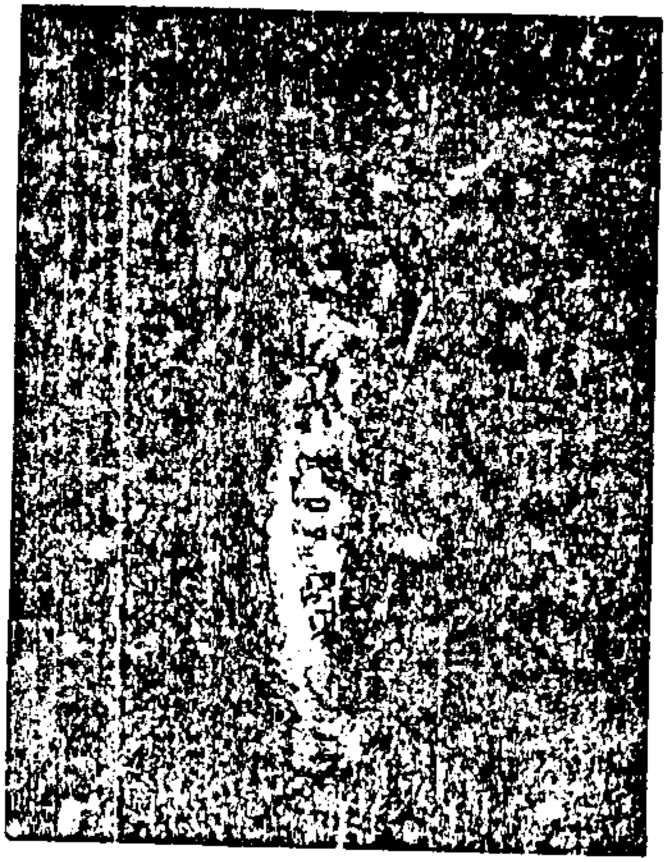

Figure 1: Impression of baseplate on wire adjacent to arcing damage

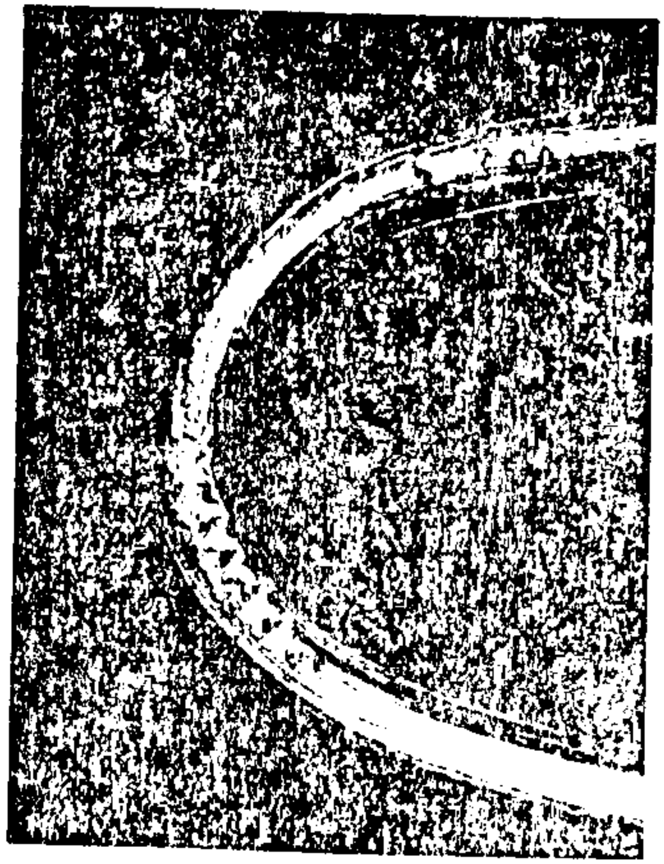

Figure 2: Impression of baseplate at 0.56 n.m. torque

Figure 3: Slightly damaged area of baseplate - Receptacle A x 140 mag

Figure 4: Another damaged area of baseplate where high zinc concentrations found x 140 mag

Figure 5: Arcing damage under screw head x 120 mag

Figure 6: Deformation and particles on plating x 600 mag

Figure 7: Surface appearance removed from contact area x 300 mag

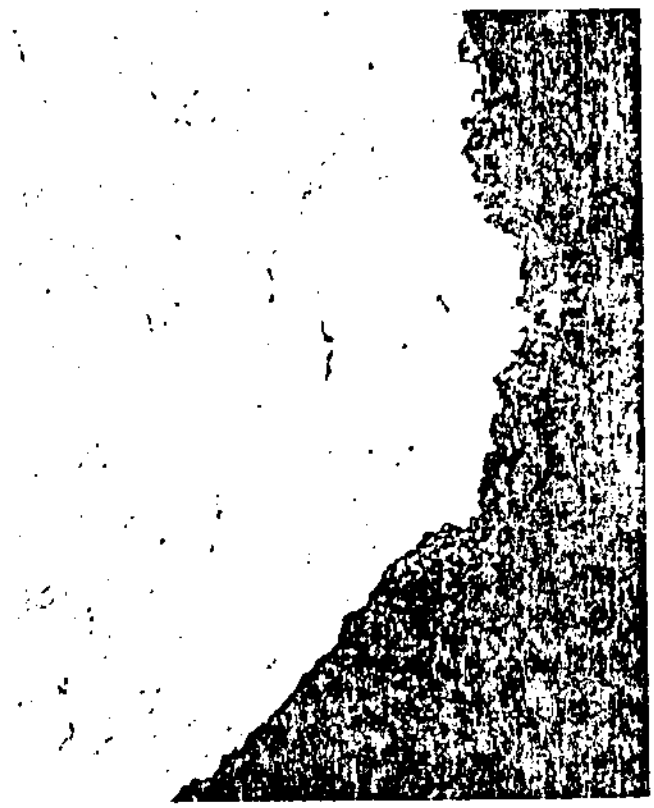

Figure 8: Dezincification of screw head - receptacle A

Figure 9: Two phase structure of plating material x 600 mag

Figure 10: Cross section of aluminum wire at contact point x 500 mag

Figure 11: Cross section of wire showing corrosion damage x 500 mag