Technical Memorandum
Corrosion Assessment of Copper Tubing from Residences in the Cobb County - Marietta Water Authority (CCMWA) Service Area

Prepared for: **CCMWA**

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Submitted: January 6, 2013

Appendices

Appendix A: Chain of Custody Documentation

Appendix B: Water Quality Documentation

Appendix C: Pipe Specimen and Processing Photo Catalogue

Appendix D: Metallurgical Specimens

Appendix E: High Resolution Imaging

The figures in this report contain a variety of images and photos, including micrographs and optical magnification photos. They are best viewed electronically using a high resolution display.

Summary
The HDR Applied Research Technology Laboratory was supplied with copper tubing samples from four different households in the CCMWA service area. All four households have reported fully penetrating pinhole type leaks over the past several years. All subject tubing specimens show the same, or similar, corrosion morphology, suggesting comparable pitting mechanism and causation between households. No evidence of tubing metallurgical abnormalities was found, nor was there evidence of microbial involvement in the pitting process. Disassembly and inspection of a number of subject tubing joints found gross evidence of solder flux run corrosion, and flux splatter. Evaluation of pitting tubercles and pitting sites found evidence of both solder and flux residue, indicating that the pits were likely the result of poor soldering practice at the time the homes were plumbed. This type of failure is generally referred to as flux-run pitting and is unrelated to a specific water chemistry factor. With the exception of the pitting, the general corrosion condition of the copper tubing is benign, essentially uniform and mild.

Objectives

This report presents an assessment of copper plumbing status in several Cobb County properties (4 single family residences) in the Northeast quadrant of the CCMWA service area. The assessment has been conducted at the request of the homeowners and with the assistance of the CCMWA.

The homeowners report pinhole-type leaks developing on portions of the household cold water copper tubing; multiple leaks in some cases. The homes are approximately 30 years old, and two are located in the same residential development. The age of the plumbing is contemporaneous with the home construction. Leaks have been limited to the cold water side of the plumbing. Figure 1 provides a map indicating the location of the four residences.

*Note- Figure 1 map is not included to provide anonymity to the home owners.

The leaking copper tubing was in most cases replaced by professional plumbers, but leaking pipe specimens and some adjacent pipe sections were retained by the homeowners. CCMWA personnel have documented the locations of the replaced pipe samples and retrieved specimens. Salvaged pipe was supplied directly to the HDR Applied Research and Technology Center (ARTC) in Bellevue WA. Chain of Custody (COC) documentation for the various pipe specimens is provided in **Appendix A**.

This study includes a materials, metallurgical and plumbing fabrication assessment, including:

- Analysis of current and past leakage sites;
- Assessment of corrosion conditions on runs with, and without, leaks;
- Assessment of potential fabrication issues; and
- Evaluation of copper pitting status and remaining plumbing service life.

Background

The pitting and penetration of copper tubing used for drinking water purposes is not a well understood phenomenon, and while rare, it is common enough to generate substantial technical discussion and internet chatter. It is generally agreed that there can be multiple causes, and that the mechanism, morphology and mineralogy (corrosion scale) associated with pitting can vary substantially from one venue to the next. The Copper Development Association (http://www.copper.org/environment/NACE02122/nace02122c.html) is the trade organization representing copper manufacturers. It lists the three most common causes of copper tubing failure as:

- Erosion Corrosion - *excessive water velocities resulting in scouring and erosion of plumbing surfaces,*
- Flux-Induced Corrosion - *fabrication issue related to excessive use of an acidic paste (flux) used in the joint soldering process,*
- Concentration Cell Corrosion - *corrosion that occurs underneath mineral deposits and often related to hot water heater sediment.*

There are other recognized causes, including specialized forms of microbial action (Microbially Influenced Corrosion (MIC)), and water quality related causes usually associated with extremes of pH and/or alkalinity. Fortunately, the failure of copper tubing is rare, and because of its strength and durability, it remains the material of choice for a large portion of today's commercial and residential plumbing installations.

Copper tubing does not always carry a manufacturer's mark, and even when it does those marks can be obscured by surface tarnish, paint and structural cover. It was not possible to precisely date the year of manufacture for the plumbing specimens taken from the CCMWA service area. It is understood (communication with CCMWA personnel) that the homes were constructed in the mid 1980s and that the failed tubing specimens are contemporaneous with home construction. It could be determined through both manufacturer's mark and pipe wall measurements that the tubing in question is ½" and ¾" Type M tubing. This is the thinnest wall tubing approved (Universal Plumbing Code) for residential plumbing - generally 0.08 – 0.09 inches in wall thickness.

A shortcoming of this investigation is the limited number of plumbing specimens available for inspection. When possible, it is desirable to sample both hot and cold water tubing at a number of different locations across a property, including leaking sections and other sections that have not developed a problem. In this case, specimens are limited to leaking tubing and some adjacent sections. All specimens were from the cold water side, primarily from horizontal pipe runs. There were no examples of pitting on hot water tubing.

As part of the corrosion assessment, a review of CCMWA water quality reports and published water quality data was conducted. Basic CCMWA water chemistry information relative to sources, treatment and distributed water quality is available on line at www.mariettaga.gov/sf-docs/powerwater/**ccr**2011.pdf?sfvrsn=2. The CCMWA distributes relatively low mineral content water that is poised in an appropriate pH range to minimize lead and copper solubility. It is adequately buffered, and contains low levels of chlorides, sulfates and silicates. The CCMWA has been in full compliance with the EPA's Lead and Copper Rule for the past 15 years, meaning that the CCMWA has instituted what the US EPA recognizes as Optimal Corrosion Control Treatment (OCCT). OCCT is designed to

minimize both lead and copper corrosion, but also provides corrosion benefits relative to other materials. Lead and copper levels (90th percentile) as reported by the CCMWA are exceptionally low. A short list of CCMWA corrosion related water quality parameters is provided in **Appendix B**.
The CCMWA water quality reports suggest that the water delivered to its customers is minimally corrosive towards domestic plumbing systems, and is not indicative of any specific copper related corrosion issue. Based on studies conducted in the early 1990s, pH and alkalinity control were identified as the preferred corrosion control strategy. The CCMWA does not add a phosphate-based corrosion inhibitor to its distributed water.

Analytical Methodology

Pipe specimens received at the ARTC facilities were inspected, photographed and then sectioned (lateral split). After sectioning, specimens were subject to gross physical assessment which included:

- Partial surface polish/metallurgical assessment
- Corrosion scale identification
- Wall thickness measurement
- Pit identification
- Corrosion morphology of pipe wall and floor (surface underlying corrosion scale)
- Deposition and/or tubercle assessment

Selected specimens were evaluated for their deposition quantity (mass/unit area), and a limited number of specimens were subjected to further metallurgical examination and high resolution surface imaging techniques using Scanning Electron Microscopy (SEM) and Electron Dispersion and X-ray (EDAX).
The presence of sulfides in (and under) tubing deposits was assessed using an azide/iodide in-situ methodology.

A photographic record of pipe samples from the four subject homes (as received) is provided in **Appendix C**.

Gross Physical Assessment

All tubing specimens have likely been in service for 20-30 years. Absent pitting sites and joints, the various tube samples are similar in their underlying (uniform) corrosion morphology. There is some variation in texture, thickness and mineralogy of overlying corrosion scales, but these variations are probably due to differences in age and water scour (flow rate velocity). The general overlying corrosion scale (yellowish-brown) is largely a cupric oxide (Cu_2O) with a mix of other minerals. This overlies a more adherent, thinner and dark layer of tenorite (CuO).

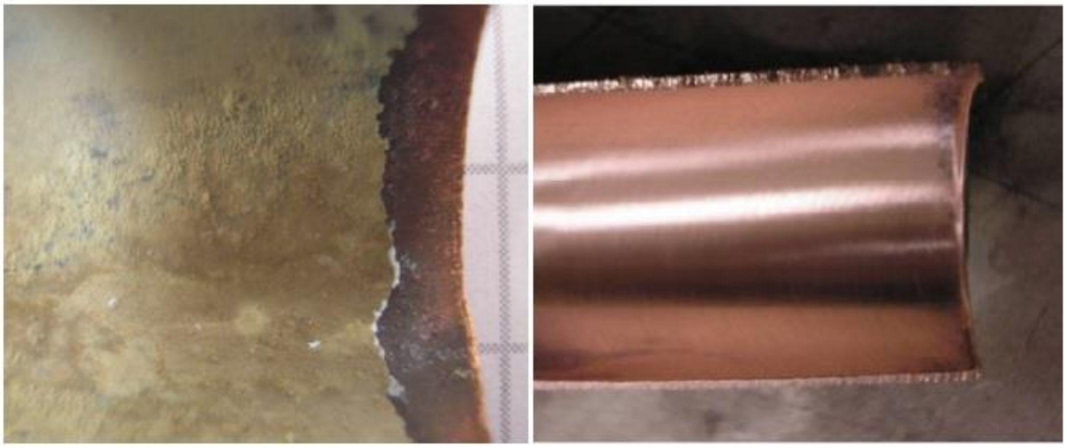


Figure 2: Photo on left shows interior of cold water tubing with moderate buildup of cuprite based corrosion scale overlying a more adherent tenorite scale. Photo on right shows the polished underlying surface (pipe floor) with the corrosion scale removed. *Note: this surface is typical of a uniformly corroding copper pipe.*

Of most importance is the evidence of pitting. **Appendix C** catalogues the pitting sites on the various samples. The following figure presents a magnified photo of a typical pitting site on both the interior and exterior pipe surfaces.

Figure 3: (specimen Z) Photo on left shows a typical water-side pitting site with characteristic blue green tuberculation. Photo on right shows the pinhole sized point of penetration on the exterior of the pipe opposite the pit.

The gross pitting morphology of all samples is similar between households. The blue-green tuberculation on the penetratin pits are of comparable size and indicative of a copper carbonate sulfate mineral (bronchantite). The cross-sectional shape of the pits (relatively broad and shallow) are similar.

The following gross physical observations are pertinent:

- No evidence of serious pipe-wall thinning, or uneven wall thinning (pitting sites excepted);
- General corrosion scale accumulation is minimal and typical of older copper tubing;
- Very little irregular mineral deposition of identifiable form, and no evidence of concentration cell corrosion;
- Corrosion scales consist largely of cuprite overlying a tenorite floor – based on color and mineral texture;
- Corrosion can generally be characterized as "uniform" (pitting sites excepted);
- No evidence of erosion related corrosion.

The specimens show no meaningful loss of service life due to water (quality) induced corrosion. The tubing specimens are typical of old copper exposed to an oxidizing environment (chlorinated drinking water) for long periods. Remaining service life of the tubing (absent pitting) would likely be in the range of 20 - 30 years.

Microbially Influenced Corrosion (MIC)

Efforts to verify presence of a meaningful sulfide residue in the pits (definitive indication of MIC) were unsuccessful (azide/iodide test). Because the pipe specimens were dried and exposed to air for substantial periods of time prior to testing, the results of the azide/iodide test are of dubious value. However, while the test could not prove the existence of MIC, the general condition of the specimens and the lack of substantial organic surface residue, suggest an absence of the biomass necessary to promote MIC.

Metallurgy

Selected samples were cross-sectioned adjacent to the pitting perforation, mounted in epoxy and then polished to highlight the metallurgical properties. Selected samples were acid-etched to highlight the grain boundaries. The Figures in **Appendix D** show magnified photos of metallurgical cross-sections and etched surfaces.
The corrosion was found to occur in a non-discriminatory fashion attacking both grains and grain boundaries. There were no observed metallurgical abnormalities that would have encouraged the pitting attack. In short, the pitting did not appear to be a result of defects in the manufacture of the pipe.

Joint Fabrication and Plumbing Issues

Large structures and homes all have their share of plumbing defects, and plumbing joints are always a source of potential leakage. This is because fabrication and soldering issues often generate corrosion problems; and these are frequently confused with water quality corrosion issues. A proper joint consists of the tube fully penetrating the pipe couple, and the bimetallic solder completely filling all voids on the couple mating surface. Incomplete penetration of the couple, or incomplete solder wicking (capillary action that draws the solder into the joint) may lead to a form of crevice corrosion that significantly shortens the useful life of the joint. Conversely, excessive application of solder or excessive application of soldering flux may also lead to serious corrosion problems.

As indicated earlier, soldering flux-Induced corrosion is one of the most common causes of pitting (as recognized by the CDA). Flux related corrosion occurs almost exclusively on cold water lines and is usually associated with the excessive use of an aggressive petrolatum based flux paste containing high concentrations of “activating agents” such as ammonium chloride and zinc chloride. The flux paste is (by design) highly corrosive and “sticky”, and is intended to dissolve the surface patina of new copper tubing so that molten solder can more effectively bond to the copper surface.

When flux and solder are applied excessively under the heat of the soldering torch, globules of both flux and solder can be splattered over the interior of the pipe. If a large enough portion of the paste-type flux sticks to the pipe surface, and is not subsequently flushed from the surface by water flow, it can serve as the site of a future pit. Depending on the water chemistry the pitting process may take as little as a year to achieve pipe wall penetration, or, in some cases, may take many years if the water chemistry is minimally corrosive.

Flux-induced pits tend to occur preferentially along bands that are parallel to the longitudinal axis of the pipe, or on the periphery of the petrolatum-based flux residue. These are sometimes referred to as “ghost runs” because the outline of the long-absent flux residue can be seen in the corrosion effect. Flux induced pitting occurs primarily on cold water tubing because hot water tends to melt and soften the residual flux globules, eventually leading to their dissipation. While flux related pitting occurs most frequently at, or near, soldered joints, the mobilization of the residual flux globule can produce flux-type pitting at considerable distances from the soldered joint.

Soldering flux induced pitting can sometimes be confirmed using surface imaging and energy dispersive spectroscopy (also known as EDAX). The presence of chlorides and or solder residue within the pitting site is strong confirmation of a flux related issue.
Samples of tubing joints were available only from specimens acquired in the Resident G home. Although none of the joints had failed, almost every sweated joint showed clear evidence of excessive solder and flux application, and also supported active pitting sites. The following figures are typical of flux-runs and pitting sites on the Resident G pipe samples.

Figure 4: (G Specimens) Pipe samples showing strong evidence of flux runs at locations in close proximity to soldered joints. *Note: photo on left shows both halves of sectioned pipe.*

Figure 5: (G Specimens) Pipe joints showing incomplete solder penetration (wicking) into the crevice between the tubing and the connector, un-reamed tubing cuts and excessive flux and solder application. *Note: carbon residue from the original flux application is still present on these surfaces.*

Examination of the G samples showed evidence of substandard joint fabrication with incomplete solder penetration and un-reamed tubing ends. The tubing exterior surfaces displayed evidence of excessive solder application, and the interiors showed evidence of excessive flux and solder application. Carbon deposits resulting from heating of a large quantity of petrolatum-flux during the soldering process remain on the interior surfaces.

High Resolution Surface Imaging

SEM and EDAX were conducted on a limited number of samples to better define morphology of the pitting surfaces and identify elemental constituents in the pits, tubercles and on the uniformly corroding surfaces. **Appendix E** presents both the SEM and EDAX data from several samples.

Corrosion scale samples were lifted from the pipe wall and the underside analyzed for elemental constituents. Some lifted samples showed relatively high levels of lead, indicating there was lead on the pipe surface before the scale formed. This would be indicative of solder splatter during the soldering process. Some tin was also detected, again indicating solder splatter. (*Note: prior to 1990, lead/tin solder was the plumbing material of choice for residential tubing*.)

Minerals within a test pit (Z sample) were found to contain a relatively high concentration of chloride, likely as cupric chloride. This is indicative of a soldering flux residue that likely initiated the pitting process at that site.

Corrosion scale on the uniformly corroding surfaces (at a distance from the pitting sites) contained no meaningful chloride, or solder residue. The uniformly corroding scale did contain a relatively high proportion of silica, which is somewhat surprising since the distributed water chemistry of the CCMWA indicates low silica content.

Tubing Assessment Summary

The following conclusions can be drawn regarding copper tubing at the subject properties:

Pitting Morphology. Specimens undergoing pitting show essentially the same, or very similar, corrosion morphology, suggesting pitting mechanism and causation is the same between households. The pit face is relatively broad, and the pit floor is irregular (indicative of flux related pitting). The tubercle cap is largely composed of copper carbonate-sulfate minerals, while the pit floor is populated with cupric chloride minerals. The pitting process appears to be relatively slow. Pits give the appearance of having been active for many years.

General Corrosion Conditions. Absent pitting, the general corrosion condition of the copper tubing is concomitant with reported age, readily identifiable and generally benign. The corrosion condition is essentially uniform in nature and mild.

Service Life. Remaining service life (absent pitting) is likely in excess of twenty years.

Microbially Influenced Corrosion. Although it is not possible to rule it out as a potential contributor to the pitting, the presence of microbially influenced corrosion is unlikely.

Metallurgy. Metallurgical examinations showed no obvious tubing defects or abnormalities.

Pit Sites. A tubercle sample lifted from a pitting site was found to contain strong evidence of flux residue.

Fabrication Defects. Disassembly and inspection of a number of subject tubing joints found evidence of solder flux run corrosion, and flux splatter. These factors likely played a principal role in the leaks that developed on the tubing specimens in question. This type of failure is unrelated to a specific water chemistry factor.
Taken together the evidence suggests that the pitting observed on the subject samples is likely the result of poor fabrication and soldering practice. While this is a common cause of copper pitting, this case is unusual in that the pitting has taken in excess of twenty years to achieve full penetration. A probable explanation is that the basic water chemistry of the CCMWA system is not conducive to copper corrosion, and that CCMWA's corrosion control program has been highly effective.

Recommendation

Plumbing Replacement. The copper pitting examples are likely related to plumbing fabrication defects and not a CCMWA systemic distribution system problem. Even in homes where pitting has occurred, future pipe leaks are likely to occur only on cold water tubing in proximity to joints where poor soldering practice was employed, and possibly not at all. Unless a clear pattern of poor soldering practice affecting the entire home is evident, whole household cold water tubing replacement is not warranted at this time.

APPENDICES

Corrosion Assessment of Copper Tubing from Residences in the Cobb County - Marietta Water Authority (CCMWA) Service Area

The following Appendices contain substantial numbers of high resolution surface images, as well as scanned images. They are best viewed using a high resolution electronic display:

Appendix A: Chain of Custody Documentation
Appendix B: Water Quality Documentation
Appendix C: Pipe Specimen and Processing Photo Catalogue
Appendix D: Metallurgical Specimens
Appendix E: High Resolution Imaging

Appendix A: Chain of Custody Documentation for Resident G

The chain of custody that is pictured in the report is not included to protect the homeowners' privacy.

Figure A1: Resident G Sample Documentation

Figure A2: Resident Z Sample Documentation

Figure A3: Resident C Sample Documentation

Figure A4: Resident H Sample Documentation

Cobb County - Marietta Water Authority
Typical Drinking Water Analysis

Updated Jan 2012

PARAMETER	ANALYTICAL RESULTS	UNITS	MAXIMUM CONTAMINANT LEVEL (MCL)	REMARKS
Inorganic Non-Metals				
pH	7.1 - 8.5	Std units	n/a	Not regulated
Free Chlorine Residual	0.1 - 1.2	mg/L	n/a	MRDL (Maximum Residual Disinfectant Level) is 4.0 mg/L
Fluoride	0.7 - 1.0	mg/L	2.0	Secondary Standard
Conductivity	96 - 169	umhos/cm	n/a	Not regulated
Hardness (Total) as $CaCo_3$	21	mg/L	n/a	Not regulated
Hardness (Total) as CaCo3	1.2	gr/gal	n/a	Not regulated
Total Dissolved Solids	79 - 87	mg/L	500	Secondary Standard
Nitrate / Nitrite	0.27 - 0.89	mg/L	10 as (N)	
Sulfate	< 25	mg/L	250	Secondary Standard
Asbestos	< 0.16	mf/L	7	
Silica	2.95 - 3.44	mg/L	n/a	Not regulated
Alkalinity	16 - 36	mg/L	n/a	Not regulated

Metals*				
Aluminum	Not Detected	ug/L	50-200	Secondary Standard
Antimony	Not Detected	ug/L	6.0	
Arsenic	Not Detected	ug/L	10.0	
Barium	Not Detected	ug/L	2000	
Beryllium	Not Detected	ug/L	4.0	
Cadmium	Not Detected	ug/L	5.0	
Chromium	Not Detected	ug/L	100	
Iron	Not Detected	ug/L	0.3	Secondary Standard
Manganese	Not Detected	ug/L	0.05	Secondary Standard
Mercury	Not Detected	ug/L	2.0	
Nickel	Not Detected	ug/L	100	
Selenium	Not Detected	ug/L	50.0	
Silver	< 30	ug/L	0.10	Secondary Standard
Sodium	3.3 - 8.4	mg/L	n/a	Not regulated
Thallium	Not Detected	ug/L	2.0	
Zinc	Not Detected	ug/L	5	Secondary Standard

*Results from GA EPD Laboratory

Appendix C: Pipe Specimen and Processing Photo Catalogue

Figure C1: Photo of all Resident G household samples (as received)

Figure C2: Photo of all Resident G household samples (longitudinally sectioned)

Appendix C: Pipe Specimen and Processing Photo Catalogue

Figure C3: Resident G Samples as Labeled

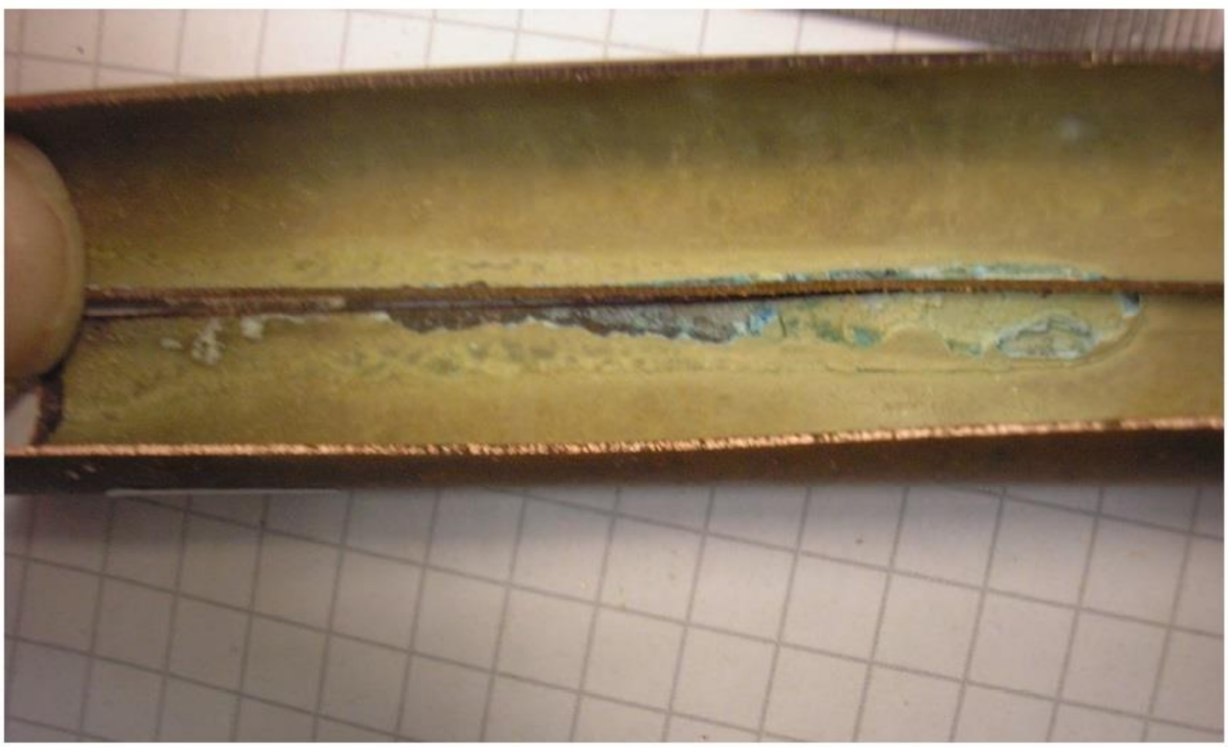


Figure C4: 5-inch long flux run on Resident G horizontal cold water tubing

Appendix C: Pipe Specimen and Processing Photo Catalogue

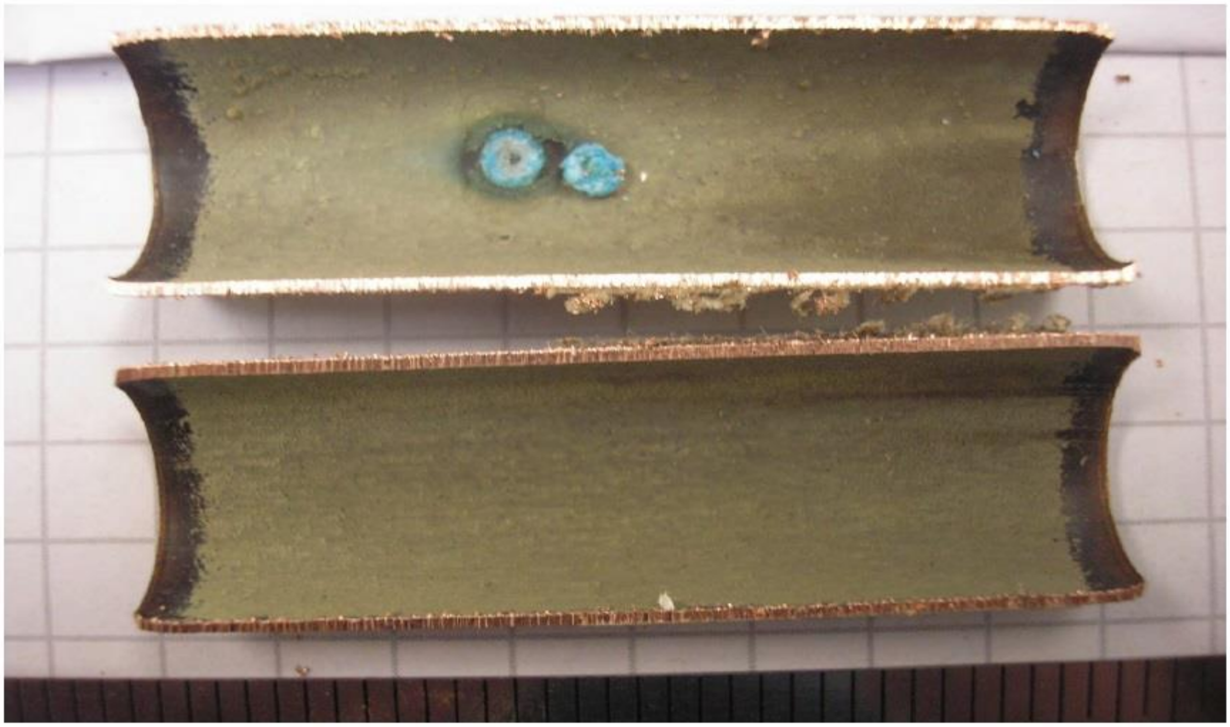


Figure C5: Non-perforating pit with tubercle cap removed. *Note: corrosion on the pipe wall of the opposing section is entirely uniform.*

Figure C6: Resident G joint sample. *Note: this is a good example of corrosion damage done by excessive solder and flux application.*

Appendix C: Pipe Specimen and Processing Photo Catalogue

Figure C7: Resident G joint sample. *Note: the dark cracked surface appears to be carbonized flux residue.*

Appendix C: Pipe Specimen and Processing Photo Catalogue

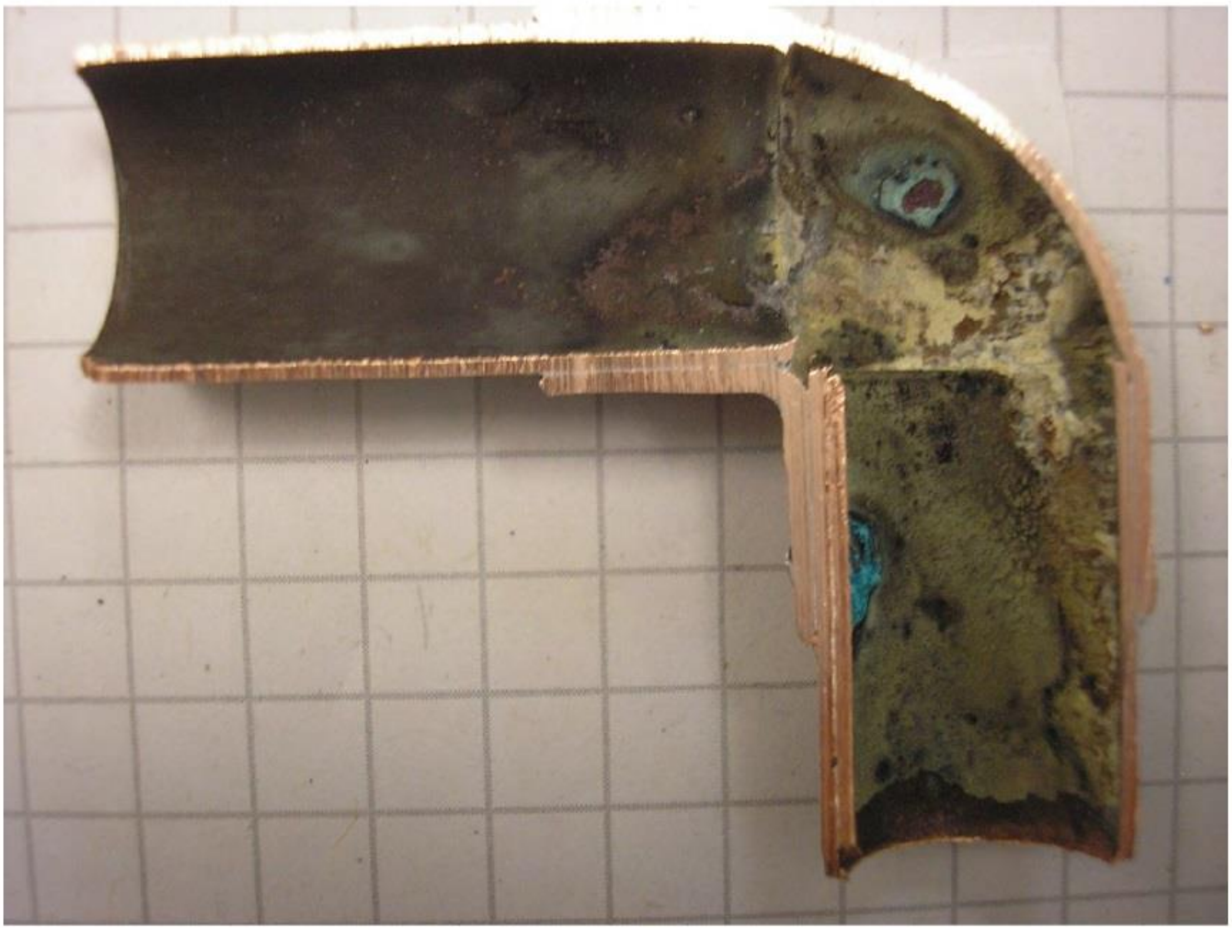


Figure C8: Resident G joint sample. *Note: excessive flux application ran down one arm of the joint causing corrosion damage and pitting while the other arm of the joint was largely unaffected. Also note the poorly reamed tubing flairs – this is indicative of poor fabrication quality.*

Appendix C: Pipe Specimen and Processing Photo Catalogue

Figure C9: Photo of Resident Z household sample (as received).

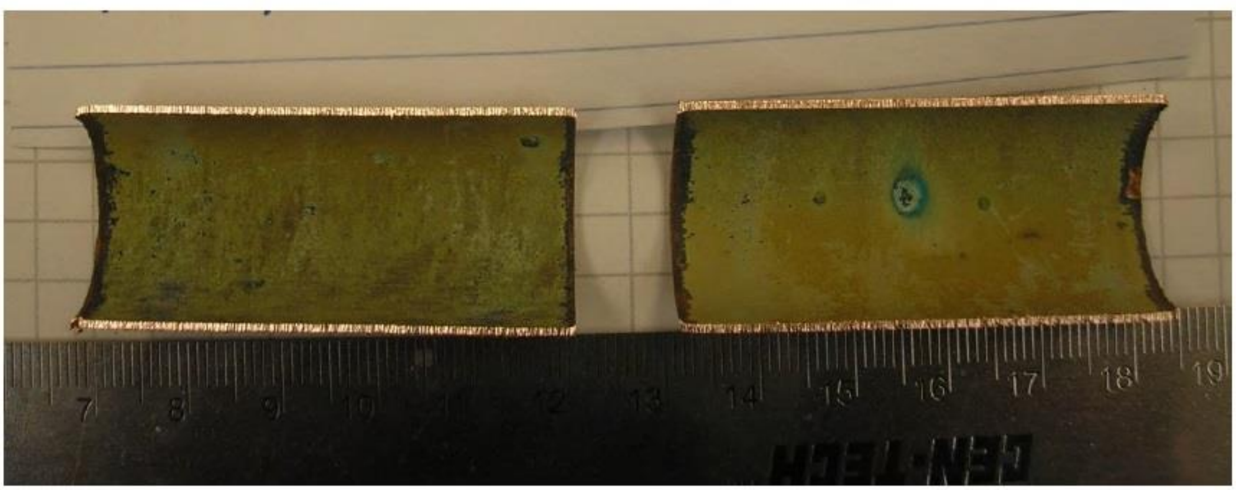


Figure C10: Photo of Resident Z household samples (longitudinally sectioned).

Appendix C: Pipe Specimen and Processing Photo Catalogue

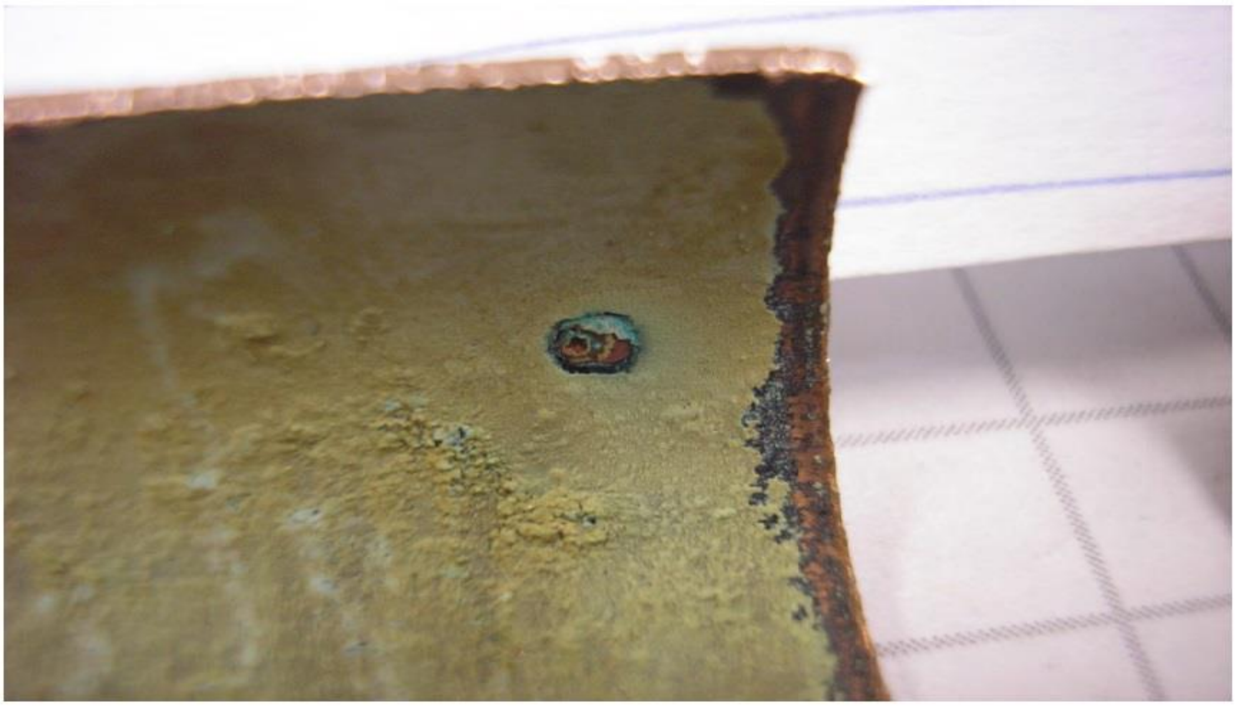


Figure C11: Photo of active pitting site on the Resident Z household samples (tubercle cap removed).

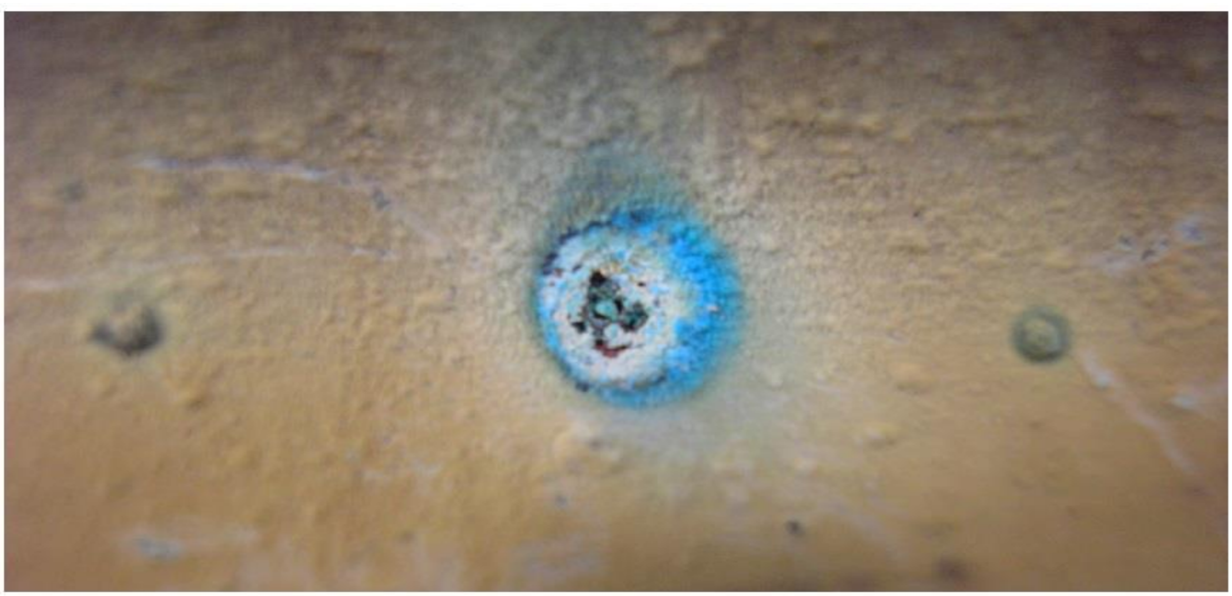


Figure C12: Photo (15X) of active pitting site on the Resident Z household samples. *Note: the friable tubercle cap has been lost in transit revealing the broad shallow nature of the pitting morphology.*

Appendix C: Pipe Specimen and Processing Photo Catalogue

Figure C13: Photo of Resident C household samples (as received)

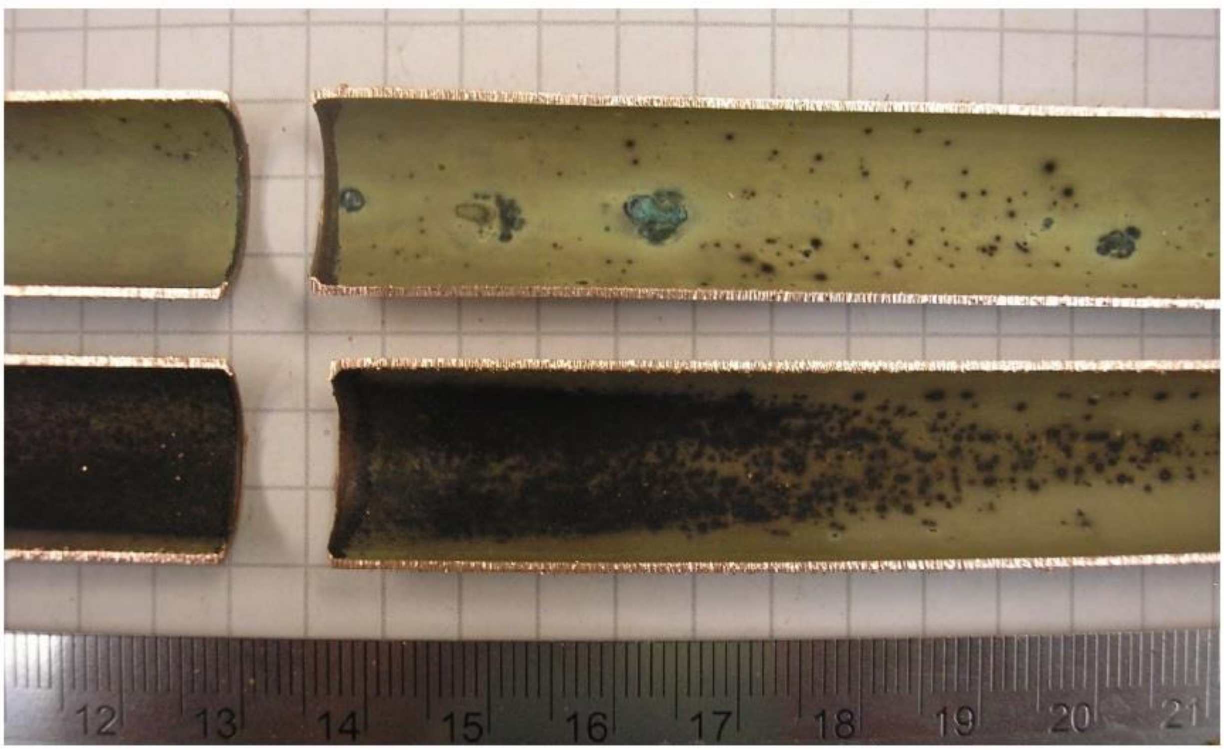


Figure C14: Photo of Resident C household samples (longitudinally sectioned). *Note: the dark speckled surface may be the result of flux splatter at the time of joint fabrication.*

Appendix C: Pipe Specimen and Processing Photo Catalogue

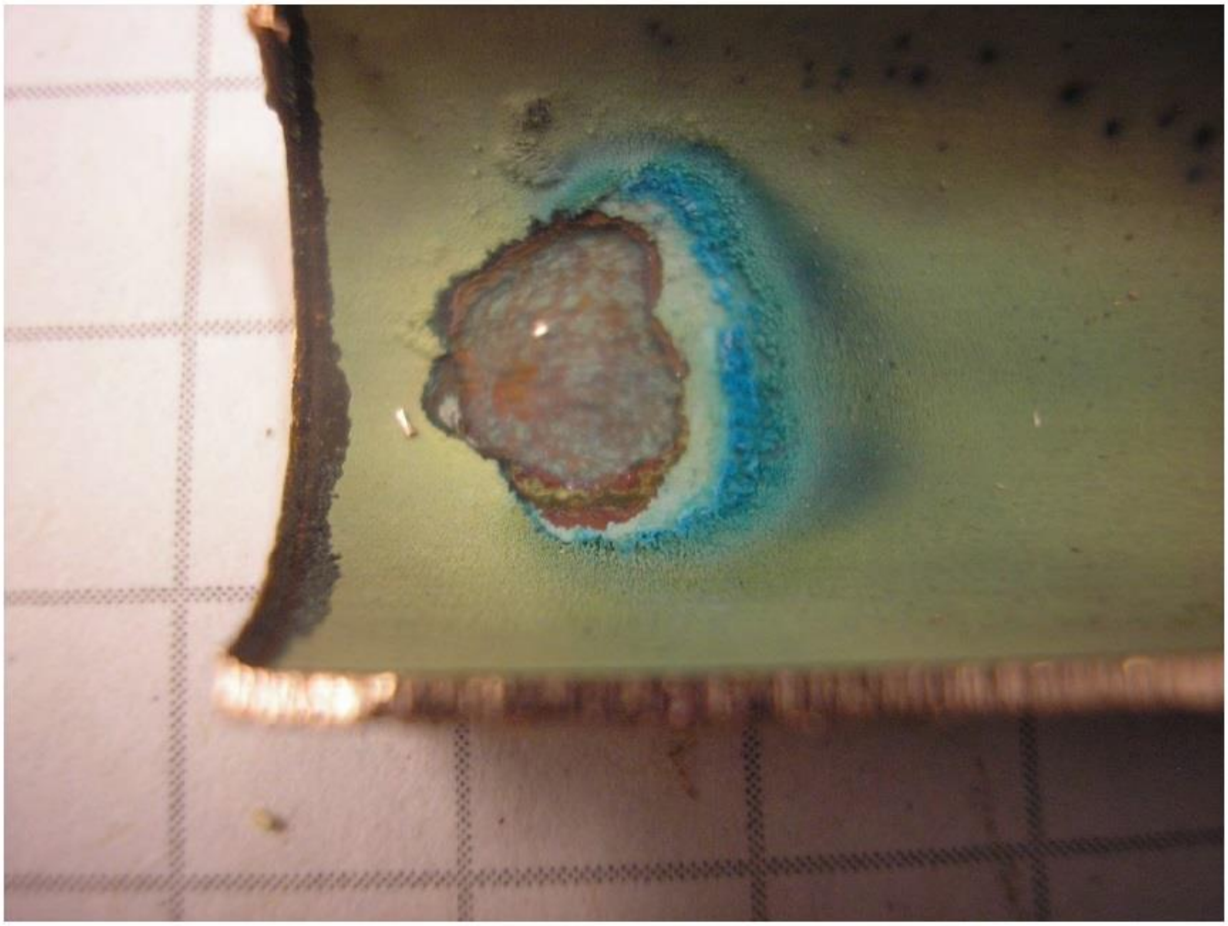


Figure C15: Photo of large pitting site (tubercle cap removed) on the Resident C household samples. *Note: while the pit is non-penetrating, it gives the appearance of an active pit site.*

Appendix C: Pipe Specimen and Processing Photo Catalogue

Figure C16: Photo of Resident H household sample (as received)

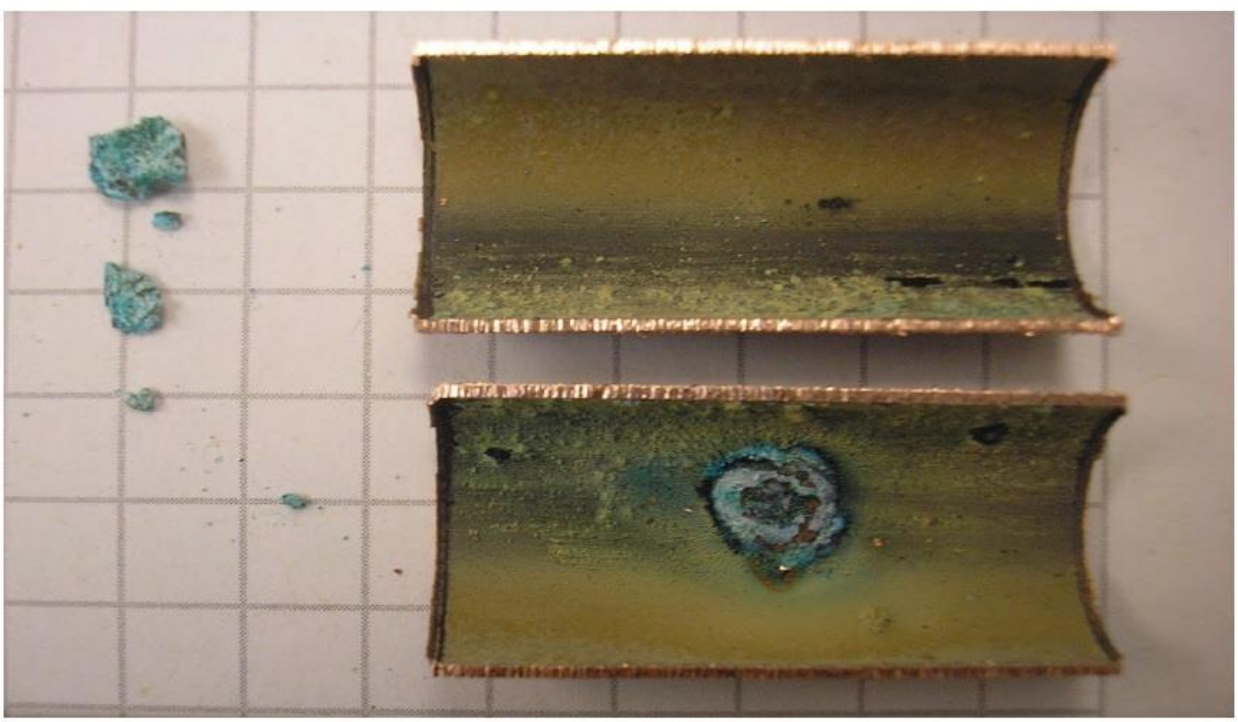


Figure C17: Photo of Resident H household sample (longitudinally sectioned) showing fully penetrating pit and tubercle cap (removed).

Appendix D: Metallurgical Specimens

Figure D1: Metallographic cross-sectional view (50X) of the Resident Z pipe sample at the area of perforation. *Note: the grey material above and below the copper tubing is an epoxy mounting compound.*

Figure D2: Metallographic cross-sectional view (100X) of the pitting site on the Resident Z pipe sample.

Appendix D: Metallurgical Specimens

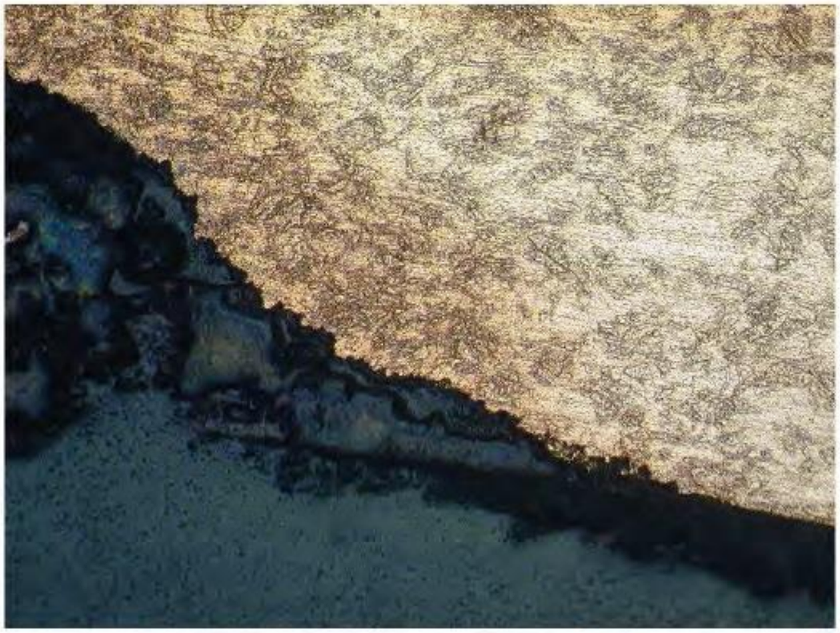


Figure D3: Metallographic cross-sectional view (100X) of the pitting site on the Resident Z pipe sample after etching. *Note: the etching process involves exposing the metal surface to a strong mineral acid to reveal grain boundaries and crystalline structure.*

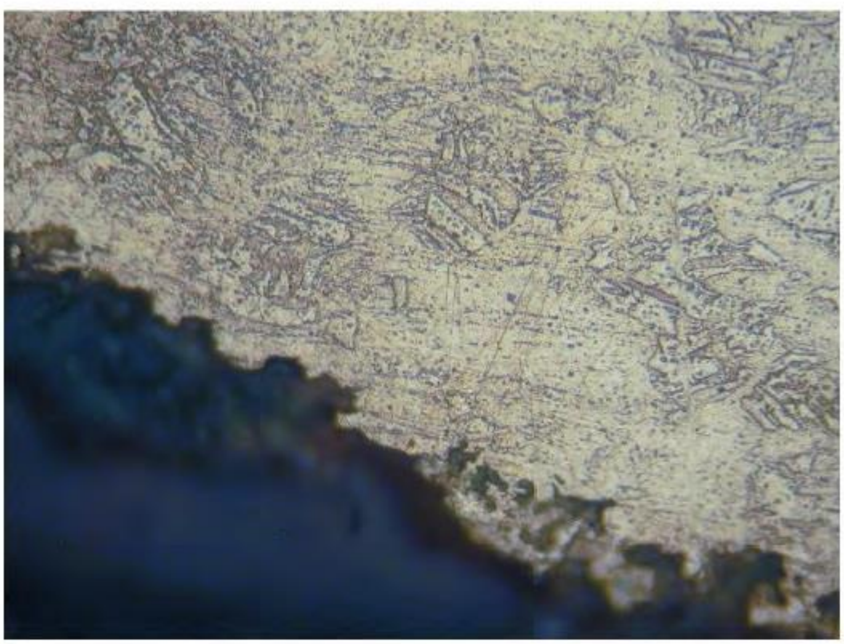


Figure D4: Metallographic cross-sectional view (400X) of the pitting site on the Resident Z pipe sample after etching. *Note: the etching has not revealed defects or abnormalities in the copper tubing structure at the pitting sites.*

Appendix E: High Resolution Surface Imaging

Figure E1: Optical image (15X) of an active pitting site on the Resident G tubing.

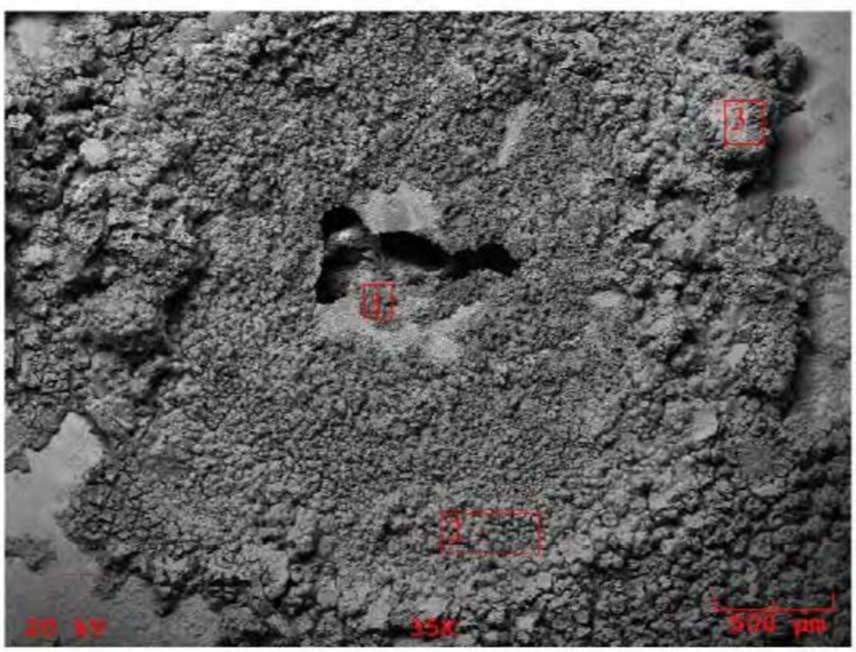


Figure E2: SEM image (35X) of the active pitting site on the Resident G tubing.

Appendix E: High Resolution Surface Imaging

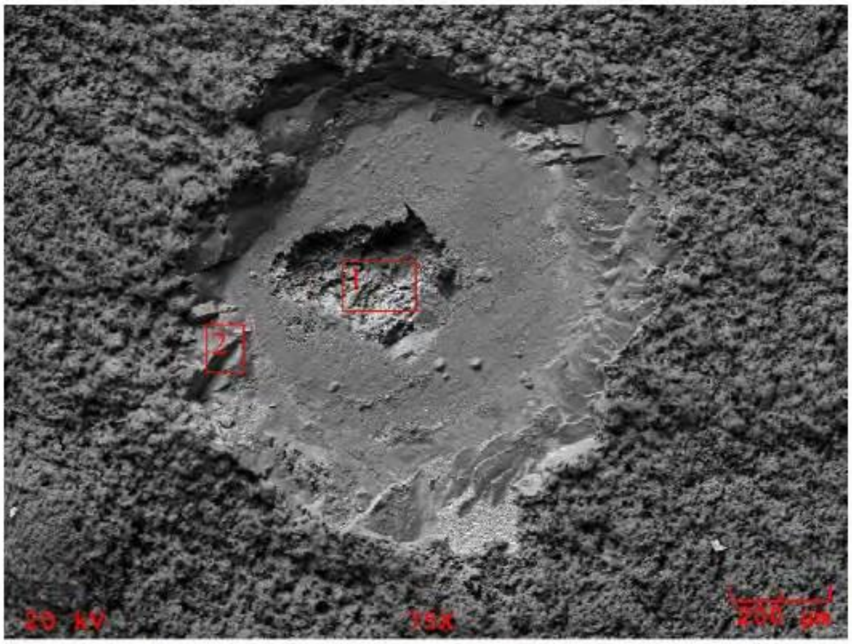


Figure E3: SEM image (75X) of the pit initiation site where a tubercle was removed (Resident Z sample).

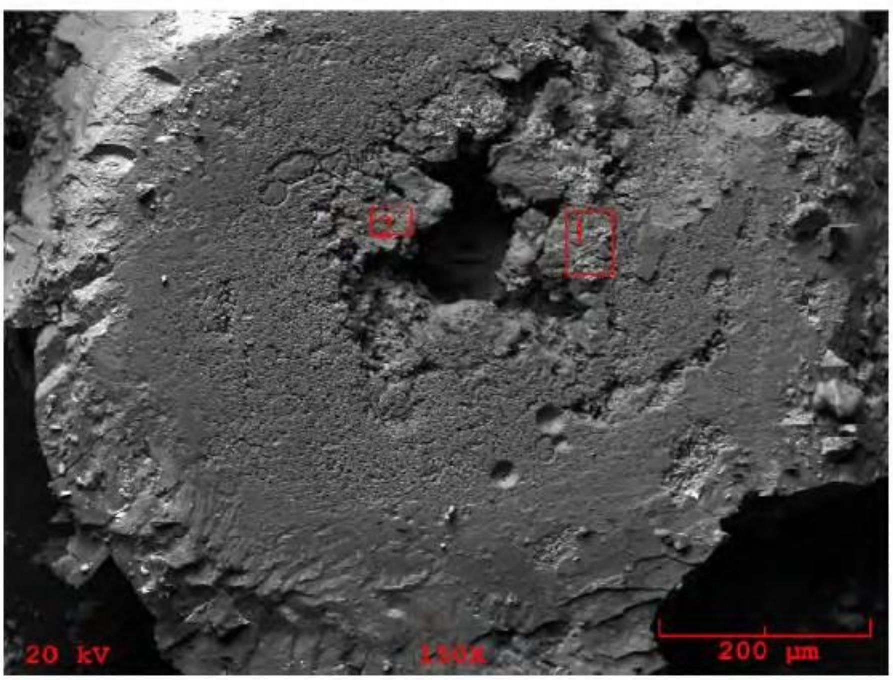


Figure E4: SEM image (150X) of the underside of the tubercle removed from the Resident Z pit initiation site. *Note: the porous and hollow nature of the tubercle – characteristic of this form of pitting.*

Appendix E: High Resolution Surface Imaging

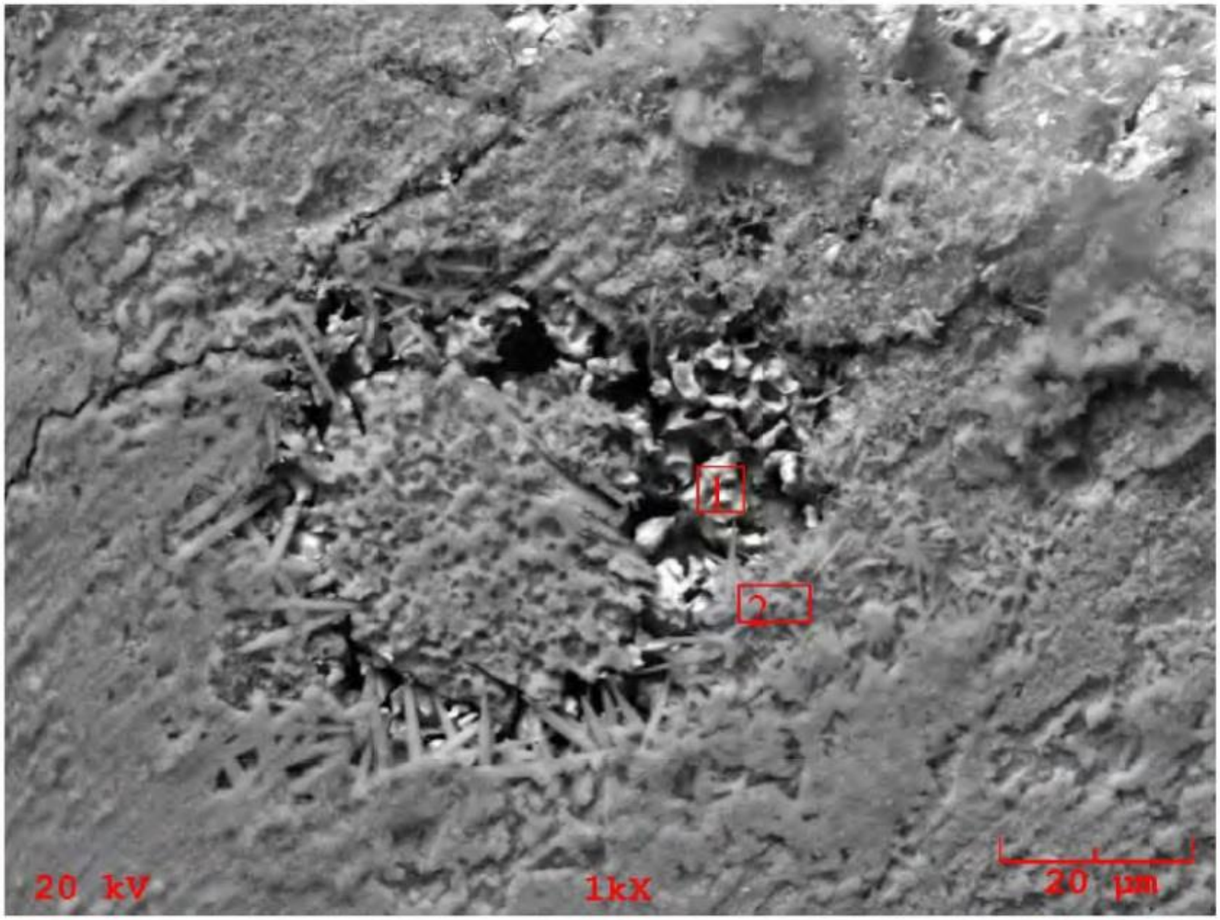
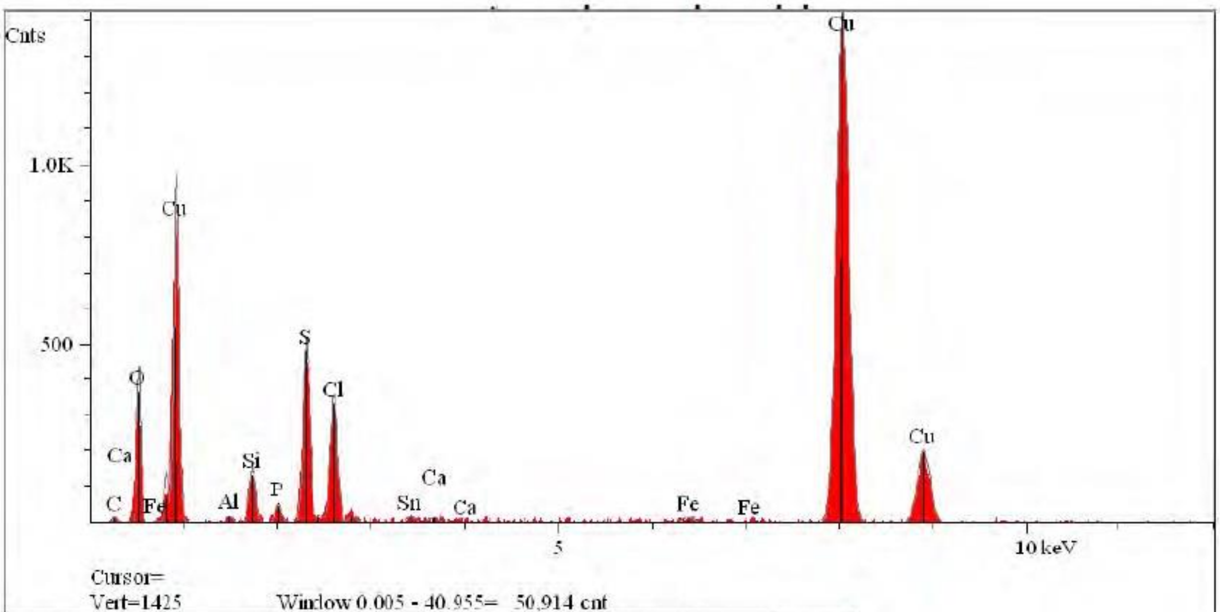


Figure E5: SEM image (1000X) of the crystalline structures at the base of the pit on the Resident Z sample.

Appendix E: High Resolution Surface Imaging



Elt.	Line	Intensity (c/s)	Error 2-sig	Atomic %	Conc	Units	Error 2-sig	
C	Ka	3.72	1.235	5.887	1.542	wt.%	0.512	
O	Ka	78.84	3.336	22.348	7.797	wt.%	0.330	
Al	Ka	4.74	1.944	0.324	0.191	wt.%	0.078	
Si	Ka	41.68	3.209	2.238	1.371	wt.%	0.106	
P	Ka	13.09	2.866	0.576	0.389	wt.%	0.085	
S	Ka	153.31	5.332	6.091	4.259	wt.%	0.148	
Cl	Ka	110.63	4.934	3.989	3.084	wt.%	0.138	
Ca	Ka	2.09	2.856	0.069	0.060	wt.%	0.082	
Fe	Ka	6.90	2.520	0.230	0.280	wt.%	0.102	
Cu	Ka	754.58	10.247	57.989	80.357	wt.%	1.091	
Sn	La	6.96	3.065	0.259	0.671	wt.%	0.295	
				100.000	100.000	wt.%		Total

Figure E6: EDAX qualitative elemental composition of the pit floor on the Resident Z sample. *Note: the exceptionally high chloride content – indicative of flux residue.*

Appendix E: High Resolution Surface Imaging

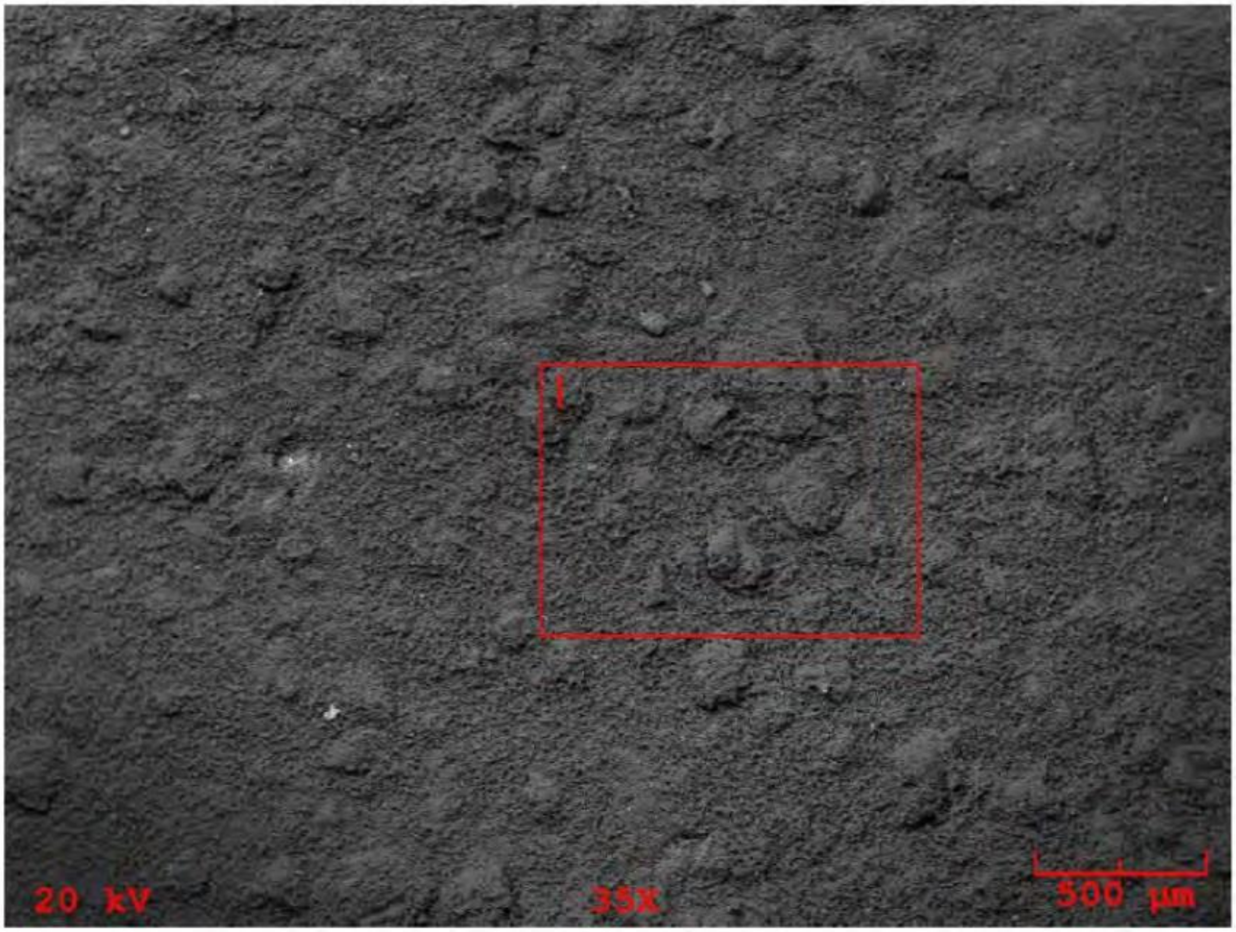
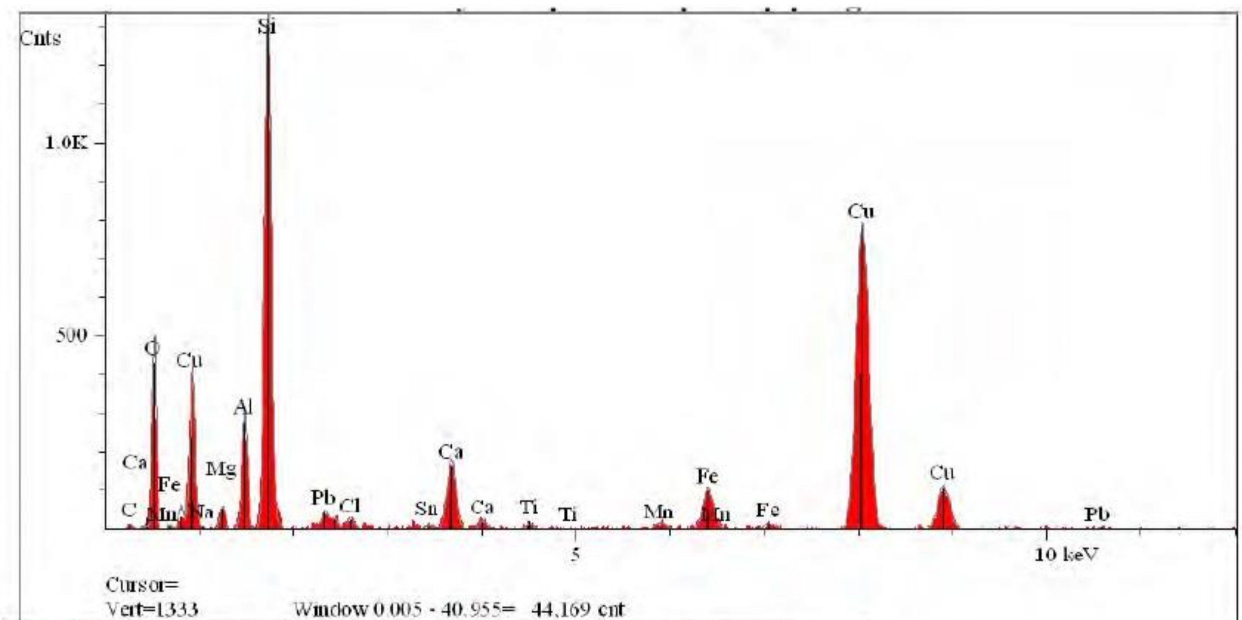


Figure E7: SEM image (35X) of the uniform corrosion scale across the bulk of the Resident C sample.

Appendix E: High Resolution Surface Imaging



Elt.	Line	Intensity (c/s)	Error 2-sig	Atomic %	Conc	Units	Error 2-sig	
C	Ka	3.14	1.163	4.875	1.507	wt.%	0.558	
O	Ka	87.36	3.478	27.547	11.342	wt.%	0.452	
Na	Ka	1.29	1.209	0.163	0.096	wt.%	0.090	
Mg	Ka	14.35	1.985	1.248	0.781	wt.%	0.108	
Al	Ka	73.80	3.587	4.631	3.216	wt.%	0.156	
Si	Ka	385.38	7.445	20.106	14.532	wt.%	0.281	
Cl	Ka	9.54	2.594	0.367	0.335	wt.%	0.091	
Ca	Ka	64.57	3.804	2.292	2.364	wt.%	0.139	
Ti	Ka	5.25	2.573	0.193	0.238	wt.%	0.117	
Mn	Ka	8.53	2.431	0.354	0.500	wt.%	0.143	
Fe	Ka	51.05	3.395	2.230	3.205	wt.%	0.213	
Cu	Ka	419.93	7.730	35.069	57.351	wt.%	1.056	
Sn	La	4.08	2.540	0.175	0.534	wt.%	0.333	
Pb	La	2.36	1.507	0.750	4.000	wt.%	2.548	
				100.000	100.000	wt.%		Total

Figure E8: EDAX qualitative elemental composition of the uniform corrosion scale on the Resident C sample. *Note: the exceptionally high silica content.*

Technical Memorandum
Supplemental Report:
Corrosion Assessment of Copper Tubing from a Residence in the Cobb County - Marietta Water Authority (CCMWA) Service Area

Prepared for: CCMWA
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Project Principal: Dr. Steve Reiber
Submitted: March, 2013

Supplemental Summary Information

This supplemental memorandum presents a corrosion assessment of copper plumbing removed from a single residence G in the Northeast quadrant of the CCMWA service area.
Copper tubing in this residence suffered “pinhole-type” perforations (leaks) and were analyzed in conjunction with pipe samples from several other homes in the CCMWA service area in December 2012. Since that time, the household has undergone a whole-house plumbing refit. The pipe specimens discussed in this supplemental report are random examples of pipes and joints removed during that refit. This assessment has been conducted at the request of the homeowner and with the assistance of the CCMWA.

The earlier Resident G plumbing assessment (December 2012) looked at two sections of pipe (horizontal runs) that both gave evidence of multiple pitting sites (two fully penetrating pits), and several joints that gave evidence of workmanship related problems. The conclusion of that assessment was that the observed pitting was largely the result of workmanship issues, specifically an over-application of soldering flux, over-heating of the joints prior to solder application, and both the splatter and mobilization of acidic petrolatum flux residue at a distance from the soldered joints. That report also documented other workmanship issues, including incomplete insertion of pipes into joints, undreamed pipe ends, excess solder application and voids in the annulus of the soldered joints.

This supplemental report looks at corrosion conditions on an additional ten pipe samples from the Resident G residence, six from the cold water side of the home and four from the hot water side in close proximity to the water heater. For the most part these were horizontal pipe runs, and most samples included at least one soldered joint or elbow. As were the original copper pipe samples, these supplemental samples have been in service since the home was constructed in the early 80s.

All ten supplemental samples have been photo-documented in “as received” condition, then longitudinally sectioned and visually examined. The figures in this report contain a variety of images and optical magnification photos intended to illustrate the observations catalogued below. The following bullets summarize information gained from the supplemental samples

- Overall, evaluation of the ten additional samples supports the initial observations (December 2012) that copper plumbing at the Resident G household was severely compromised by shoddy workmanship during the original construction of the home.
- All six of the cold water side specimens showed serious evidence of excess solder and excess solder flux application (flux runs). Figures 1 - 4 document some of these

soldering issues. The examples presented are not all-inclusive and represent only a fraction of the identified workmanship issues.

- All of the cold water tubing samples show evidence of other workmanship issues including incomplete insertion, un-reamed tube ends, and solder voids - some of which support crevice corrosion.
- The exterior surfaces of the hot and cold water tubing samples all displayed evidence of excessive solder application
- Corrosion scales on the hot water specimens have a somewhat different mineralogy than the cold water samples (see Figure 13). The hot water specimens derive from pipe immediately downstream of the hot water heater, and these samples show evidence of sediment carryover from the hot water tank. There is also evidence of minor concentration cell corrosion on the hot water tubing.

    Concentration cell corrosion occurs beneath mineral deposits and is often related to water heater sediment carryover into the household plumbing. The concentration cell corrosion in the G residence is minor and would not have diminished the service life of the tubing.

The initial and supplemental assessments (December and March) taken together strongly suggest that the corrosion and leakage issues in the Resident G home were likely the result of poor plumbing fabrication and soldering practice. It is also important to recognize that the pitting and flux runs that ultimately lead to perforation and leakage were initiated at the time of the home construction, and that the bulk of the corrosion damage was done early in the life of the plumbing system. The fact that in circumstances where workmanship issues contributed to corrosion related failures, the actual tubing failures occurred three decades later speaks to the minimally corrosive character of the CCMWA water.