F Note #472

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FERMILAB

FAILURE ANALYSIS OF TEV I ELECTRODE (TIE) ARRAY SOLDER JOINTS

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September 2, 1987

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PURPOSE:

Failure of TIE array loop assembly solder joints within Stochastic Cooling Tanks during system operation resulted in the loop base plate dropping into the beam region. This caused a non-operational condition to exist within the system.

In order to understand the failure mechanism, several loop assemblies were submitted to Midwest Materials and Engineering Consultants for complete metallurgical evaluation and failure analysis. Because of the similarity between the loop assembly material construction and the TIE resistor assemblies, several resistor assemblies were also evaluated.

SAMPLES AND SAMPLE HISTORY:

The loop assembly samples were reportedly from standard production runs, which involved the attachment of an OFHC Copper post via Sn 62 solder with RMA flux to a Beryllium Copper plate. The solder joint has a ring-and-plug type of configuration, figure 1. Samples evaluated were as-soldered and from disassembled cooling tanks that had experienced approximately 2 years of service.

The resistor assemblies were also standard production. This involved the attachment of a small, reportedly carbon composition resistor via Sn 62 to the beryllium copper housing. The terminations of the resistor were gold plated over their metallization. The solder joint has a cup-and-plug configuration, figure 2. Samples evaluated were from the same disassembled cooling tanks as the loop assemblies.

Loop assemblies are attached to the resistor assemblies with a small spring clip within the loop post. One loop post-resistor assembly is attached to a printed circuit card and the other is attached to a stainless steel frame, figure 3.

The service environment within the tanks is as follows:

- -The tanks are vacuum baked prior to system operation at 150°C for 7 days at 10^{-6} Torr. This procedure is repeated whenever the tanks have been open to air.
- -The tanks operate at 10^{-9} Torr.
- -Temperatures range from liquid nitrogen temperatures to nominally 150°C in Pickup Cooling Tanks. In Kicker Cooling Tanks, which are water cooled, temperatures range from approximately 55°C to 150°C (nominal).
- -Time subject assemblies were in service is approximately 2 years.

In addition to the gravitational force of the loop assembly, the forces experienced by the solder joints are mainly shear tensile forces due to thermal expansion from material differences within the assembly. Thermal expansion forces are translated down the posts and cause the plate to flex.

Likewise, the resistor solder joints are placed in tension and may experience slight bending moments.

PROCEDURE/ANALYSIS:

The samples were observed macroscopically with a stereo microscope prior to metallographic preparation. Once prepared, microstructures were evaluated with a metallograph.

Macroscopic evaluation of the loop assembly solder joints revealed that as-soldered, both the post and the plate appear to be well wet. The solder fillets are fairly bright and good feathering can be seen at the base of the fillet adjacent to the plate. The samples taken from the cooling tank that were still intact had a similar fillet appearance, some cracking was noticed at the fillet-plate interface, figure 4.

The resistor assembly solder joint configuration is not externally visible; this prohibited macroscopic evaluation.

Microscopic evaluation of the as-soldered sample revealed intermetallic formation at both the post and the plate. Intermetallic formation confirms that a metallurgical bond was formed between the components during soldering, figure 5.

Two intermetallic layers could be discerned at each of the solder-component interfaces in the samples taken from the cooling tank. One layer appeared white and the other, gray. Cracking could be seen primarily along the gray intermetallic, although the white layer also exhibited some cracking. The cracks were only visible adjacent to the Beryllium Copper plate, figure 6.

The resistor assembly, viewed in cross-section, exhibited good wetting at both the copper cups and the resistor terminations. Gold-tin intermetallic needles could be seen within the solder joints. The beryllium copper cups were designed with weep holes to avoid flux and air entrapment; this maximized solder coverage, figure 7. At high magnification, crazing and cracking were noted in the intermetallic layers at both interfaces, figure 8.

CONCLUSION:

Intermetallic formation is essential for a good solder joint; however, intermetallic phases are brittle and can reduce the reliability of an apparently good solder joint. Therefore, while it is necessary to have the intermetallic, it is just as necessary to keep it to a minimum. This means limiting the amount of high temperature exposure to prevent accelerated solid state diffusion between the host metal and the solder. High temperatures are those within 50°C of the melting point of the solder.

Time is also a consideration since diffusion is time-temperature related. Obviously, longer high temperature exposure times are more deleterious than shorter times. Depending on the solder and the host, a period of minutes, even seconds, can adversely affect the quality of a solder joint.

It is well documented that copper and tin form two main intermetallics; Cu_6Sn_5 and Cu_3Sn. Cu_6Sn_5 is the white-appearing intermetallic and is created during wetting. Cu_3Sn, the gray intermetallic, only occurs upon prolonged high temperature exposure and has a more brittle character than Cu_6Sn_5.

The above intermetallic phases can be seen along both the OFHC copper post - solder interface and the Beryllium Copper plate-solder interface; however, fracture of the loop assembly solder joints occurs primarily within the gray Cu_3Sn intermetallic layer, only along the Beryllium Copper interface.

Introducing another constituent to the intermetallic layers serves to decrease joint strength even more. Formation of a ternary Be-Cu-Sn phase at the solder-plate interface, adjacent to or within the Cu_3Sn layer promotes the failure at this interface.

As the tin is depleted from the solder during intermetallic formation, a lead-rich phase predominates at the intermetallic-solder interface. This relatively soft region offers little resistance to crack propagation and, at higher magnifications, one can see that the solder joint has many small cracks through the brittle intermetallic. This condition exists within the resistor assembly solder joints.

Continued use of the resistor assemblies with degraded soft solder joints may result in their failure. Initially, an intermittent electrical condition may exist; as the system experiences temperature excursions, the resistor connection will become electrically open. Ultimately, tensile forces may actually pull the resistor out of the copper housing.

RECOMMENDATIONS:

If it is desirable to provide infinite joint life, a redesign of the loop and resistor assembly should be considered. The following areas should be explored:

1. Silver brazing the loop assemblies.

2. Hard soldering the resistor assemblies with 80Au-20Sn solder. This solder is of the eutectic composition, i.e. has a direct solid-to-liquid transition, which means actual dwell time at the 320 C soldering temperature would not be long enough to damage the component.

3. Use of an OFHC copper plate with the loop assemblies and continue to soft solder.

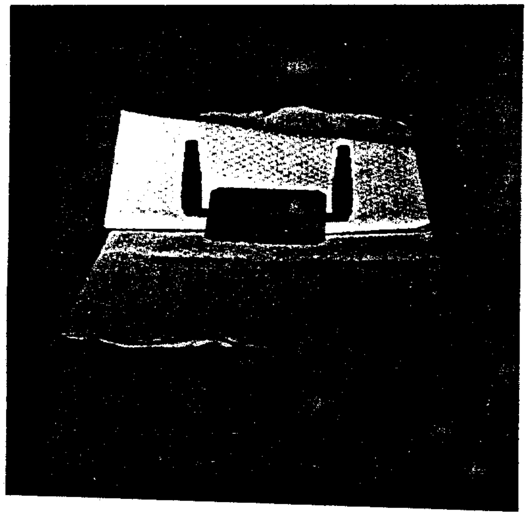

Figure 1:Documentary photograph of a soldered loop assembly. The plate is beryllium copper and the posts are OFHC copper. The solder joint configuration is ring-and-plug.

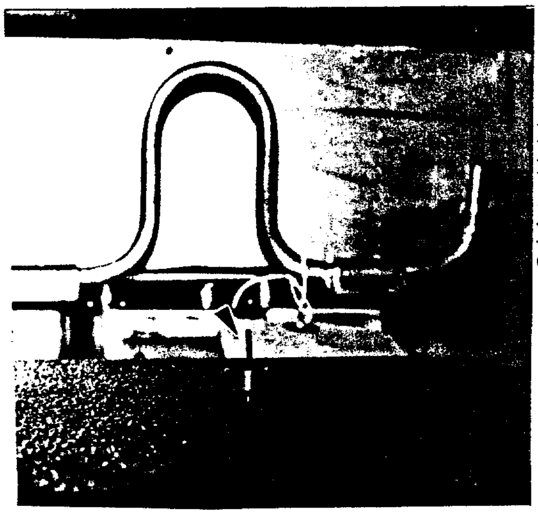

Figure 2:Documentary photograph of a resistor assembly. The housing is beryllium copper and the resistor has gold plated terminations. All solder joints evaluated were made with Sn 62.

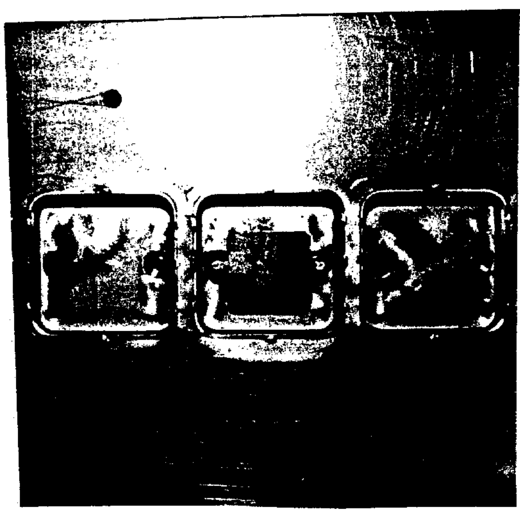

Figure 3:Loop assembly installed within the cooling tank. The loop posts fit onto the resistor assembly pins and are fixed with a spring clip.

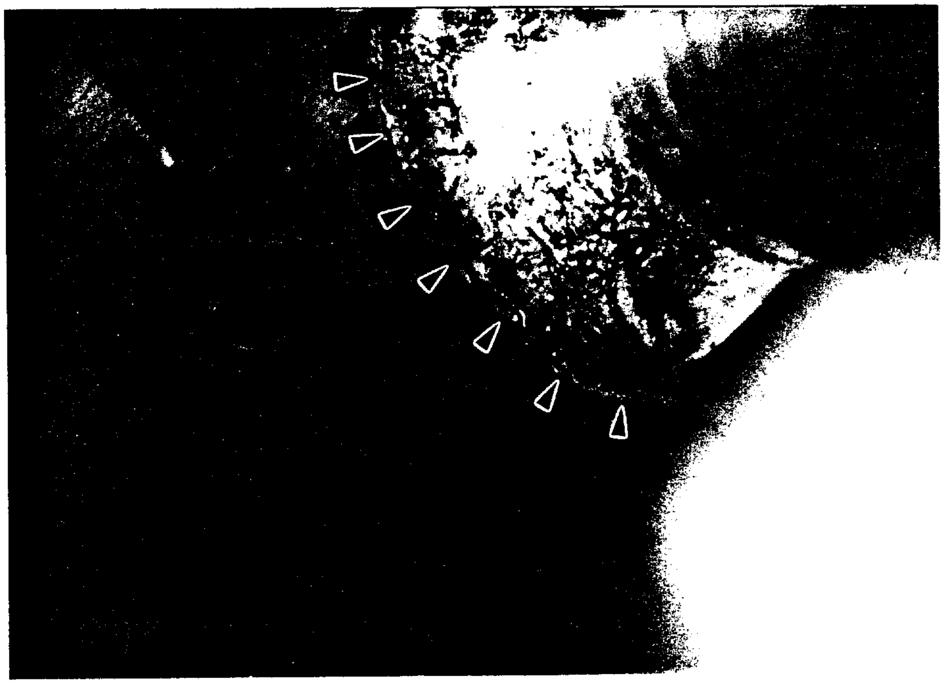

Figure 4:Although the solder joints on service samples appeared fairly bright, cracking was noticed at the base of the fillet adjacent to the beryllium copper plate.

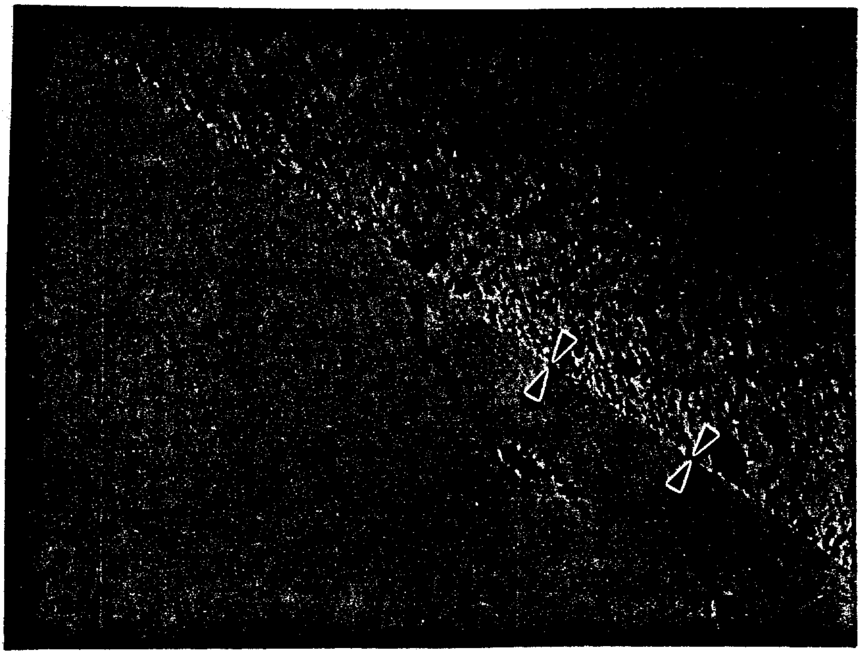

Figure 5:Cross section of an as-soldered loop assembly solder joint at the plate-solder interface X400. Arrows bracket the Cu_6Sn_5 inter -metallic formed during soldering.

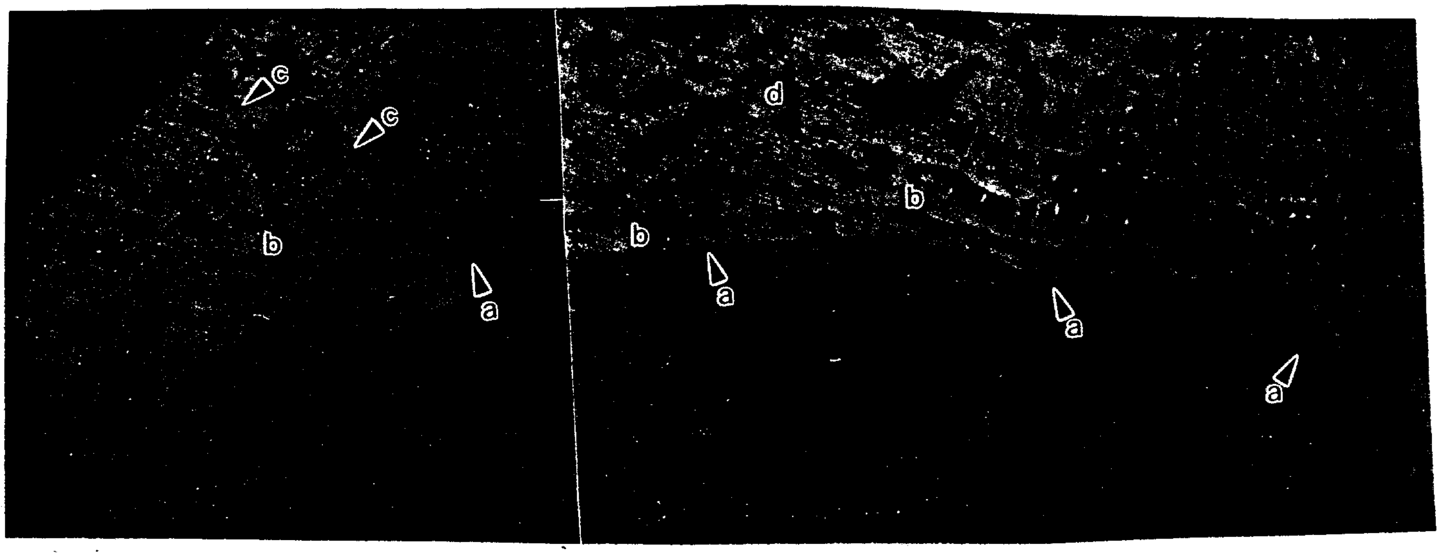

Figure 6: Cross section of a loop assembly solder joint after 2 years of service and an undetermined amount of high temperature exposure. Note the presence of two intermetallic layers. Cracking is occuring primarily along the Cu_3Sn layer, a; however, cracks are also within the Cu_6Sn_5 layer, b, and along the lead phase, c, of the solder, d. Note the immense thickness difference between the as-soldered sample and the above. Intermetallic growth occurred as a result of high temperature exposure.

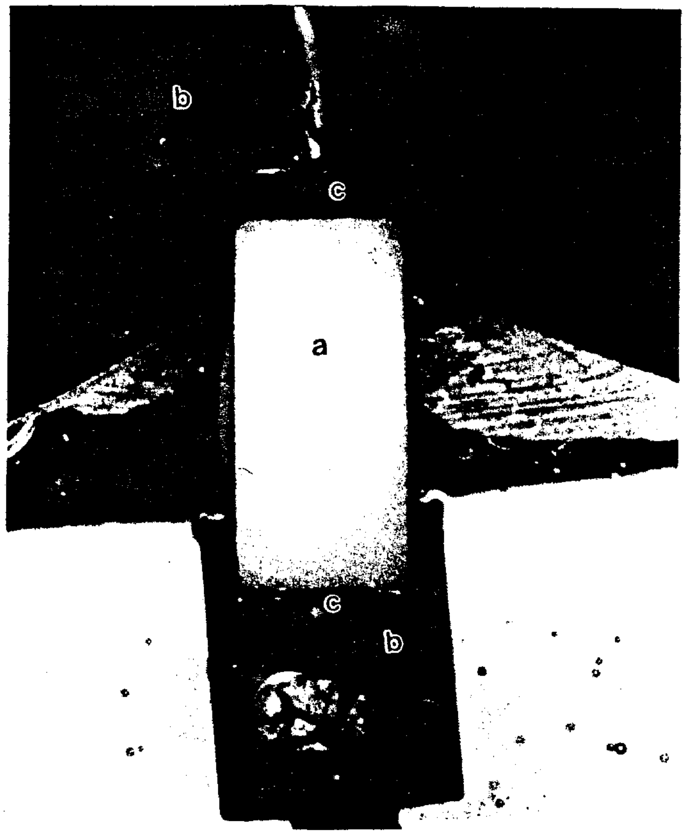

Figure 7a: Cross section of a resistor assembly.
a) resistor
b) BeCu housing
c) solder joint
Weep holes within the BeCu housing permitted flux and air to outgas, maximizing solder coverage.

Figure 7b: Resistor solder joint X100. Arrows indicate gold-tin intermetallics.
d) resistor metallization

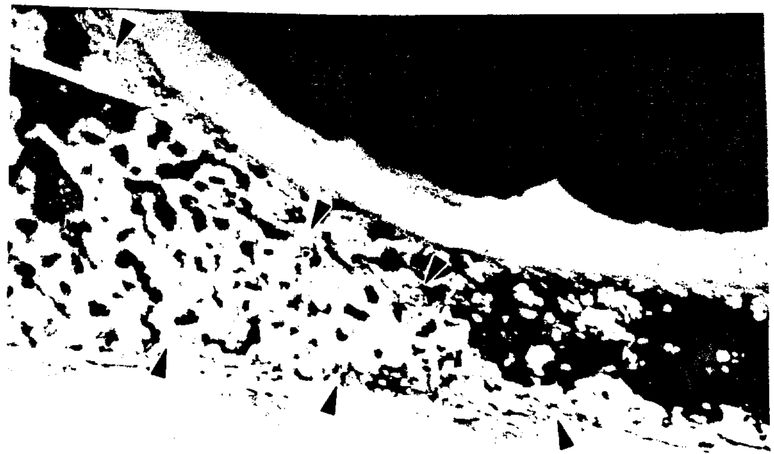

Figure 8: High magnification observation of the resistor solder joints revealed micro-cracks at both intermetallic interfaces. Cracking is most severe at the copper-solder interface. Both micrographs are X400.