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Project No. **41994**

Report for: **Aquatherm**

PO Box 785,
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Attention: **Mr Bryce Christian**

Subject: **Erosion-Corrosion of Copper Pipes in Hot Water Reticulation Systems — Case Studies and Wider Implications**

Date: **7 July 2014**

Prepared By: **J.D. Gates**, BSc(Hons), PhD, CPEng, NPER, RPEQ, CMatP

Signed for & on behalf of UQ Materials Performance | **Checked by**

.... | ....

Dr Jeff Gates | **Dr Ray Low**

UniQuest

PROJECT 41994 — REPORT

Erosion-Corrosion of Copper Pipes in Hot Water Reticulation Systems — Case Studies and Wider Implications

EXECUTIVE SUMMARY

UQ Materials Performance (UQMP) was engaged by Aquatherm to examine samples of copper hot water pipes that had been collected from the Jacksons Landing residential project at Pyrmont in Sydney. In March 2012 UQMP submitted a brief interim report, and Aquatherm has now engaged UQMP to submit a formal report giving the findings of the examination. We have also been asked to express opinions on the wider implications highlighted by this case, and have done this by means of a summary of literature on the topic and three additional case studies.

The examination of the provided samples from Jacksons Landing revealed one case of severe Erosion-Corrosion. This was evidenced by extensive regions of undercut pits showing bare copper between islands of intact protective film, and by the association of the attacked regions with a turbulence-promoting joint. The occurrence of even one example of Erosion-Corrosion of this level of severity raises a strong suspicion that water velocities are too high in the system.

Three other case studies confirm that Erosion-Corrosion is not just a hypothetical risk, nor a gradual problem that might marginally reduce system life. Rather, it is a problem that has caused multiple pipe leakages (and consequent property damage) within 5–10 years of system construction. This experience highlights a disturbing disconnect between what has been known internationally for many years and what is permitted by current Australian Standards. Clear evidence of the danger of Erosion-Corrosion and clear guidelines for its prevention have been available in international water industry publications since 1985. Well-established international experience indicates that in recirculating hot water systems both flow velocity and temperature must be tightly controlled. By contrast, the current Australian Standard AS/NZS 3500.4 (1994/1997) permits water velocities and temperatures that are elsewhere known to strongly promote Erosion-Corrosion.

It is recommended that AS/NZS 3500.4 must urgently be updated. Failure to do so would be expected to lead to further failures, likely consequences of which could include litigation against designers and unnecessary damage to the reputation of copper. A rational set of guidelines to prevent Erosion-Corrosion would include (but not be restricted to) the following:

- Maximum water temperature not to exceed 70°C.
- For water temperatures in the range 60 to 70°C:
  - Continuous recirculating flow: 0.5 m/s.
  - Short-term simultaneous flow demand: 0.6–0.9 m/s.

PROJECT 41994 — REPORT

Erosion-Corrosion of Copper Pipes in Hot Water Reticulation Systems — Case Studies and Wider Implications

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REVISION HISTORY

Revision	Date	Authorised
Draft	27 June 2014	JDG
0	7 July 2014	JDG

PROJECT 41994 — REPORT

Erosion-Corrosion of Copper Pipes in Hot Water Reticulation Systems — Case Studies and Wider Implications

1. BRIEF

In February 2012, UQ Materials Performance (UQMP) was engaged by Aquatherm to examine samples of copper hot water pipes that had been collected from the Jacksons Landing residential project at Pyrmont in Sydney. We were asked to examine the samples for evidence of corrosion of the copper. On 9-March-2012 UQMP submitted a brief interim report in email format, followed on 12-March-2012 by a recommendation to collect further samples.

Aquatherm has now engaged UQMP to submit a formal report giving the findings of the above examination. We have also been asked to express opinions on the wider implications highlighted by this case, and have done this by means of a summary of literature on the topic and three additional case studies.

2. LITERATURE AND INTERNATIONAL GUIDELINES

2.1 Mechanisms of Erosion-Corrosion

Copper is a reasonably corrosion-resistant material and has a long history of successful use in both cold and hot water reticulation systems. Under normal operating conditions the inner surface of a copper water pipe develops a protective surface layer of copper oxides, carbonates and/or sulphates. This protective scale greatly reduces the rate of corrosion and prevents excessive dissolution of copper ions into the water.

However, at high water velocities and/or high temperatures, the flowing water can dislodge portions of the protective scale from the surface, exposing patches of bare metal. When this occurs, the exposed regions of metal tend to suffer relatively rapid, ongoing active corrosion. This is so for a number of reasons, listed below:

- Firstly, the flowing water provides a continuous supply of dissolved oxygen and flushes away the dissolved copper ions, thus facilitating the corrosion reaction at the metal surface;
- Secondly, in the electrochemistry of corrosion reactions it is commonly found that a distribution of patches of actively corroding bare metal surrounded by a larger surface area of passive oxide film can lead to generation of local "galvanic cells". Cathodic electrochemical reactions occuring at the surface of a stable oxide film can consume the electrons generated by the anodic dissolution reactions occuring at the nearby regions of bare metal — thereby facilitating what might otherwise be a rate-limiting step in the corrosion process.

- Thirdly, if the water velocity was sufficient to damage the original oxide scale then it is likely to prevent the re-deposition of a plaque of corrosion products, thus preventing development of a protective scale.

The first and third of the above points have the effect of negating any mechanisms which would otherwise progressively slow down the rate of corrosion — hence the corrosion of the exposed patches can continue at a constant rate. The second point has the effect that this local corrosion rate may be higher than would occur on a freshly abraded copper surface. The combined result is rapid, ongoing corrosion at the exposed patches of metal, potentially leading to perforation of the pipe wall and leakage well within the design life of the system.

A feature of Erosion-Corrosion is the phenomenon of the critical velocity, also known as the breakaway velocity. The critical velocity is the water flow velocity at which there is a distinct transition from low corrosion rates (when the protective scale remains intact) to high corrosion rates (when portions of the protective scale are dislodged leading to active corrosion of the exposed metal). The acceptable maximum water velocity is decreased when water temperature is high. Recirculating hot water systems are particularly challenging, because there are no quiescent periods in which the protective films can be re-established. According to the U.S. Copper Development Association, 95% of cases of Erosion-Corrosion of copper occur in circulating hot water systems[1,*].

2.2 Factors Promoting Erosion-Corrosion

The most widely recognised and well understood factors that determine the tendency for copper water pipes to suffer from Erosion-Corrosion are (i) flow velocity and (ii) water temperature. It is well understood that the critical velocity decreases when temperature increases. However, there are several other factors which affect the tendency for Erosion-Corrosion and which therefore influence the maximum safe water velocity.

The following is a summary of the main recognised factors:

(i) *High water flow velocity*. Velocity is the most commonly cited influence, although it is important to recognise that it is not the only significant factor. There is a critical velocity above which Erosion-Corrosion is a serious risk and below which it should not usually occur (plus some margin to provide an adequate factor of safety); but the value of the permissible velocity depends significantly on other factors, several of which are listed below.

(ii) *Elevated temperature*. In publications dating back to at least 1960[2] it has been recognised that flow velocity and temperature must be considered together. Permissible water velocities are recognised to decrease as temperature increases from cold (<25°C) to warm (~25–49°C) to hot (~54–60°C) to very hot (~71°C[1] – 82°C[3]). At temperatures above 71°C the increase in severity of Erosion-Corrosion is said to be associated with a change in the oxide type, from cuprous to a less protective cupric form[1].

[*] Superscript numbers in square brackets indicate endnote references — see page 16.

(iii) *Recirculating systems*. Most of the cases of Erosion-Corrosion reported in literature occur in continuously recirculating hot-water systems[1,4,5], and for such systems it is recommended that water velocity not exceed 0.5 m/s. The requirements for continuously recirculating systems are more stringent than those for on-demand (intermittent-use) systems, since in the latter there might be time for protective scales to re-form.

(iv) *Pressure*. In addition to high velocity and elevated temperature, high water pressure may also promote Erosion-Corrosion. According to the U.S. Copper Development Association[1], even in cold water the pressure should be limited to a maximum of about 550 kPa.

(v) *Turbulence*. Turbulence causes local impingement velocities that are higher than the general flow velocity. Turbulence is promoted by any deviation from smooth transitions in the pipe's internal profile, highlighting the importance of good workmanship. Turbulence and related hydrodynamic effects can also be promoted by rapid closure devices. At even relatively low flow velocities, it is possible for turbulence to promote Erosion-Corrosion (especially where water has high CO_2, very low hardness, and temperature above 43°C)[6]. However turbulence cannot occur under zero-flow conditions, and for a given pipe profile turbulence is more likely when the general flow velocity is high.

(vi) *Water chemistry*: Hard waters with a positive calcium scale-formation tendency are generally less corrosive (both to copper and to steel alloys) than very soft waters. Similarly, waters with pH above 6.9 are generally less corrosive than waters with lower pH. These general corrosion tendencies are reflected in the tendency for Erosion-Corrosion, with higher flow velocities permissible in high pH, positive scale-forming waters than in softer, lower pH waters[6]. Water with high dissolved CO_2 ($\geq$10 ppm) is also more aggressive for Erosion-Corrosion.

(vii) *Suspended solids*: Abrasive suspended solids, including sand and iron oxide, can further promote Erosion-Corrosion[1] because they contribute to the damage of protective films.

2.3 Quantitative Guidelines

The above factors affecting the tendency for Erosion-Corrosion could require construction of a fairly complex matrix of interactive factors. In practice, it is necessary for temperature and velocity guidelines to take account of "reasonable" or "realistic" variations in water pressure, water chemistry, and pipe workmanship.

Drawing upon information and guidelines from a wide variety of scientific and industry authorities, Table 1 lists guidelines regarding maximum velocity to give an adequate factor of safety.

Table 1: Quantitative Guidelines to Prevent Erosion-Corrosion

Temperature and Design	Max Velocity	References
Cold water <25°C	1.8 m/s	AWWA 1985[4], AWWA 1996[5]
Warm to hot water 43–60°C in on-demand domestic systems only (**not** recirculating)	1.5 m/s	US-CDA 2001[1], PHCC NSPC 2006[6], ASM 2005[7], US-CDA 2006[8]
Hot to very hot water >60°C, on-demand domestic only	0.6–0.9 m/s	PHCC NSPC 2006[6], ASM 2005[7], US-CDA 2006[8]
Hot to very hot water >60°C, **recirculating**	0.5–0.6 m/s	AWWA 1985[4], AWWA 1996[5], PHCC NSPC 2006[6]

3. JACKSONS LANDING CASE STUDY

3.1 Samples

UQ Materials Performance was engaged by Aquatherm Australia to examine samples of copper tube, reported to have been cut from recirculating hot water reticulation systems in the "Distillery" and "Quarry" Buildings at Lend Lease's Jacksons Landing residential project at Pyrmont (Sydney).

Aquatherm provided UQMP with photographs of the samples being cut from the system on site. Some of these photographs, stated to have been from the Quarry building, are reproduced in Figure 1 and Figure 2 below. Aquatherm also provided UQMP with a copy of a form in which representatives of Lend Lease, Aquatherm and Aurecon signified that they had witnessed the removal of copper pipe samples from two locations in the Quarry building on 22-Feb-2012.

(a)

(b)

Figure 1: Cropped reproductions of photographs provided by Aquatherm showing pipe samples being cut from Jacksons Landing, Quarry Building.

(a)

(b)

Figure 2: Cropped reproductions of photographs provided by Aquatherm showing pipe samples after cutting from Jacksons Landing, Quarry Building.

3.2 Observations and Interpretation

Quarry Building

Two tube samples were provided to UQMP — one large diameter and one small diameter (see Figure 3 below). The smaller diameter tube showed clear evidence of Erosion-Corrosion (see Figure 4 and Figure 5). Characteristic features of Erosion-Corrosion seen in this sample included:

- Extensive regions of attack showing bare copper with no protective film;
- Islands of intact protective film, with undercutting;
- The regions of attack are associated with a joint which creates an internal step, hence turbulence;
- The joint also appears to be downstream from a bend in the tube.

The larger diameter tube had no obvious signs of either Erosion-Corrosion or Pitting Corrosion.

Figure 3: Jacksons Landing, Quarry Building — Samples provided for examination.

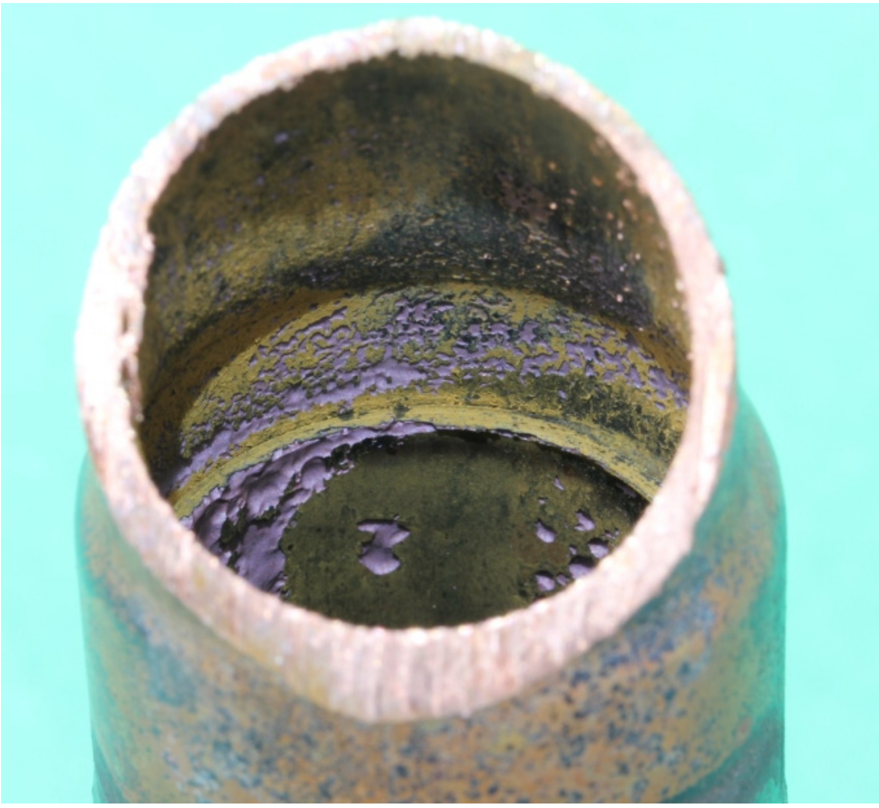


Figure 4(a): Jacksons Landing, Quarry Building — Smaller diameter tube before sectioning. Evidence of Erosion-Corrosion visible from the open end.

Figure 4(b): Quarry Building — Sample sectioned to reveal interior surfaces of tube.

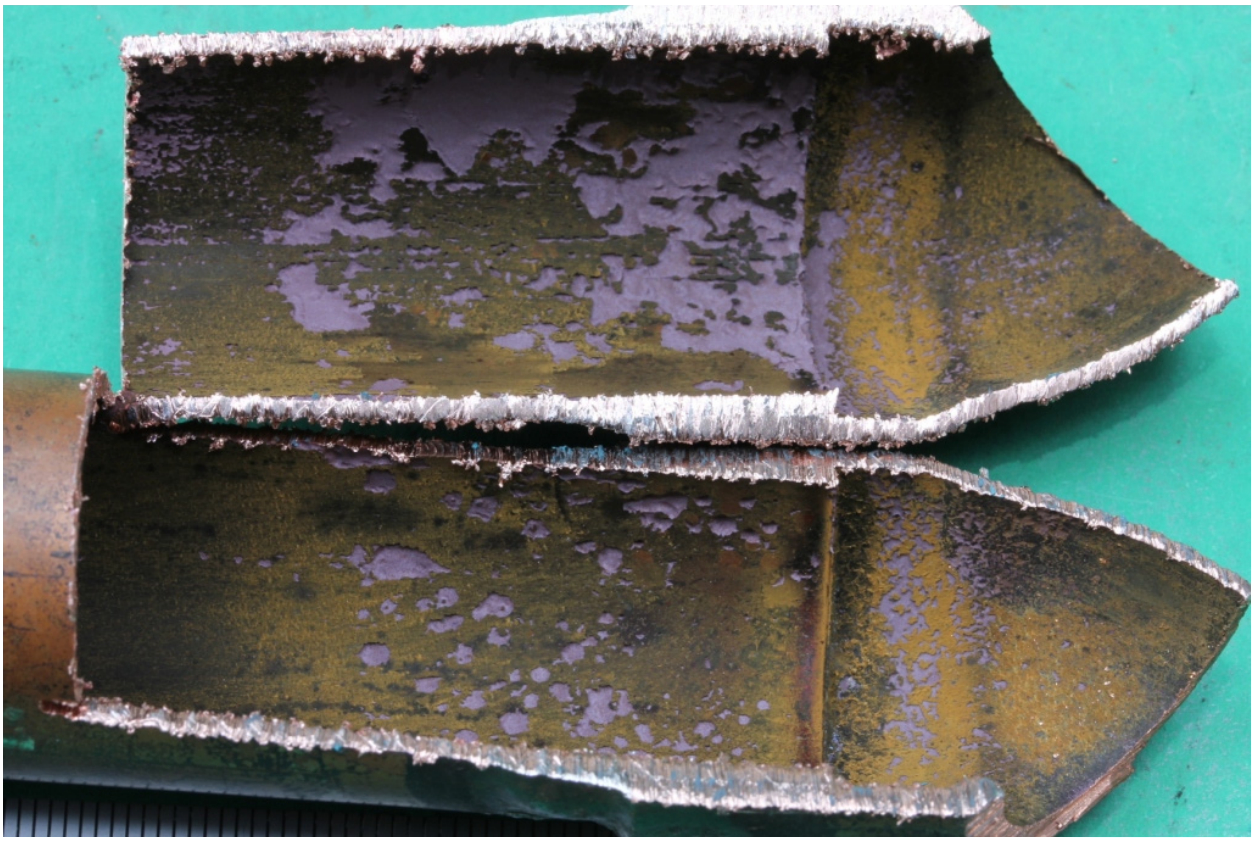


Figure 5: Jacksons Landing, Quarry Building — Closer view of Erosion-Corrosion attack on inner surface of tube; Extensive regions of bare metal in undercut pits and troughs between intact copper oxide scale; Distribution of attack suggests the role of turbulence associated with the joint.

Distillery Building

Three samples were provided, two large diameter and one small (see Figure 6). The small diameter tube was a straight section with neither bends nor joints.

None of the three samples showed any obvious signs of Pitting Corrosion or Erosion-Corrosion.

Figure 6: Jacksons Landing, Distillery Building — Samples provided for examination.

3.3 Interpretation

The examination of the provided samples revealed one case of severe Erosion-Corrosion. The occurrence of even one example of Erosion-Corrosion of this level of severity raises a strong suspicion that water velocities are too high in the system.

As is usual in such cases, the attack has occurred in a small-diameter tube within the system. This is expected since, for a given volume flow rate, water velocities are highest in small diameter tubes. It is similarly typical that the worst problems occur at bends (increasing the angle of impingement of the water stream on the tube surface) and at joints which create turbulence (again increasing angle of impingement and potentially increasing local velocity).

However, bends and joints are only capable of triggering Erosion-Corrosion if the water velocity is systemically excessive. These local geometric features only magnify the effects of generally high water velocities.

3.4 Need for Further Sampling

3.4.1 Introduction

To conduct a reliable assessment of the condition of the copper tubes in the recirculating hot water systems at the Jacksons Landing site, and to judge whether or not the excessive water velocities represent a systemic problem at the site, would require access to a larger number of samples of tubes of the high-risk type.

3.4.2 Principles of Sampling to Detect Effects of Excessive Velocity

High-risk tubes are those with small diameters, bends, and/or joints. The highest risk occurs when all three of these features coincide, as they do in the Quarry building sample described above.

Several further examples of small-diameter tubes would need to be provided for examination, before it would be possible to judge whether the Erosion-Corrosion occurs only in cases where all three of these precipitating features occur together or whether it sometimes occurs when only one or two of these features occur.

To establish freedom from systemically excessive velocity in a building, it is not sufficient to provide, for example, a single sample of small diameter tube in which there is no sign of Erosion-Corrosion. A given sample of small diameter tube could be associated with manifolds or multiple parallel lines in which the total cross-sectional area is comparable to that of the larger diameter tubes, hence experience only average velocities. Other small-diameter tubes might represent choke points, hence experience higher water velocities. Thus, sample collection needs to be conducted with the benefit of a knowledge of the hydraulic design of the system, concentrating on tubes with the highest expected flow velocities.

3.4.3 Request for Further Samples

The need for further sampling from Jacksons Landing, as outlined above, was set out in the UQMP preliminary report dated 9-March-2012. This was followed by a specific recommendation to collect further samples, in an email dated 12-March-2012.

UQMP has been informed that Aquatherm lodged these requests for further samples but that the requests were declined.

3.5 Conclusion

The Jacksons Landing site contains at least one example of severe Erosion-Corrosion, and this is suggestive of systemically excessive velocities.

4. OTHER CASE STUDIES

4.1 Brisbane Nursing Home 2002

In 2002, UQ Materials Performance was engaged by a Queensland-based hydraulic and fire services consultancy firm to conduct a metallurgical failure investigation on copper tubes that had leaked. The copper tubes were from the hot water reticulation system in a Brisbane nursing home. Leaks had occurred in several of the facility's buildings, which were approximately ten years old at the time.

UQMP was provided with four samples of 19 mm diameter copper pipe that had been removed from the nursing home after the failures. UQMP's examinations identified several features which together provide unambiguous diagnosis of Erosion-Corrosion:

(a) Extensive regions of pitting, clearly exposing the bare copper.

(b) Deep, undercut, longitudinal geometry of troughs and pits. The longitudinal orientation and undercutting are recognised characteristics of Erosion-Corrosion, resulting from the action of fluid flow in the pipe.

(c) Many of the pits having a characteristic horseshoe shape. Horseshoe-shaped pits (with their open ends facing downstream) are a readily recognised diagnostic feature of Erosion-Corrosion, clearly indicating the importance of fluid flow in the mechanism.

(d) The surface between the pits covered by a dark copper oxide/carbonate/sulphate scale.

(e) Absence of tubercules of corrosion products covering the pits. This is one of the recognised diagnostic differences between Erosion-Corrosion and Type 2 Pitting Corrosion. In Type 2 Pitting the pits are usually capped by friable greenish-black tubercules of brochantite ($CuSO_4.3Cu(OH)_2$), cuprite (Cu_2O), and/or malachite ($Cu_2CO_3(OH)_2$). In Erosion-Corrosion such tubercules would not withstand the flow conditions.

(f) There was some association between the damage and poorly profiled joints (at which turbulence can be expected to occur).

Some scanning electron microscope (SEM) images of the damaged surfaces are shown in Figure 7(a) and (b) below.

The Erosion-Corrosion attack was most severe at poorly profiled joints, and at bends, but was not restricted to these locations. UQMP was not informed of the water velocities or temperatures, but the widespread nature of the Erosion-Corrosion attack indicated systemically excessive velocities and/or temperatures.

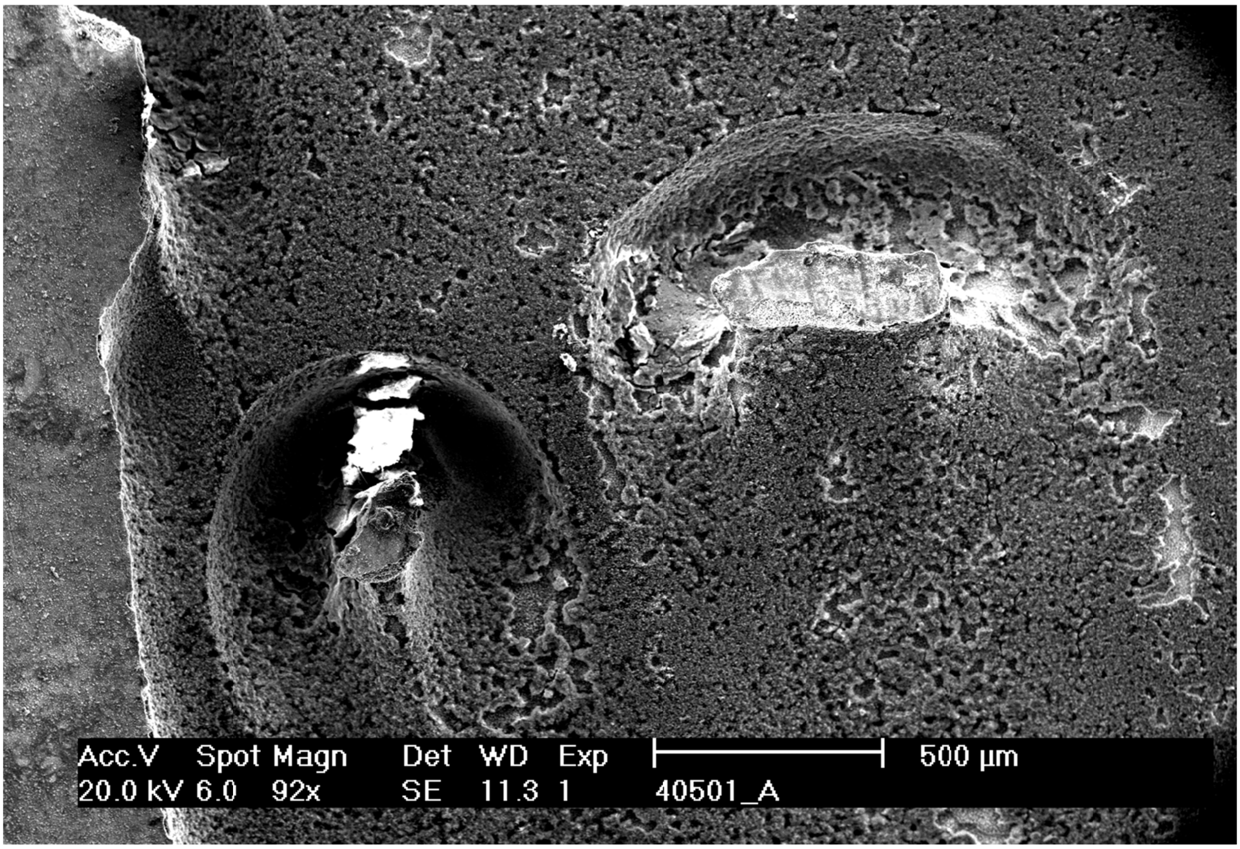


Figure 7(a): Nursing Home — Horseshoe-shaped pits within a longitudinal trough; Remaining scale-protected surface visible at left. SEM secondary electron image.

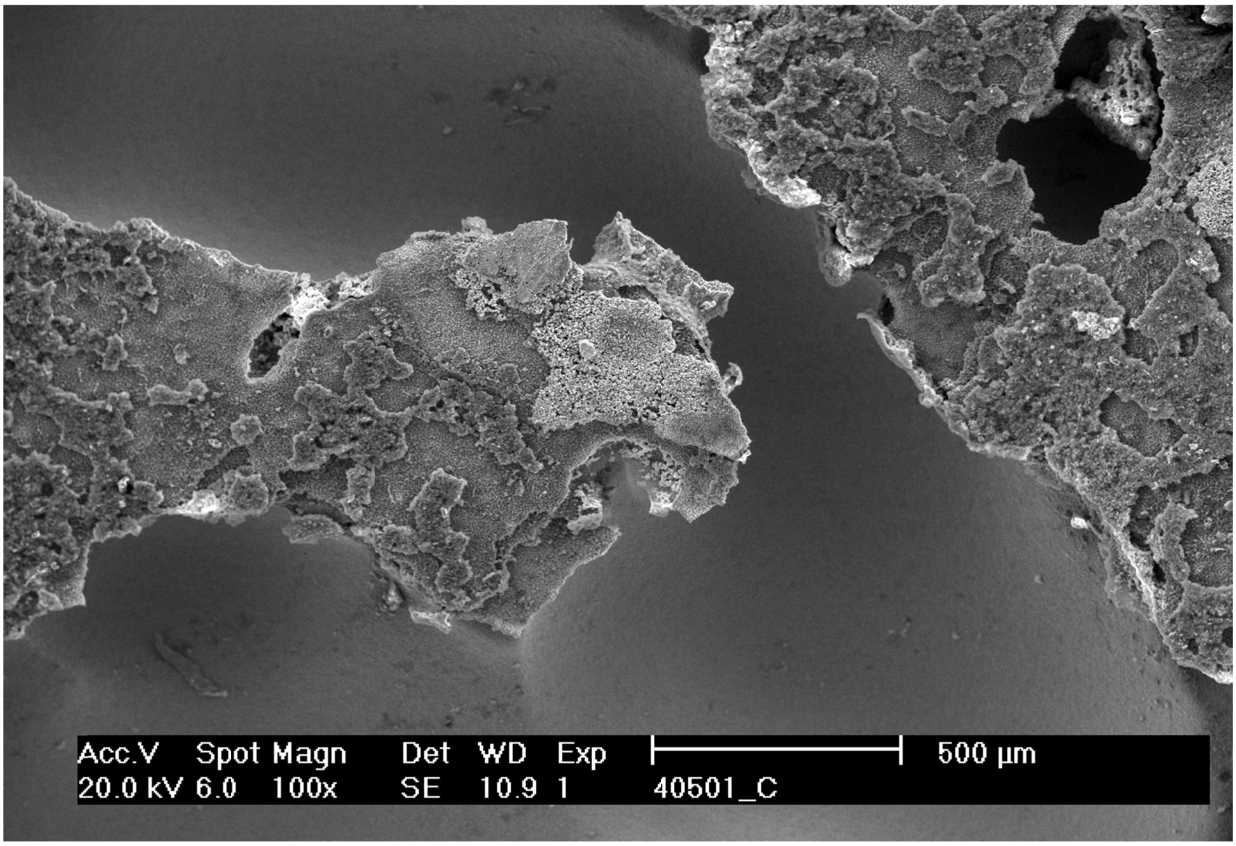


Figure 7(b): Nursing Home — Planar scale-protected surface and deeply undercut pits.

4.2 Brisbane Residential Tower 2005–2008

4.2.1 Introduction

This 18 storey building in inner-suburban Brisbane was designed in 1999, constructed in 2000–2001 and occupied in November 2001. It has 11 residential floors serviced by a recirculating hot water system. Eight gas fired hot water heaters at the top of the building supply the apartments below via 15 lines. Water is in constant circulation in the system even when no water is drawn by the apartments. Unused water is collected in a manifold at the bottom and returns to the hot water tanks via a single 40 mm diameter riser.

According to an investigation report by a hydraulic services and fire and risk engineer[9], the hot water pipes suffered twelve leaks between June 2005 and June 2007 (commencing within 5 years of occupancy). Leaks were reported in a wide variety of locations, including branch lines, droppers, the lower manifold and the 40 mm riser.

4.2.2 UQMP Investigation

UQMP staff inspected the site in September 2008, coincident with repair of a recently diagnosed leak.

Figure 8(a) shows one of the water heaters. Figure 8(b) shows one of the temperature controllers, which appears to be set to about 73°C. From the seven water heaters that were operational at the time of inspection, outlet temperatures were measured to range from 54°C to 80°C.

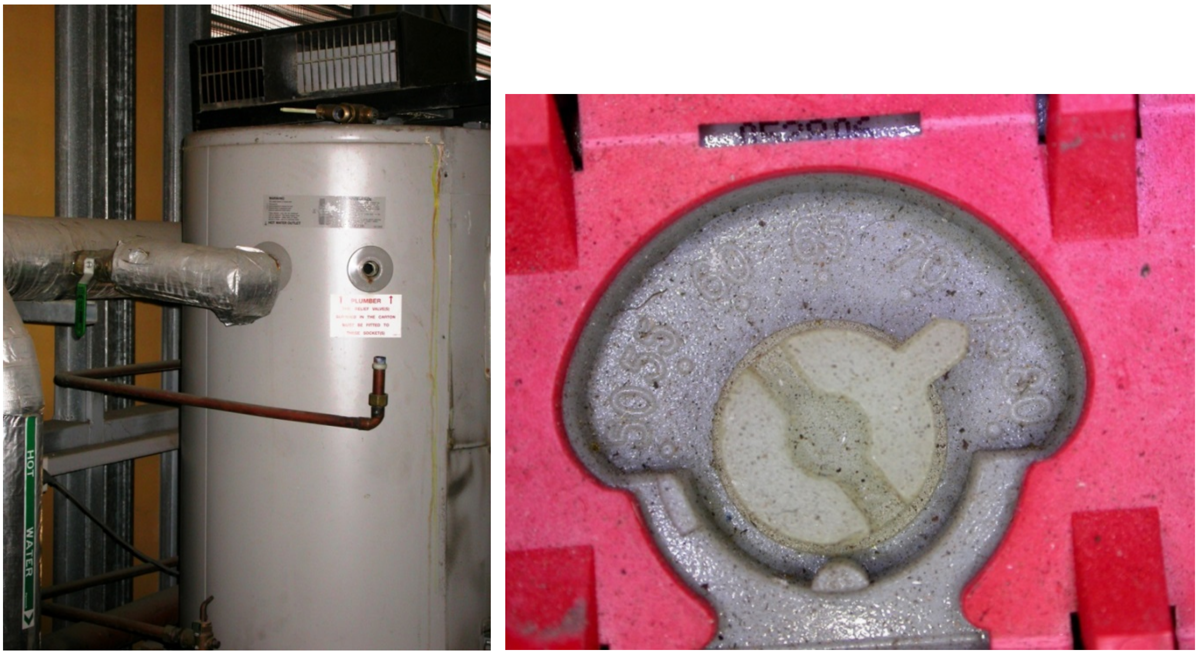
(a)  (b)

Figure 8: Brisbane residential tower water heater and temperature controller. The controller appears to be set to about 73°C.

The building's design specifications called for a maximum velocity of 1.5 m/s, but reports from hydraulics investigators suggested actual velocities may have routinely exceeded 2.0 m/s and possibly as high as 2.8 m/s.

A water sample was collected from the outlet of one of the heaters and delivered directly to a water analysis laboratory. Among other things the water analysis showed that the ratio of bicarbonate to sulphate (HCO_3/SO_4) was approximately 4.

Some macro photographs and scanning electron microscope images of the damaged surfaces are shown in Figure 9 and Figure 10.

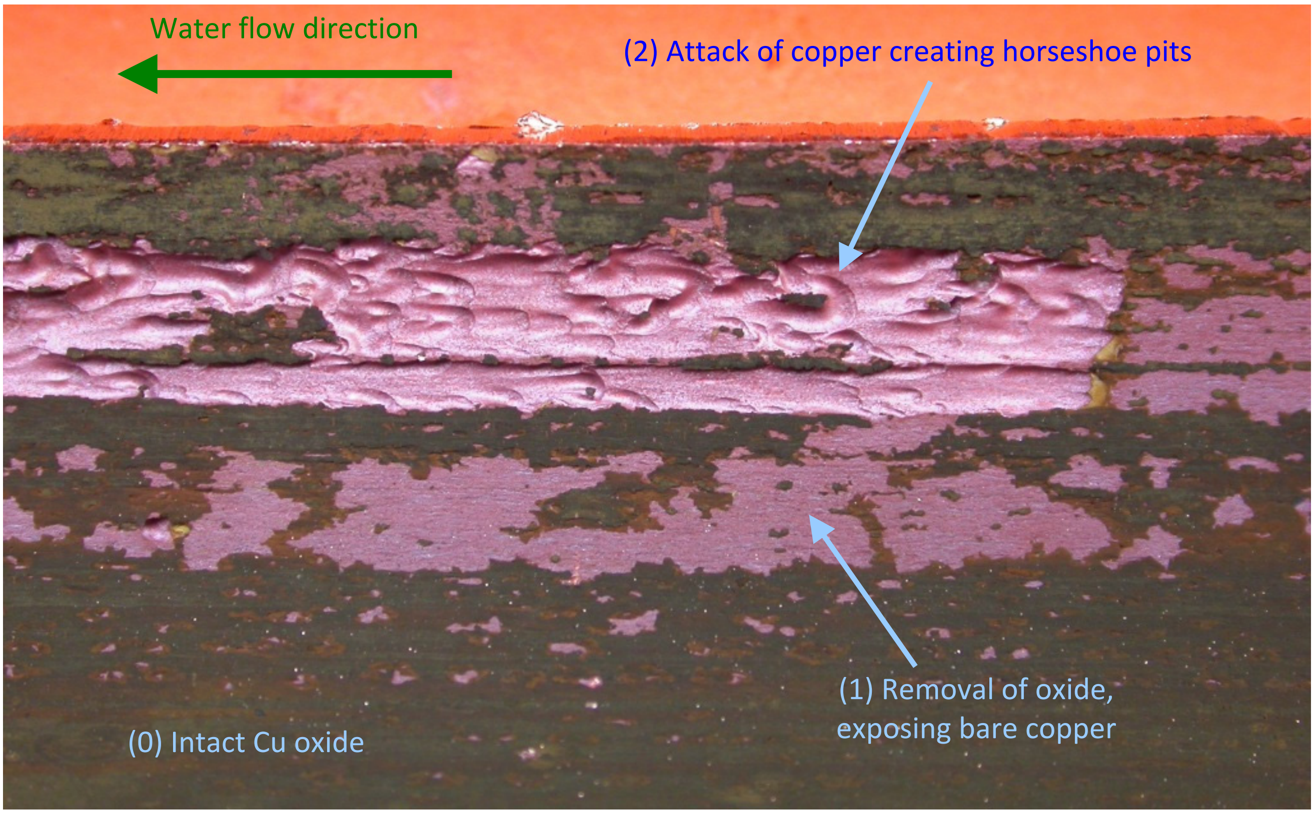


Figure 9(a): Brisbane residential tower — Early stages of Erosion-Corrosion attack; Horseshoe-shaped pits have open end downstream.

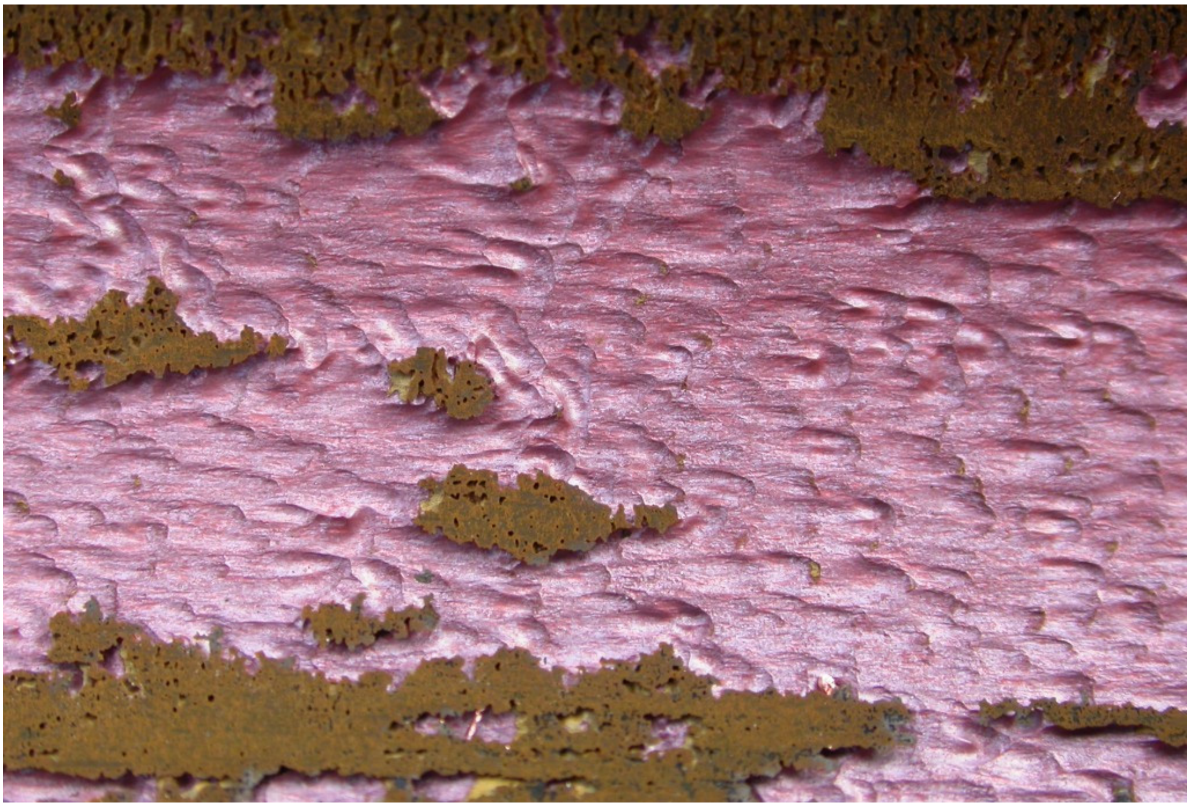


Figure 9(b): Brisbane residential tower — Detail of Erosion-Corrosion, showing coalescence of horseshoe-shaped pits, undercutting islands of intact oxide/carbonate/sulphate.

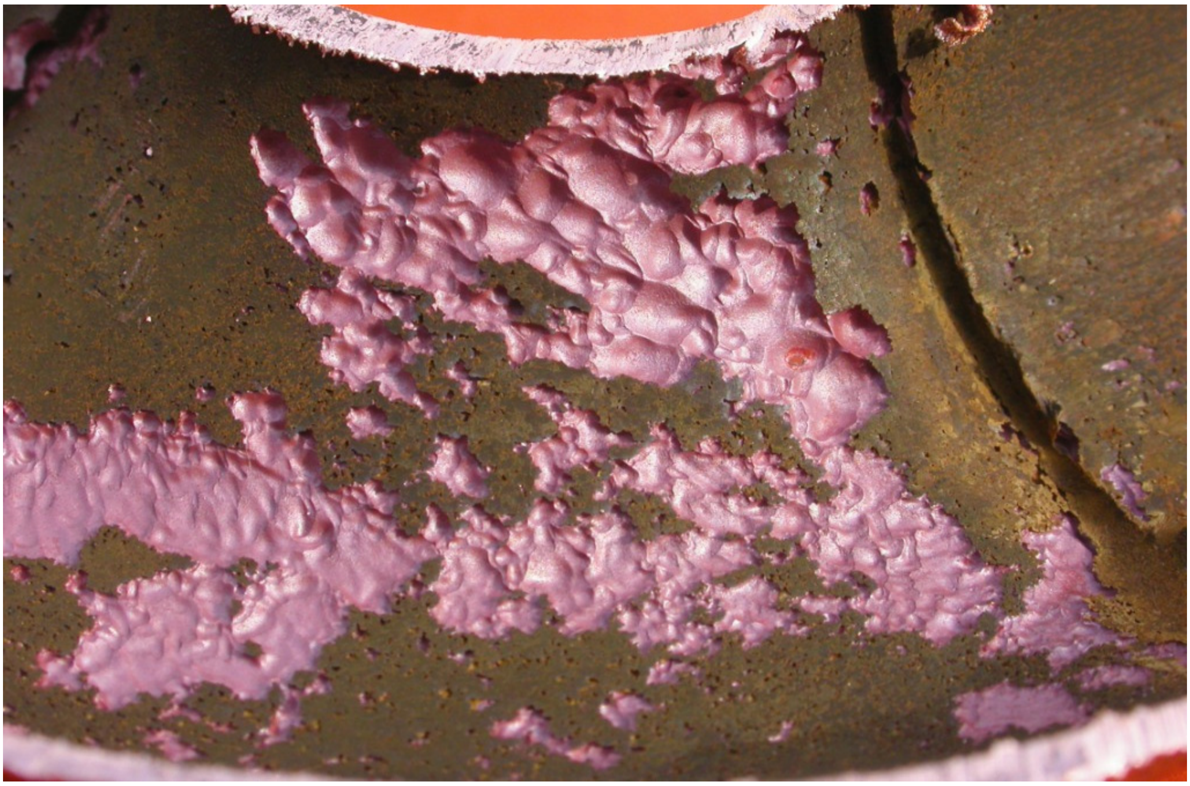


Figure 9(c): Brisbane residential tower — Erosion-Corrosion associated with turbulence downstream of a joint.

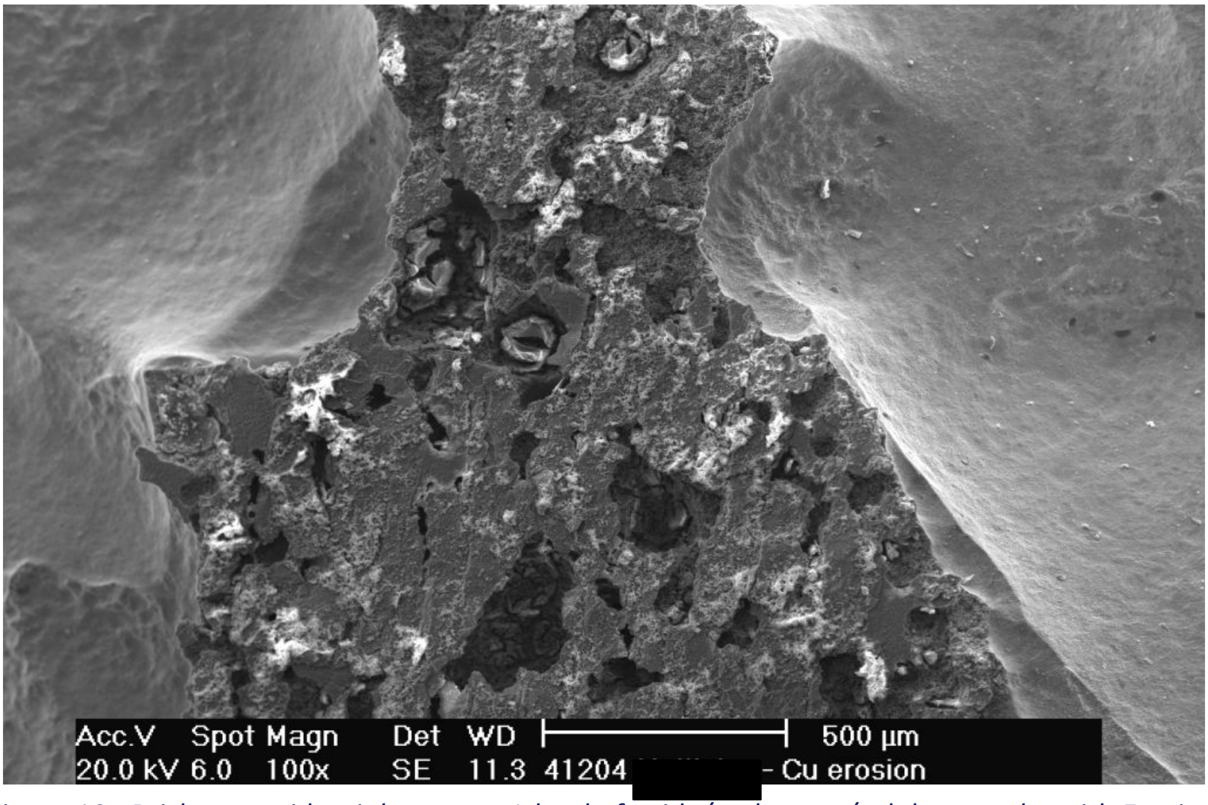


Figure 10: Brisbane residential tower — Island of oxide/carbonate/sulphate scale, with Erosion-Corrosion pits on either side. SEM secondary electron image.

4.2.3 Findings

UQMP's examinations of tube samples from the site unambiguously identified features characteristic of Erosion-Corrosion:

(a) Extensive corroded regions showing bright metal surfaces, free from oxide scales.

(b) Deep, undercut, longitudinal geometry of troughs and pits.

(c) Horseshoe-shaped pits with their open ends facing downstream.

(e) Absence of tubercules of corrosion products covering the pits.

(f) Clear observation that the damage occurred preferentially (though not exclusively) at obvious sources of turbulence such as joints creating an internal step in the pipe.

(g) Ratio of bicarbonate to sulphate (HCO_3/SO_4) measured to be approximately 4. Scandinavian research[[10]] has suggested that Type 2 Pitting only occurs when this ratio is low, $HCO_3/SO_4 < 1.0$. However, other research[[1,11,12]] indicates that Type 2 pitting may be caused by deposition of cathodic substances such as manganese dioxide, hydrated hematite and aluminium hydroxide, hence the bicarbonate to sulphate ratio may not be strongly diagnostic.

4.2.4 Queensland Civil and Administrative Tribunal

In 2010 the Queensland Civil and Administrative Tribunal directed that a Joint Statement of Experts be prepared by expert witnesses engaged by opposing parties in a dispute regarding liability for the costs associated with the leakage events at the Brisbane residential tower. The two experts were myself (metallurgical engineer) and the hydraulic services engineer referred to in section 4.2.1.

The joint report expressed agreement between the two experts in most respects, including the following:

- The failure of the copper tubes at the Brisbane residential tower occurred by the mechanism of Erosion-Corrosion.
- In general, the main factors affecting the rapidity of development of Erosion-Corrosion of copper in hot water piping are:
  - Water velocity (general flow velocity);
  - Proportion of the time that these velocities are experienced (hence continuously recirculating hot water systems more prone than on-demand systems);
  - Water turbulence – created by any features of the pipe which interrupt the smooth flow;
  - Water temperature.
- Based on a survey of industry standards and scientific literature, the recommended maximum water velocity for continuously recirculating hot water systems at temperatures above 60°C is probably 0.5 m/s but certainly no higher than 0.6–0.9 m/s.
- Literature indicates that increasing temperature significantly above 60°C, for example up to 75–80°C, can be expected to result in an increase in the rapidity of development of Erosion-Corrosion.
- A specification which calls for a flow velocity of 1.5 m/s under the circumstance of continuously recirculating flow must be regarded as excessive and likely to promote Erosion-Corrosion.
- The risk of Erosion-Corrosion and the role of water velocity and temperature have been known and published in specialist water distribution literature (notably the American Water Works Association) since about 1985.
- In 1999 when the Brisbane residential tower building was designed, this information had not been transferred either to applicable national standards governing hot water systems (such as AS3500.4[[13]] or BS6700[[14]]), nor to authoritative metallurgical handbooks such as the ASM Handbook.
- At the time the Brisbane residential tower building was being designed, "best practice" for flow velocities in the design of recirculation systems for hot water above 60°C would have been:
  - Maximum water velocity for continuous recirculation — preferably 0.5 m/s and certainly no higher than 0.6–0.9 m/s;
  - Maximum flow velocity for short-term simultaneous flow demand — 1.5 m/s.

The only identified point of disagreement between the two experts was in respect of "what a competent engineer should have known" in 1999 concerning flow velocities when designing a recirculating hot water system.

- The hydraulic services engineer's opinion in this respect was as follows:
  - It is clear both what would have been regarded as "best practice" and "what a competent engineer should have known" when designing recirculation systems for hot water.
  - That is, a competent engineer designing recirculating hot water systems should have been familiar with best practice as set out [above].
- The metallurgical engineer's opinion in this respect was as follows:
  - It is not clear whether or not a competent engineer designing recirculating hot water systems in Australia in 1999 could be expected to have been familiar with the specialist water distribution literature referred [above].
  - If an engineer in 1999 had consulted all of the then-current versions of AS3500.4, BS6700 and the ASM Handbook, that engineer would not have been alerted to the need to limit flow velocities to no more than 0.5–0.9 m/s. Such guidelines did not enter the ASM Handbook until 2005, and even the now-current version of AS/NZS 3500.4 does not contain such guidelines.
  - A competent engineer in 1999 might reasonably have regarded familiarity with the guidelines given in all of AS3500.4, BS6700 and the ASM Handbook as being sufficient to permit appropriate selection of design parameters such as maximum water velocity.

4.3 Admiralty Apartments 2013

UQMP was engaged by Aquatherm Australia to examine a sample of copper tube, reported to be from a plant room of a recirculating hot water reticulation system at Admiralty Apartments, Breakfast Point (Sydney).

The sample (see Figure 11) showed the characteristic features of Erosion-Corrosion:

- Extensive regions of attack showing bare copper with no protective film;
- Islands of intact protective film, with undercutting;
- These regions being associated with a bend and joints which create turbulence.

Figure 11: Admiralty Apartments — Regions of Erosion-Corrosion associated with bend and joint.

5. WIDER IMPLICATIONS

The experience from these four case studies highlights a disturbing disconnect between (i) what has been known internationally for many years and (ii) what is permitted by current Australian Standards and is apparently being implemented in current building construction.

(i) Current Knowledge and International Guidelines:

- Based on earlier published research and experience, in 1985 the American Water Works Association[4] published warnings about the risk of Erosion-Corrosion and provided data showing the combined effects of temperature and velocity. For continuously recirculating hot-water systems the AWWA recommended that water velocity not exceed 0.5 m/s. It is significant that this information was published almost 30 years ago.
- Notwithstanding any minor disagreement between the hydraulic services engineer and myself in the matter of what an Australian engineer "ought to have known in 1999" [see section 4.2.4 above], there is no question that, in 2014, well-established international experience indicates that in recirculating hot water systems both flow velocity and temperature must be tightly controlled.
- As shown in Table 1 on page 4 above, current international guidelines (agreed by bodies such as the American Water Works Association, the U.S. Plumbing-Heating-Cooling Contractors Association, and the U.S. Copper Development Association) for maximum flow velocity for hot water >60°C are as follows:
  - Continuous recirculating flow: 0.5–0.6 m/s.
  - Short-term simultaneous flow demand: 0.6–0.9 m/s.
- As listed at item (ii) in section 2.2 on page 2 above, water temperature must be considered in addition to velocity. While the literature recommends the above-listed permissible velocity values for temperatures of "60°C and above", it is likely that temperatures of 71°C and above may create even greater challenge for protective scales. Rather than try to further restrict permissible velocities, it would be more appropriate to stipulate that temperatures should not exceed 70°C.

(ii) Current Australian Standard and Practices

- In respect of water velocity, the current Australian Standard AS/NZS 3500.4 [15] specifies only that the maximum permissible water velocity in piping shall be 3.0 m/s.
- The Standard contains no explicit mention of Erosion-Corrosion, and no distinction is drawn between permissible peak velocities for short-term simultaneous flow demand and permissible velocities for continuous recirculation.
- In AS/NZS 3500.4, temperature is only discussed in terms of <u>minimum</u> temperature of 60°C to inhibit growth of Legionella bacteria, and maximum delivery-point temperatures of 45–50°C to prevent scalding. As exemplified by the Brisbane residential tower measurements (section 4.2 above), temperatures above 71°C are likely to be quite common, since the Australian Standard only lists a minimum temperature and no warning is given of a detrimental effect of higher temperatures.

- Regardless of whether one considers continuous recirculation velocity or short-term simultaneous flow demand, it is apparent that the velocities permitted by AS/NZS 3500.4 for heated water services put the systems at significant risk of Erosion-Corrosion.
- The four case studies presented in this report make it clear that this risk of Erosion-Corrosion is not just a hypothetical risk, nor a gradual problem that might marginally reduce system life. Rather, it is a problem that has caused multiple pipe leakages (and consequent property damage) within 5–10 years of system construction.

Recommendations

In order that no Australian hydraulic designer, plumber or related person be in any doubt about the practices necessary to prevent Erosion-Corrosion failures, Australian Standards must urgently be updated to reflect what has been long established by overseas authorities. Failure to update the Standard would be expected to lead to further failures, likely consequences of which could include (a) litigation against designers and (b) unnecessary damage to the reputation of copper.

In an updated version of AS/NZS 3500.4, a rational set of guidelines to prevent Erosion-Corrosion would include (but not be restricted to) the following:

- Maximum water temperature not to exceed 70°C.
- For water temperatures in the range 60 to 70°C:
  - Continuous recirculating flow: 0.5 m/s.
  - Short-term simultaneous flow demand: 0.6–0.9 m/s.
- Maximum water pressure 550 kPa.

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