Water-to-Air Heat Exchanger Failure

By

Merlin E. Williams, P.E.

## Subject

Copper tube, aluminum fin, water-to-air heat exchangers are efficient and used in many applications, industrial, commercial, and residential. This particular unit was from a commercial application. When these systems fail, the losses can amount to millions of dollars. The two primary failure modes in these systems are corrosion and freezing. The prevention of corrosion involves very good water management. In every case that I have encountered, including this one, the water management has failed. This particular unit failed by corrosion and multiple freezing events, both of which were the result of failed water management.

## Heat Exchanger Examination


Figure 1 – Failed Fan Coil Leaks

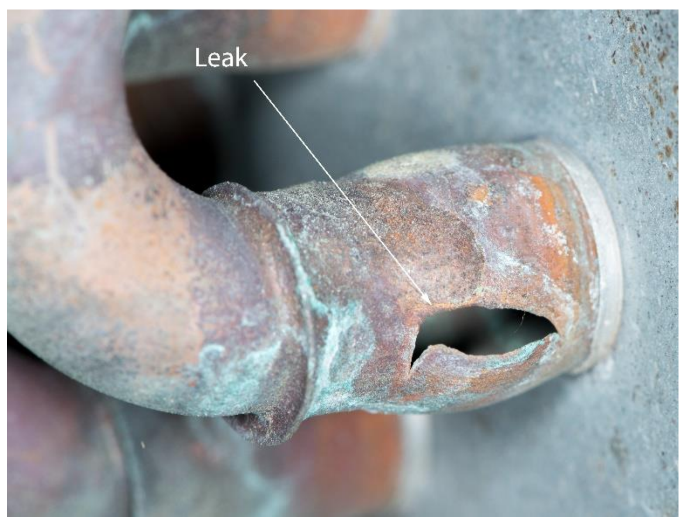


Figure 2 – Longitudinal Split in Sheet Tube

Figure 1 shows the return bend end from the failed fan coil. Initial examination shows that the fan coil failed by freezing. Longitudinal splits, such as the ones shown in Figures 2, 3, and 4, are typical of freeze failures in copper tubing. The longitudinal split of the sheet tube shown in Figure 4 was chosen for further examination with the scanning electron microscope. The section of the sheet tube with the leak in it was split in half, Figure 5, to facilitate examination in the scanning electron microscope.

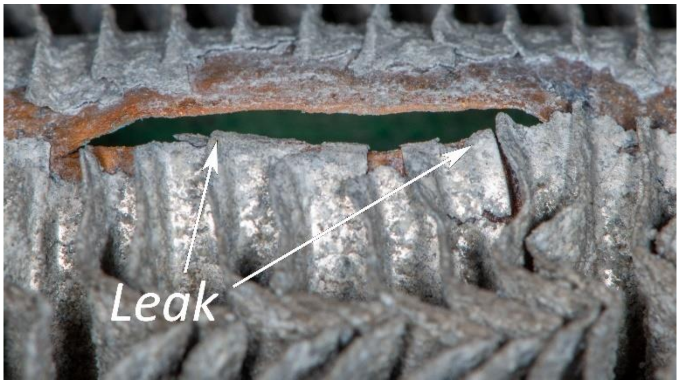


Figure 3 – Longitudinal Split in Sheet Tube


Figure 4 – Sheet Tube Examined in SEM

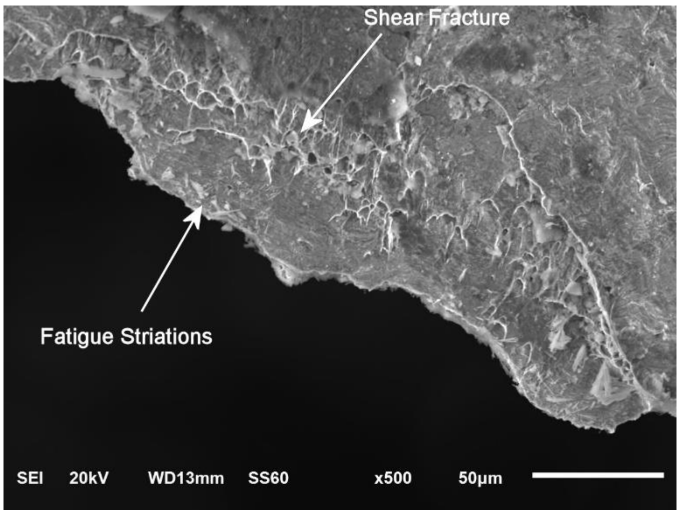


Figure 5 - 500X Fracture Surface

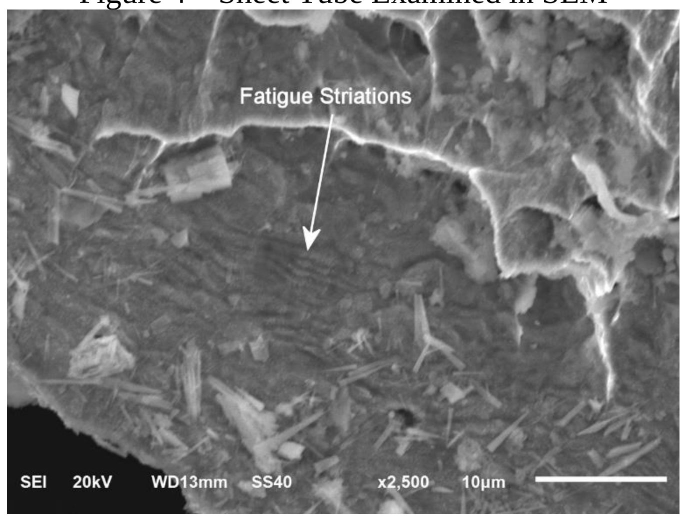


Figure 6 – 2500X Fatigue Striations in Fracture in Sheet Tube

Figure 5 shows the fracture surface. The initial failure mode was fatigue, which was followed by shear. Figure 6 shows the fatigue striations more clearly. Each striation represents one over-pressure event. Eighteen fatigue striations are clearly shown in the photo. The failure was the result of freezing. This section of the coil was frozen at least 18 times prior to failure.

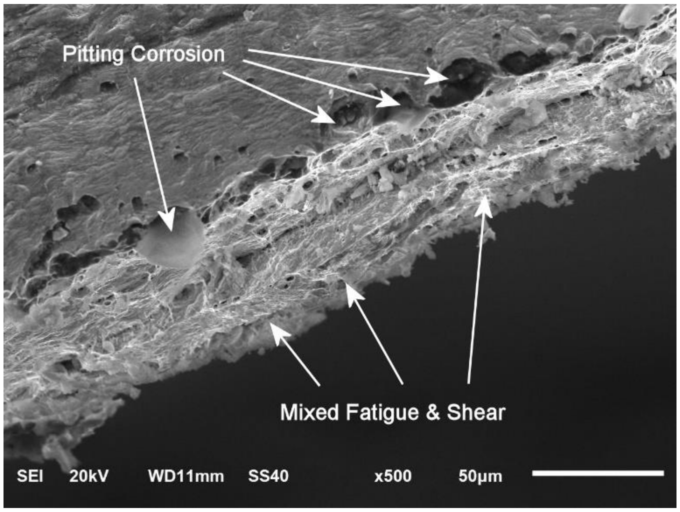


Figure 7 – 500X Mixed Mode Fracture and Pitting Corrosion of Sheet Tube

Figure 8 – Tube with Radial Fracture

The fracture surface is shown in a different location in Figure 7. On the outside diameter, there was a mixture of fatigue and shear fracture, indicating that the cyclic stress exceeded the shear strength of the copper tubing.

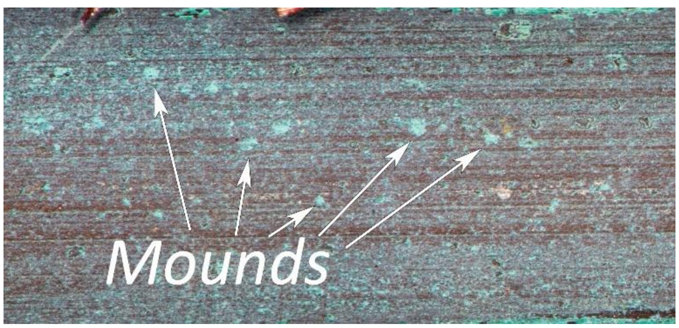


Figure 9 – Small Mound Deposites in the Sheet Tube with the Radial Fracture

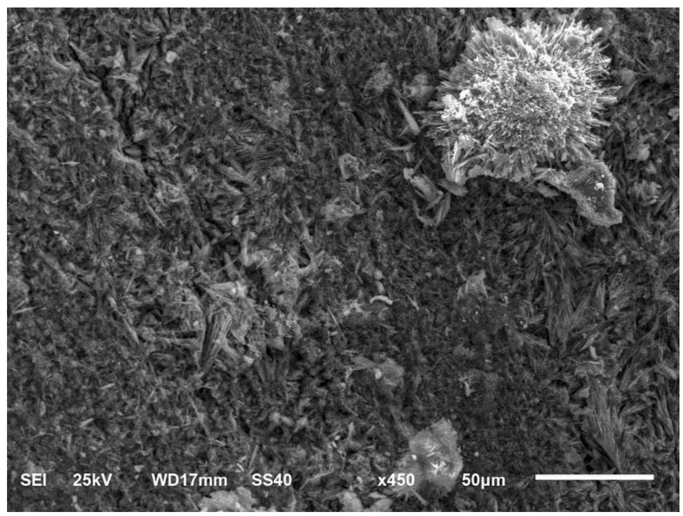


Figure 10 – 450X Small Mound Deposit in Sheet Tube with Radial Fracture

On the inside diameter of the sheet tube there were initiation sights for pitting corrosion, which are indicated by small mounds of corrosion products, Figure 9. Figure 10 shows one of the small mounds on the inside diameter of the sheet tube.

Figure 11 shows pitting corrosion at the end of a sheet tube that failed radially. There are small mounds of corrosion deposits present in the sheet tube. These small mounds are likely the result of microbiological activity, and are often found in water systems that are not adequately treated. Characteristics of the tube surface may be similar to the pits shown in Figure 7.

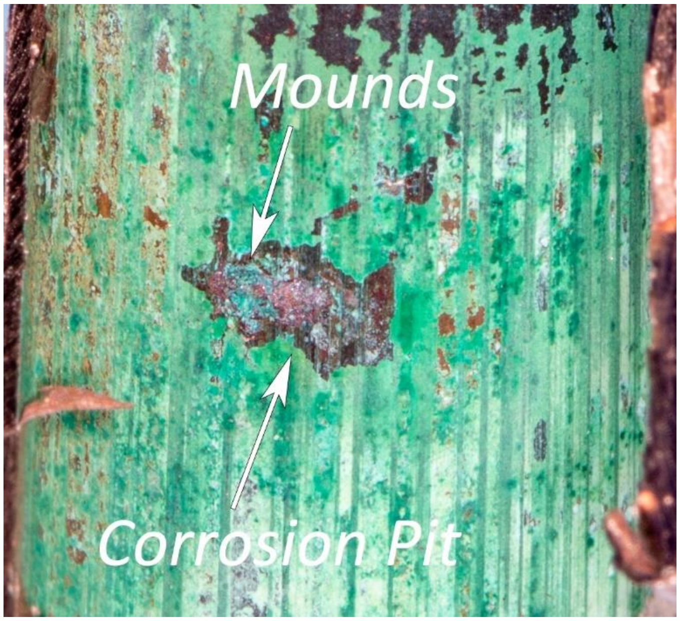


Figure 11 – 7X Corrosion Pit and Mound Deposits in Sheet Tube with Radial Fracture

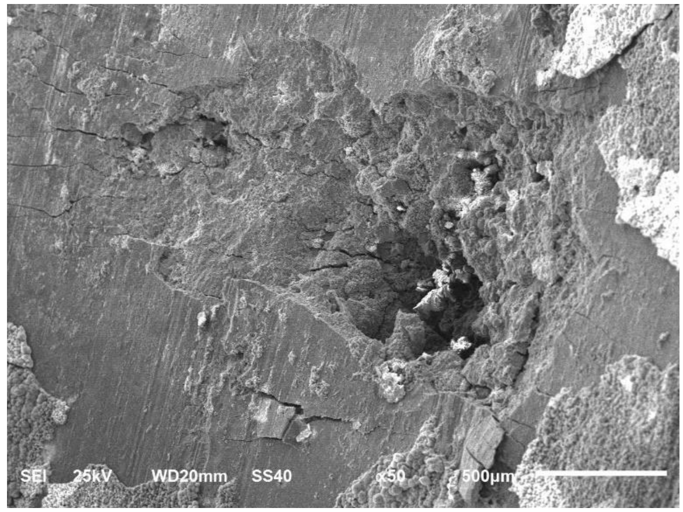


Figure 12 – 50X Corrosion Pit in Sheet Tube with Radial Fracture

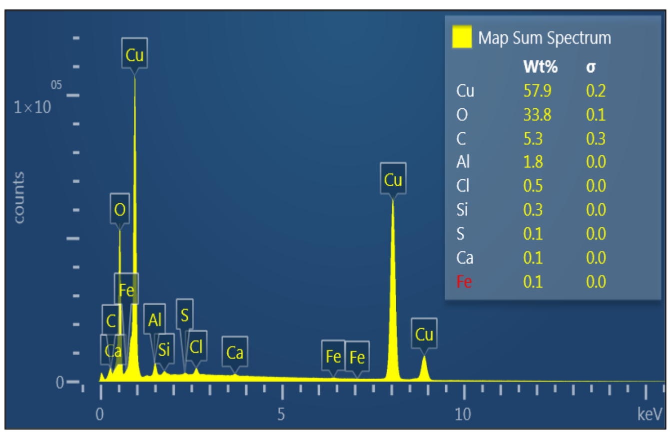


Figure 13 – EDS Spectrum of Corrosion Pit in Sheet Tube with Radial Fracture

The corrosion pit in the sheet tube with a radial crack, Figure 12, has the appearance of microbiologically induced corrosion, MIC. The pitting appears to be similar to pits formed by sulfur reducing bacteria. There were mounds of corrosion products over portions of the pit. The remnants of the mound are still present. There is a visible radial crack emerging from the pit. A scanning electron microscopic view of the corrosion pit is shown in Figure 12. Sulfur reducing bacteria was likely present, and the cracks shown are characteristic of stress corrosion cracking, SCC, caused by hydrogen sulfate produced by sulfur reducing bacteria. Since DNA testing was rejected from the Testing Protocol, positive identification of sulfur reducing bacteria was not determined. The EDS spectrum and semi-quantitative analysis data for the corrosion pit are shown in Figure 13. The sulfur levels are not elevated, but in my experience that is not unusual, and does not indicate that the bacteria is not present.

The Ball Valve leak is shown in Figure 14. Figure 15 shows the leak opened up so that it could be examined with the scanning electron microscope.

Figure 14 – Crack in Ball Valve

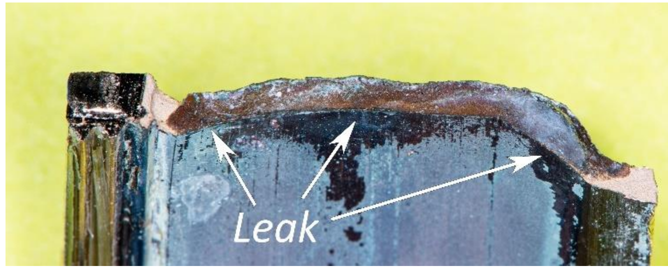

Figure 15 – Ball Valve Crack

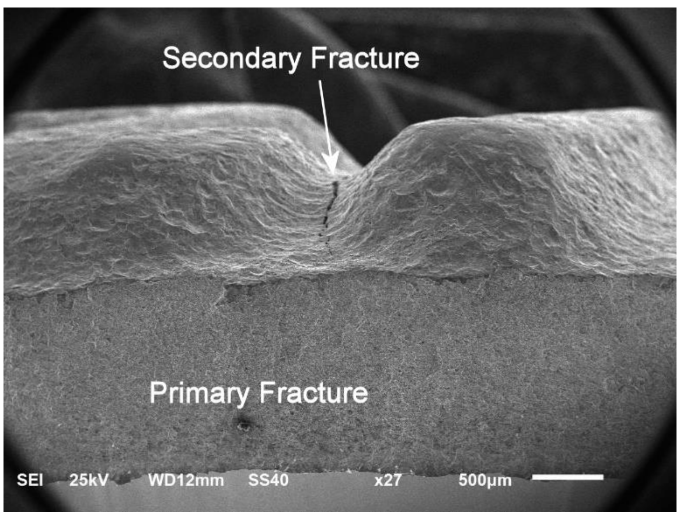

Figure 16 – 27X Ball Valve Fractures

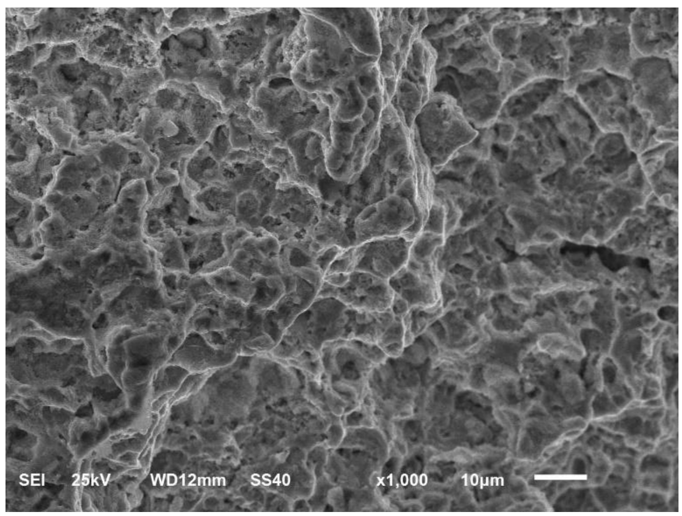

Figure 17 – 1000X Ductile Primary Fracture, Ball Valve

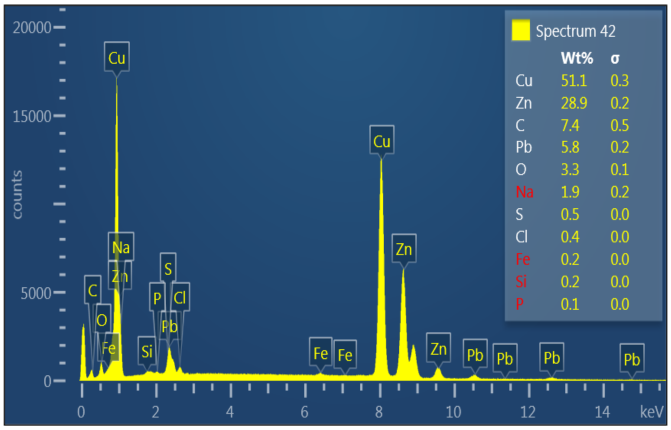


Figure 18 – EDS Spectrum of Primary Fracture Surface of Ball Valve

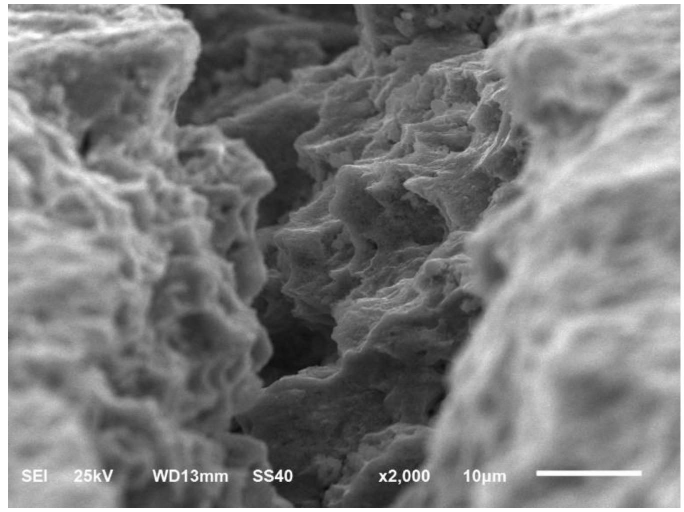


Figure 19 – 2000X Ductile Secondary Fracture, Ball Valve

The scanning electron microscopic view of the Ball Valve showed both primary and secondary fractures, Figure 16. The primary fracture, shown in Figure 17, is ductile. EDS, Figure 18, of the fracture surface shows a higher concentration of sulfur and chloride compounds on the Ball Valve fracture surface than was found in the sheet tube fractures. The secondary fracture, Figure 19, was ductile. The probable cause of failure of this ball valve was a single freezing event.

## Discussion

This water-to-air heat exchanger was one of many that failed. The freezing and pitting corrosion were likely the result of the unit sitting idle for prolonged periods of time when heating or cooling were not needed. Potable water was recirculated in the system, but the free chlorine in the municipal water was somehow removed by the water softener. The chlorine removal was the likely cause of bacterial growth in the softener resin bed. The lack of free chlorine and prolonged periods with no water flow in the heat exchangers allowed the growth of sulfur reducing bacteria to form mounds on the copper surfaces resulting in pitting corrosion and stress corrosion cracking.

The freezing of the unit and other units could have been prevented by allowing water to continually flow in the units. Continuous water flow would also have reduced the likelihood of sulfur reducing bacteria forming mounds in the sheet tubes and return bends.