Failure Analysis of Eutectic and Pb-Free Solder Alloys after High Stress Exposure

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Abstract
Failure analysis was performed on fourteen thermally cycled or vibration tested PDIP components from the JCAA-JG-PP Lead-Free Joint Test Project. The components differed in component finish, solder alloy used for assembly, test vehicle/circuit board type, rework (yes or no), and rework alloy (if relevant). Components were either vibration or thermally tested. A qualitative comparison was made between the extent of damage visible using 3D digital microscope images of the solder joint surfaces and the damage seen in optical microscopy cross-sectioned joints. It was found that use of a digital microscope, in conjunction with resistance measurements, made the decision of which joints to cross-section easier. However, it was not found that the digital microscope can be used exclusively, without cross-sectioning samples, to reveal the important damage features on stressed solder joints.

Introduction
Failure analysis of mechanically or thermally stressed solder joints is one of the most time consuming steps in assessing solder joint reliability. It typically consists of cross-sectioning individual solder joints identified via resistance measurements as having failed during thermal cycling, vibration tests, or other tests that stress solder joints, and then examining the cross-sections for specific types of damage. Cross-sectioning is a destructive technique: it requires mounting the specimen in a hard polymer, and grinding or cutting the sample to reveal specific solder joints. It is inherently 2-D, giving a planar "section" through the solder joint and eliminates the possibility of re-examining other features in the same joint or in joints removed to reveal the solder joint of interest. In this paper we compare the damage revealed by digital microscopy with damage seen through the corresponding 2D cross-sections. To provide greater relevance to these comparisons, the analyses were performed using PDIP components from the JCAA-JG-PP Lead-Free Joint Test Project,[1,2] that had been either thermally cycled or vibration tested. The component selection included PDIPs with two different surface finishes, Sn and Au/Pd/Ni, on boards with Tg = 140 °C, with some being reworked prior to mechanical testing. The aim of this study was to determine whether digital microscopy can reveal the important damage features in stressed solder joints without cross-sectioning, and, therefore, whether this technique can be used effectively for large-scale manufacturing and reliability trials, such as the current NASA-DOD Pb-Free Study. This study is part of a larger effort on repair and rework of legacy systems funded by NAVSUP, under PO N00164-D-0007 through Task Order 1722 - NWSC Crane to SAIC.

Components Evaluated
The 14 assembled and tested PDIP components from the JCAA-JG-PP Lead-Free Joint Test Project [1,2] evaluated in this study were removed from PWBs 50, 58, 163, 167, 191, and 194. The information on the boards, the components, and the testing were obtained from Hillman and Wilcoxon[1], and Woodrow[2]. The board layout is shown in Figure 1. The PDIPs were located along the right edge of a board. Table 1 lists the component finish, solder alloy used for assembly, test vehicle/circuit board type, rework (yes or no) with rework alloy noted if relevant, testing method, and time or number of cycles for failure for each of the components examined. The thermal cycle range was from -55°C to 125°C using a 30 minute dwell at the high temperature extreme, a 10 minute dwell at the low temperature extreme, and a maximum temperature ramp of 10°C/min. Electrical continuity was monitored continuously through the tests in accordance with the IPC-9701 specification.

As seen in Table 1, not all thermally cycled components had failed at the end of testing. The vibration test conditions are described in detail in Woordrow[2]. During vibration testing, z-axis vibration levels were increased every 60 minutes, until a total of 420 minutes had been reached. Continuous electrical monitoring was used to identify time to failure.

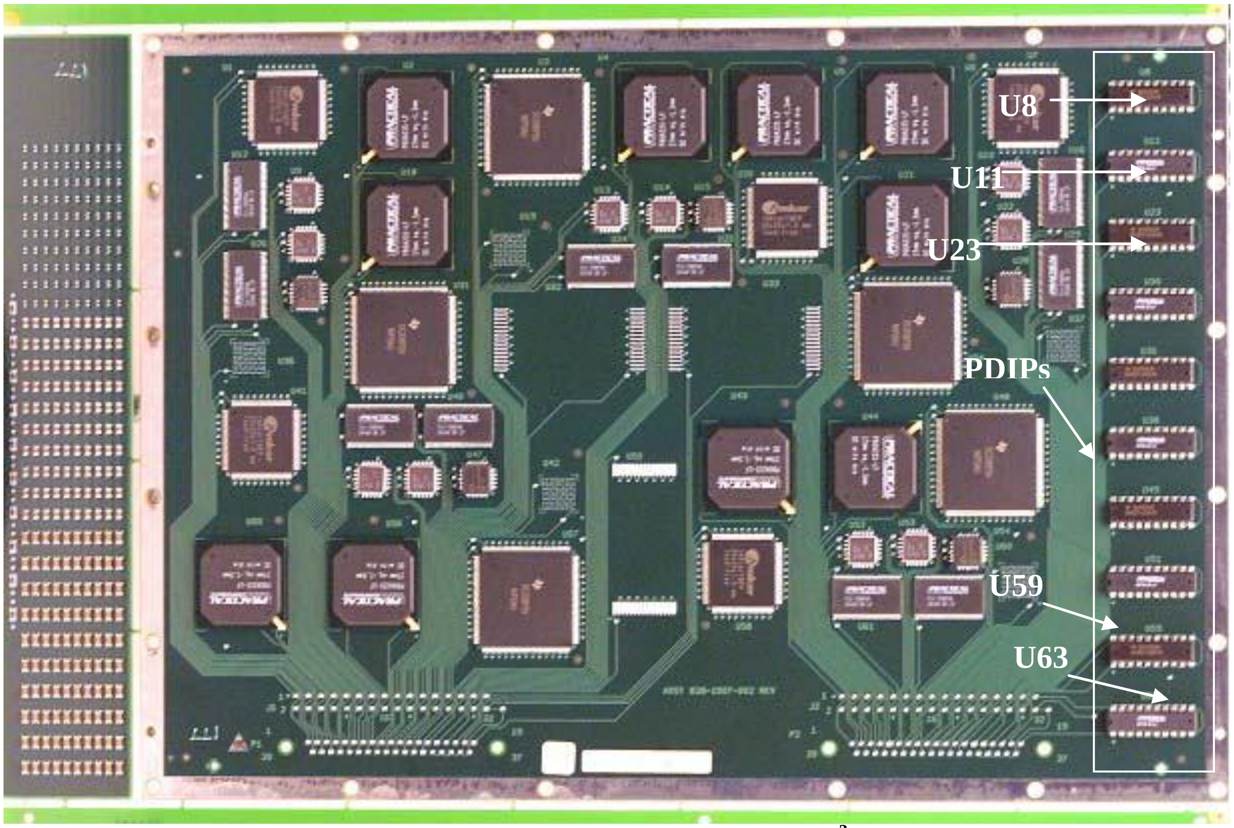

Figure 1 – Printed Wired Board Design[3]

Table 1 – Components Evaluated

Board	Component	Rework (Y/N)	Component Failure (Y/N)	Surface Finish	Rework Solder Composition	Stress Test Vibration or Thermal Cycling	Time to Failure Vibration (min) Thermal Cycling (# Cycles)
50	U59	Y	Y	Au/Pd/Ni	Sn37Pb	Vibration	390
50	U63	N	Y	Sn	---------	Vibration	121
58	U59	Y	N	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	---------
58	U63	N	N	Sn	---------	Thermal Cycling	---------
163	U8	N	N	Au/Pd/Ni	---------	Thermal Cycling	---------
163	U11	N	N	Sn	---------	Thermal Cycling	---------
163	U23	Y	N	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	---------
167	U59	Y	N	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	---------
167	U63	N	N	Sn	---------	Thermal Cycling	---------
191	U59	Y	Y	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	842
191	U63	N	Y	Sn	---------	Thermal Cycling	1595
194	U8	N	N	Au/Pd/Ni	---------	Thermal Cycling	---------
194	U11	N	N	Sn	---------	Thermal Cycling	---------
194	U23	Y	N	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	---------

Experimental Procedure

Digital Microscope

The solder joints on each component were evaluated using a digital microscope (Keyence Model VHX-600). Such a microscope permits taking images of an object with great depth of field. Images are taken of the solder joints at various points of focus and then stitched together to construct a 3D image. Very high resolution digital images are obtained by a 54 megapixel 3CCD camera. A zoom lens was used and the magnifications of the images ranged from 30x to 150x. Solder joint fillets on the top and bottom sides of the PWBs were examined.

Resistance Measurements

Resistance measurements were used to determine daisy chain continuity. Measurements were taken from pin to pin on a component starting with pins 1 and 2 and continuing with 2 and 3 until the last pair, 19 and 20 were tested. All resistance measurements greater than 1MΩ were designated as > 1MΩ.

Cross-Sections

The resistance measurements in conjunction with the damage observed in the 3D digital images were the basis for the solder joint cross-sectioning plan. Pins with either resistance readings significantly higher than average and/or showed surface evidence of damage, such as pad lifting, incomplete pad wetting or surface cracks, were selected for cross-sectioning. The samples were mounted in a quick setting acrylic, ground using 180, 320, 400 and 600 grit papers, and polished with 0.3 and 0.05 alumina polishing media. Optical micrographs of as-polished samples were taken for comparison with the damage observed using the digital microscope. In addition, microstructures for two of the samples from PWB 191 were obtained after etching using a typical NH_4OH, H_2O and H_2O_2 etchant. The cross-sectioning was performed by Trace Laboratories, Palatine, IL.

Comparison of Surface Images and Cross Sections

For specific joints, a qualitative comparison was made between the damage observed in the digital microscope images and in the cross-sections examined using a typical metallographic light optical microscope. Such a comparison was used to determine if there were characteristic fracture patterns seen on the surface that corresponded to specific fractures or failures observed in cross-sections.

Results and Discussion

The orientation of the assembled PDIPs is shown for reference in Figure 2, using the bottom side of Component U8 from board 104 (a salt fog tested board also from the JCAA-JG-PP study) as the example. Pins are numbered 1 though 20 using the lower bullet tab in the lower right hand corner as a fiducial mark. A schematic of how a PDIP was daisy chained is given in Figure 3.

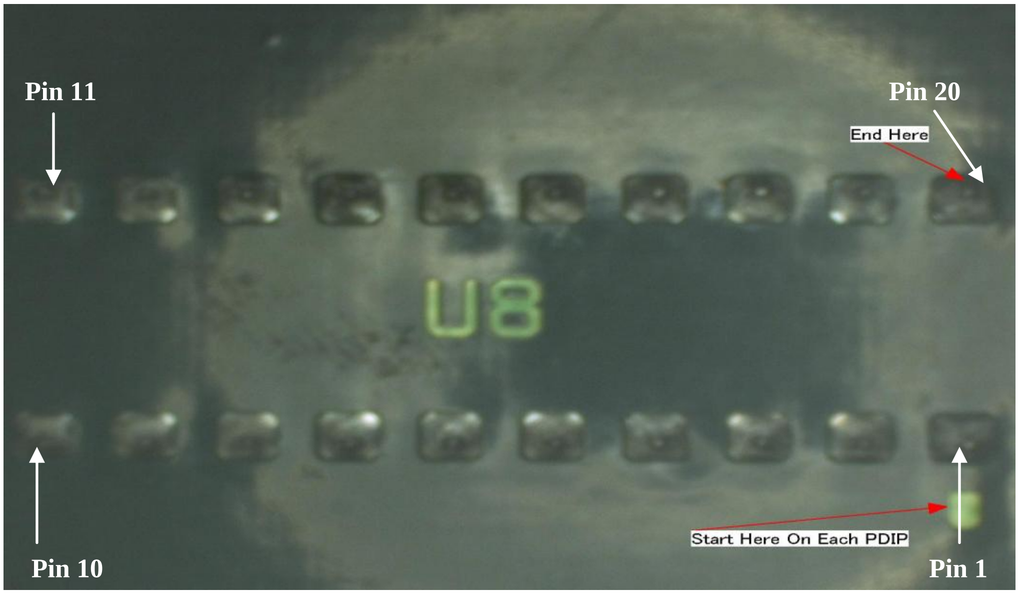

Figure 2 – Example of a PDIP from PWB

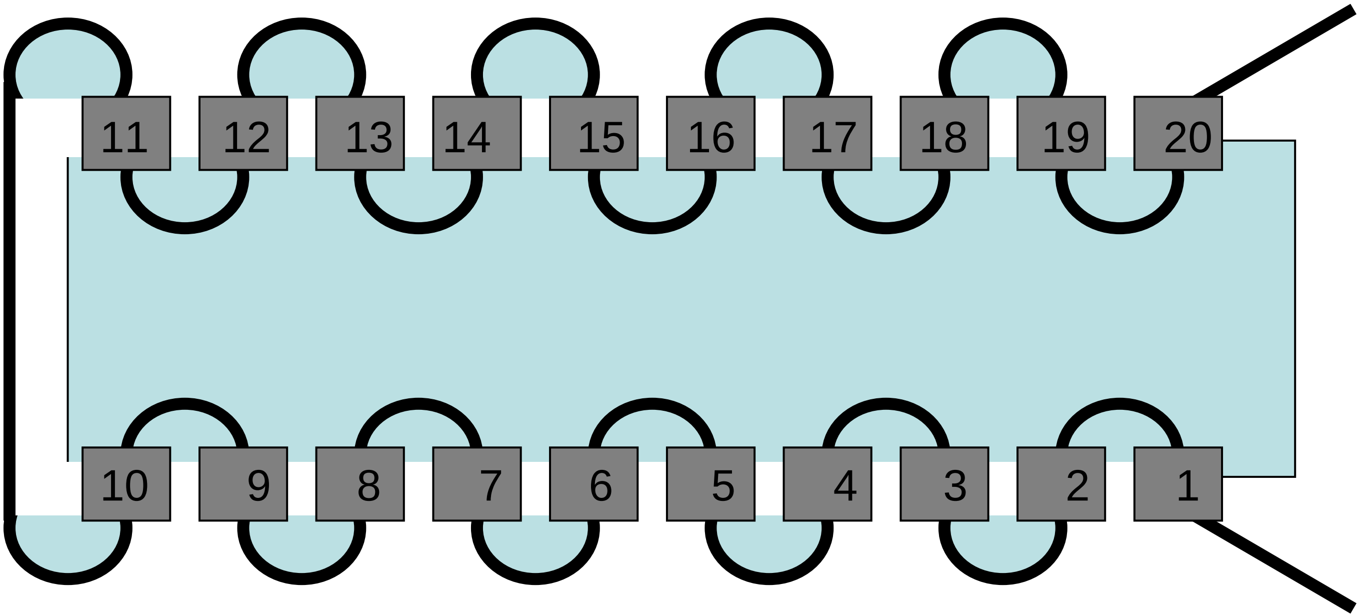

Figure 3 – Daisy Chain for Pins on a PDIP

Boards with No Component Failure

The individual solder joints of components listed in Table 1 that did not fail during testing had measured resistances between 0.2 and 0.7Ω. Figures 4 – 17 show pictures of pins from the components that did not fail. From the components that did not fail, almost all those that had a Sn finish showed more visual evidence of damage (surface cracking and pad lifting) than those with an Au/Pd/Ni Finish.

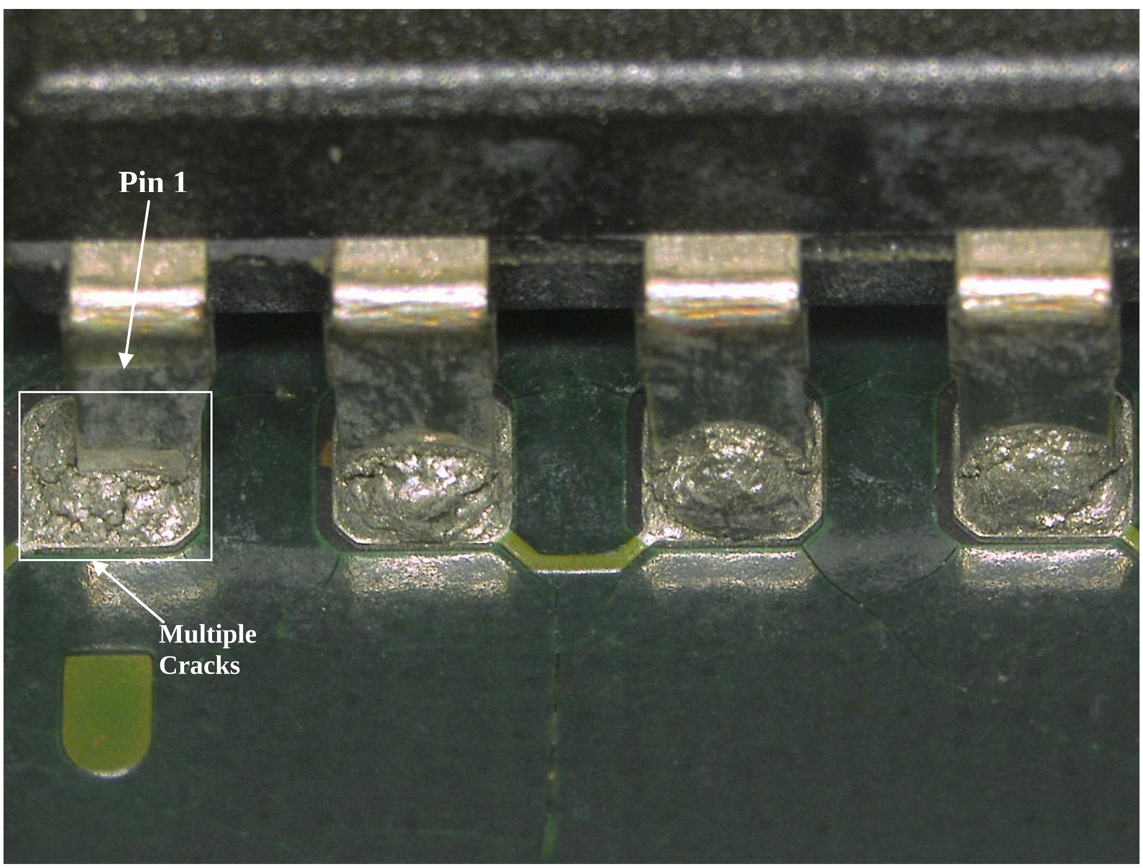

Figure 4 – PWB 58 - U59, Pins 1 – 4 (Au/Pd/Ni Finish)

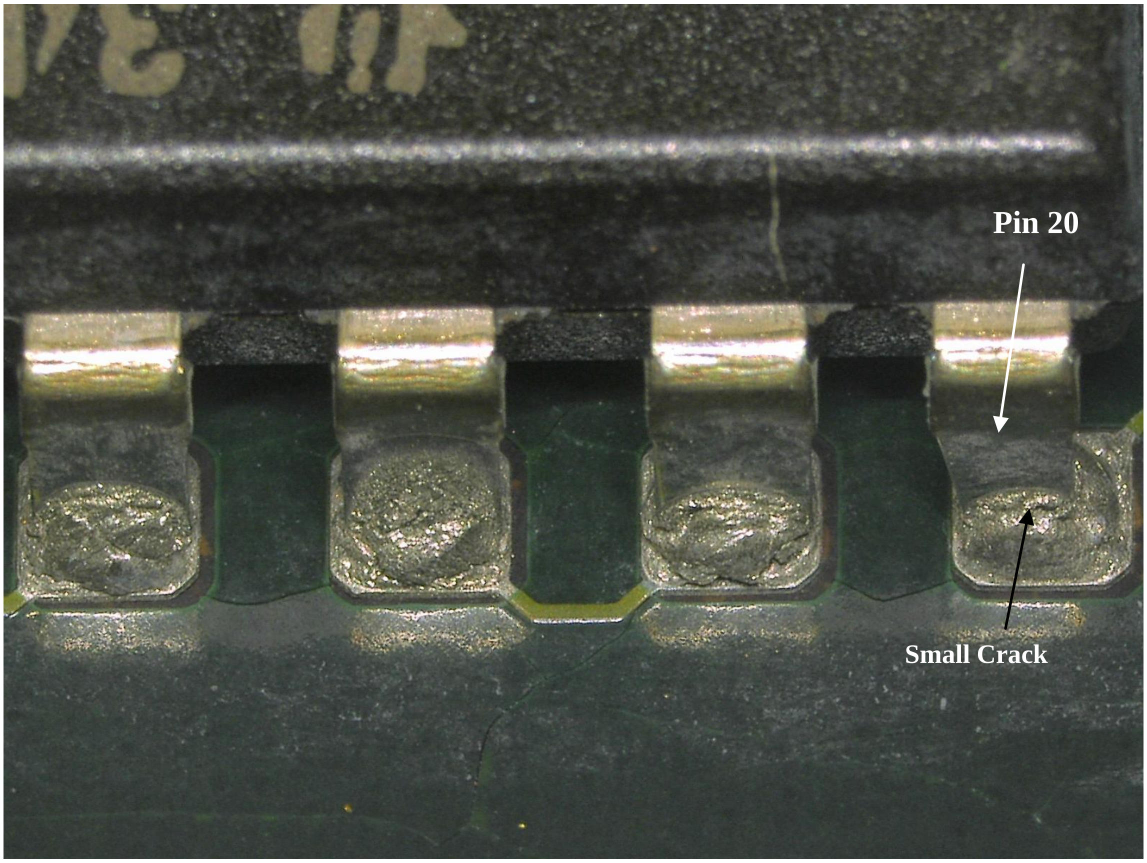

Figure 5– PWB 58 - U59, Pins 17 – 20 (Au/Pd/Ni Finish)

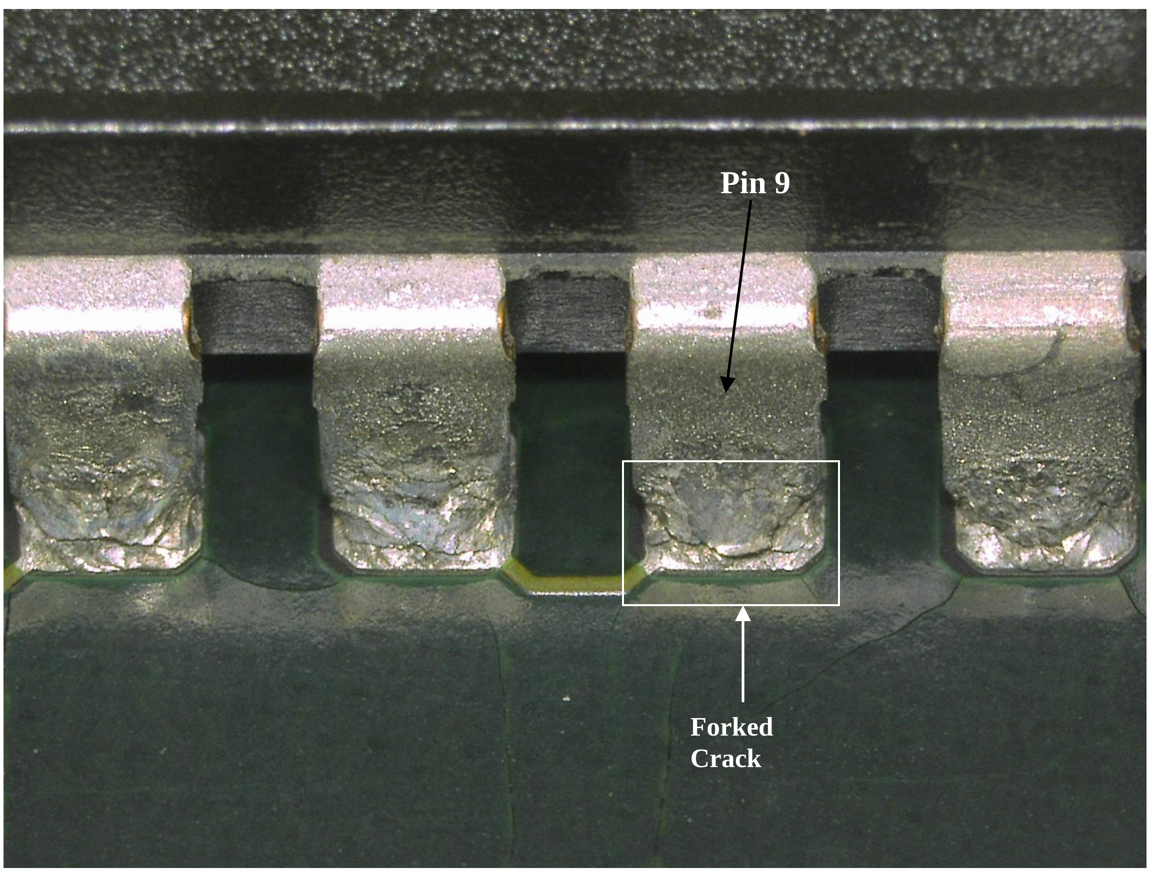

Figure 6 – PWB 58 – U63, Pins 7 - 10 (Sn Finish)

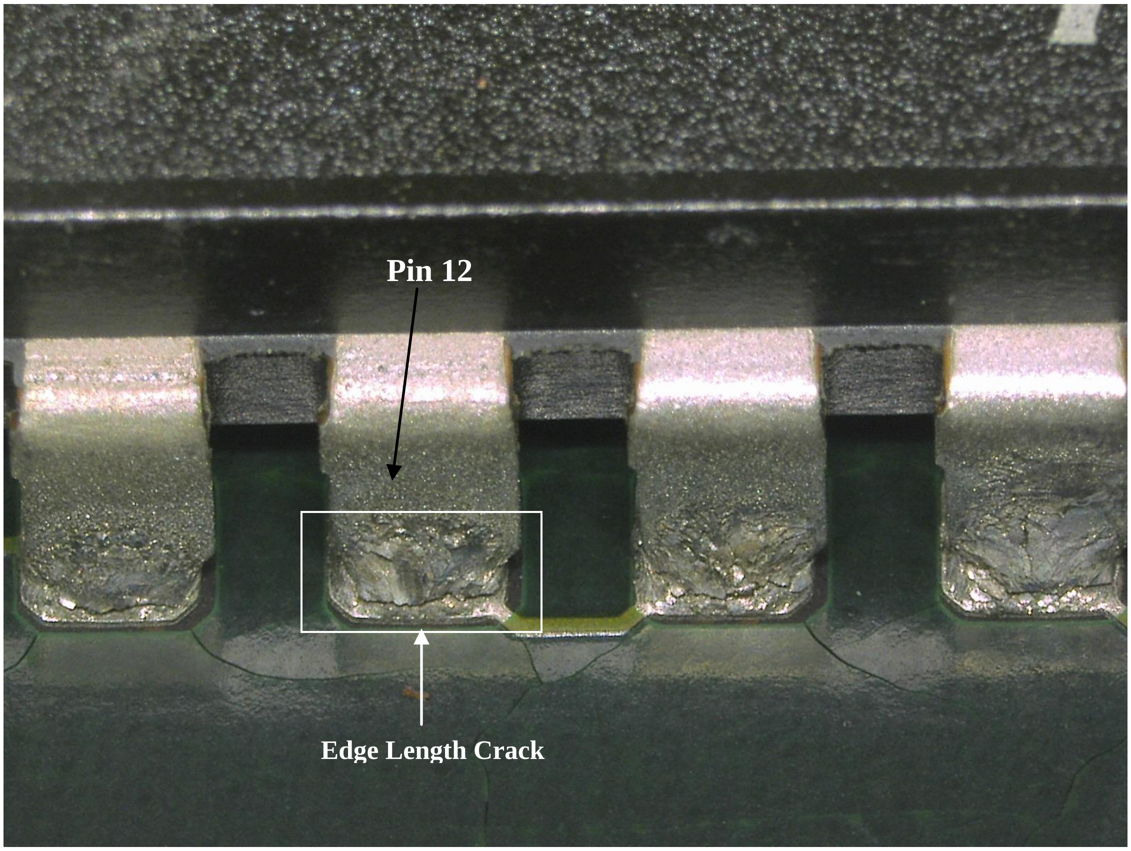

Figure 7 – PWB 58 – U63, Pins 11 – 14 (Sn Finish)

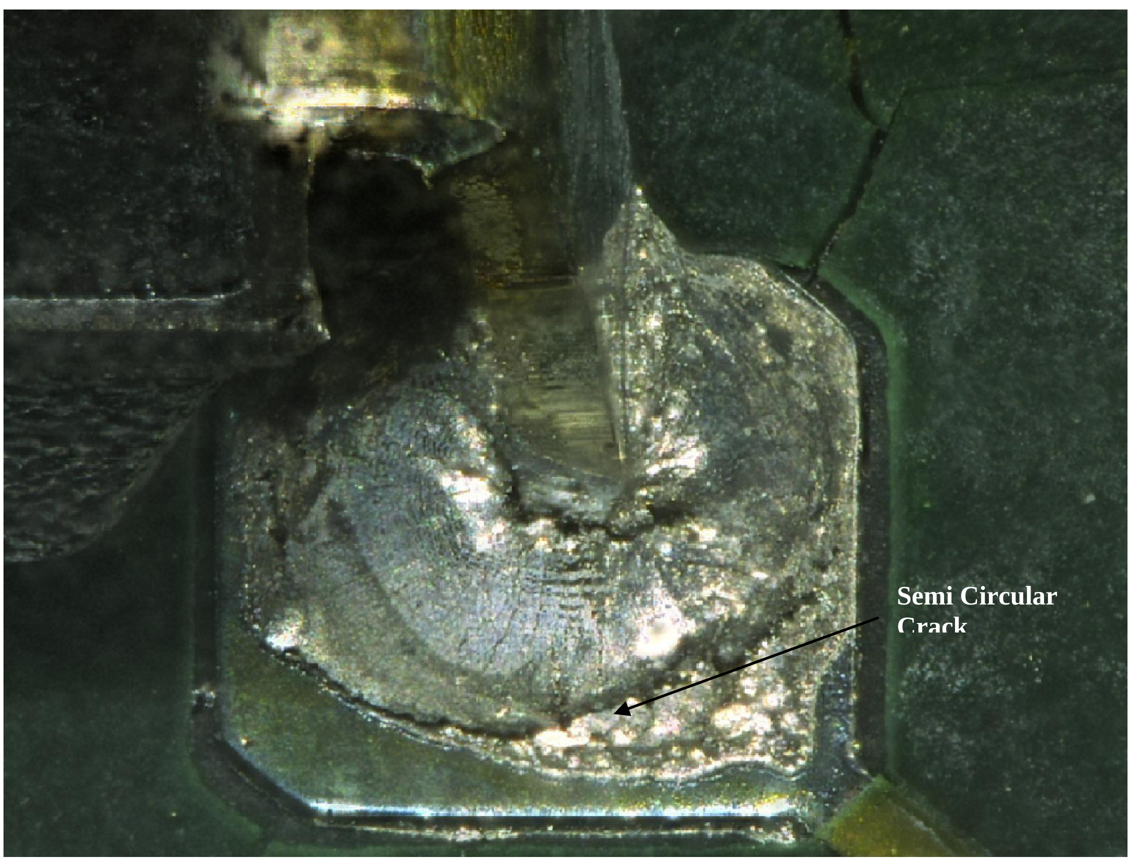

Figure 8 - PWB 163 - U8, Pin 1 (Au/Pd/Ni Finish)

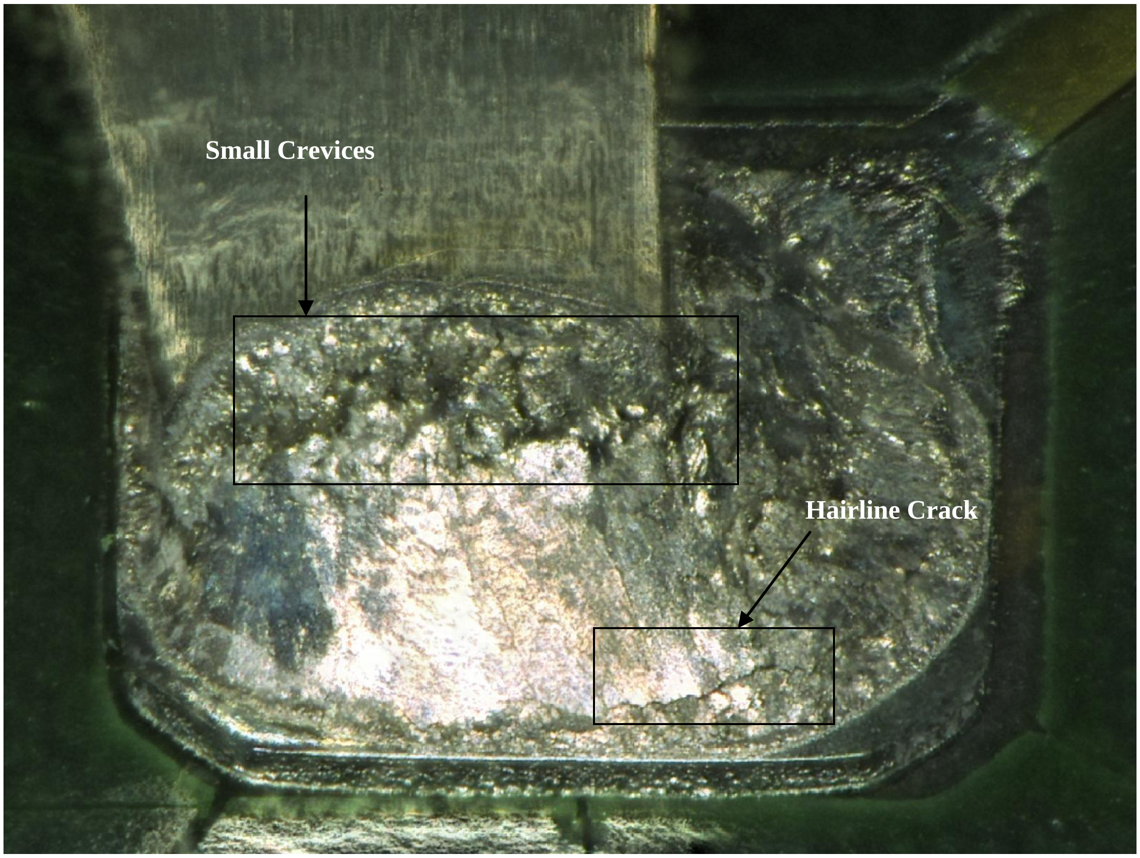

Figure 9 - PWB 163 - U8, Pin 20 (Au/Pd/Ni Finish)

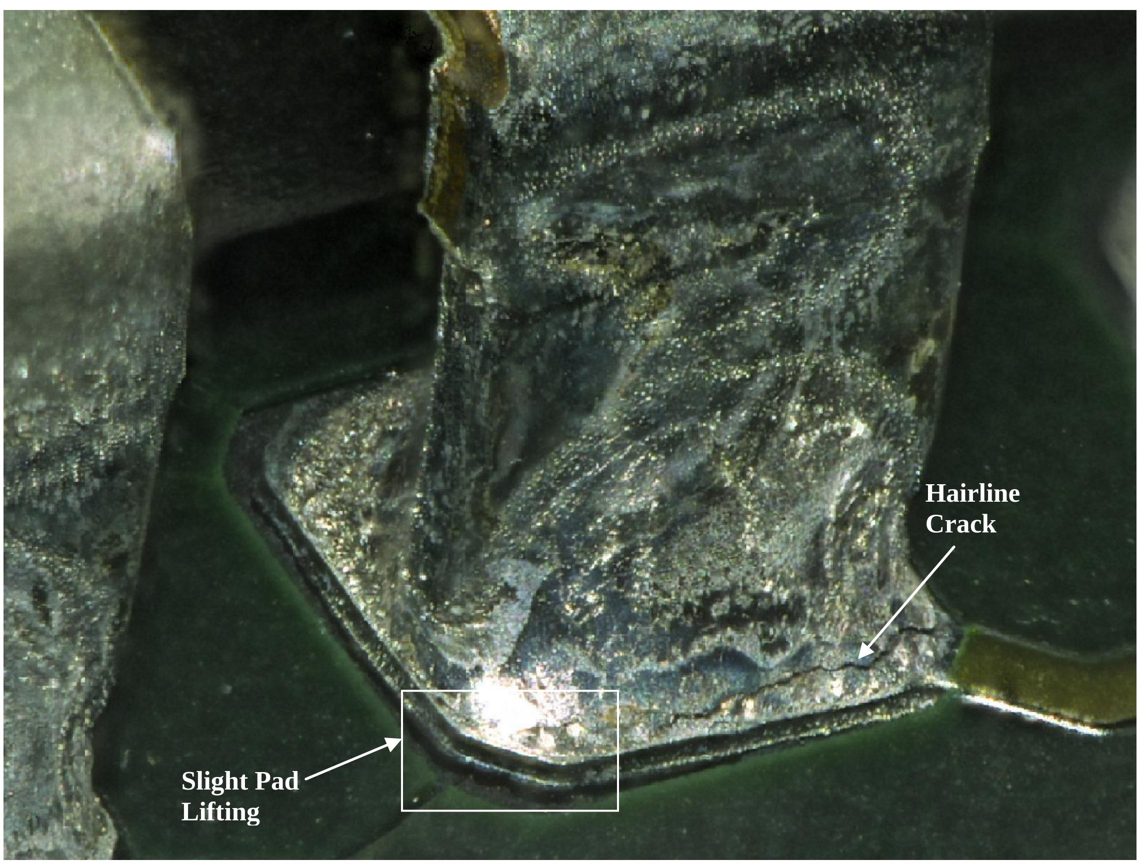

Figure 10 - PWB 163 - U11, Pin 6 (Sn Finish)

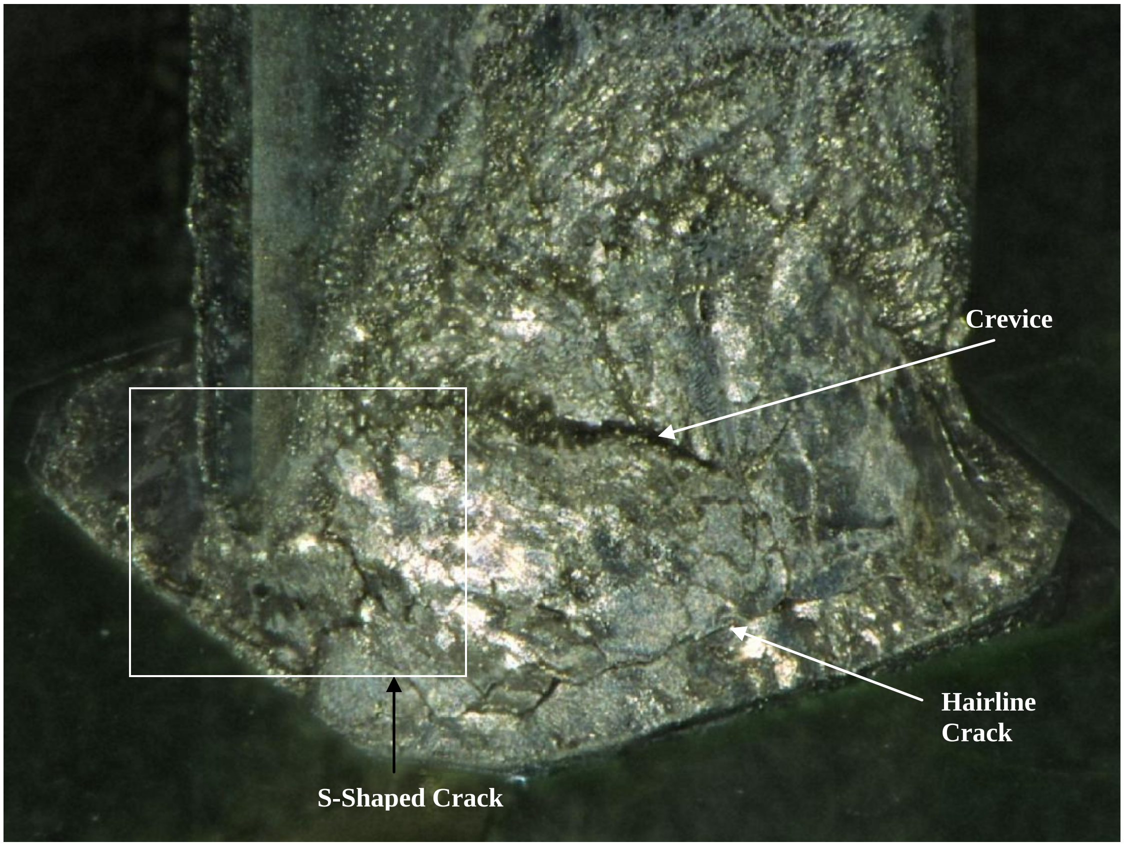

Figure 11 - PWB 163 - U11, Pin 15 (Sn Finish)

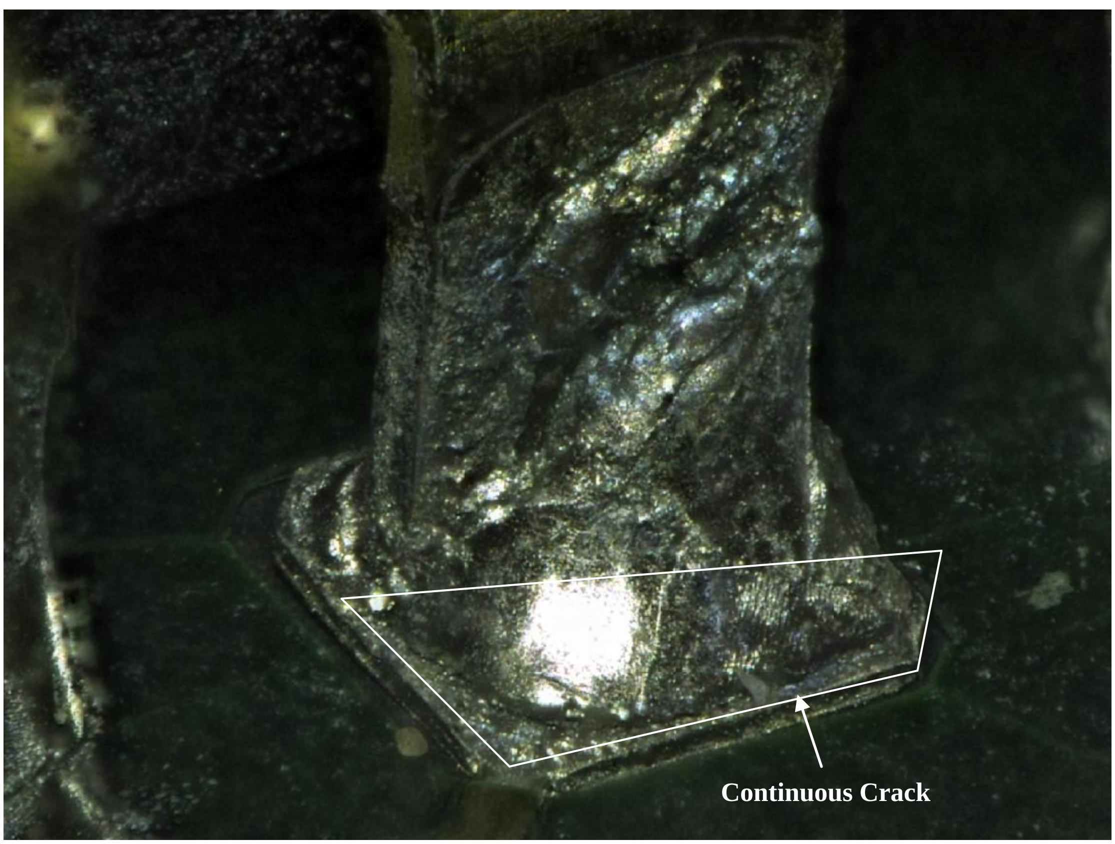

Figure 12 – PWB 163 – U23, Pin 9 (Au/Pd/Ni Finish)

Figure 13 - PWB 163 – U23, Pin 12 (Au/Pd/Ni Finish)

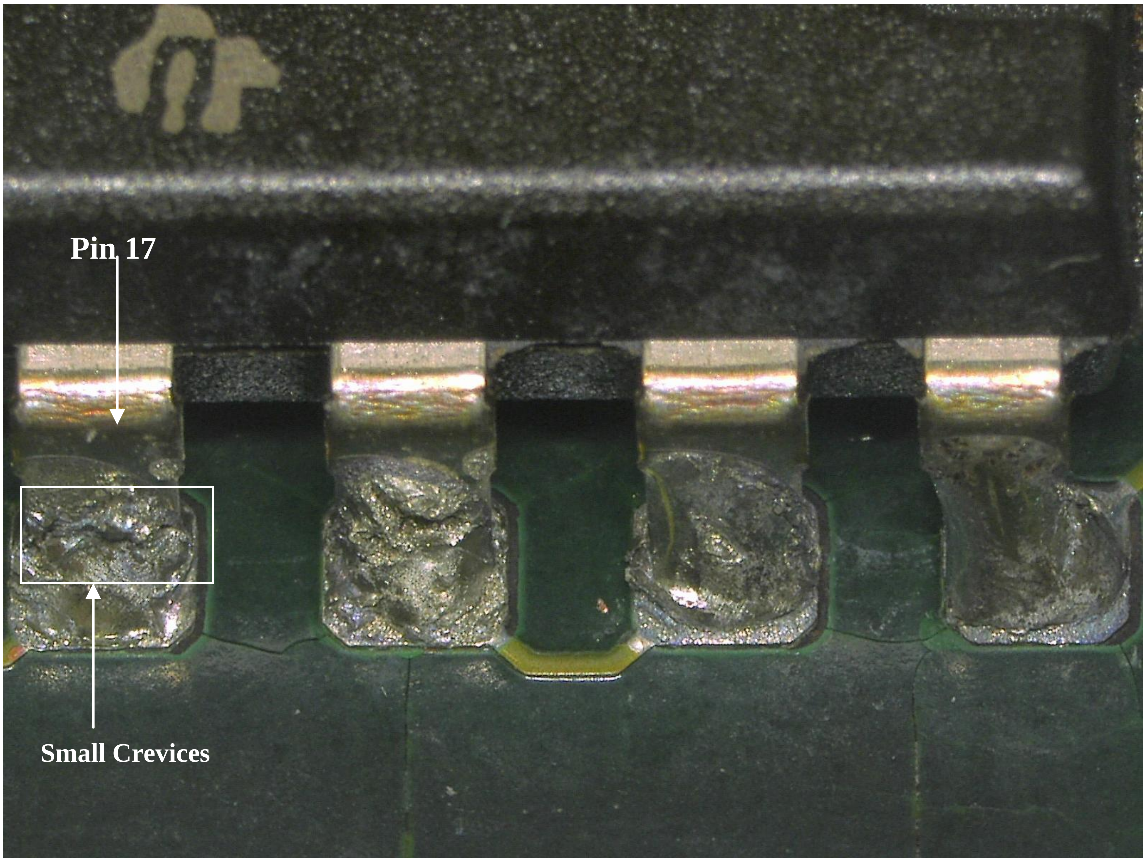

Figure 14 - PWB 167 – U59, Pins 17 - 20 (Au/Pd/Ni Finish)

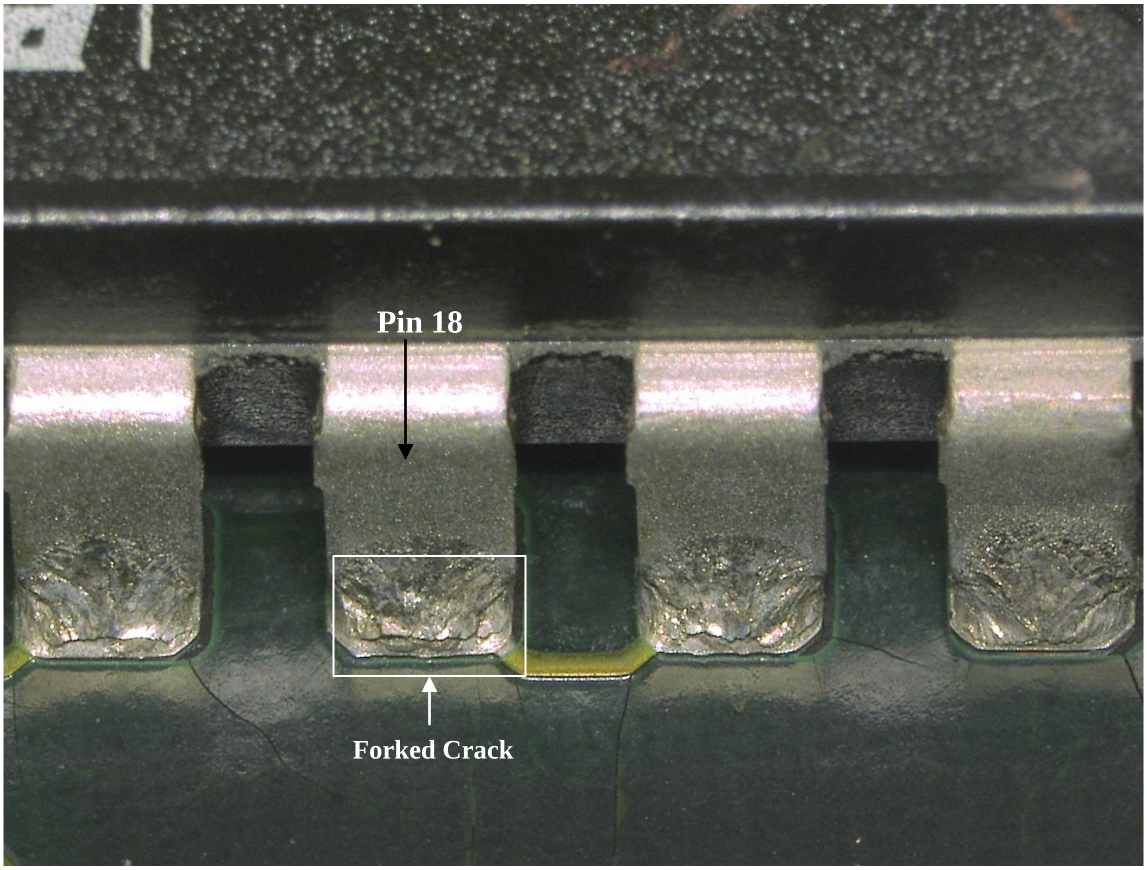

Figure 15 - PWB 167 – U63, Pins 17 - 20 (Sn Finish)

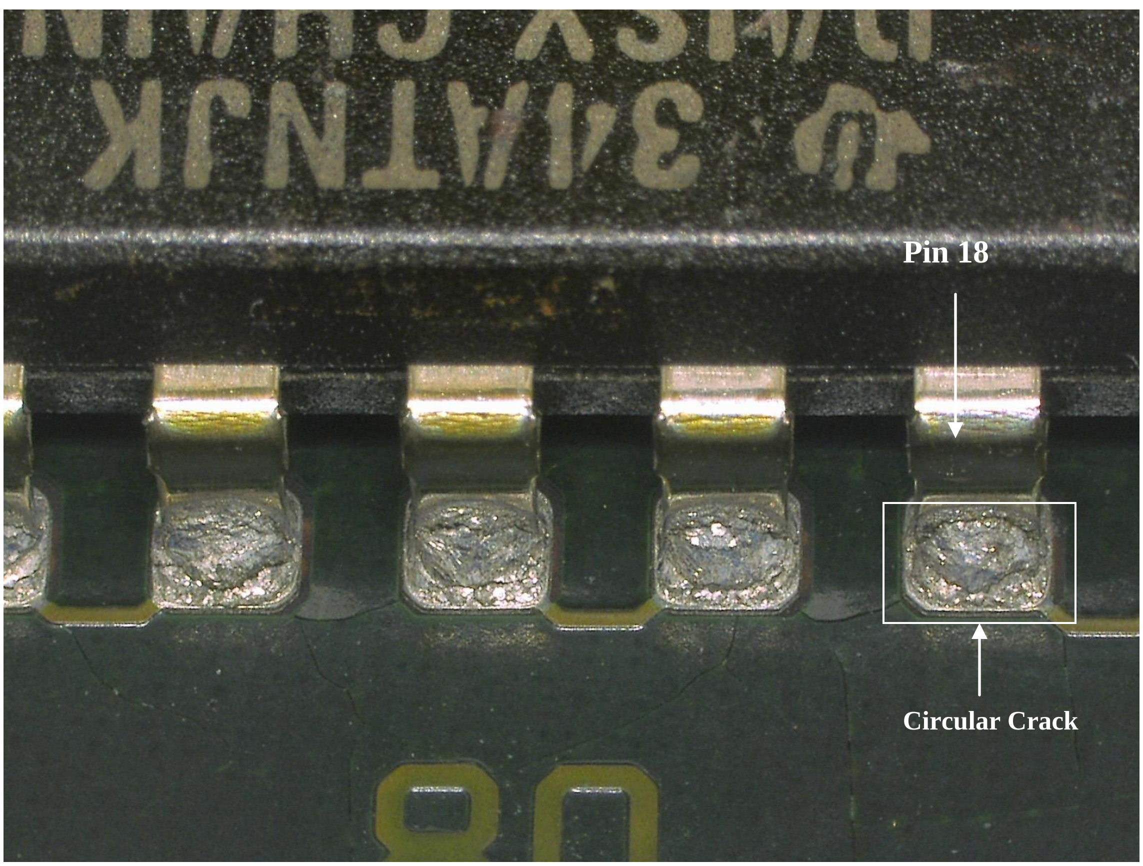

Figure 16 - PWB 194 – U8, Pins 15 - 18 (Au/Pd/Ni Finish)

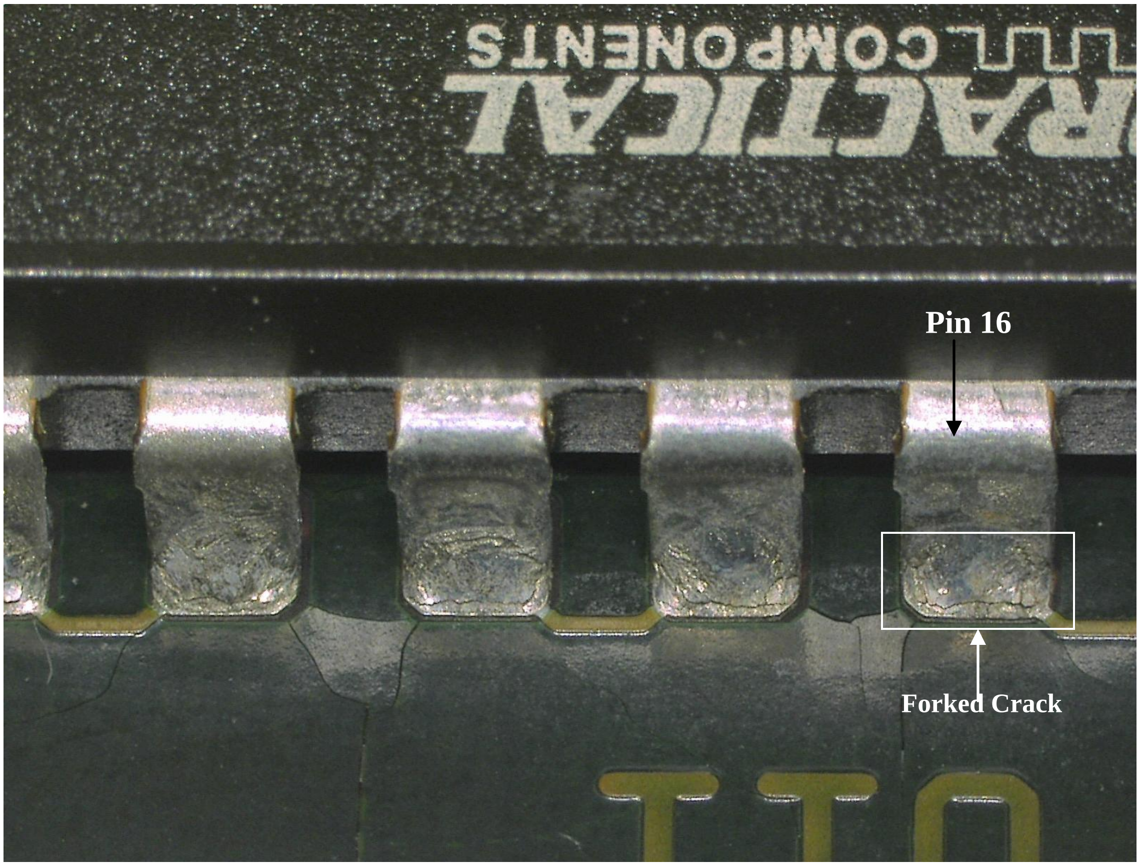

Figure 17 - PWB 194 – U11, Pins 13 - 16 (Sn Finish)

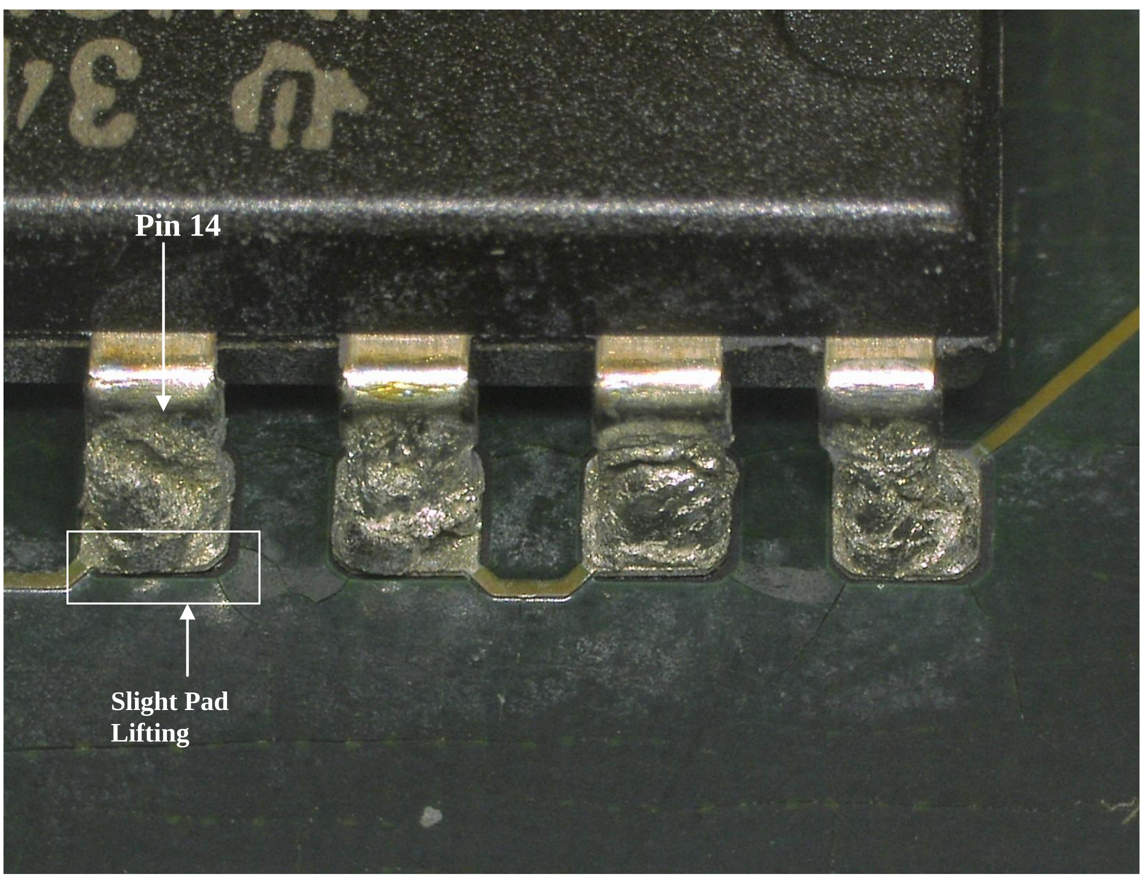

Figure 18 - PWB 194 – U23, Pins 11 - 14 (Au/Pd/Ni Finish)

Boards Chosen for Detailed Analysis
The only components that failed were from boards PWB 50 (vibration tested) and PWB 191 (thermal cycled). These components were chosen for further analysis.

Analysis of PDIP Components U59 and U63 on PWB 50

<u>Component U59</u>
Component U59 was reworked with SnPb solder and had a NiPdAu Finish.[2]

<u>Digital Microscope Images</u>
From the digital microscope pictures, it was determined that pin 3 (Figure 19) showed evidence of small cracks developing as well as incomplete pad wetting and lifting. Pin 18 (Figure 20) showed some evidence of cracking in the surface of the solder and some evidence of incomplete pad wetting. The pins, which are parallel to each other, have different appearances.

Figure 19 – PWB 50 - U59, Pin 3 (Au/Pd/Ni Finish)

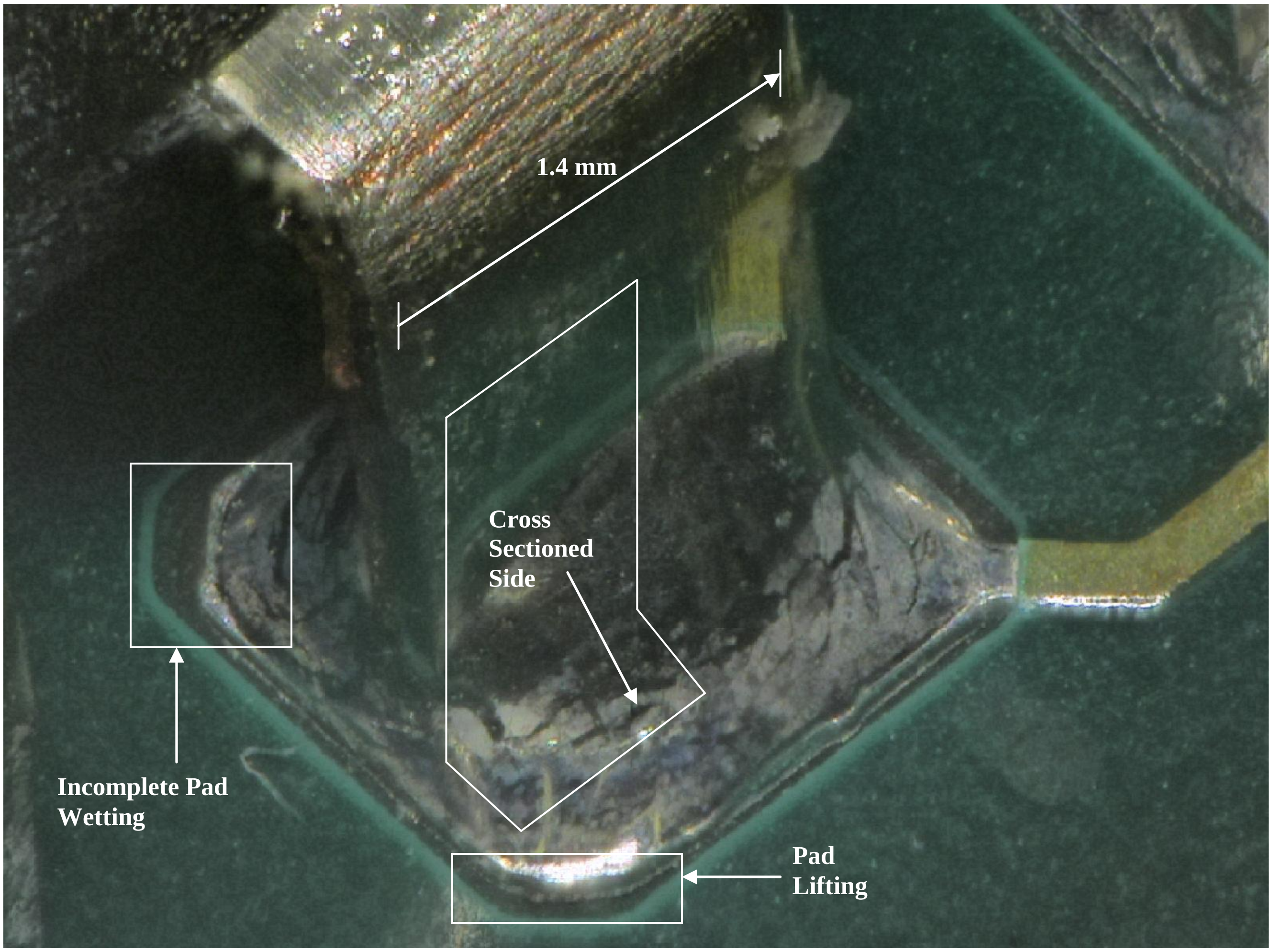

Figure 20– PWB 50 - U59, Pin 18 (Au/Pd/Ni Finish)

<u>Resistance Measurements</u>

A maximum resistance of 4.2Ω was found between pins 10 and 11. Since these pins were connected externally (Figure 3) it is possible that a break in a trace was developing. Since the greater interest is for pins that are connected through the component and have higher than average resistance readings, pins 10 and 11 were not chosen for cross sectioning. From the surface visualizations and as a result of a slightly higher than normal resistance reading between pins 17 and 18, it was determined that pin 18 would be cross sectioned, along with the opposite joint on pin 3.

Table 2 – Resistance Measurements for PWB 50

	Component U59	Component U63
Pins	Resistance (Ω)	Resistance (Ω)
1 & 2	0.4	> 1 M Ω
2 & 3	0.2	0.3
3 &4	0.4	0.3
4 & 5	0.2	0.3
5 & 6	0.4	0.4
6 &7	0.2	0.3
7 & 8	0.4	0.3
8 & 9	0.2	0.3
9 & 10	0.4	> 1 M Ω
10 & 11	4.2	94
11 & 12	0.4	> 1 M Ω
12 & 13	0.2	0.4
13 & 14	0.4	0.4
14 & 15	0.2	0.3
15 & 16	0.4	0.5
16 & 17	0.2	0.3
17 & 18	0.5	0.4
18 & 19	0.2	0.3
19 & 20	0.5	> 1 M Ω

Cross-Sections

The cross-section pictures (Figures 21 and 22) for the pins from component U59 showed no evidence of cracks or pad lifting in the solder joint. Pin 3 was cross sectioned and analyzed from the right side while pin 18 was cross sectioned and analyzed from the left side. This cross-section was used as the baseline for comparison with component U63. The pictures showed that pin 3 was ground too deep, which caused the pin to appear as if it did not go through the board hole. From the pictures, it appears that both pins would still be capable of functioning.

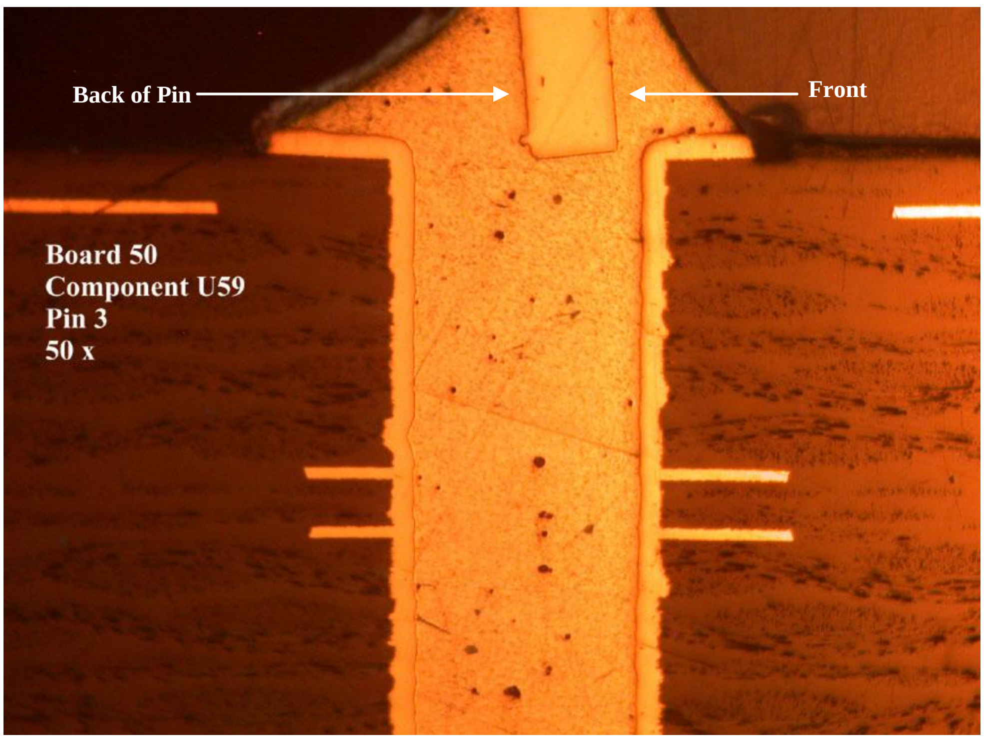

Figure 21– PWB 50 - U59, Pin 3 Cross-Section

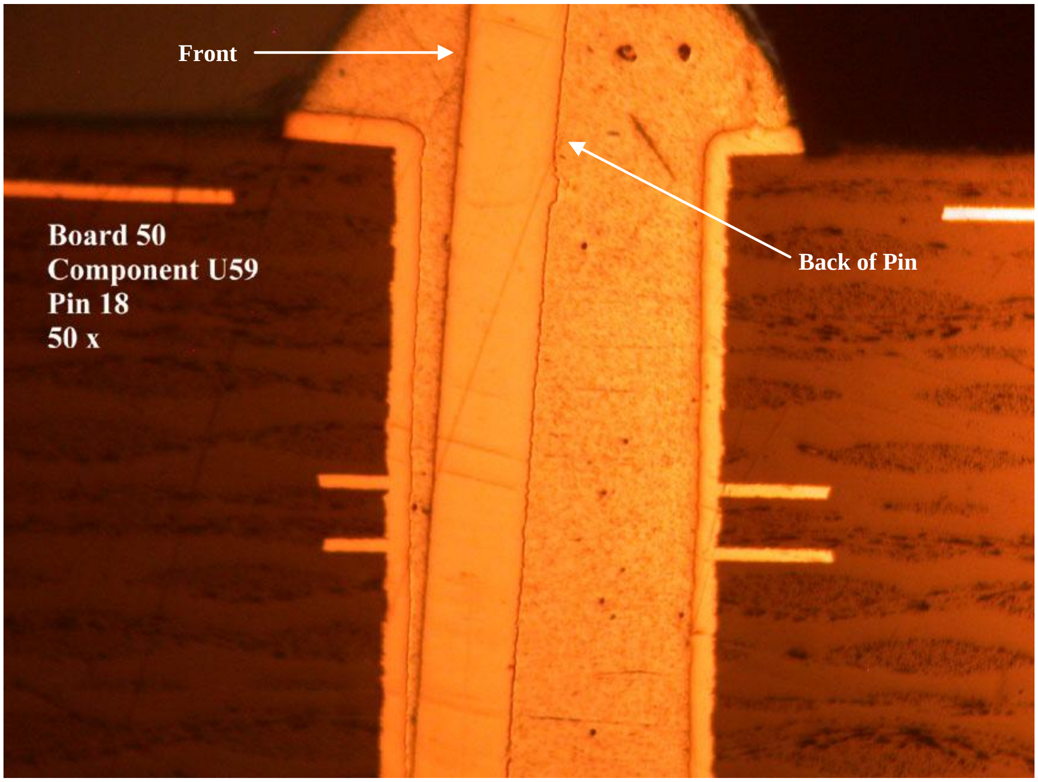

Figure 22 – PWB 50 - U59, Pin 18 Cross-Section

<u>Component U63</u>
Component U63, which was attached to the board using SnPb solder and had a Sn finish, was not reworked.

<u>Digital Microscope Images</u>
Figures 23, 25, 27, and 29 show pins 3, 18, 10, and 11, before they were cross-sectioned.

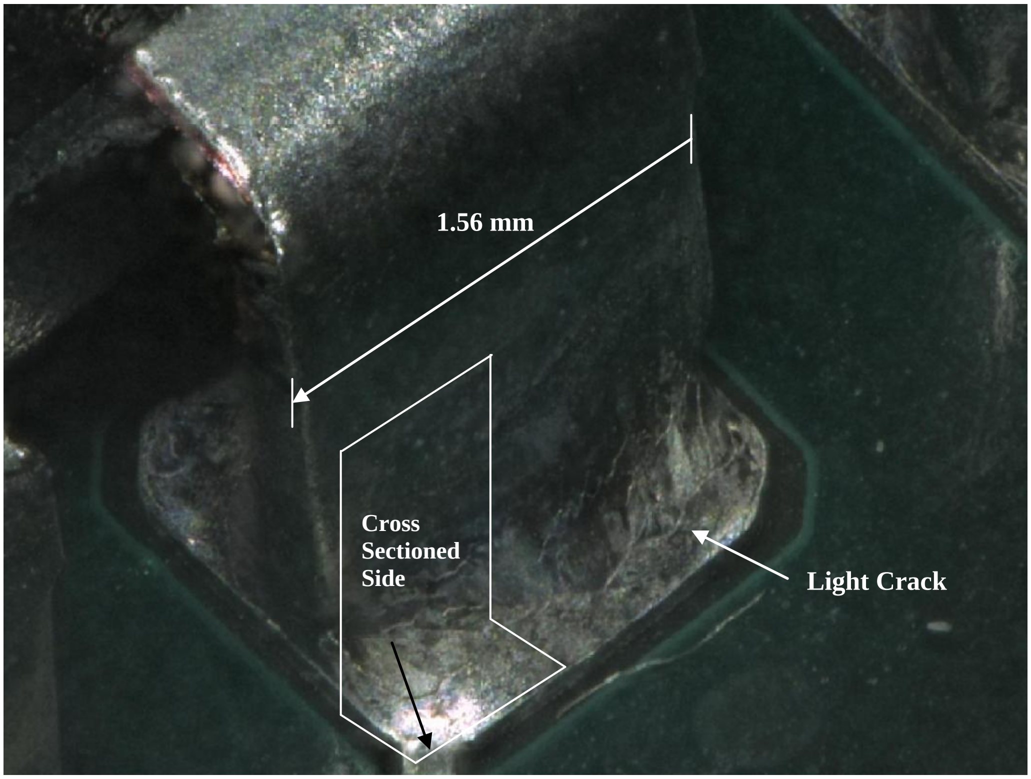

Figure 23 – PWB 50 - U63, Pin 3 (Sn Finish)

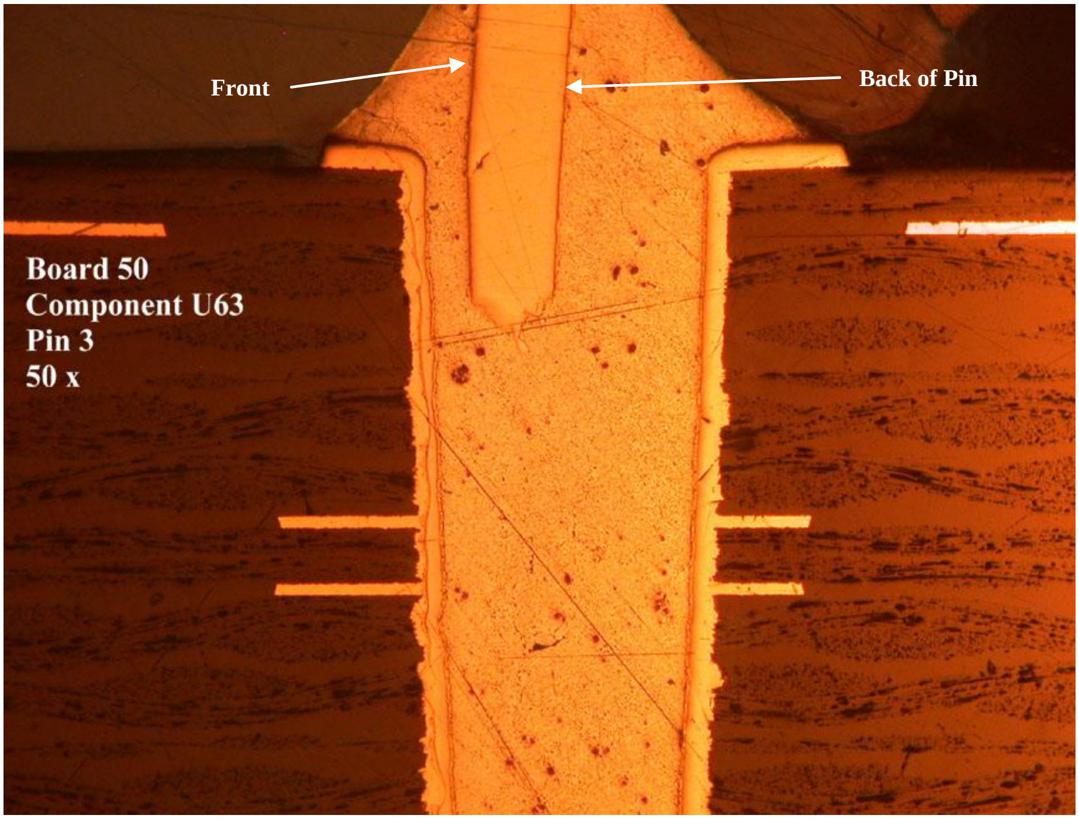

Figure 24 – PWB 50 - U63, Pin 3 Cross-Section

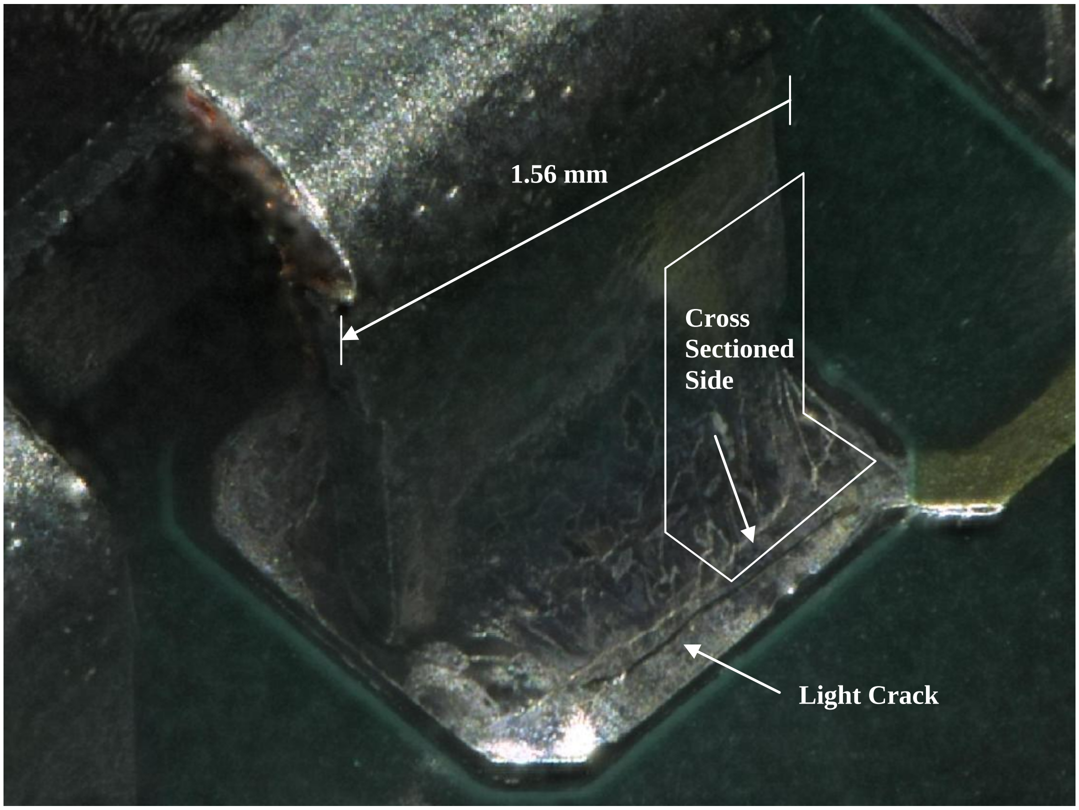

Figure 25 – PWB 50 - U63, Pin 18 (Sn Finish)

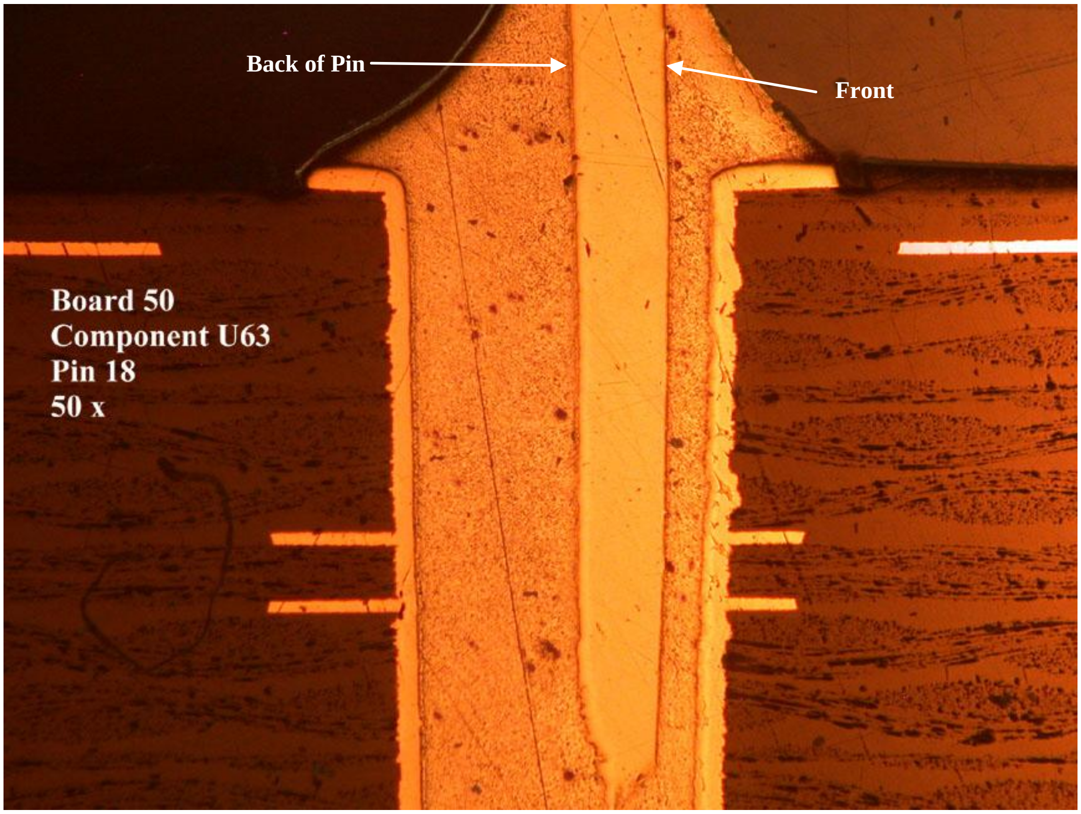

Figure 26 – PWB 50 - U63, Pin 18 Cross-Section

From Figures 23 and 25, it was determined there was some visual evidence of surface cracks in pins 3 and 18. There was also visual evidence of some pad lifting on the outer edge of pin 18. The pictures of pins 10 and 11, Figures 27 and 29, show visual evidence of cracks that may have gone deep into the solder joint. Figure 27 shows a small crater forming in one of the lower corners of its pad, while Figure 29 shows an upside down T-formation in the same location on its pad.

Resistance Measurements

The resistance measurements taken from adjacent pins on U63 gave readings between 0.3 – 0.4Ω (Table 2). Pins 3 and 18 on U63 had resistance measurements similar to those taken from the same pins on U59. As a result, it was determined that pins 3 and 18 would be cross sectioned on U63 to see if there were any similarities with these pins on component U59. The other pins that were cross-sectioned on U63 were 10 and 11. These pins were cross sectioned due to a number of high readings, in addition to the visual evidence of deep cracking. The resistance between pins 9 and 10 and pins 11 and 12 were off scale on the ohm meter used (> 1 M Ω) which indicated breaks in continuity inside the component (see Figure 3). Since the readings were normal between pins 8 and 9 and pins 12 and 13, which were externally connected, pins 10 and 11 were suspected of failure. Even externally connected, the resistance between pins 10 and 11 was 94 Ω, indicating a problem with a trace or the joints/pins themselves.

Cross-Sections

Pins 3 and 10 (Figures 24 and 28) were cross-sectioned and analyzed from the left side of the solder joint while pins 18 and 11 (Figures 26 and 30) were cross-sectioned from the right side. The pictures for pins 3 and 18 showed no evidence of cracking in the solder. Figures 27 and 29 show the pictures of pins 10 and 11 that were taken with the digital microscope before they were cross-sectioned while Figures 28 and 30 show pins 10 and 11 after they were cross-sectioned, ground, and polished. Pins 10 and 11 clearly show through cracks which are located above the barrel. The picture for pin 11 revealed that the sample was ground too deep, with part of the sample being completely removed. The cross-section pictures revealed only component U63 on PWB 50 had cracks through the solder joints and pins. As a result, the component would fail if it were in use. In general, visual evidence of other anomalies such as pad and fillet lifting, cracking in the knees, and awkward solder formation was noticeable in the pictures of the cross-sections.

Use of Digital Microscope in Conjunction with Cross-Section Images

The indications that a component could have failed were indicated from the surface cracking, along with the resistance measurements. Cross-sections were still necessary to verify through or no through cracking and damage. For U63, severe surface cracking did indeed indicate through cracks, as verified by cross-sections.

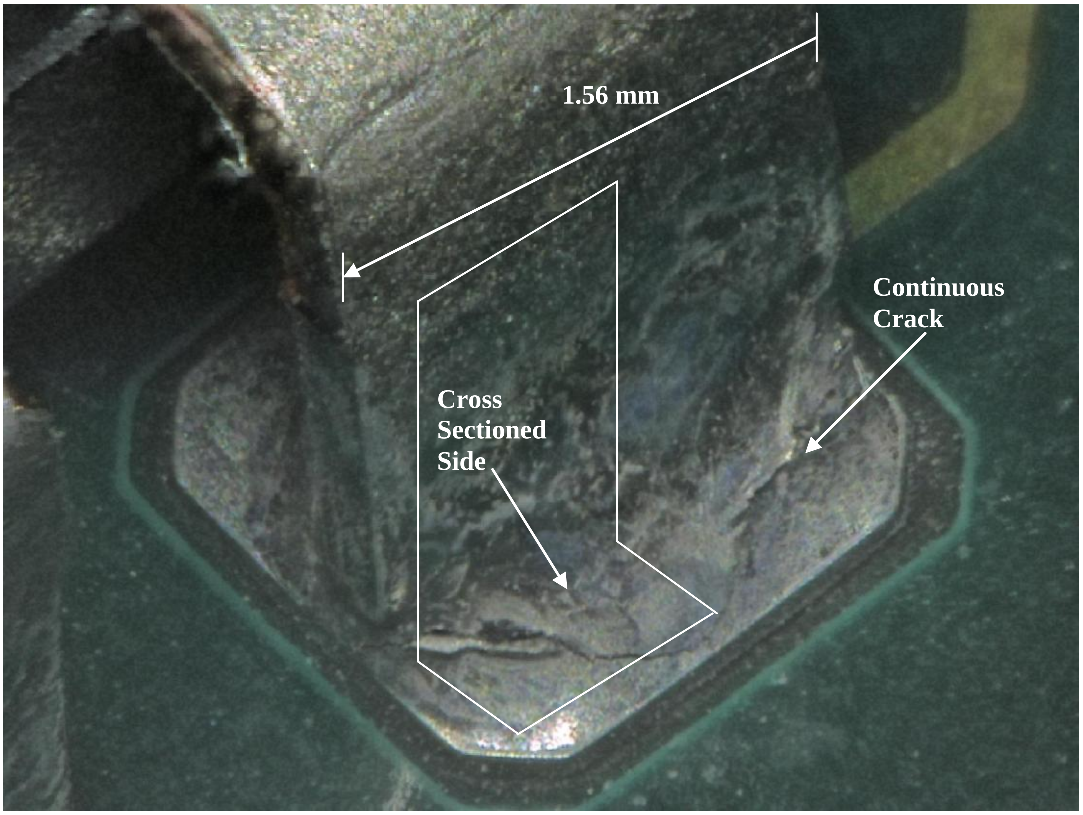

Figure 27 – PWB 50 - U63, Pin 10 (Sn Finish)

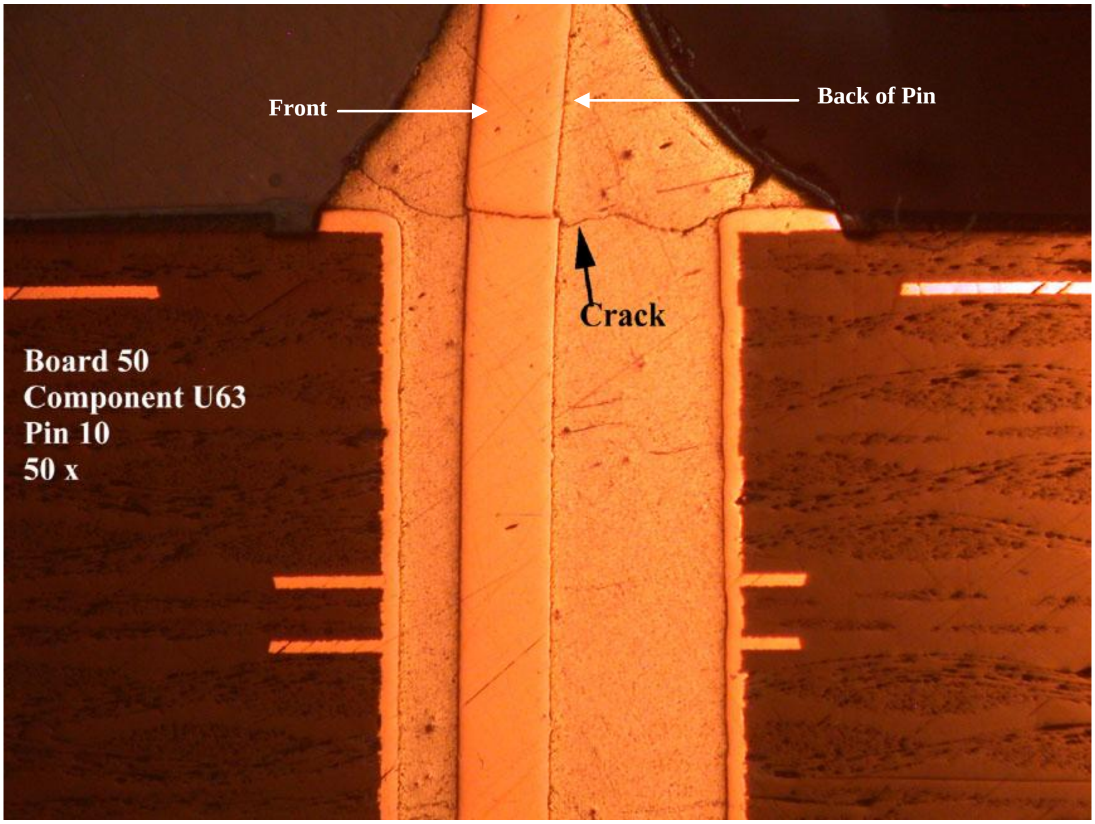

Figure 28 – PWB 50 - U63, Pin 10 Cross Section

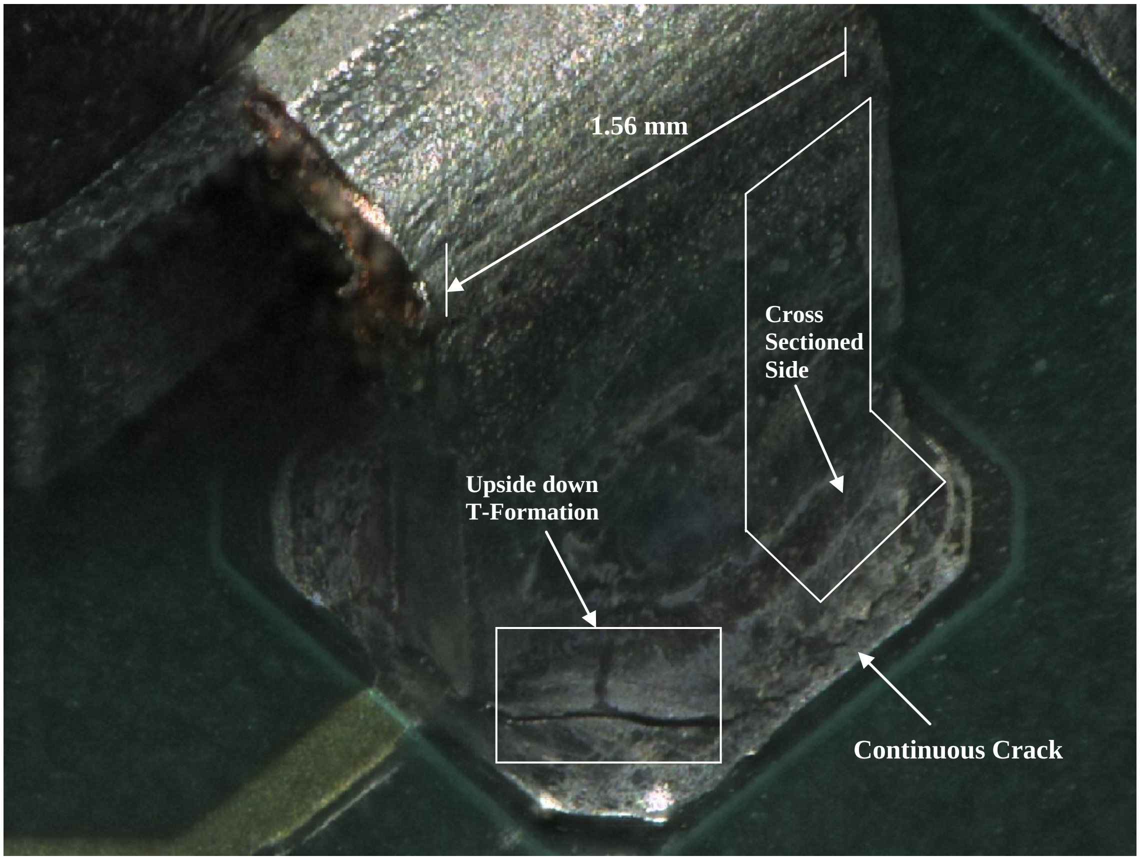

Figure 29 – PWB 50 – U63, Pin 11 (Sn Finish)

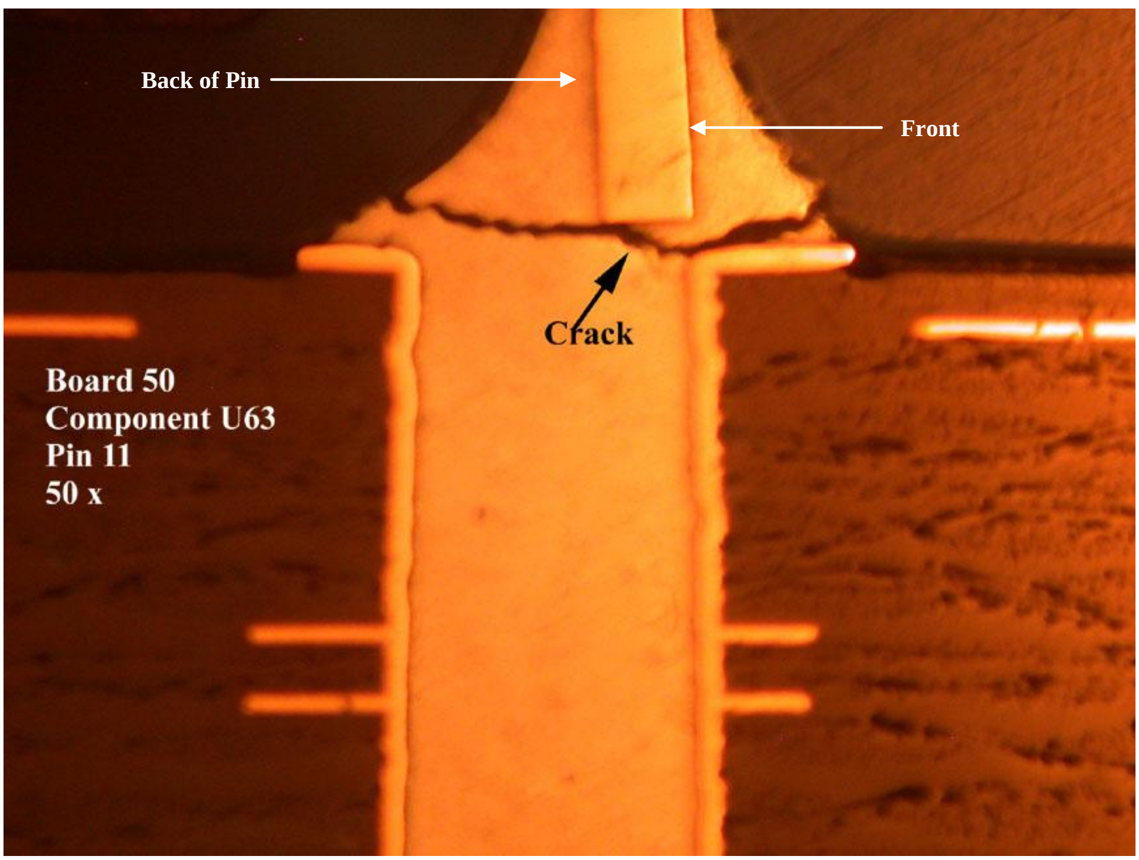

Figure 30 – PWB 50 - U63, Pin 11 Cross Section

Analysis of PWB 191

Time to Failure
For PWB 191, component U59 failed 842 cycles into testing (18% of total test), while component U63 failed at 1595 cycles (34% of total test).[1]

Component U59
Component U59 initially had SnPb eutectic solder joints and was reworked with SnPb solder. It also had an Au/Ni/Pd component finish.

Digital Microscope Images

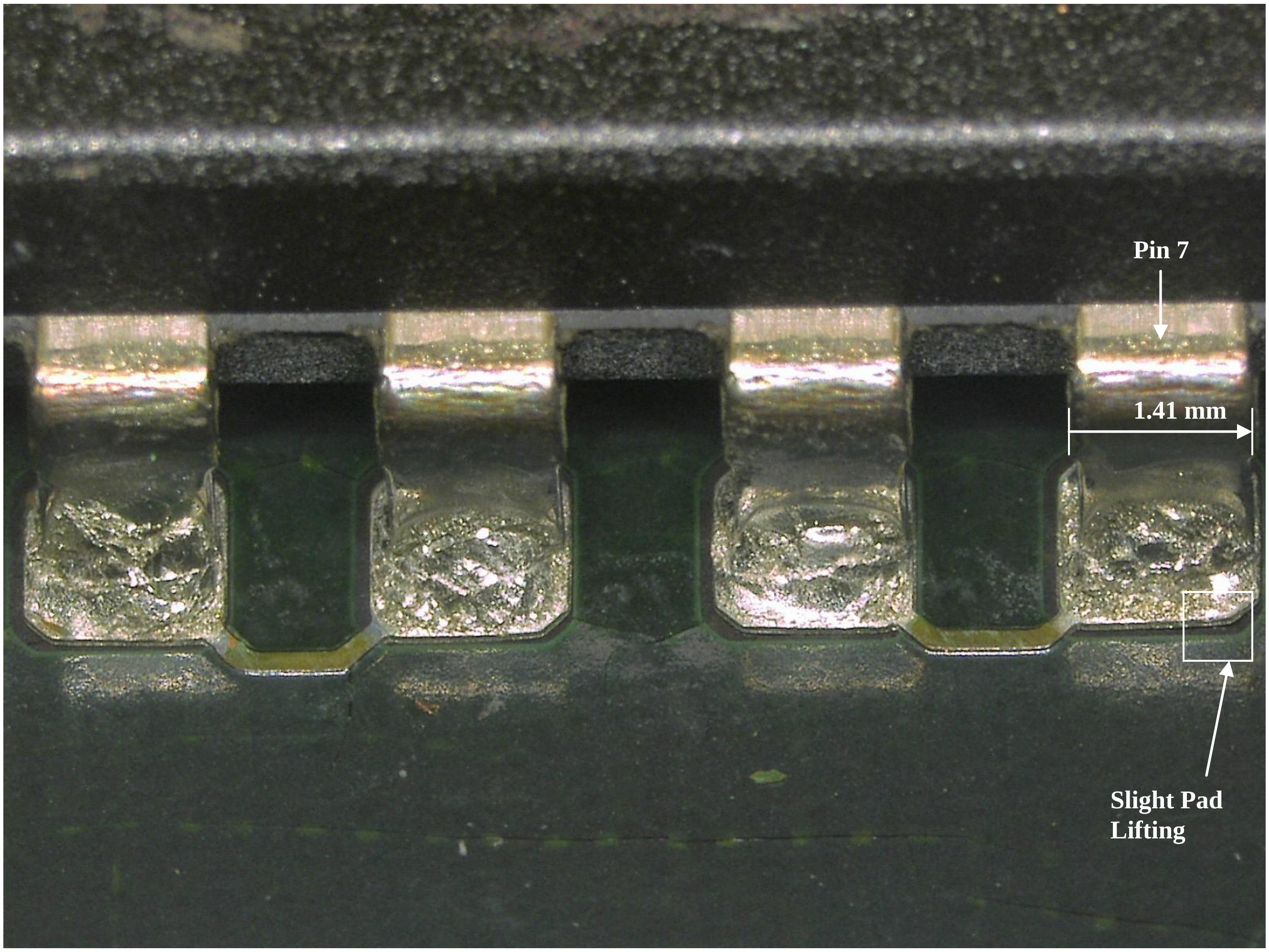

Figure 31 – PWB 191 - U59, Pins 4 - 7

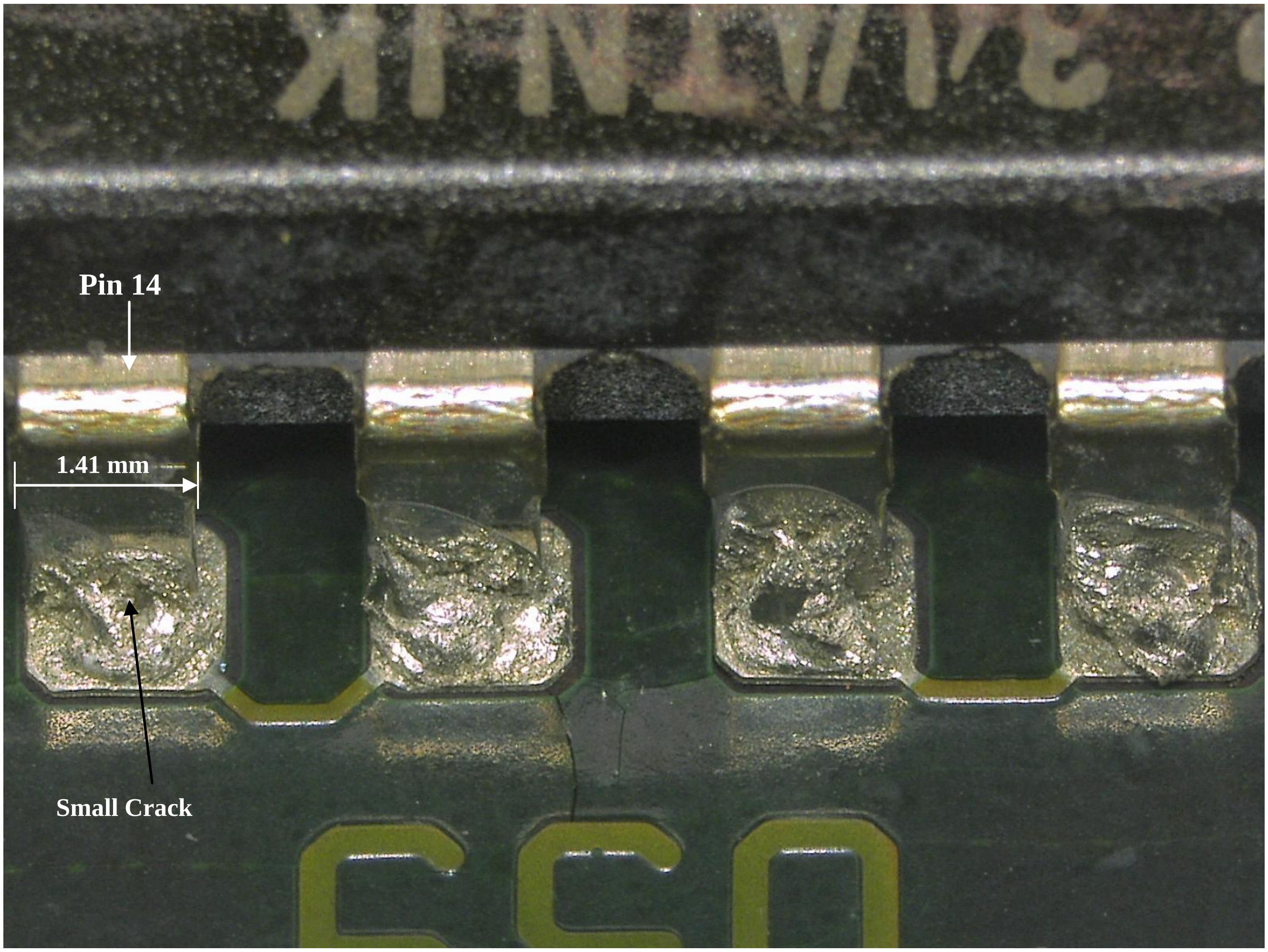

Figure 32 – PWB 191 - U59, Pins 14 – 17 (Au/Pd/Ni Finish)

All the pins were checked visually with the digital microscope. This inspection revealed a need to further examine pins 7 and 14. There was very little evidence of cracking in the solder on pin 7, but some indication of pad lifting, solder deformation and possible incomplete pad wetting (Figure 31). Small cracks and craters formed in the solder on pin 14, with some incomplete pad wetting on the edges of the lower corners of the solder joint.

Resistance Measurements

Readings greater than 1 MΩ were found between pins 18 and 19. Again this open circuit could be due to a broken trace, since these pins were externally connected (Figure 3). Due to the external connection, these pins were not chosen for further cross-sectioning. The readings between pins 7 and 8 and pins 13 and 14 were 0.5Ω, which was the same value for almost half of the measurements on the component. As a result of these measurements and based on the visual evidence, it was determined that pins 7 and 14 would be cross-sectioned. It could then be determined if these pins were developing cracks in their solder joints. Additionally, the information obtained may help in determining if a particular surface finish is more susceptible to cracking.

Table 3 – Resistance Measurements for PWB 191

	Component U59	Component U63
Pins	Resistance (Ω)	Resistance (Ω)
1 & 2	0.5	0.2
2 & 3	0.3	0.5
3 &4	0.6	0.2
4 & 5	0.3	>1 MΩ
5 & 6	0.5	0.3
6 &7	0.3	20.4
7 & 8	0.5	0.2
8 & 9	0.3	0.2
9 & 10	0.5	0.2
10 & 11	0.2	75.2
11 & 12	0.5	0.2
12 & 13	0.3	0.2
13 & 14	0.5	0.2
14 & 15	0.2	0.2
15 & 16	0.5	0.3
16 & 17	0.3	0.2
17 & 18	0.5	0.3
18 & 19	>1 MΩ	0.2
19 & 20	0.5	0.2

Cross-Sections

The 3D digital microscope images (Figures 31 and 32) showed evidence of small cracks and pad lifting that could have been capable of causing serious damage to the component. Pin 7 was cross-sectioned and analyzed from the left side of the solder joint while pin 14 was cross-sectioned and analyzed from the right side. The cross-section for pin 7 (Figure 33) showed visual evidence of severe pad lifting and incomplete pad wetting, but the cracks didn't appear to have caused much damage in the solder joint. For pin 14, the cross-section (Figure 34) revealed that the pin was ground too deep and there was no evidence of cracking in the solder. The cross-sections for both pins revealed some cracking in the knees, lifting in the pad, and barrel distortion.

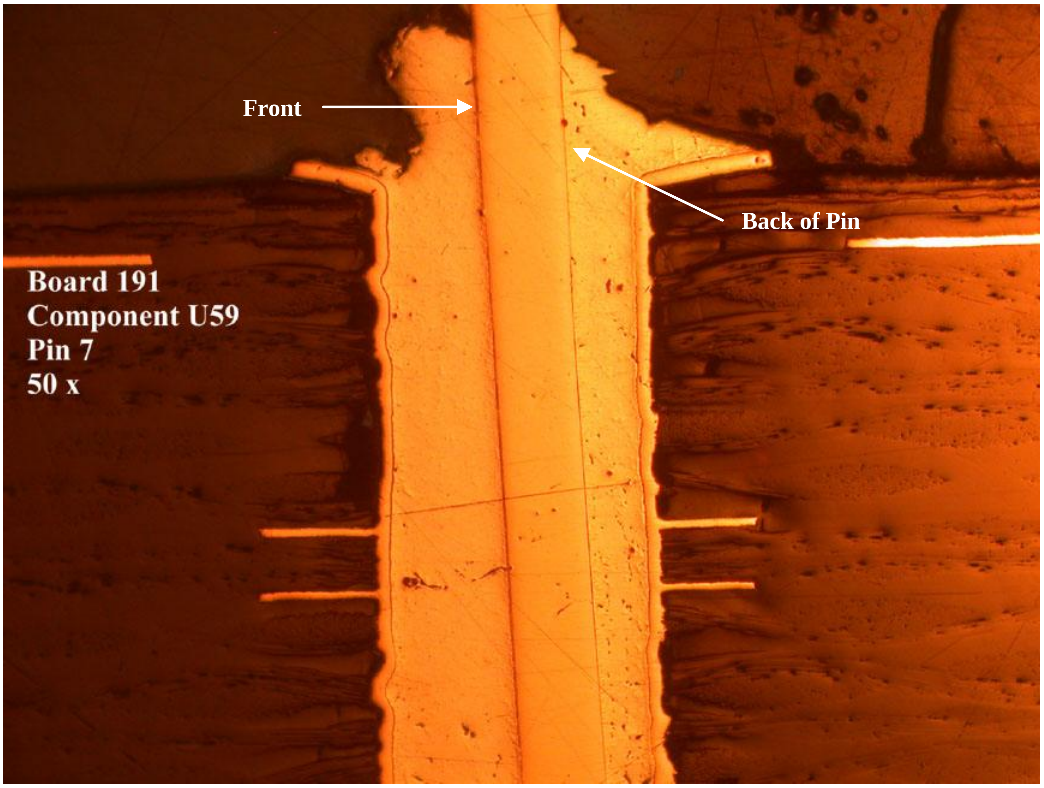

Figure 33 – PWB 191 - U59, Pin 7 Cross-Section

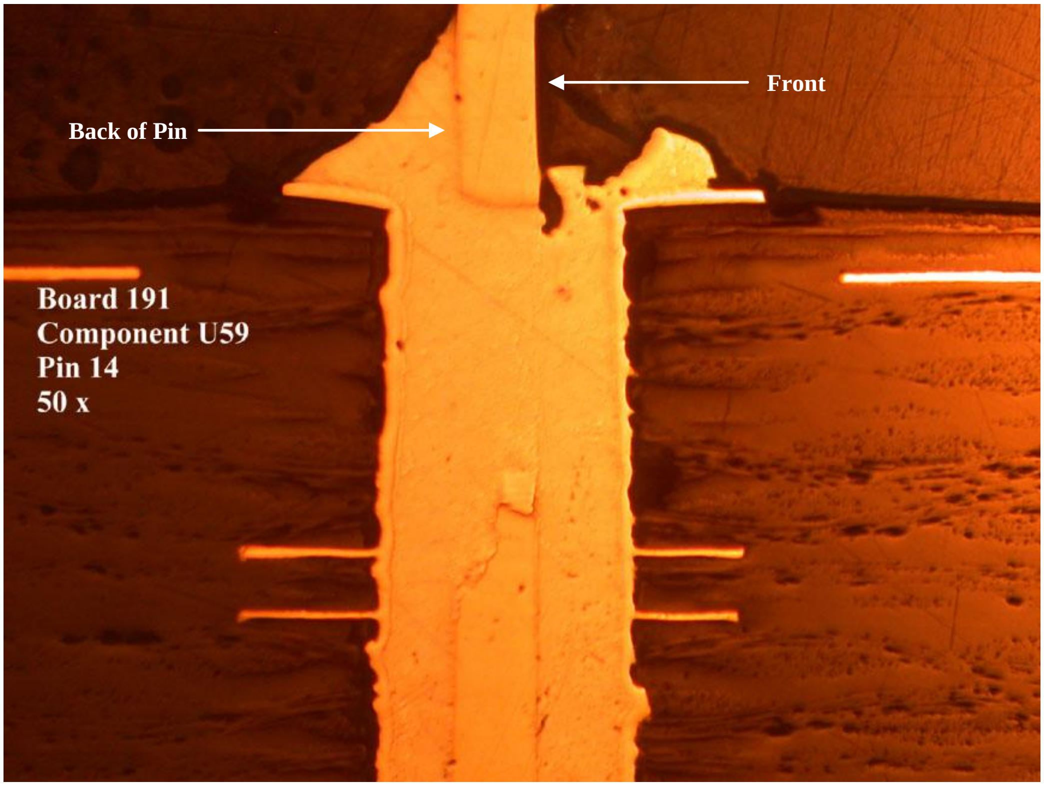

Figure 34 – PWB 191 - U59, Pin 14 Cross-Section

<u>Component U63</u>
Component U63, which used SnPb solder and had a Sn finish, was not reworked.

<u>Digital Microscope Images</u>
From the digital microscope pictures (Figures 35 - 38) pins 6 and 15 showed visual evidence of surface cracking and some pad lifting. The pins next to 6 and 15 on both the wave solder and the component side of the board showed similarities in crack patterns.

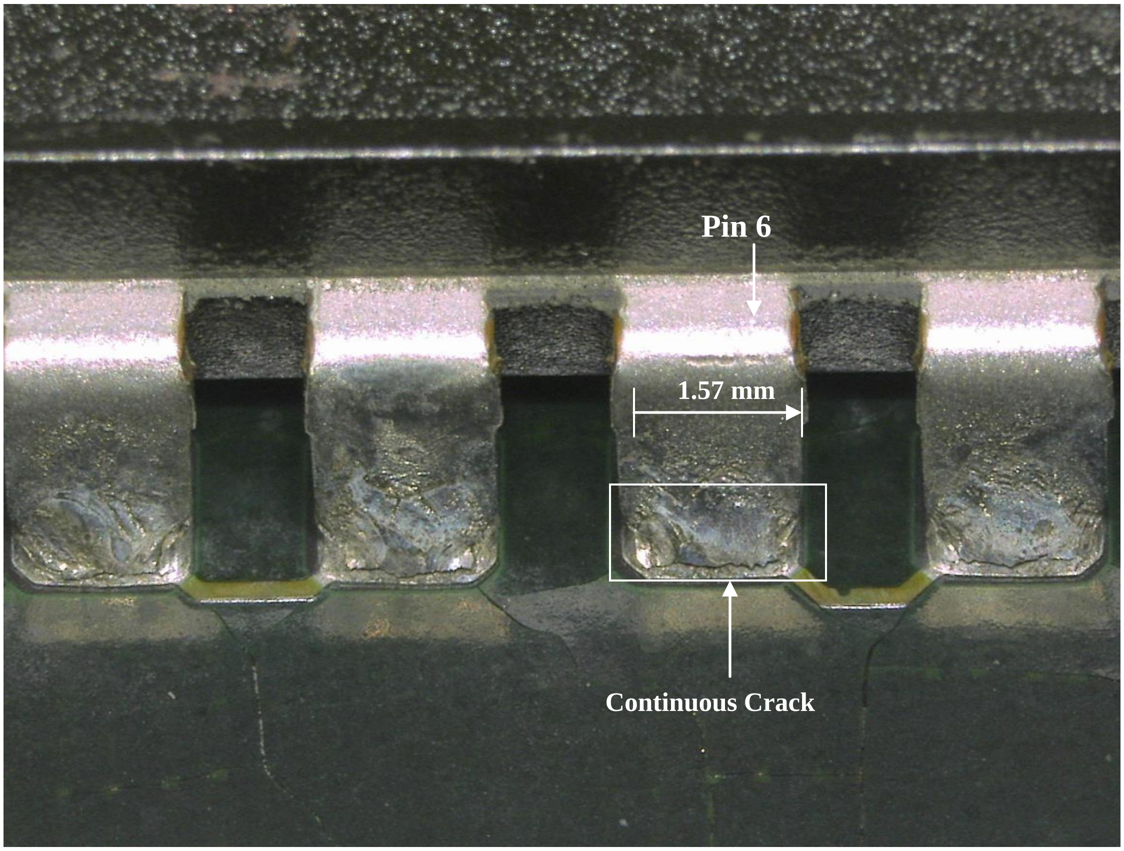

Figure 35 – PWB 191 - U63, Pins 4 – 7 (Component Side, Sn Finish)

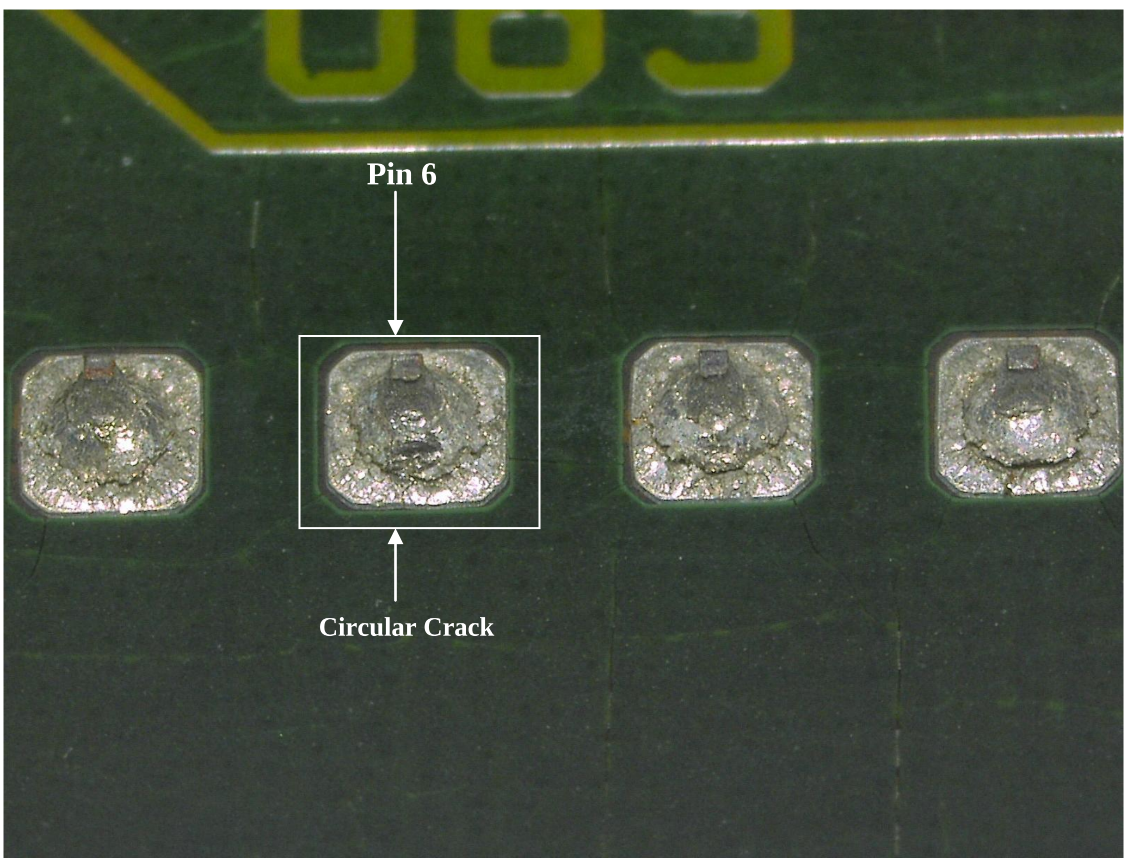

Figure 36 – PWB 191 - U63, Pins 4 - 7 (Wave Solder Side, Sn Finish)

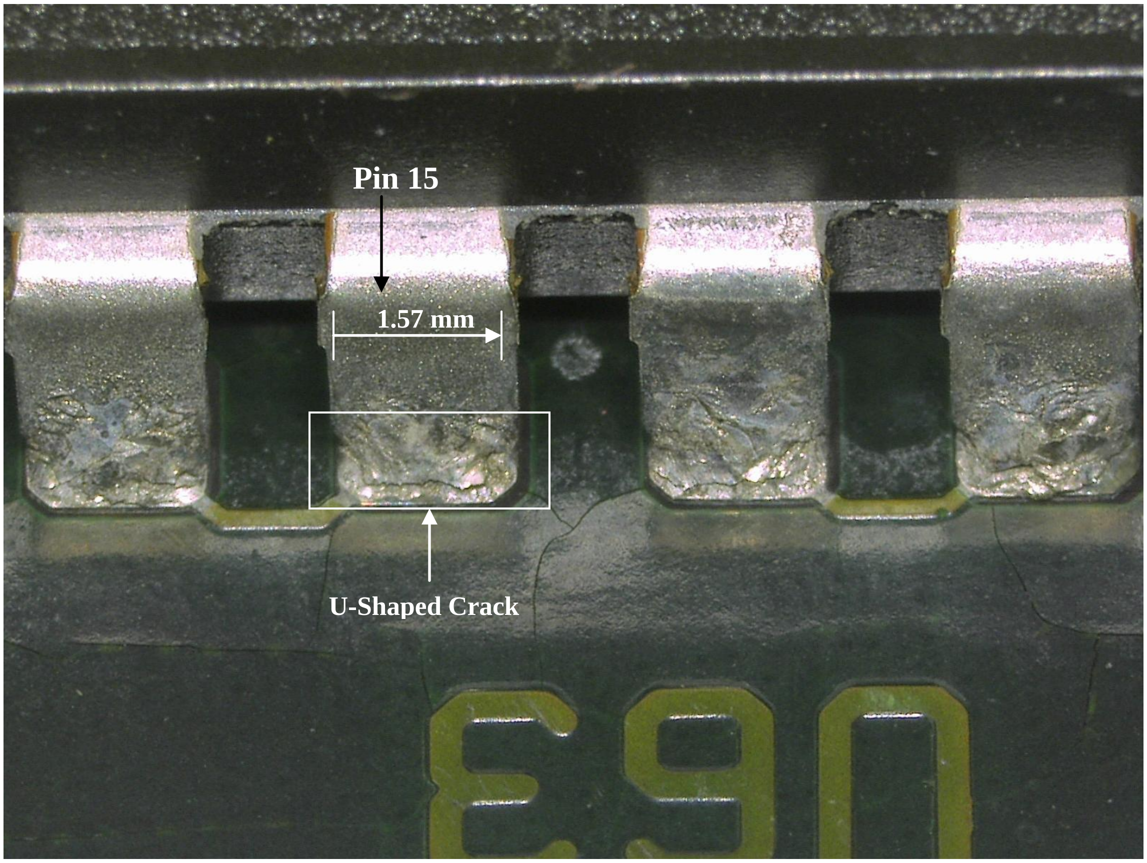

Figure 37 – PWB 191 - U63, Pins 14 - 17 (Component Side, Sn Finish)

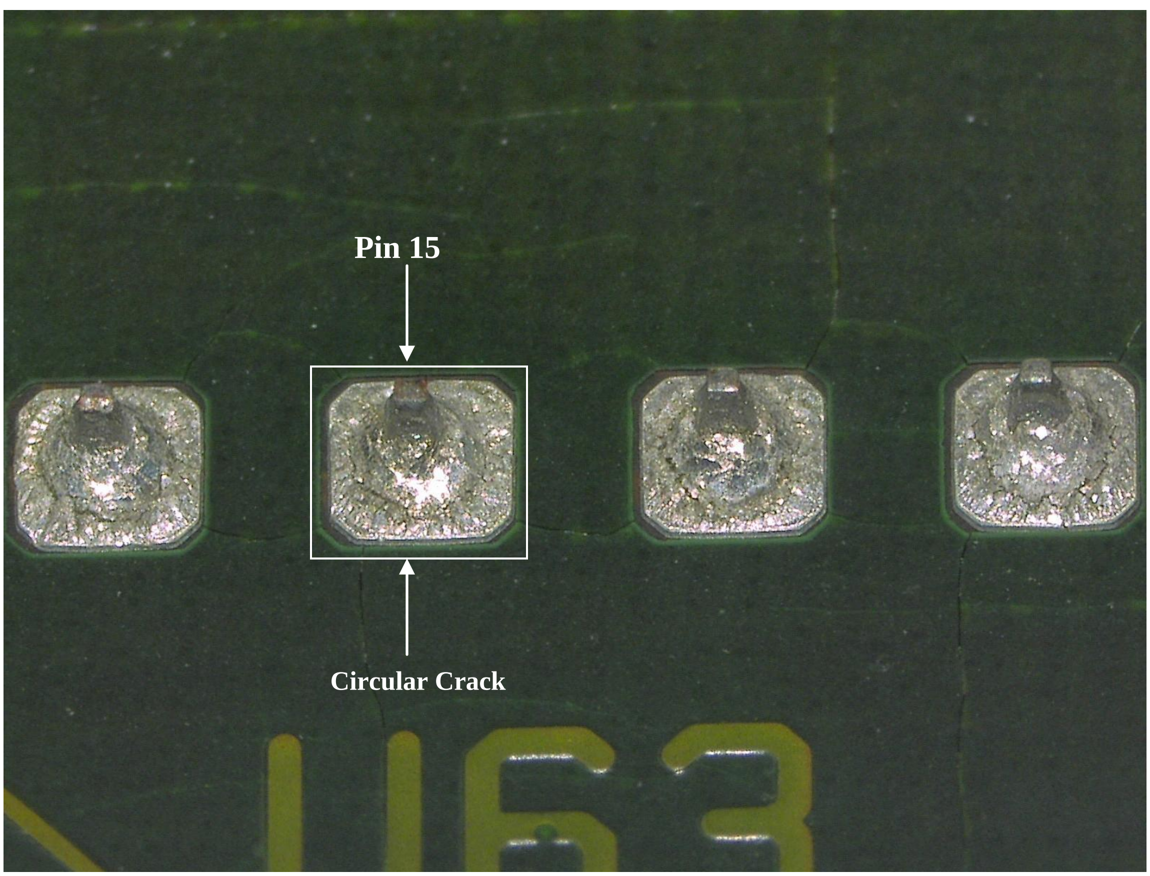

Figure 38 – PWB 191 - U63, Pins 14 - 17 (Wave Solder Side, Sn Finish)

Resistance Measurements

A reading greater than 1 MΩ was obtained between pins 4 and 5, which indicated a discontinuity somewhere external to the component, such as a trace. Two other sets of pins that were externally connected (6 and 7; and 10 and 11), also showed higher than normal resistances of 20.4 Ω and 75.2 Ω, respectively. Based on the visual examination and to a lesser extent the resistance measurements, it was determined that pins 6 and 15 would be cross-sectioned.

Cross-Sections

Pin 6 (Figure 39) was cross-sectioned and analyzed from the left side of the solder joint while pin 15 (Figure 40) was cross-sectioned and analyzed from the right side. It is apparent that some cracking did occur in these solder joints. However, these pins would still be capable of functioning since the cracks did not penetrate the entire solder joint or the component's pins. Both pictures also showed visual evidence of cracking in the knees and pad lifting. For the cross-sections from this board, there was some cracking and pad lifting apparent, but components U63 and U59, were both declared electrically sound.

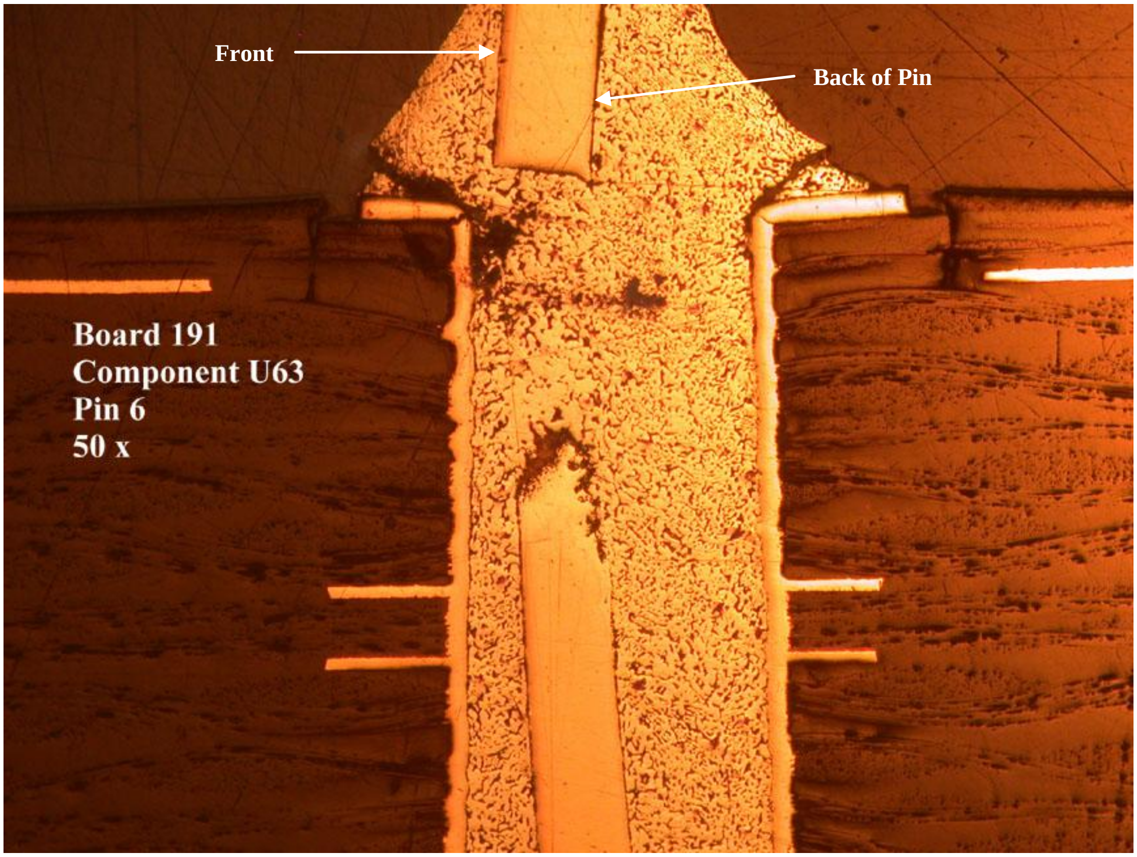

Figure 39 – PWB 191 - U63, Pin 6 Cross-Section

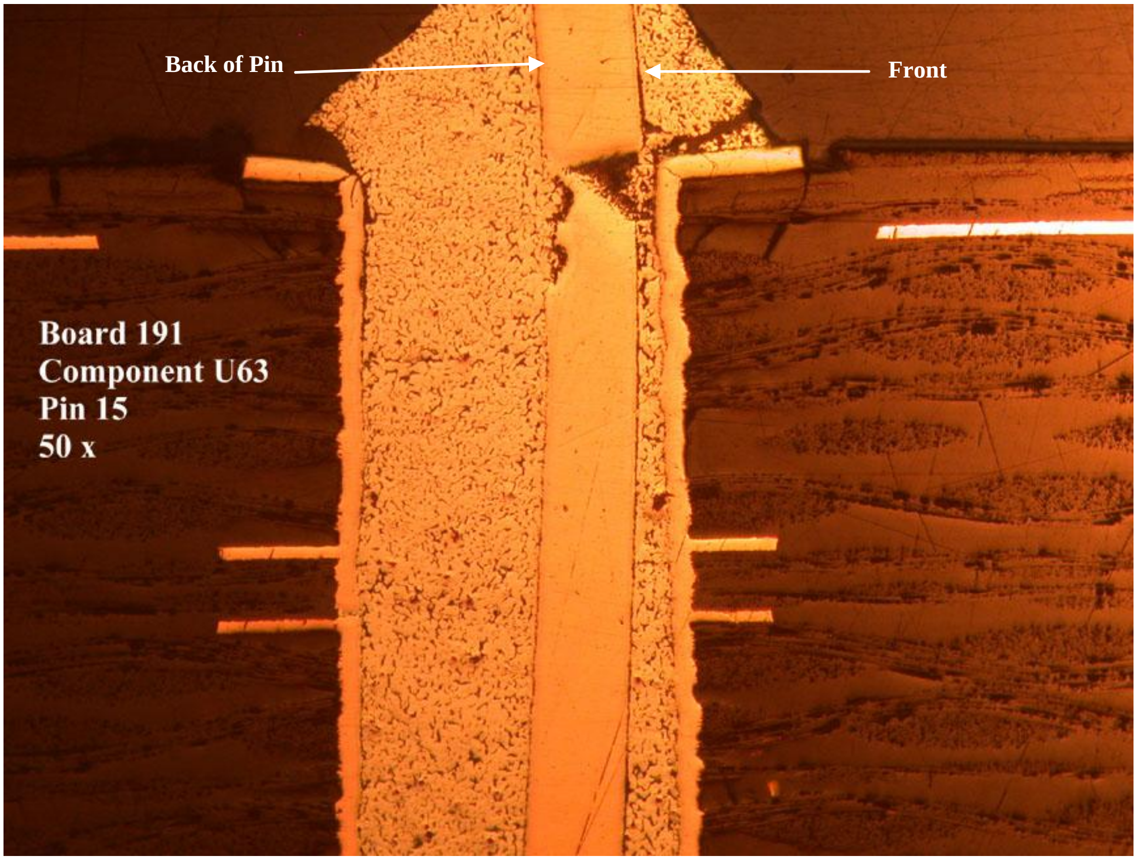

Figure 40 – PWB 191 - U63, Pin 15 Cross-Section

<u>Use of Digital Microscope in Conjunction with Cross-Section Images</u>
For the pins investigated, the more surface defects, the more cross-sections showed damage. However, the damage indicated was not deemed sufficient to disable the component.

Additional Comments about Cross-Sections
Cross-sections of non-critical components revealed a few areas where the components that did not fail had cracks in their solder joints. Some pictures revealed a coarse solder structure or the development of damage such as cracking in the barrel (Figure 41), or bad fillet lift (Figure 42). Even though the components began to crack during testing and started to develop other forms of damage in their solder joints, they were still capable of functioning. To gain a better understanding of what happened in the solder, the cross-sectioned samples will need to be further examined on the wave solder side. This will help to make a better comparison with the digital microscope images regarding how cracks, lifting, and other anomalies occurred during testing. It will also provide information on the depth of cracks, lifting, and other damage in the solder joints or their pads.

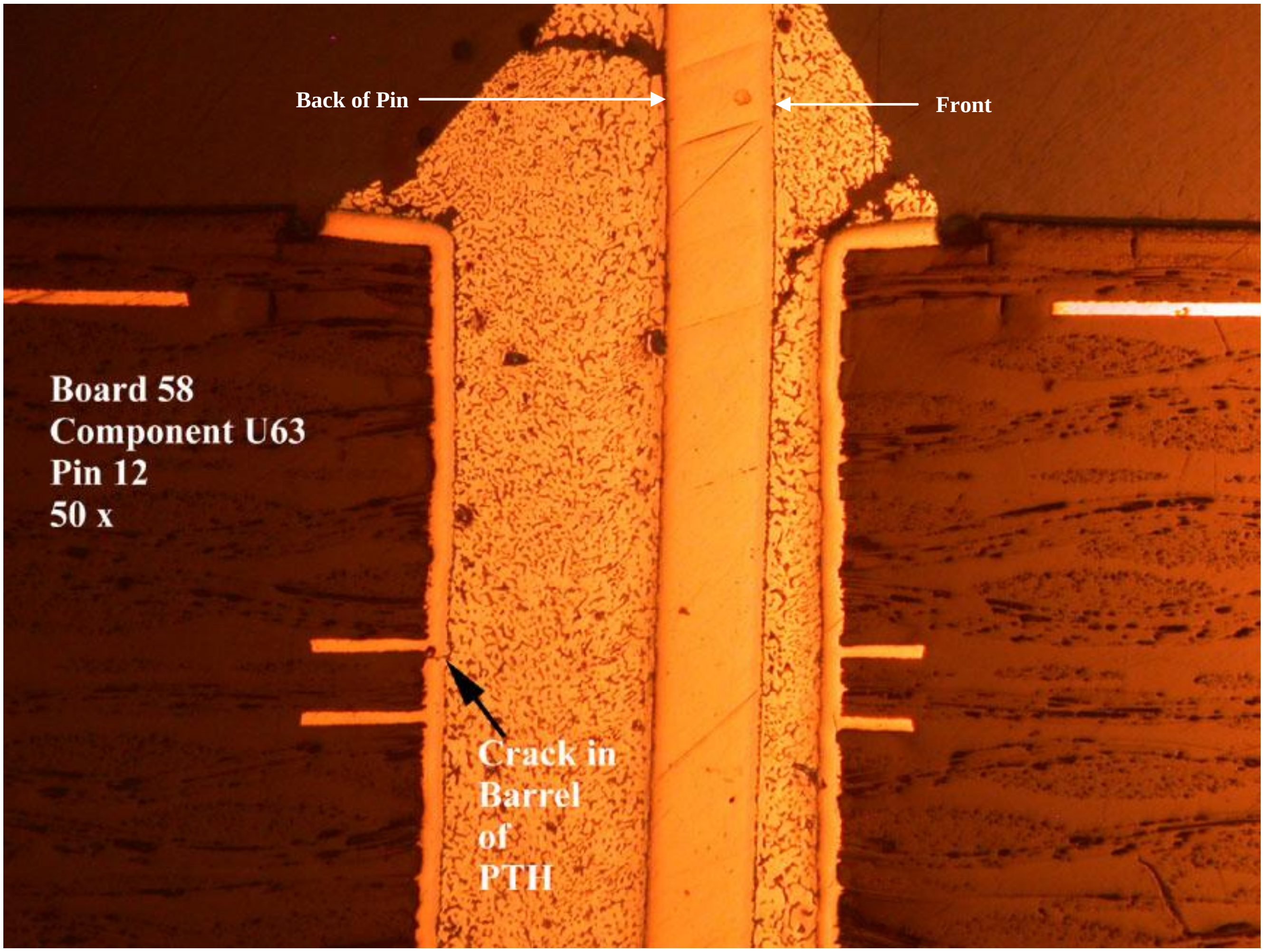

Figure 41 – PWB 58 - U63, Pin 12 Cross-Section

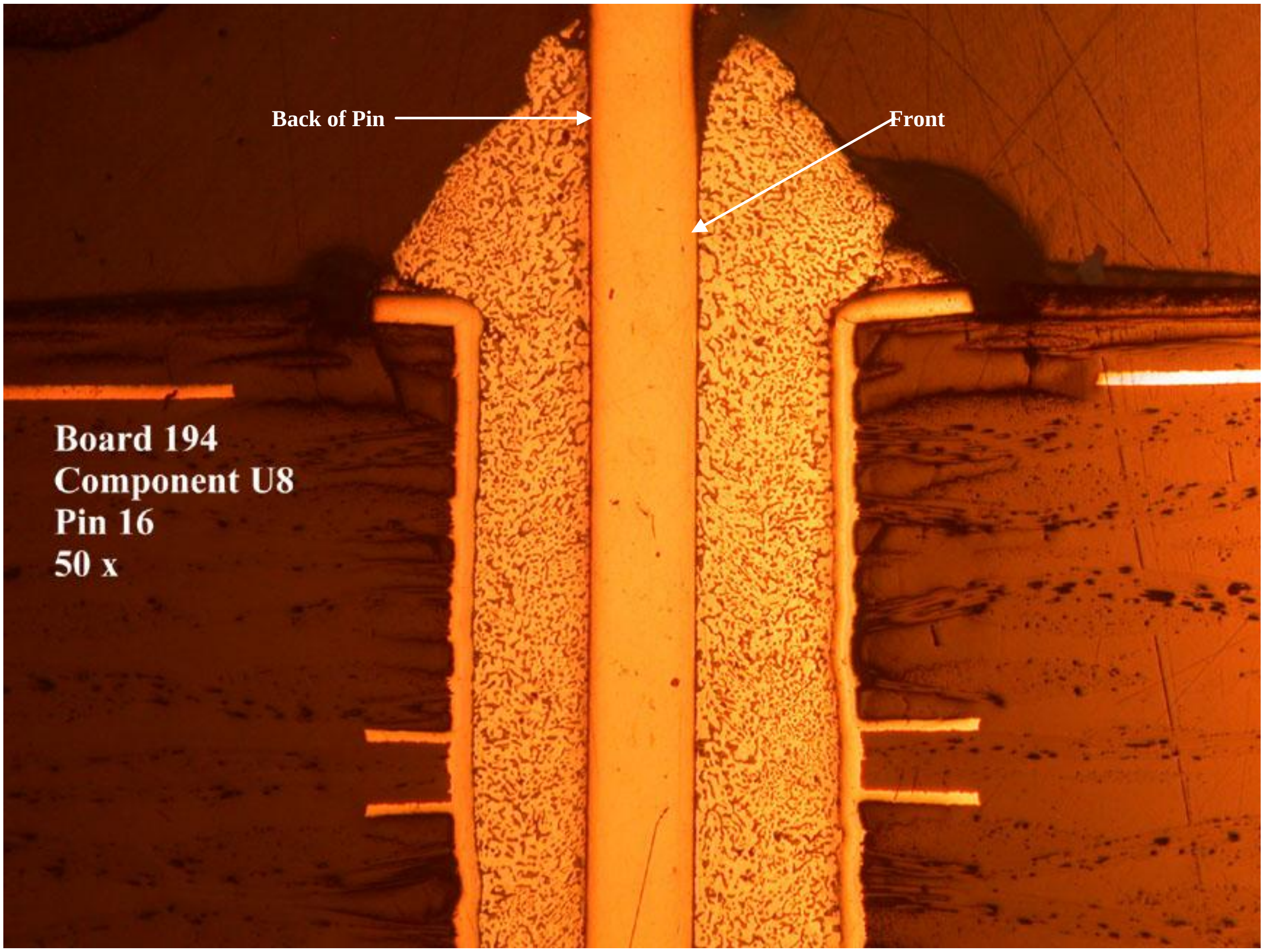

Figure 42 – PWB 194 - U8, Pin 16 Cross-Section

Conclusions about Use of a Digital Microscope in Failure Analysis

The pictures from the digital microscope showed what damage had been done to the surface of the PDIPs either after a component failed during testing, or after the testing was completed. The images, in conjunction with the resistance measurements, were used to determine which components should be cross-sectioned. The cross-sections did show some severe damage as indicated by the surface images in a number of instances. However, at this time, it does not appear possible to determine important damage features in stressed solder joints solely by digital microscopy. Cross-sections are still necessary to prove through cracking.

References

1. D. Hillman and R. Wilcoxon, "JCAA/JG-PP No-Lead Solder Project: -55ºC to +125ºC Thermal Cycle Testing Final Report", May 2006. http://acqp2.nasa.gov/LFS%20Reliability/Rockwell%20Collins%20Inc%20JCAA%20JGPP%20Final%20Report%20neg55C%20to%20pos125C%20testing%20Rev%20B.pdf
2. T. Woodrow, "JCAA/JG-PP Lead-Free Solder Project: Vibration Test", January 2006. http://acqp2.nasa.gov/LFS%20Reliability/VibEMP%20Rev.%20A%20010906.pdf
3. L. Campuzano-Contreras, "Status Report on Assembly of Lead-Free Project Test Boards", February 22, 2005. http://www.teerm.nasa.gov/LFS%20Reliability/Phase%20I%20Lead%20free%20solder%202-22-05.pdf

Acknowledgements

The authors would like to thank NAVSUP, CRANE NSWC, and SAIC for all of their help in funding the project, Dave Hillman for the specimens, Carol Handwerker for her helpful input, and Trace Laboratories, in particular Tom Pienkowski, for cross sectioning the components from the JCAA-JG-PP Lead-Free Joint Test Project.

Failure Analysis of Eutectic and Pb-Free Solder Alloys After High Stress Exposure

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Hammond, IN

Dennis Fritz
SAIC, Inc. - Merrillville, IN

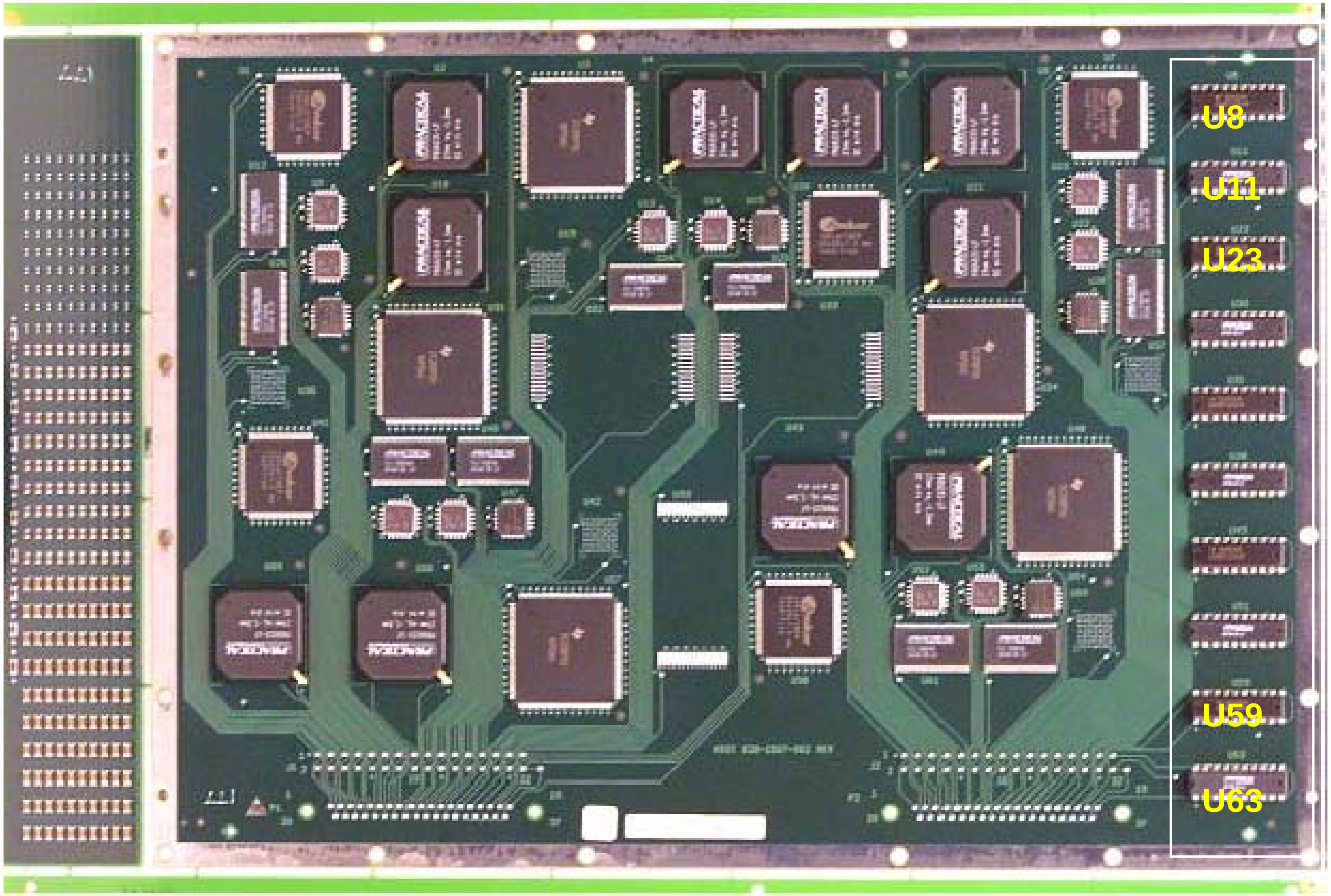
Introduction

- Failure analysis time consuming
- Cross sectioning is destructive
- Sectioning two-dimensional
- Can digital microscopy help?
  - Identify potential faults
  - Tell where to section to find problems

Components in Study

- PDIP components - JCAA-JG-PP Lead-Free Test Project – U-59, U-63
- Thermal cycle - Range from -55° C to 125° C using 30 minute high dwell and 10 minute low dwell, 10° C/minute ramp
- Vibration - Levels increased every 60 minutes, until 420 minutes had been reached

JCAA-JGPP Board



Components Evaluated

Board	Comp	Rework (Y/N)	Component Failure (Y/N)	Surface Finish	Rework Solder Composition	Stress Test Vibration or Thermal Cycling	Time to Failure Vibration (min) Thermal Cycling (# Cycles)
50	U59	Y	Y	Au/Pd/Ni	Sn37Pb	Vibration	390
50	U63	N	Y	Sn	---------	Vibration	121
58	U59	Y	N	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	---------
58	U63	N	N	Sn	---------	Thermal Cycling	---------
163	U8	N	N	Au/Pd/Ni	---------	Thermal Cycling	---------
163	U11	N	N	Sn	---------	Thermal Cycling	---------
163	U23	Y	N	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	---------
167	U59	Y	N	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	---------
167	U63	N	N	Sn	---------	Thermal Cycling	---------
191	U59	Y	Y	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	842
191	U63	N	Y	Sn	---------	Thermal Cycling	1595
194	U8	N	N	Au/Pd/Ni	---------	Thermal Cycling	---------
194	U11	N	N	Sn	---------	Thermal Cycling	---------
194	U23	Y	N	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	---------

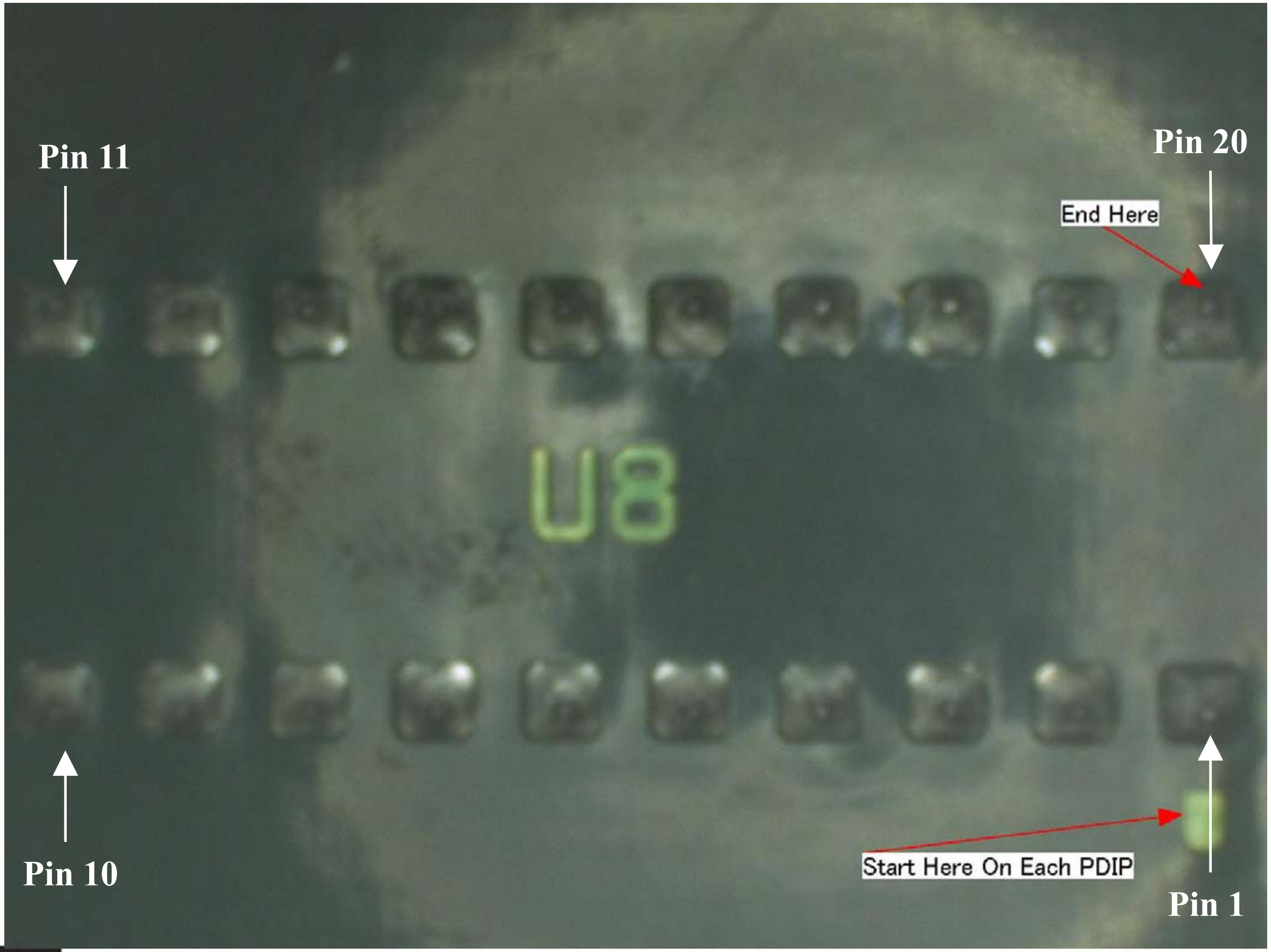
Experimental

- Digital Microscope
  - Keyence Model VHX-600
- 54 megapixel 3CCD camera
- Images ranged from 30x to 150x
- Computer - various points of focus and stitched together to construct a 3D image

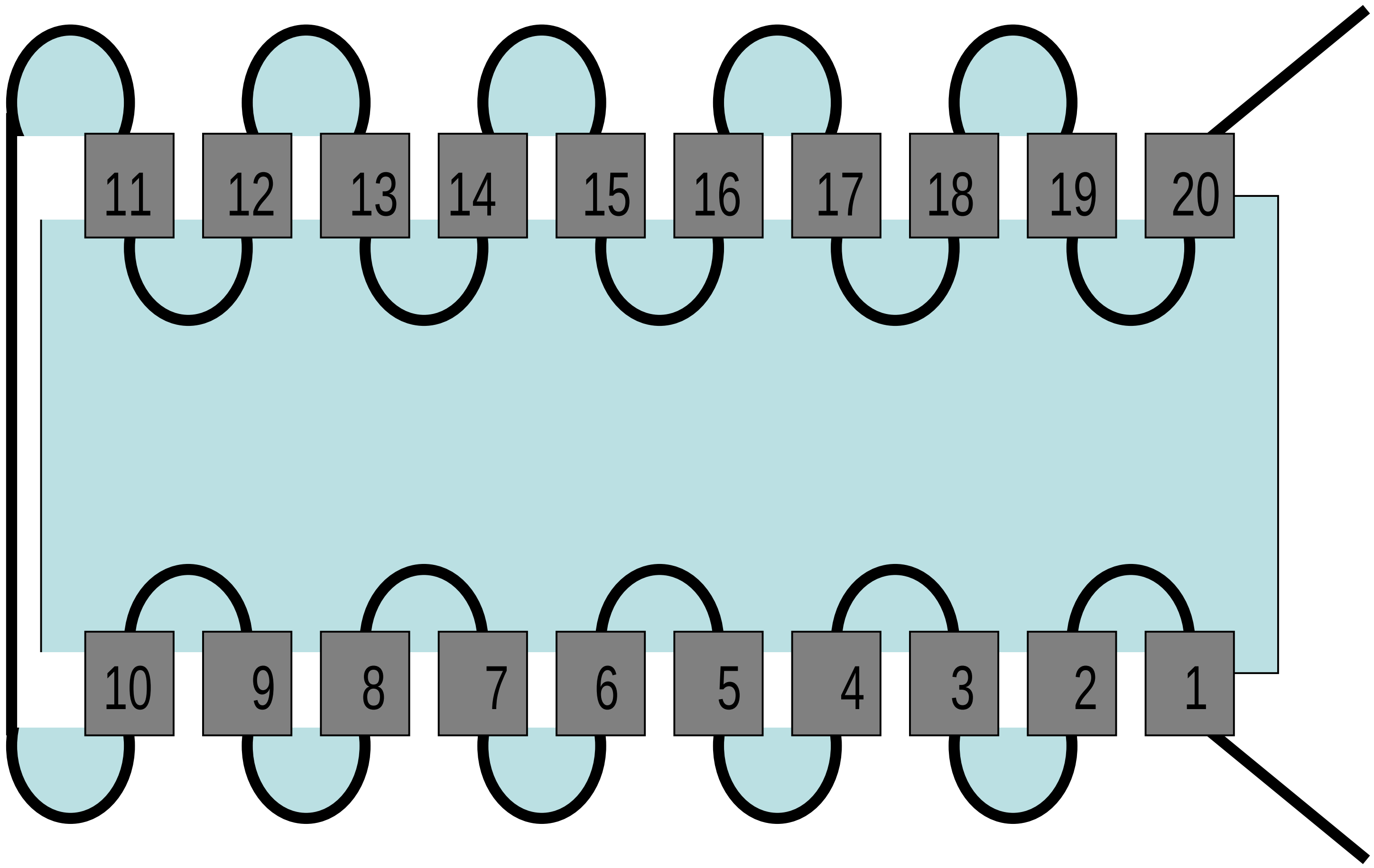
Experimental – cont.

- Resistance Measurements - pin to pin
  - Pins with resistance readings significantly higher than average and/or showed evidence of damage, such as pad lifting, incomplete pad wetting or surface cracks, were cross-sectioned
- Cross sectioning performed by Trace Laboratories, Palatine, IL

Example of a PDIP from PWB

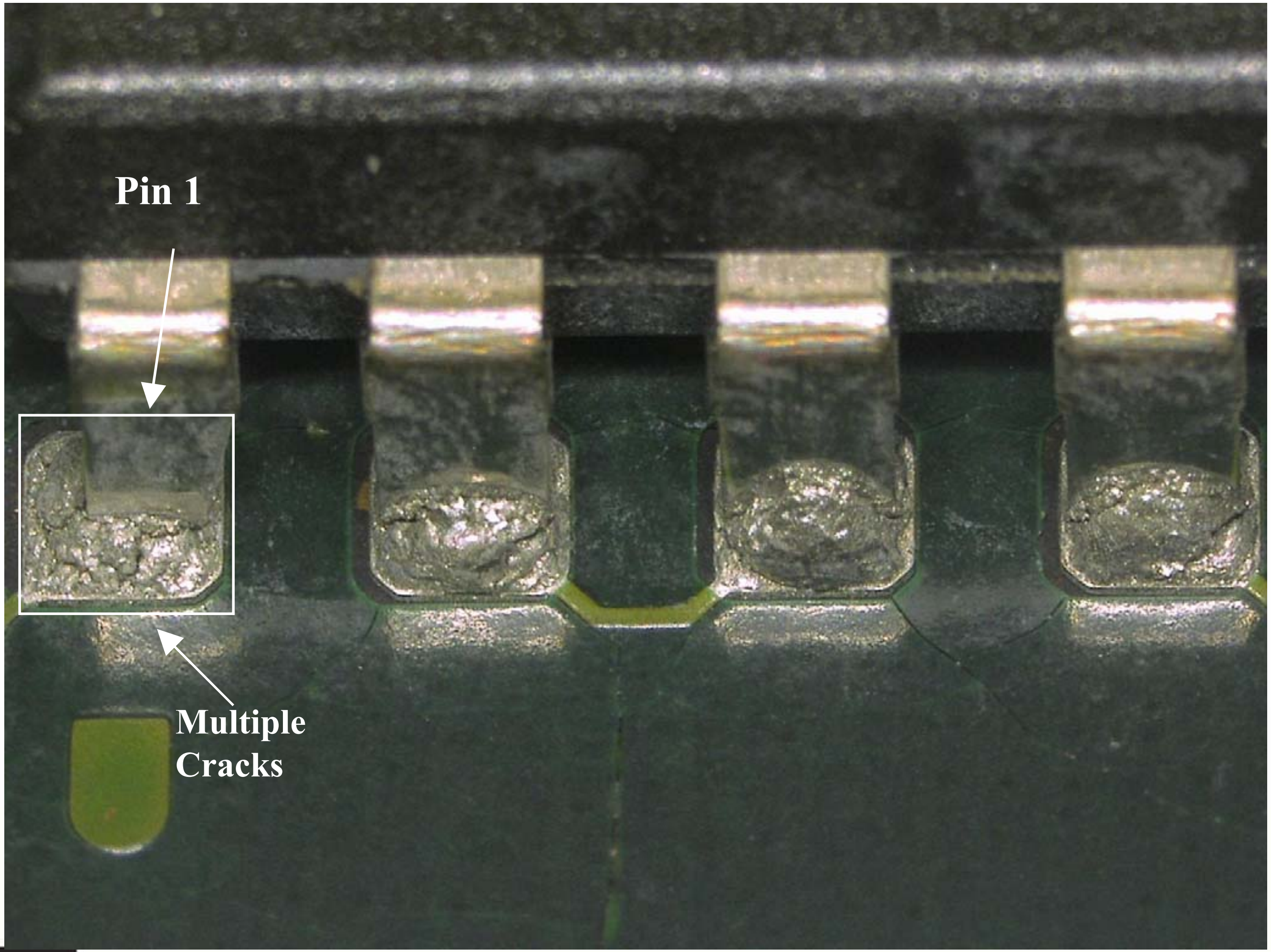


Daisy Chain for Pins on a PDIP

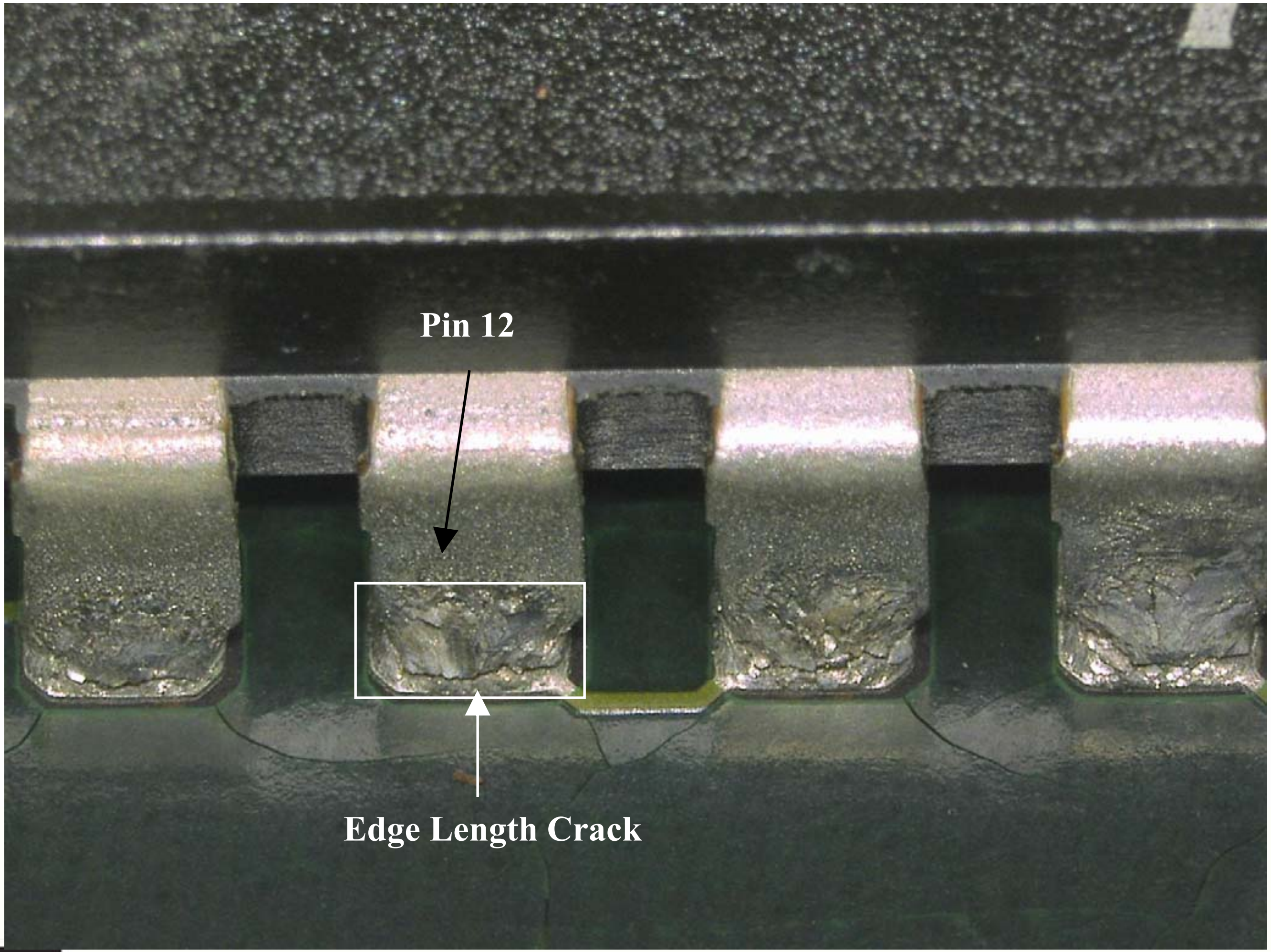


Components without Failures

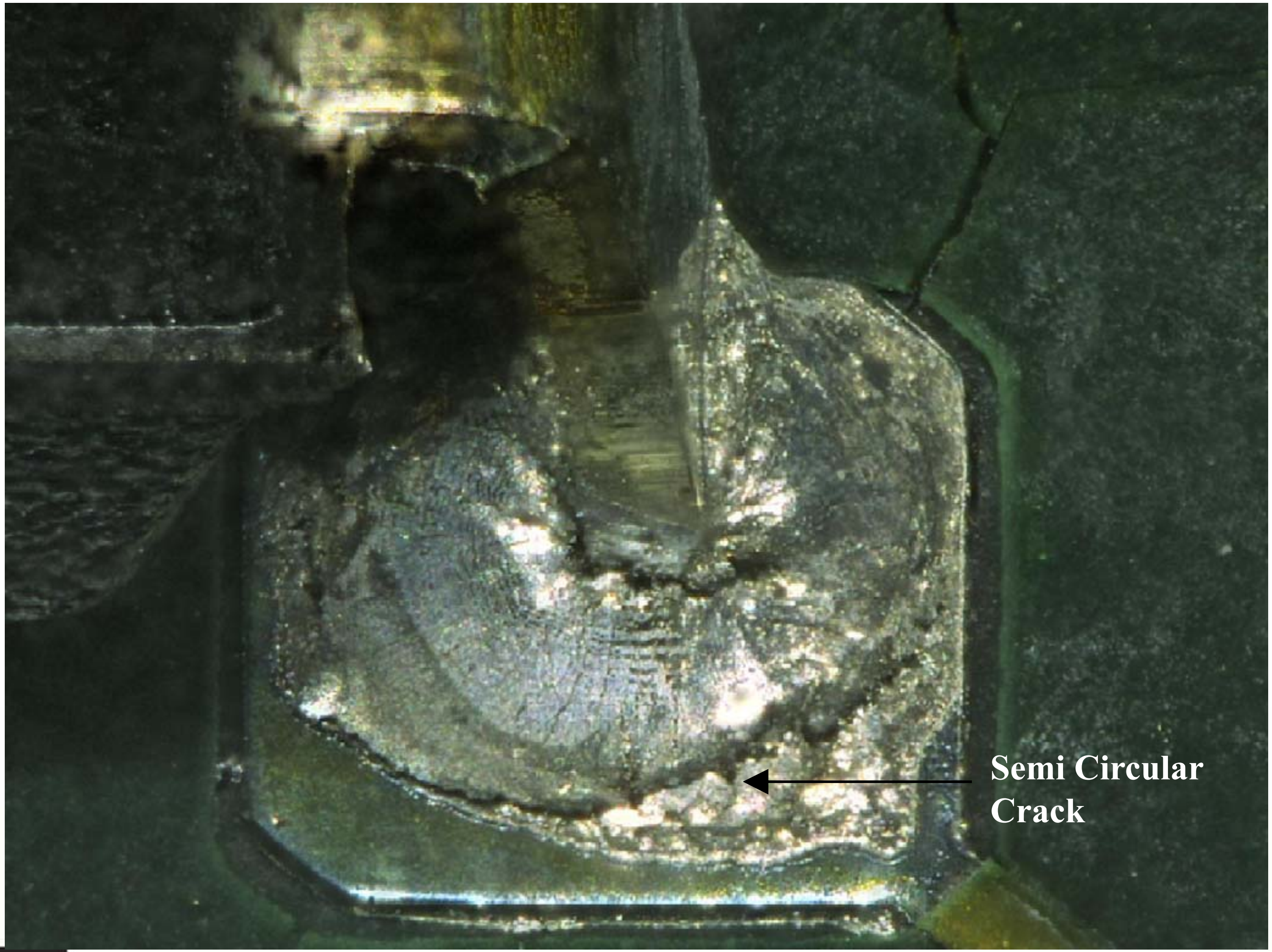
PWB 58 - U59, Pins 1 - 4



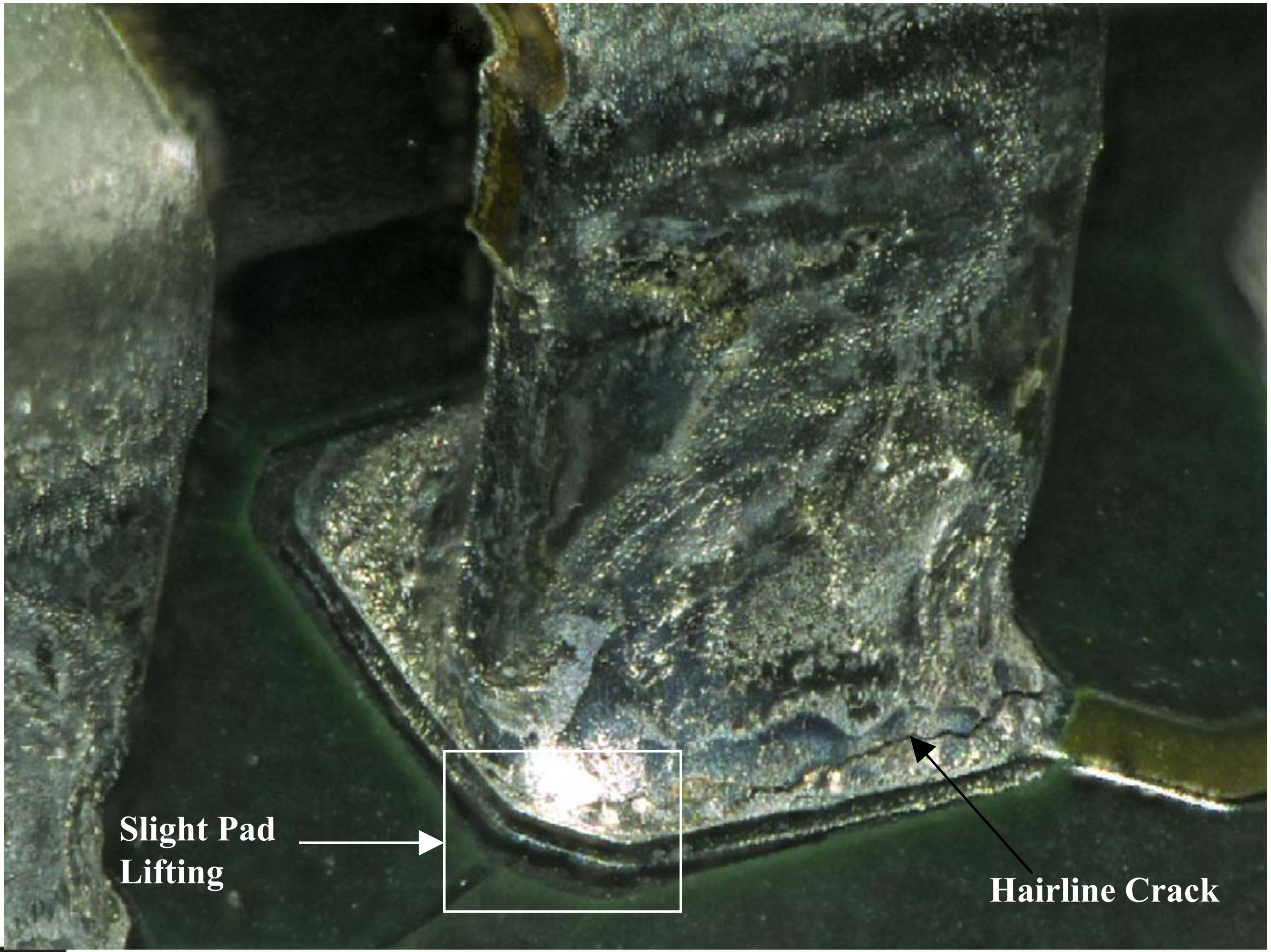
PWB 58 – U63, Pins 11 - 14



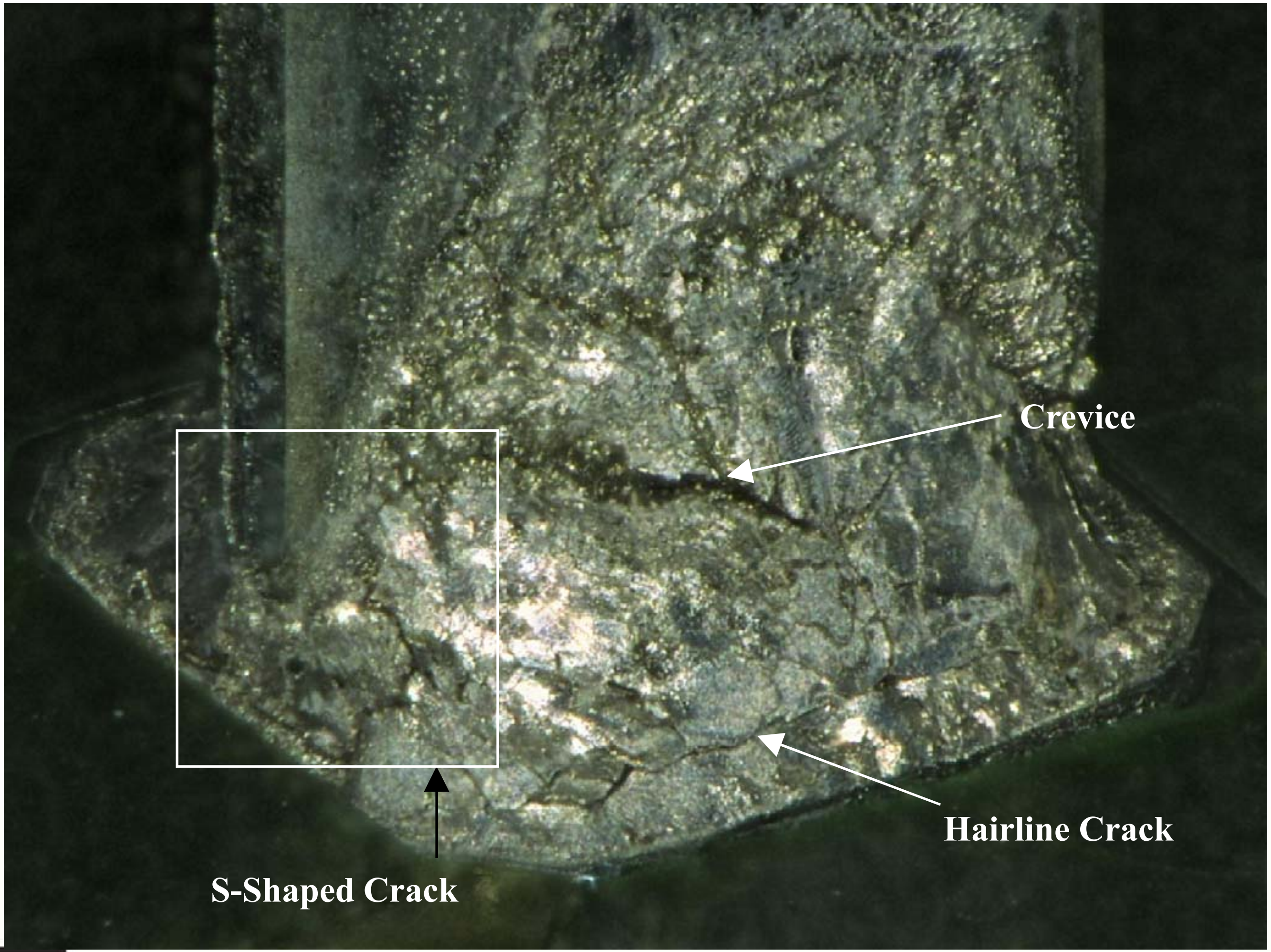
PWB 163 - U8, Pin 1



PWB 163 - U11, Pin 6

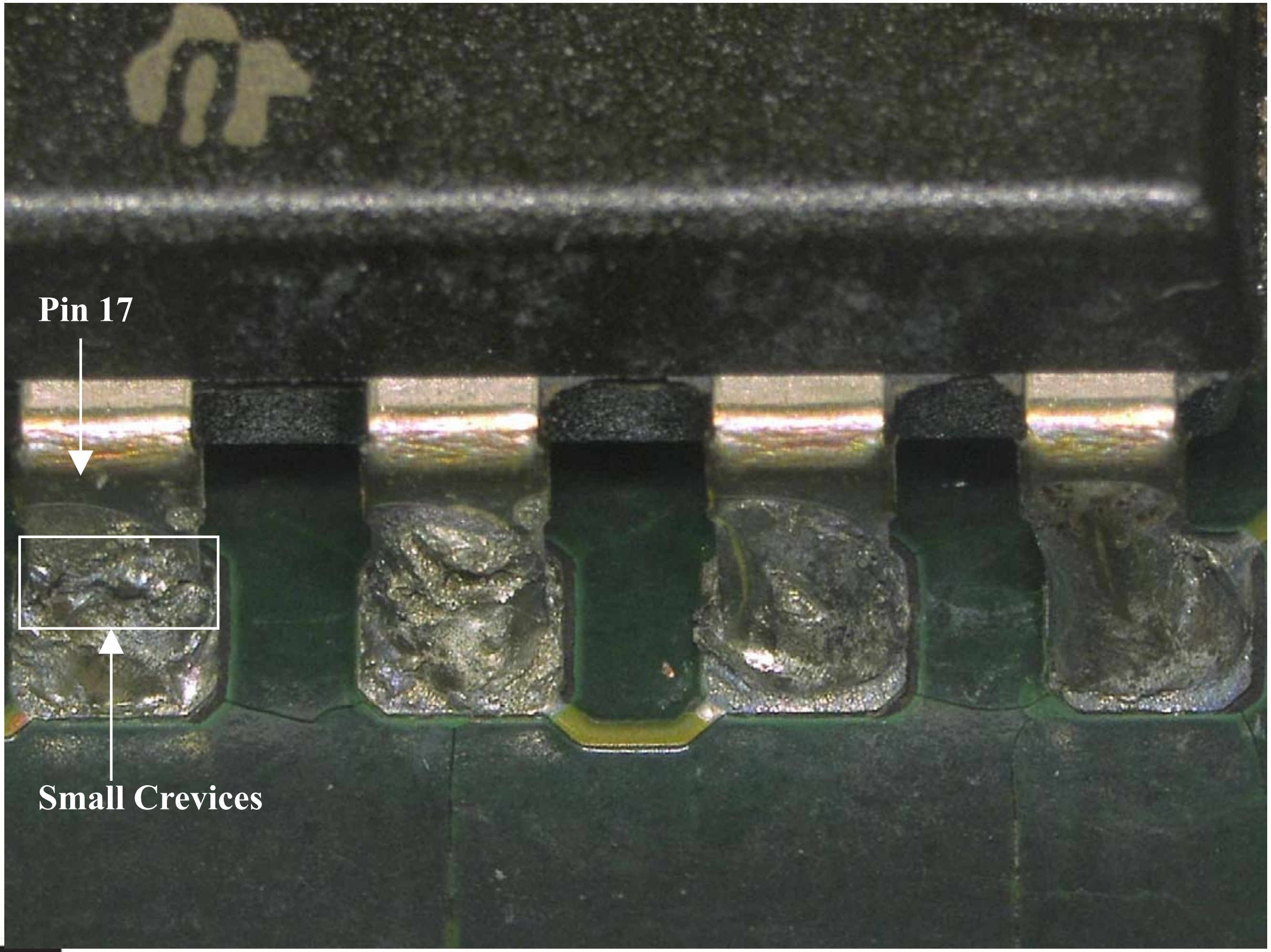


PWB 163 - U11, Pin 15

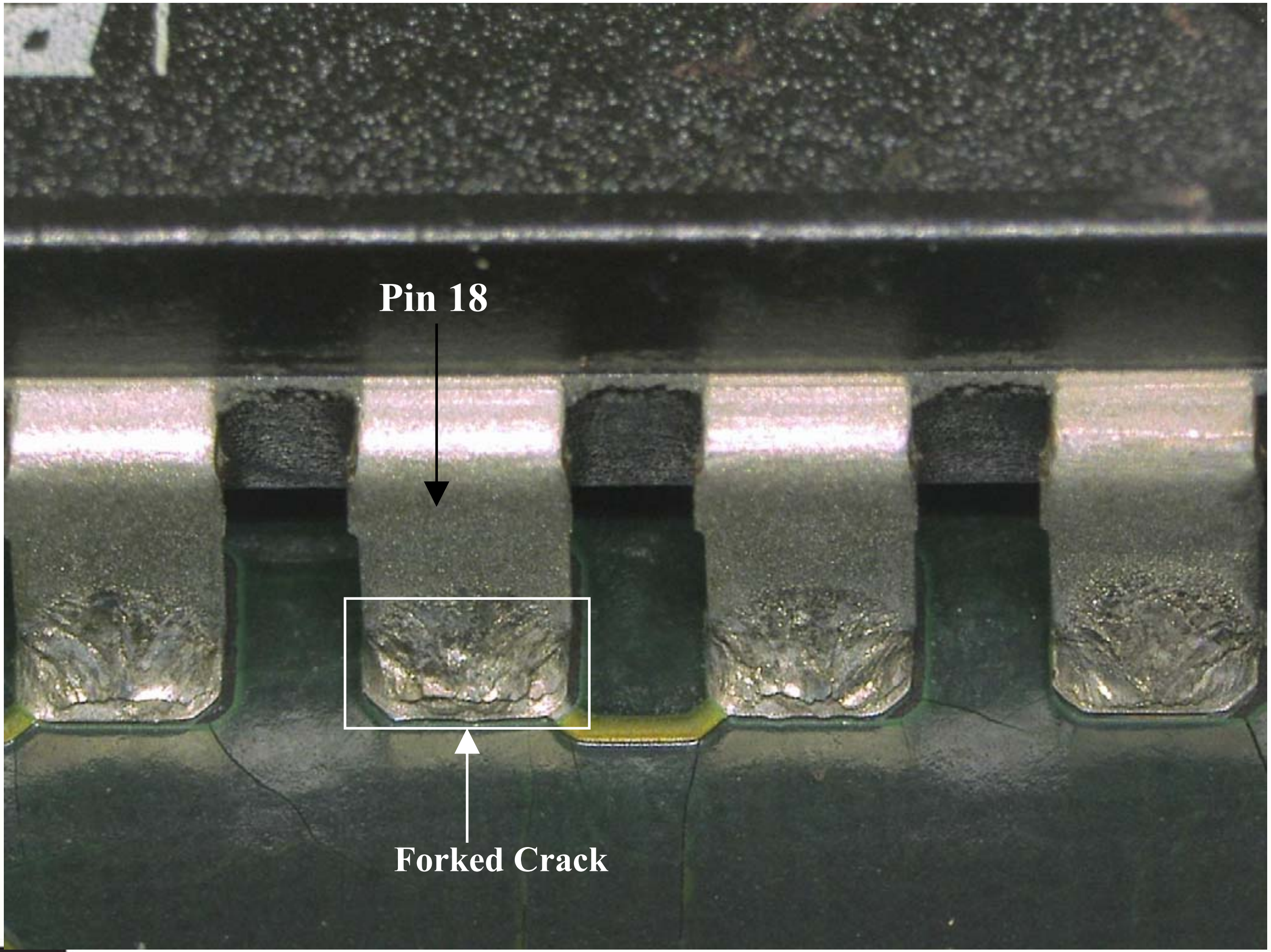


PWB 163 – U23, Pin 12

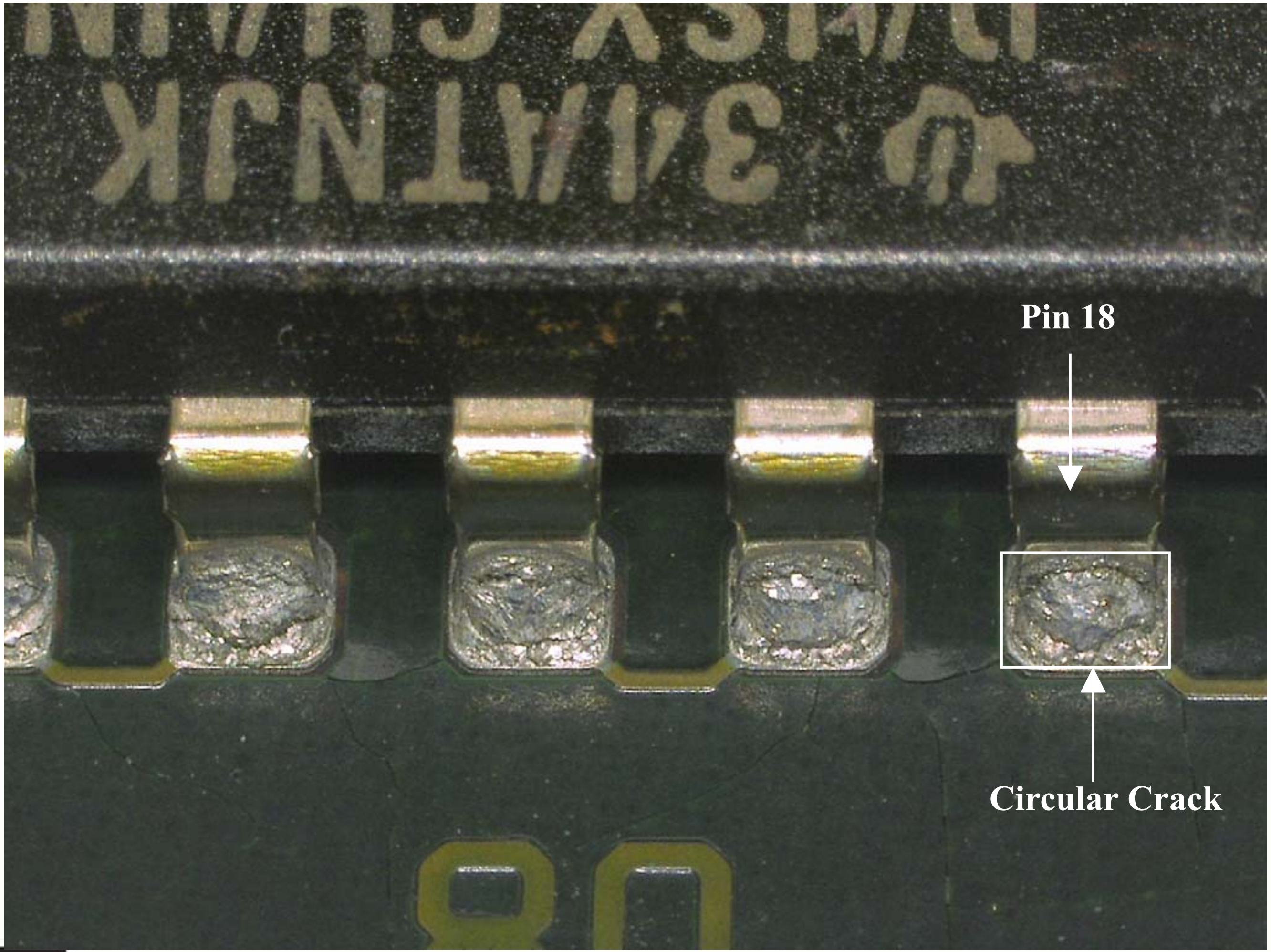
PWB 167 – U59, Pins 17 - 20



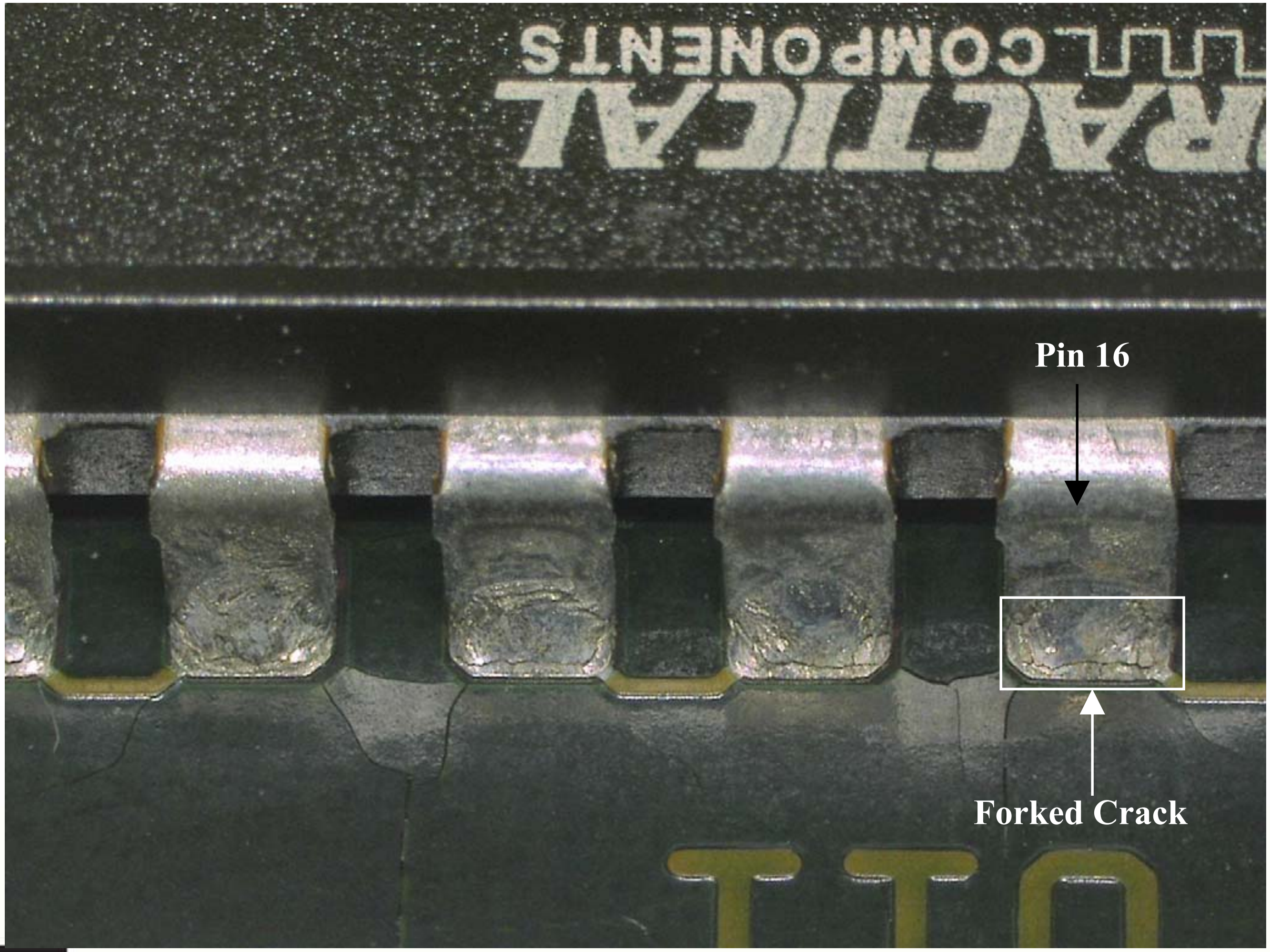
PWB 167 – U63, Pins 17 - 20



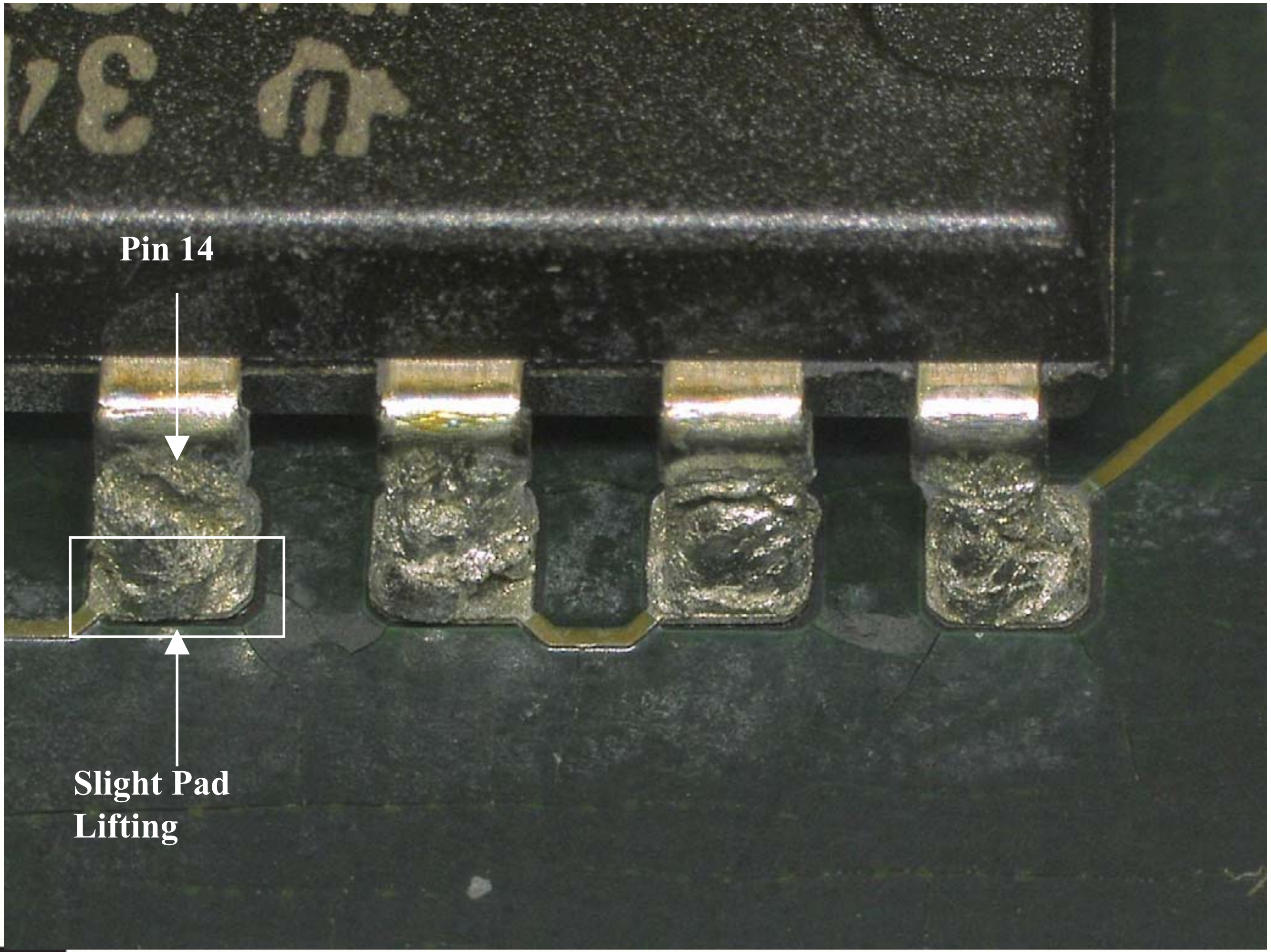
PWB 194 – U8, Pin 18



PWB 194 – U11, Pins 13 - 16



PWB 194 – U23, Pins 11 - 14



Boards with Failures

Boards Chosen for Detailed Analysis

- Failure incidences
- PDIPs from PWB 50 (vibration testing)
- PDIPs from PWB 191 (thermal cycling)

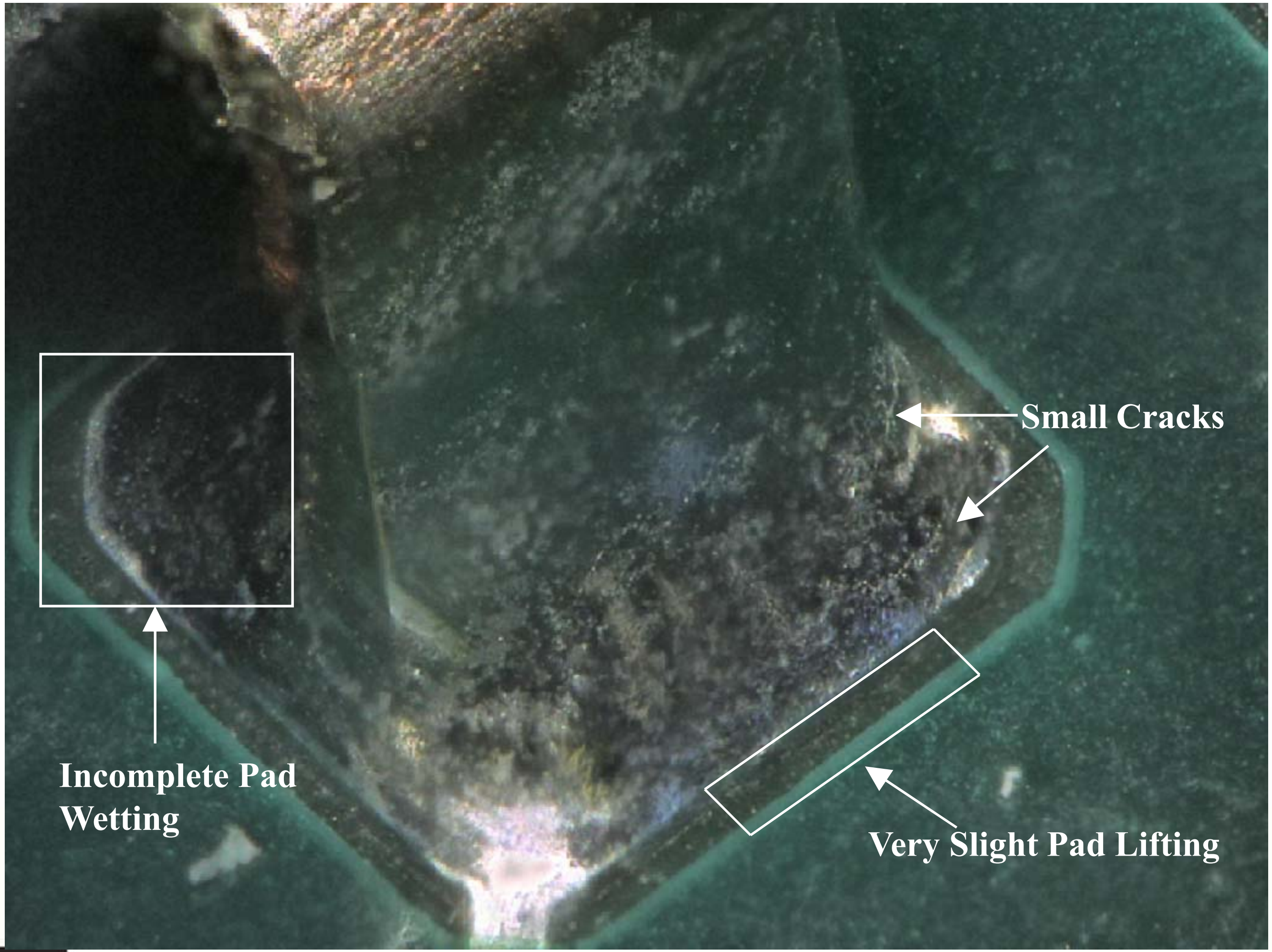
Components Evaluated

Board	Comp	Rework (Y/N)	Component Failure (Y/N)	Surface Finish	Rework Solder Composition	Stress Test Vibration or Thermal Cycling	Time to Failure Vibration (min) Thermal Cycling (# Cycles)
50	U59	Y	Y	Au/Pd/Ni	Sn37Pb	Vibration	390
50	U63	N	Y	Sn	---------	Vibration	121
58	U59	Y	N	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	---------
58	U63	N	N	Sn	---------	Thermal Cycling	---------
163	U8	N	N	Au/Pd/Ni	---------	Thermal Cycling	---------
163	U11	N	N	Sn	---------	Thermal Cycling	---------
163	U23	Y	N	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	---------
167	U59	Y	N	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	---------
167	U63	N	N	Sn	---------	Thermal Cycling	---------
191	U59	Y	Y	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	842
191	U63	N	Y	Sn	---------	Thermal Cycling	1595
194	U8	N	N	Au/Pd/Ni	---------	Thermal Cycling	---------
194	U11	N	N	Sn	---------	Thermal Cycling	---------
194	U23	Y	N	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	---------

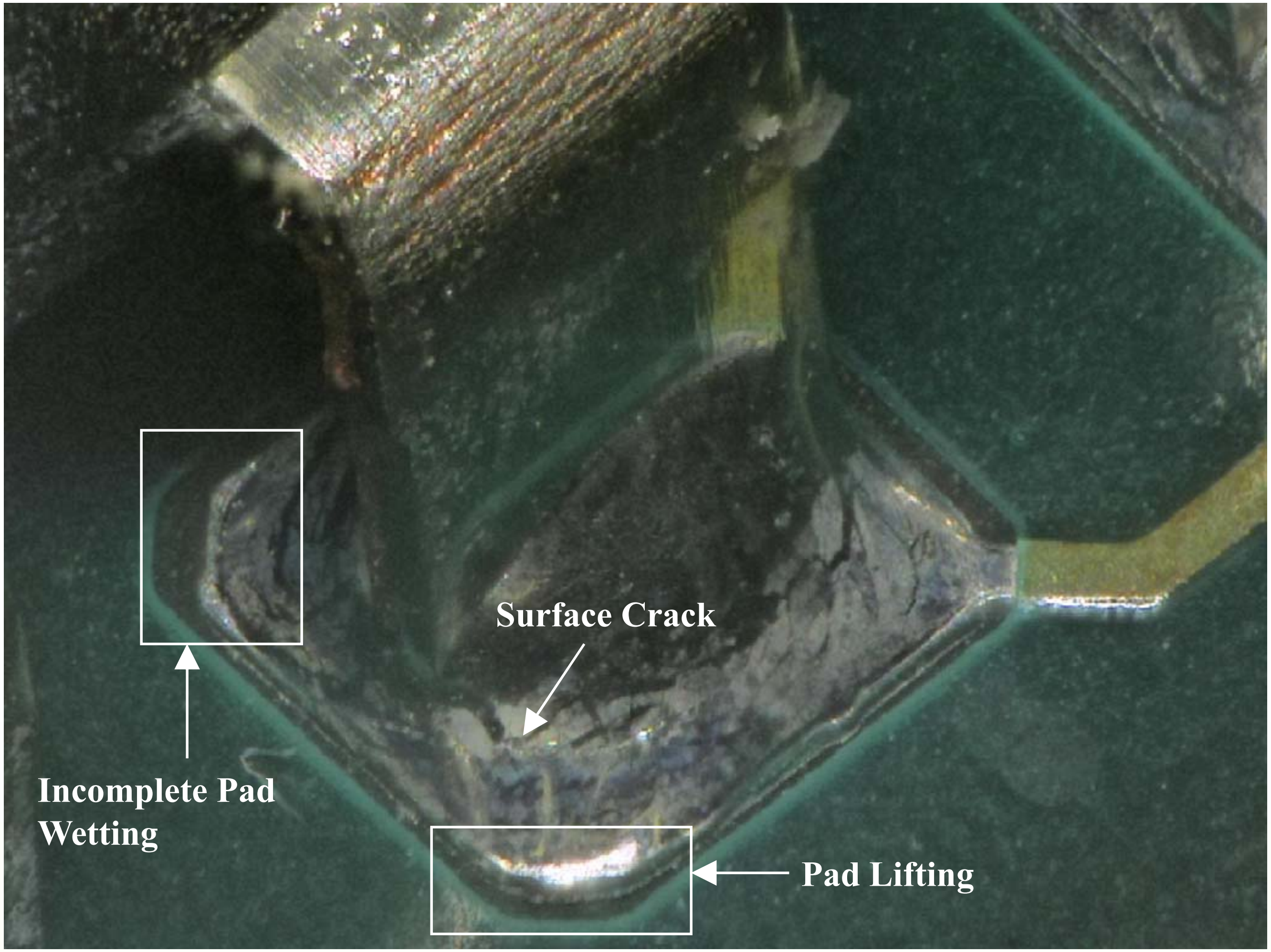
Resistance Measurements PWB 50

	Component U59	Component U63
Pins	Resistance (Ω)	Resistance (Ω)
1 & 2	0.4	> 1 M Ω
2 & 3	0.2	0.3
3 & 4	0.4 (Sectioned)	0.3 (Sectioned)
4 & 5	0.2	0.3
5 & 6	0.4	0.4
6 & 7	0.2	0.3
7 & 8	0.4	0.3
8 & 9	0.2	0.3
9 & 10	0.4	> 1 M Ω (Sectioned)
10 & 11	4.2	94 (Sectioned)
11 & 12	0.4	> 1 M Ω (Sectioned)
12 & 13	0.2	0.4
13 & 14	0.4	0.4
14 & 15	0.2	0.3
15 & 16	0.4	0.5
16 & 17	0.2	0.3
17 & 18	0.5 (Sectioned)	0.4 (sectioned)
18 & 19	0.2	0.3
19 & 20	0.5	> 1 M Ω

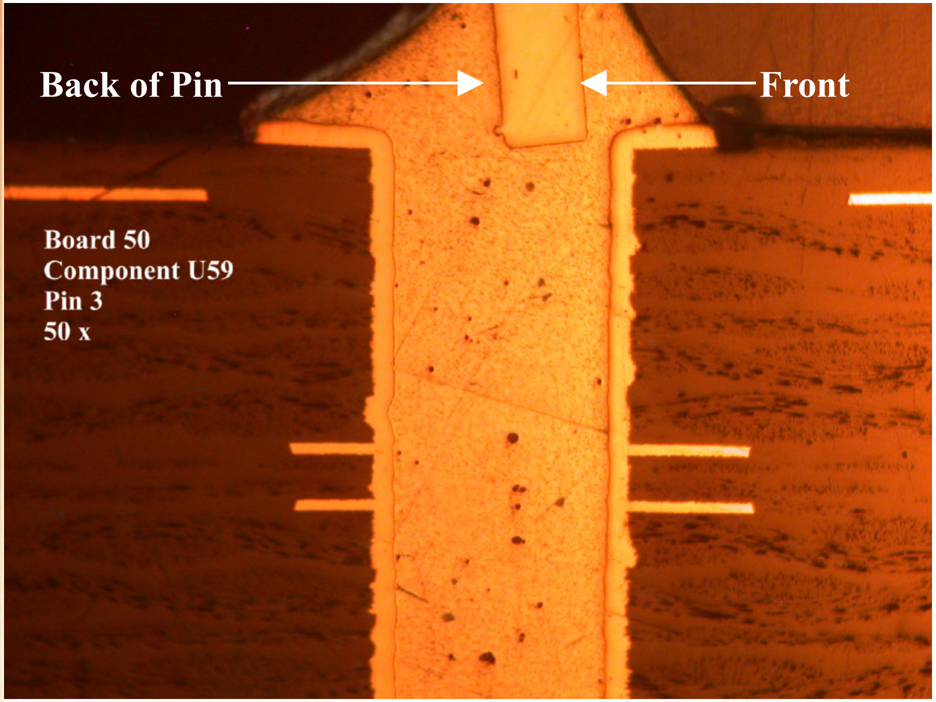
PWB 50 - U59, Pin 3

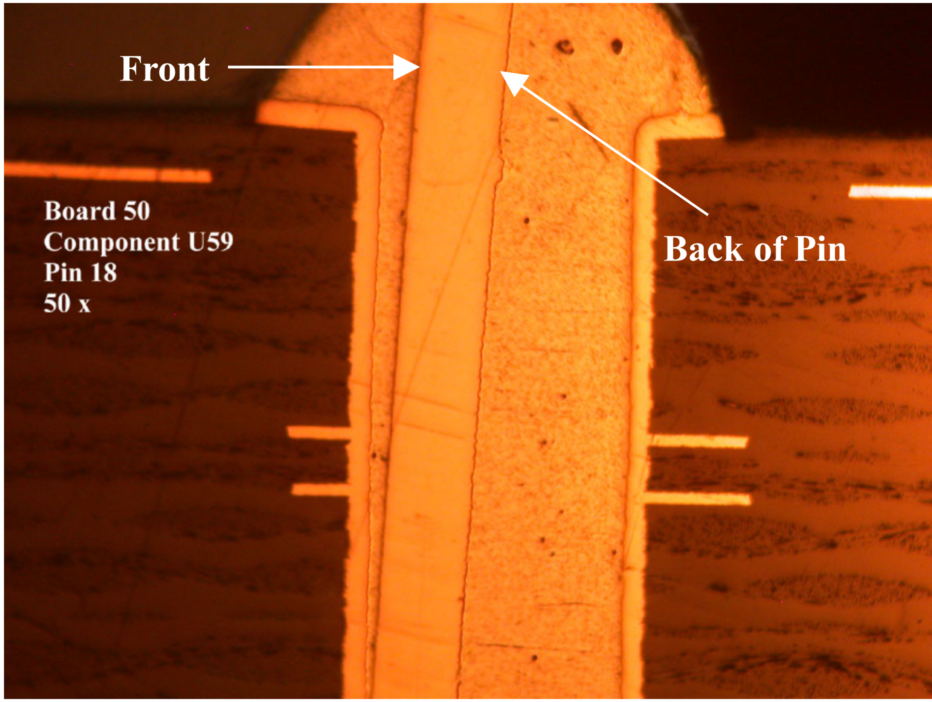


PWB 50 - U59, Pin 18



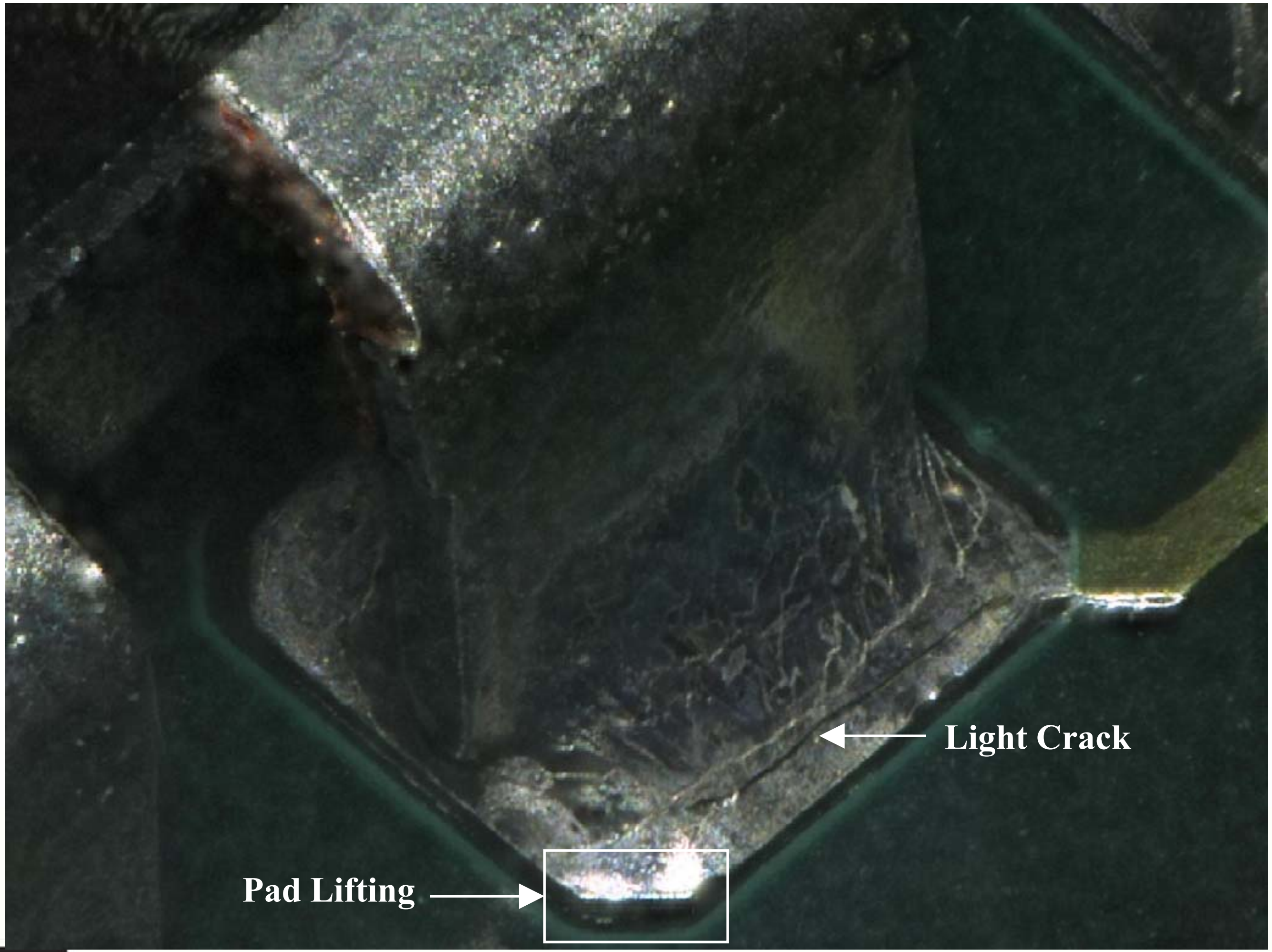
PWB 50 - U59, Cross Sections - Pins 3 & 18



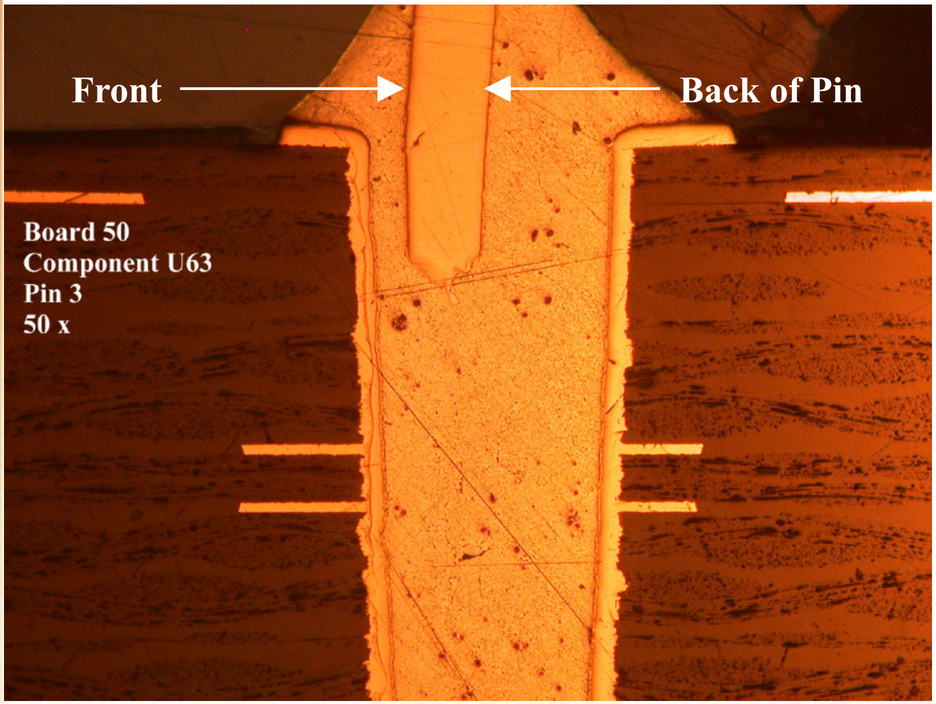


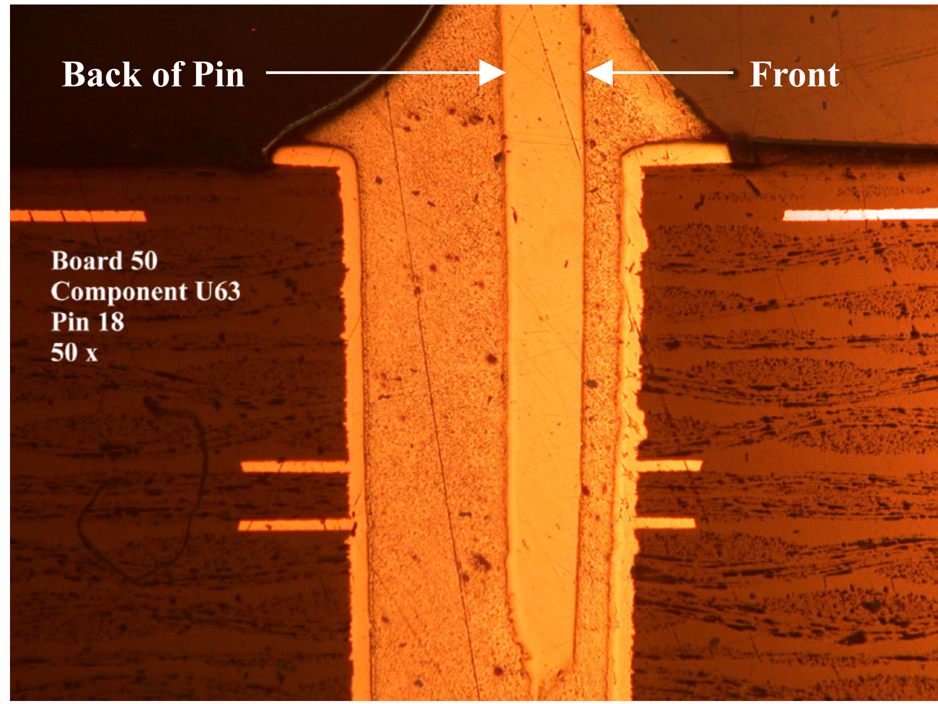
PWB 50 - U63, Pin 3

PWB 50 - U63, Pin 18

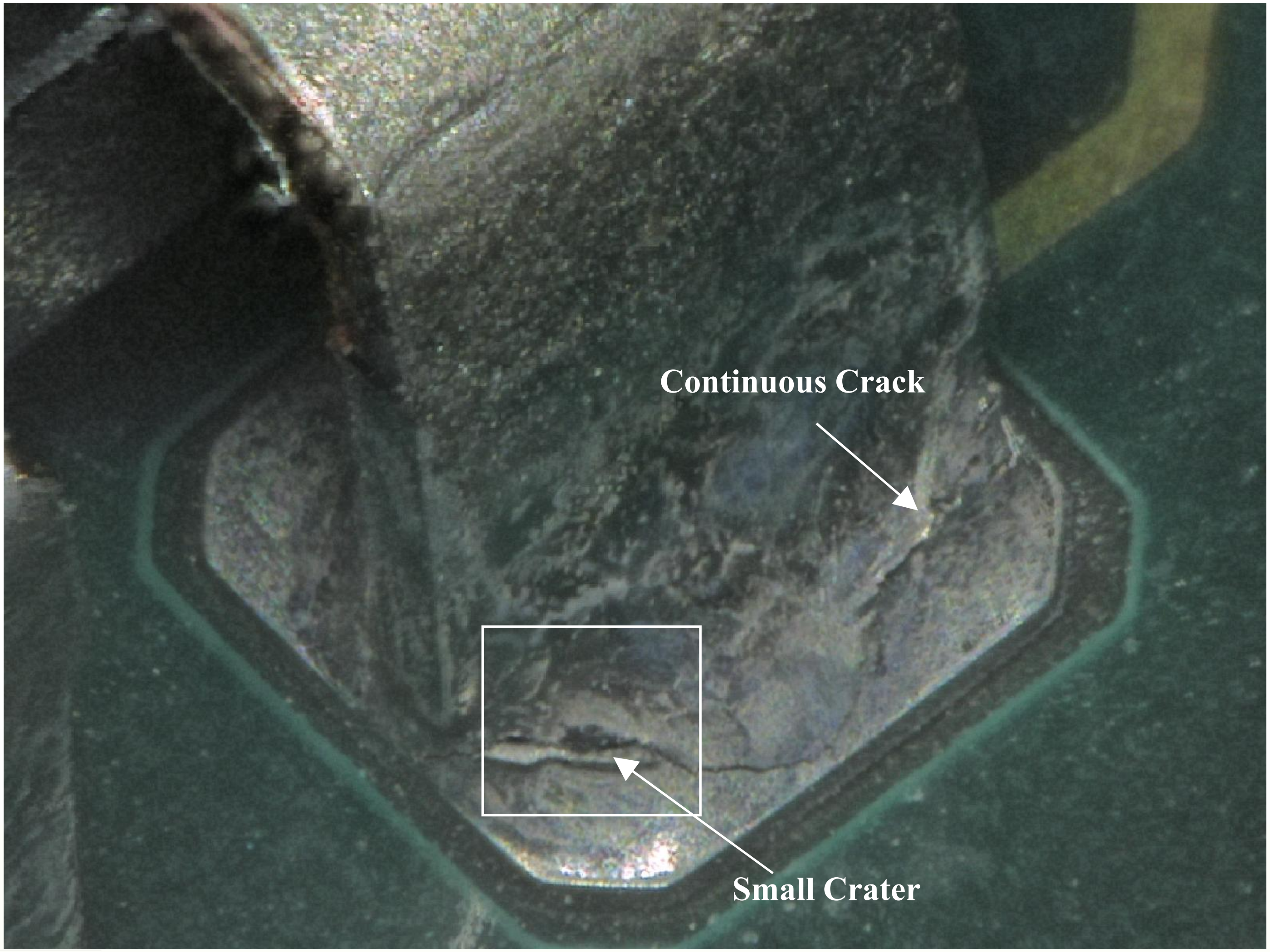


PWB 50 - U63, Cross Sections - Pins 3 & 18

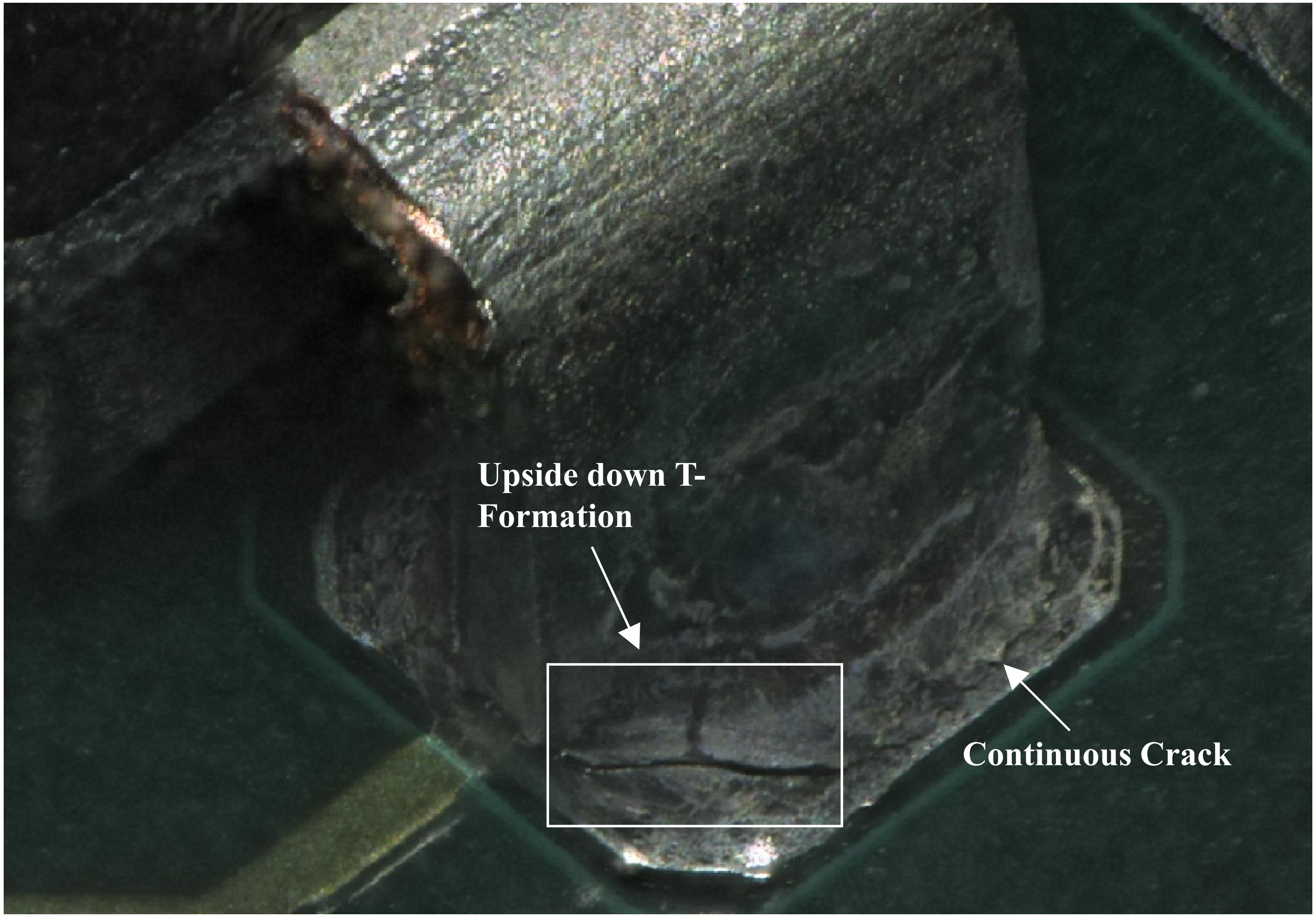




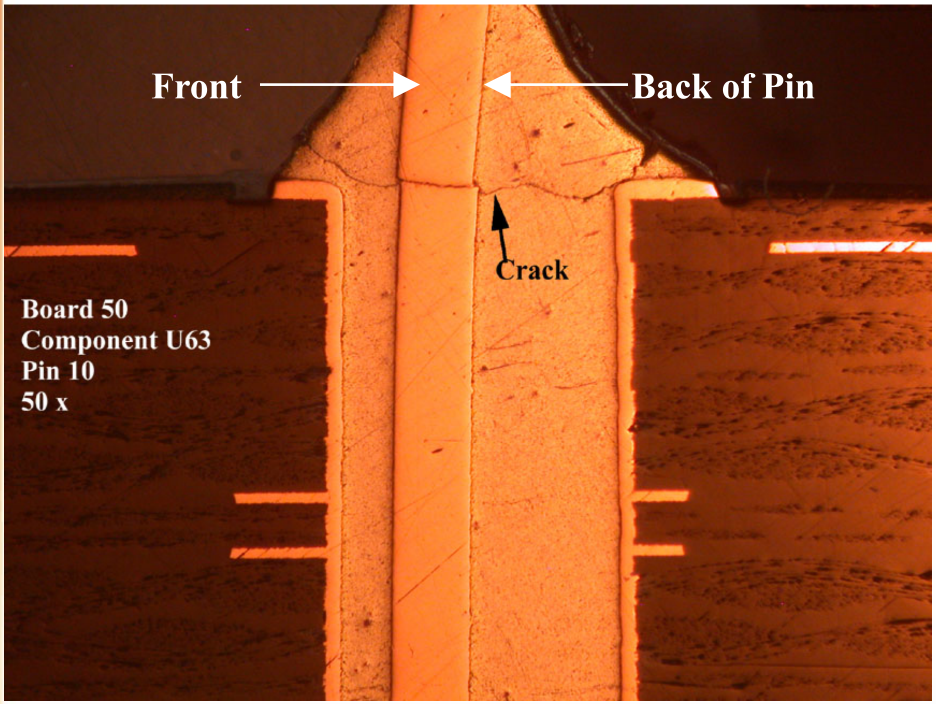
PWB 50 - U63, Pin 10

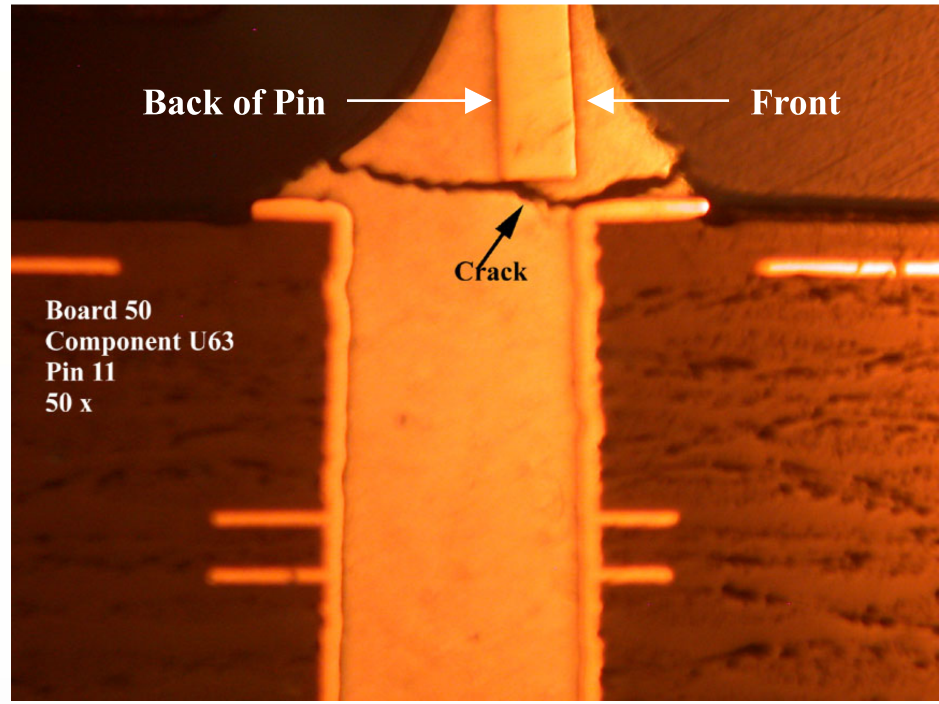


PWB 50 – U63, Pin 11



PWB 50 - U63, Cross Sections - Pins 10 & 11





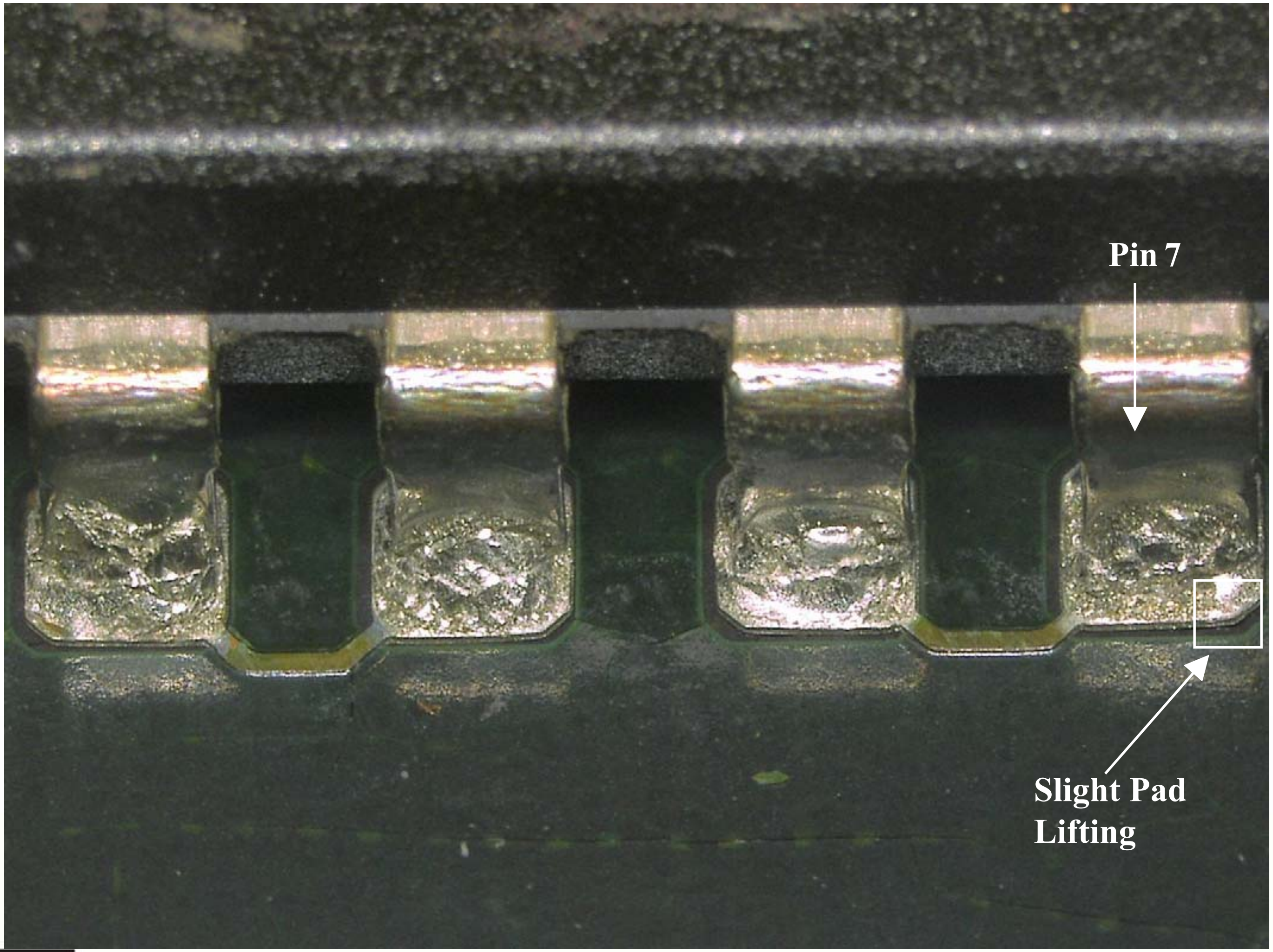
Components Evaluated

Board	Comp	Rework (Y/N)	Component Failure (Y/N)	Surface Finish	Rework Solder Composition	Stress Test Vibration or Thermal Cycling	Time to Failure Vibration (min) Thermal Cycling (# Cycles)
50	U59	Y	Y	Au/Pd/Ni	Sn37Pb	Vibration	390
50	U63	N	Y	Sn	---------	Vibration	121
58	U59	Y	N	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	---------
58	U63	N	N	Sn	---------	Thermal Cycling	---------
163	U8	N	N	Au/Pd/Ni	---------	Thermal Cycling	---------
163	U11	N	N	Sn	---------	Thermal Cycling	---------
163	U23	Y	N	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	---------
167	U59	Y	N	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	---------
167	U63	N	N	Sn	---------	Thermal Cycling	---------
191	U59	Y	Y	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	842
191	U63	N	Y	Sn	---------	Thermal Cycling	1595
194	U8	N	N	Au/Pd/Ni	---------	Thermal Cycling	---------
194	U11	N	N	Sn	---------	Thermal Cycling	---------
194	U23	Y	N	Au/Pd/Ni	Sn0.7Cu0.05Ni	Thermal Cycling	---------

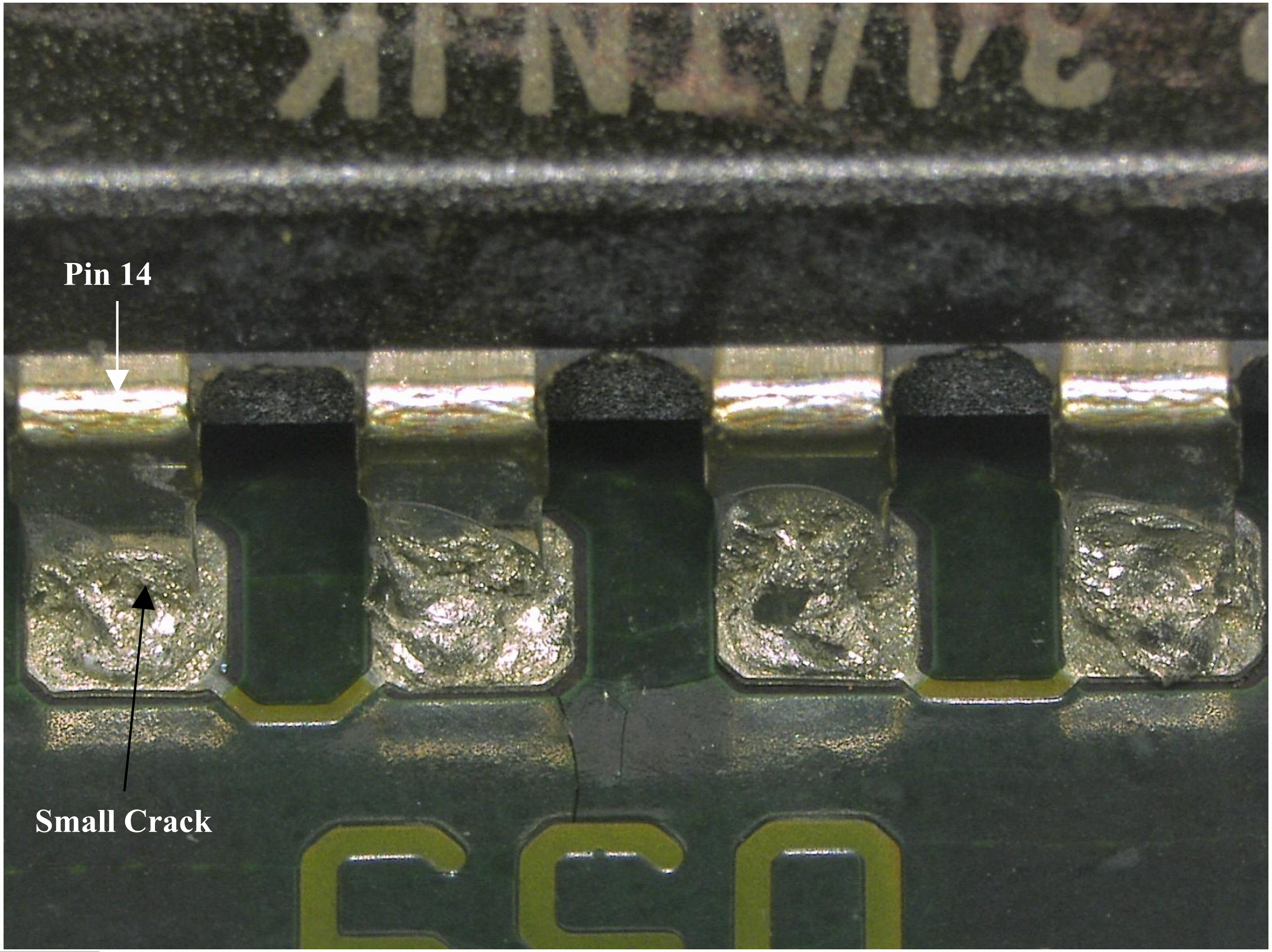
Resistance Measurements PWB 191

	Component U59	Component U63
Pins	Resistance (Ω)	Resistance (Ω)
1 & 2	0.5	0.2
2 & 3	0.3	0.5
3 & 4	0.6	0.2
4 & 5	0.3	>1 MΩ
5 & 6	0.5	0.3 (Sectioned)
6 & 7	0.3 (Sectioned)	20.4
7 & 8	0.5	0.2
8 & 9	0.3	0.2
9 & 10	0.5	0.2
10 & 11	0.2	75.2
11 & 12	0.5	0.2
12 & 13	0.3	0.2
13 & 14	0.5	0.2
14 & 15	0.2 (Sectioned)	0.2
15 & 16	0.5	0.3 (Sectioned)
16 & 17	0.3	0.2
17 & 18	0.5	0.3
18 & 19	>1 MΩ	0.2
19 & 20	0.5	0.2

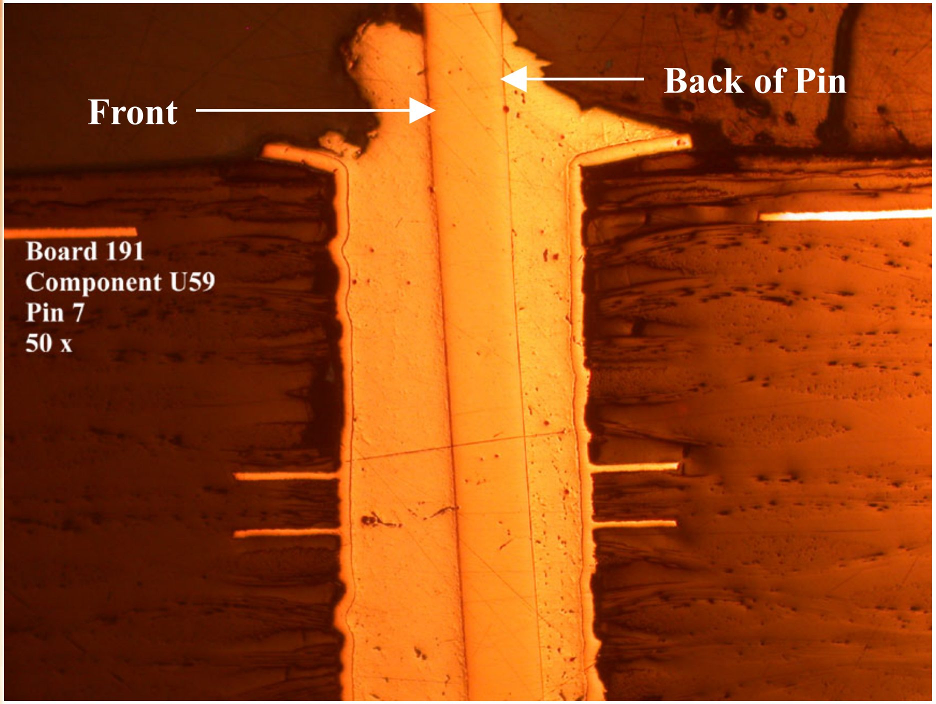
PWB 191 – U59, Pin 7

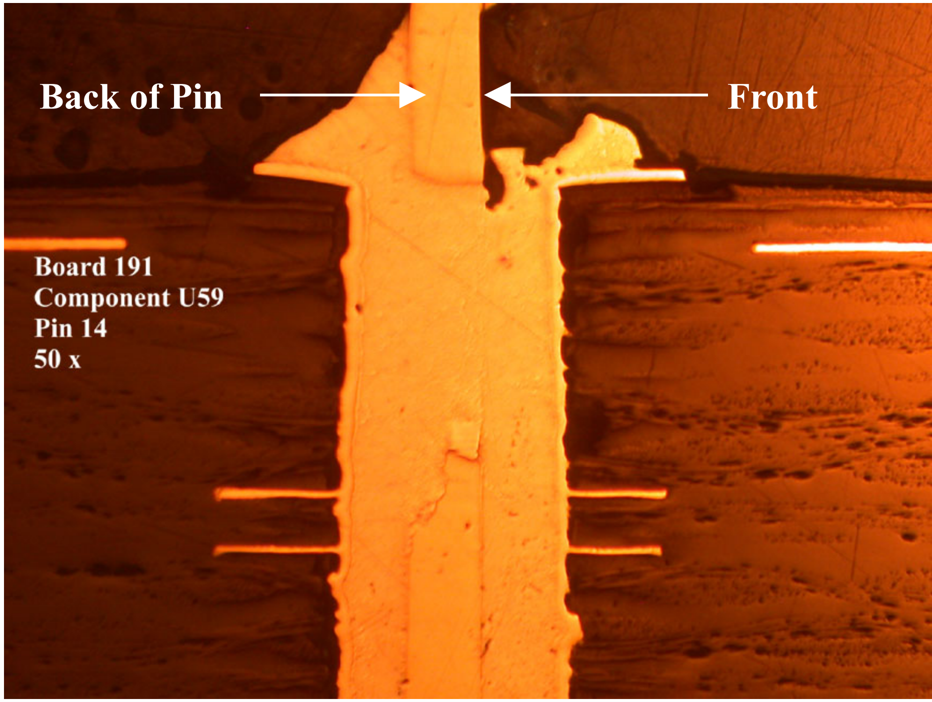


PWB 191 – U59, Pin 14

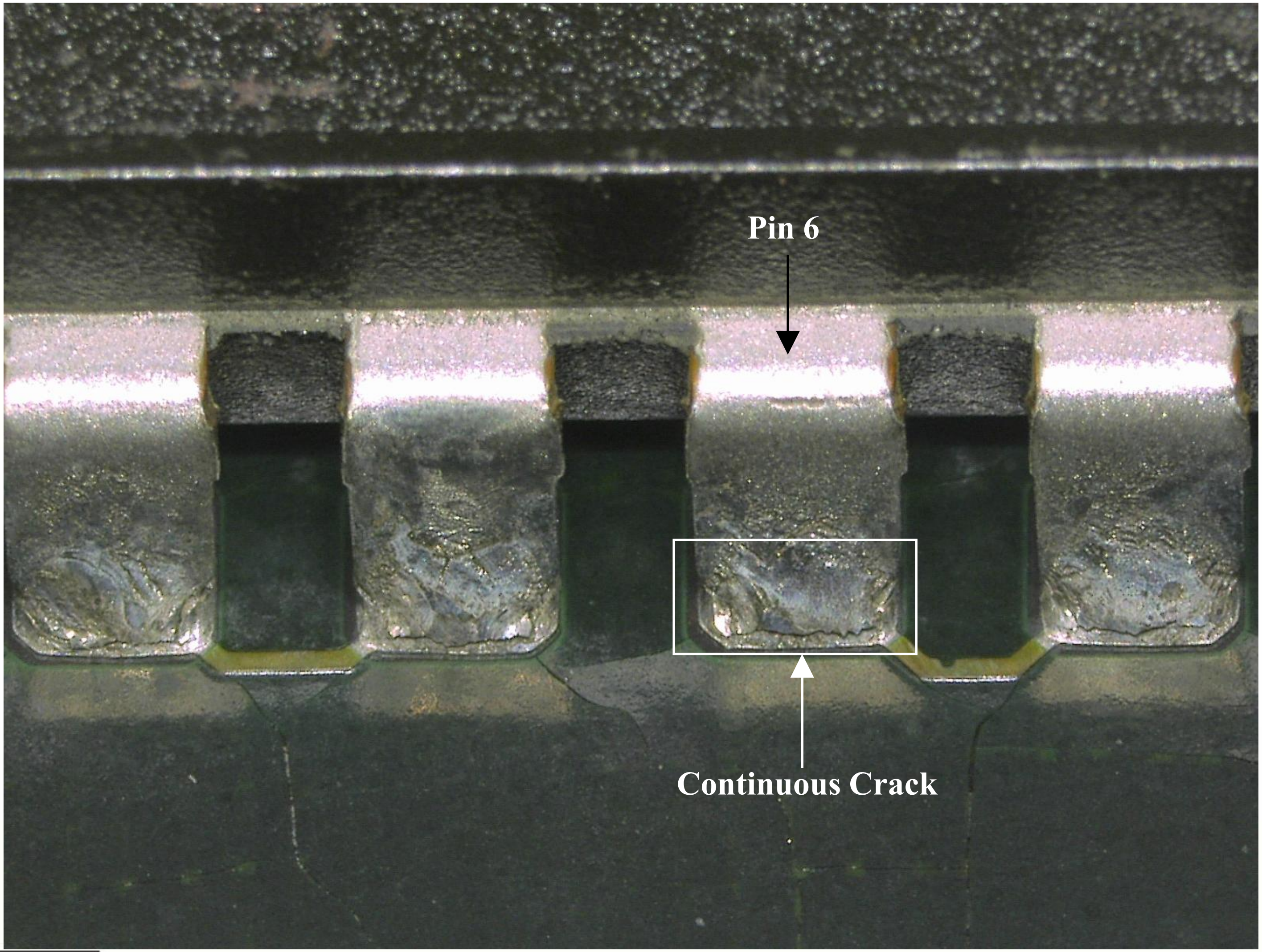


PWB 191 – U59, Cross Sections - Pins 7 & 14

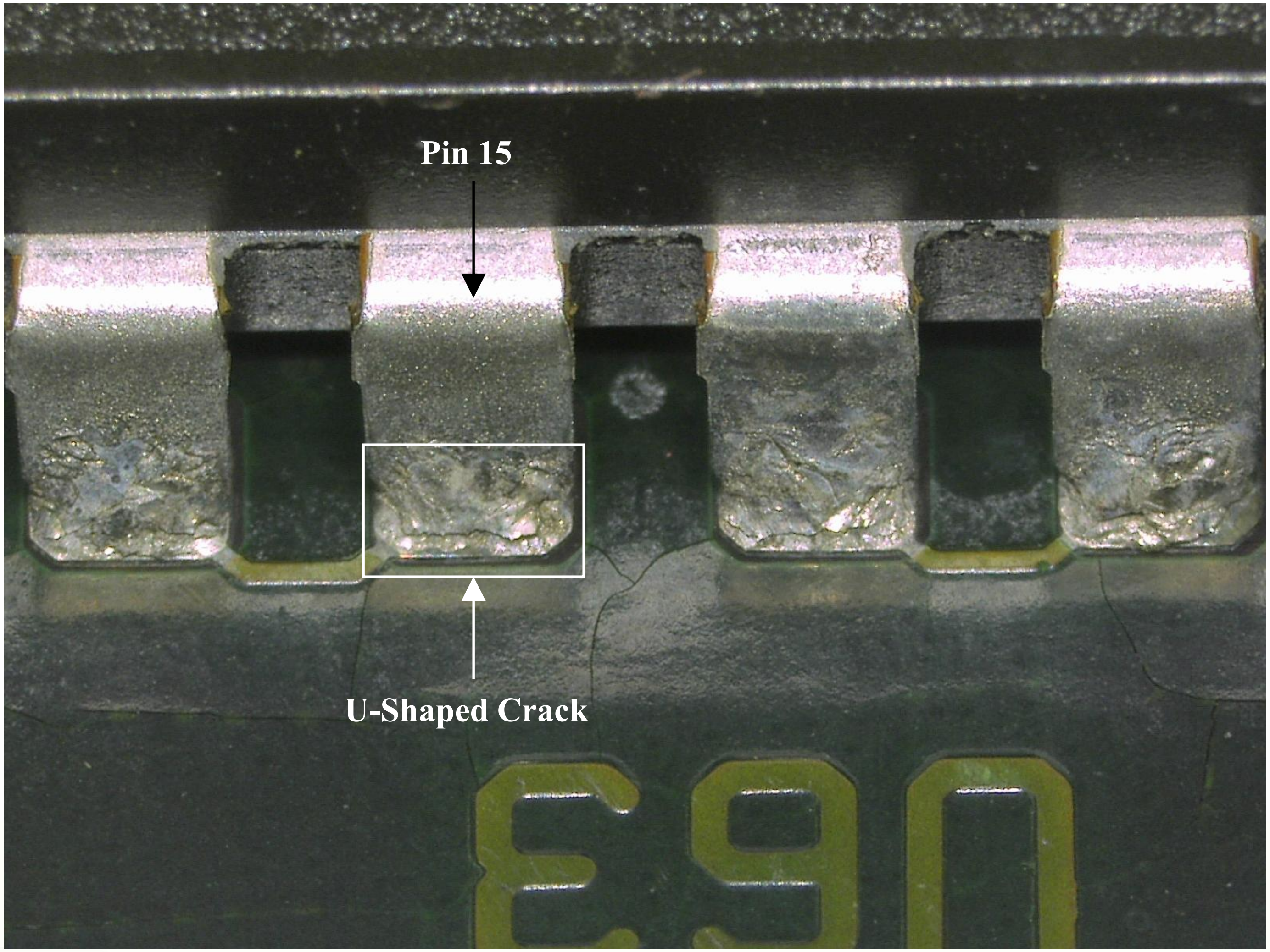




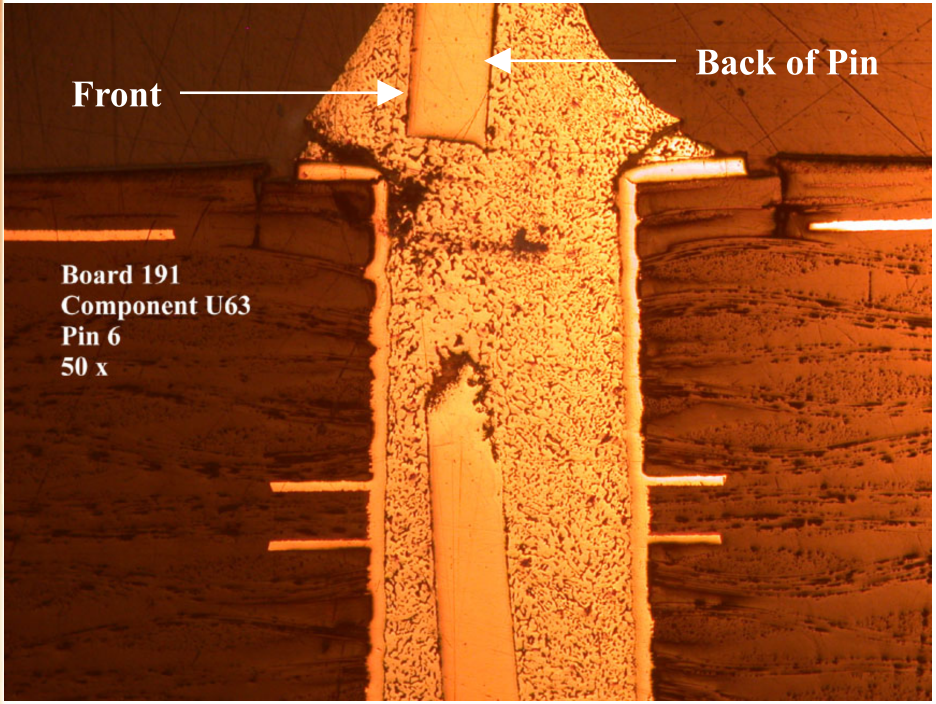
PWB 191 – U63, Pin 6

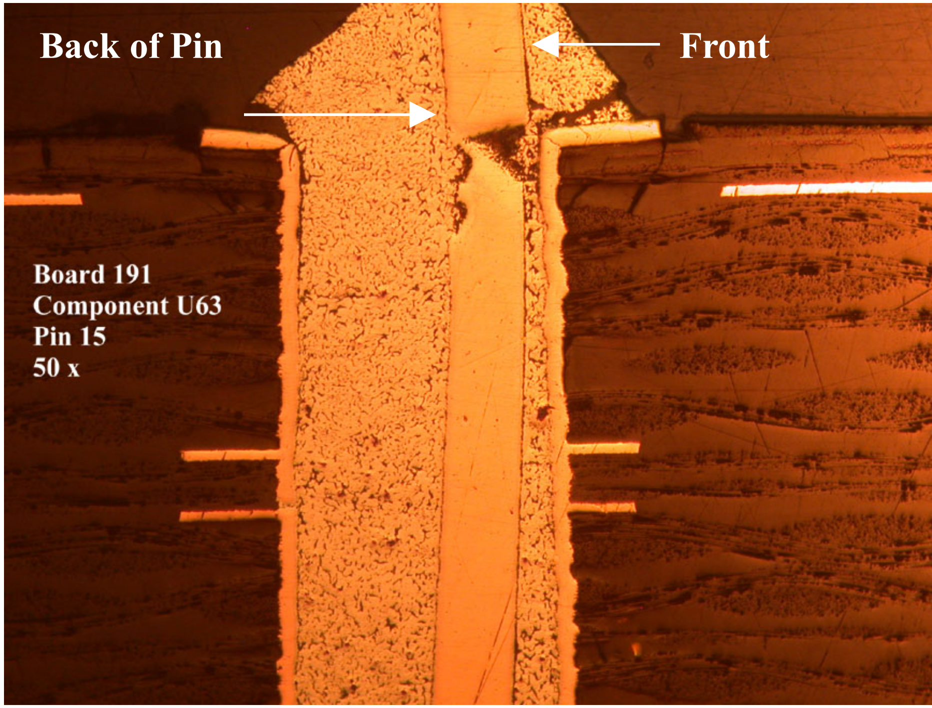


PWB 191 – U63, Pin 15

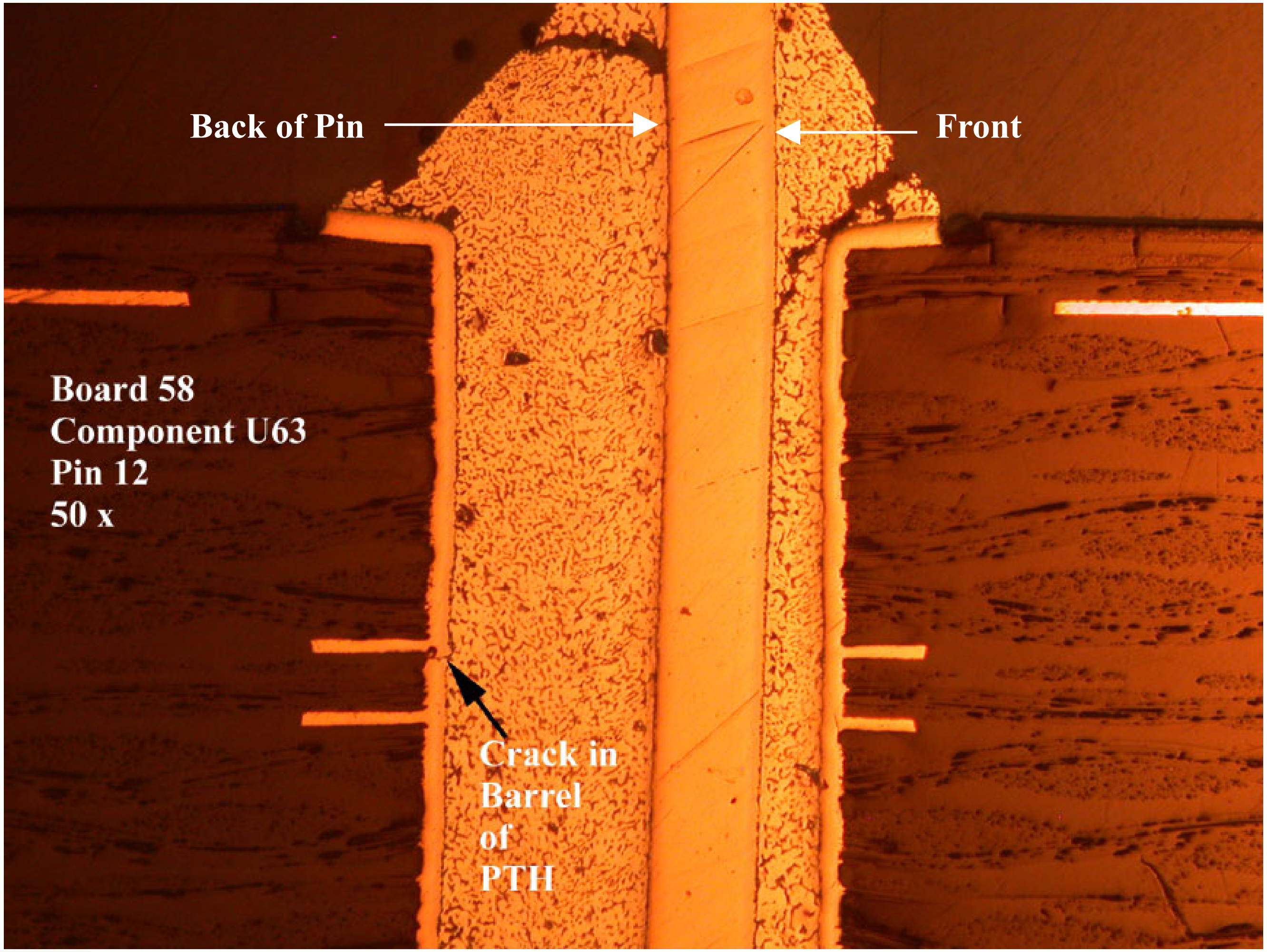


PWB 191 – U63, Cross Sections - Pins 6 & 15

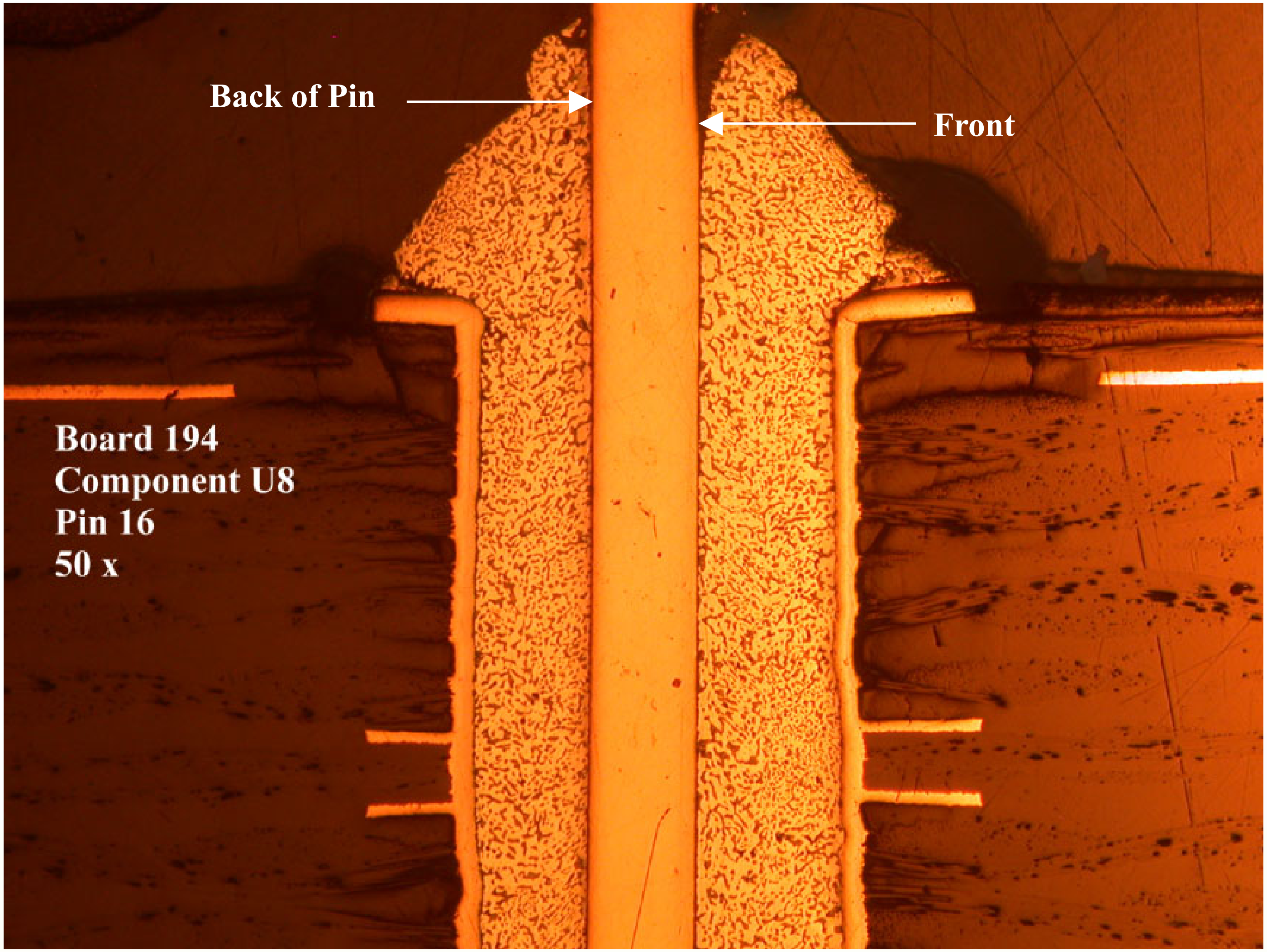




PWB 58 – U63, Pin 12 Cross Section



PWB 194 – U8, Pin 16 Cross Section



Conclusions

- Indications a component could have failed were from surface cracking
- Combine digital microscopy with resistance measurements to determine cross sections
- Cross sections still necessary to verify through or no through cracking

Acknowledgments

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