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Case Study: Erosion Corrosion

By

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Subject

Failure analysis of a heat exchanger coil that had been in service for a short period of time to determine the cause of water leakage from the coil. The coil was examined by visual examination, scanning electron microscopic examination, energy dispersive x-ray analysis (EDS), and metallographic examination. A leaking coil from this system had been examined by another company and they concluded that the leaking was due to manufacturing defects and not caused by the water used in cooling the system. Our task was to identify any manufacturing defects, and to provide recommendations on how to prevent them.

Visual Examination

With just a preliminary macro examination, it was clear that this fitting showed evidence of erosion, and of having been chemically etched. The leaks in the system were obviously the result of problems with the cooling water. Figures 1 and 2 show the chemical and mechanical attack to the fitting.

Figure 1 – Fitting

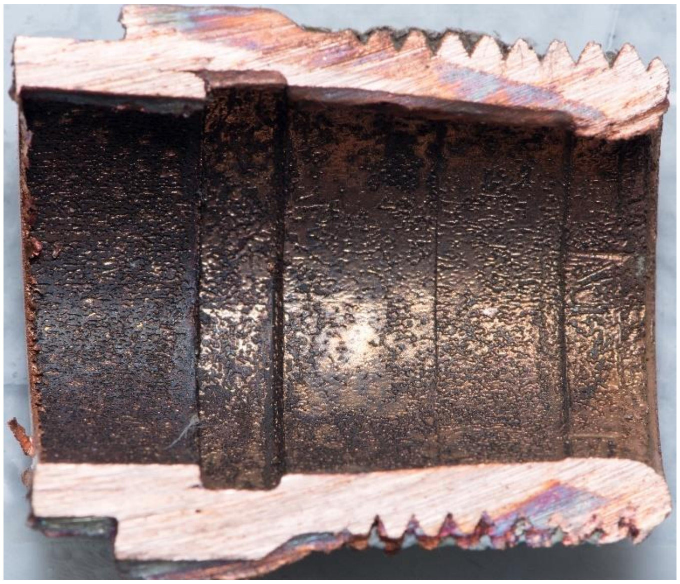

Figure 2 – Fitting after Sectioning

Figure 2 shows a fitting after sectioning. The inner surface of the fitting showed evidence of erosion, cavitation, and possible chemical etching. Erosion is caused by high velocity fluid flow. Cavitation occurs when there is a mixture of a gas and a liquid flowing over a metal surface. Some of the surfaces appeared to have been chemically etched. These surfaces were free of any deposits, and grain boundaries were visible.

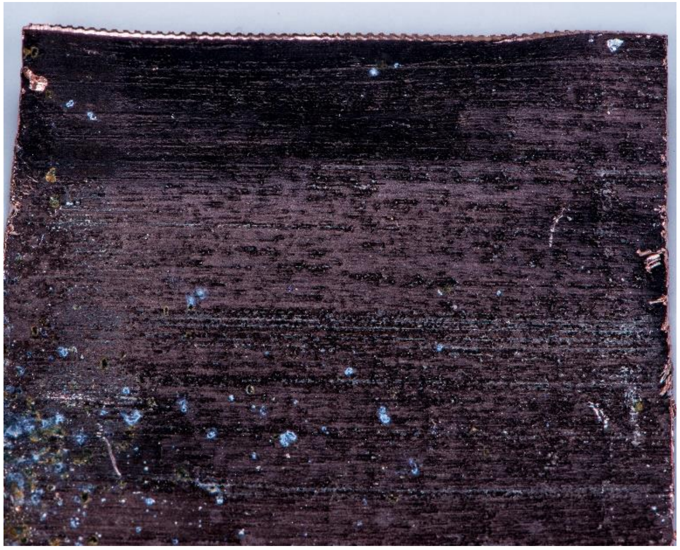

Figure 3 – Sheet Tube 1

Figure 4 – Sheet Tube 2

Figure 3 shows black copper oxide scale and longitudinal striations on the inside diameter of a sheet tube removed from the coil. The tube showed evidence of erosion and cavitation beneath the black oxide layer. Figure 4 shows another sheet tube removed from the coil. There were clear indications of erosion and cavitation on this section of tubing.

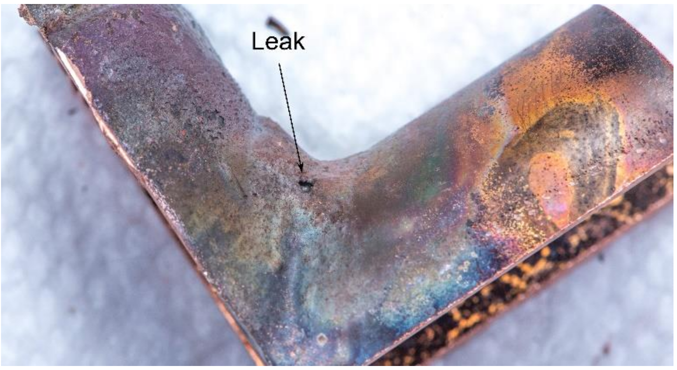

Figure 5 – Pinhole Leak

Figure 6 – I.D. Braze Joint

The location of a Pinhole Leak is shown in Figure 5. Figure 6 shows the inside diameter of the braze joint associated with the leak. There was no evidence of the leak's origin on the inside diameter. There was evidence of cavitation.

Scanning Electron Microscopic and EDS Examination

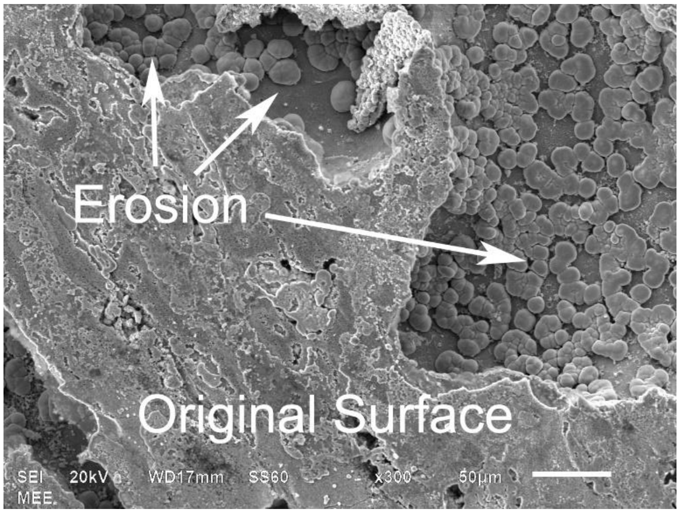

Figure 7 – 300X Fitting Surface

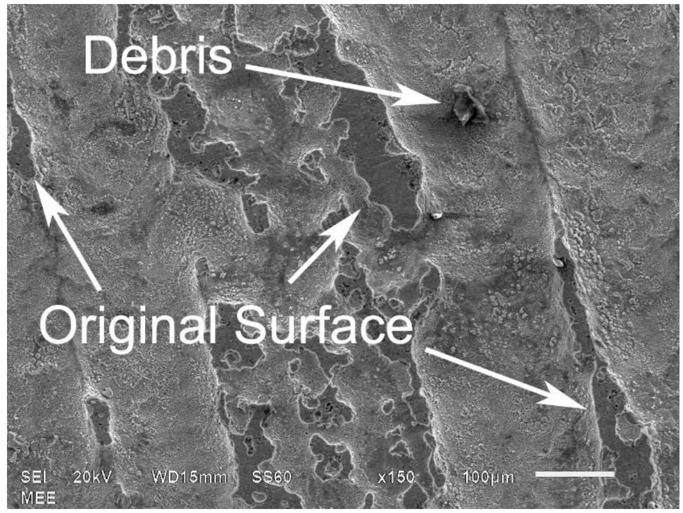

Figure 8 – 150X Tube 1 Surface

Figure 7 shows the inside diameter of the Fitting Surface using a Scanning Electron Microscope. The original surface is the smooth area. The locations of erosion are also indicated. The areas where erosion had occurred had copper oxide nodules forming on them, indicating that the conditions causing the erosion had stopped, and normal water circulation had resumed.

The inside diameter of Sheet Tube 1, from Figure 3, is shown in Figure 8 at a higher magnification using the SEM. The longitudinal ridges were formed by material having been eroded away. Copper oxide nodules were forming in the eroded areas, indicating that the condition that caused the erosion had ended. The debris particle indicated was less than 50 microns in size, and had been circulating in the water system. Figure 9 is the EDS spectrum of the debris particle. The two elements present that indicated possible corrosion problems were nitrogen and sulfur. Nitrogen compounds can cause stress corrosion in copper, and sulfur can cause pitting corrosion.

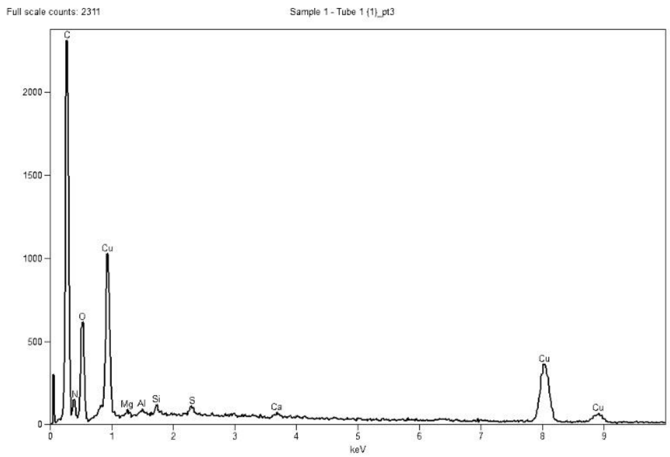

Figure 9 – EDS Spectrum of Debris Particle Tube 1

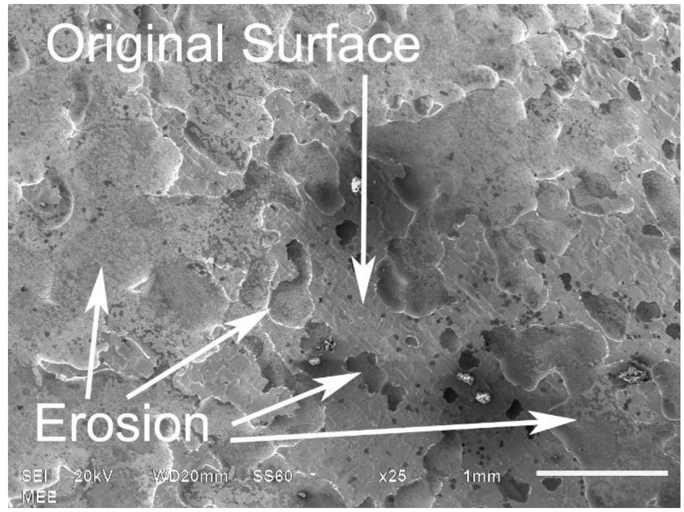

Figure 10 – 25X Tube 2 Surface

The surface on the inside diameter of Sheet Tube 2 shown in Figure 4, is shown at higher magnification in Figure 10. Figure 11 shows an eroded area at higher magnification. The EDS spectrum of one of the black spots on the original surface is shown in Figure 12. The spectrum shows that nitrogen was present.

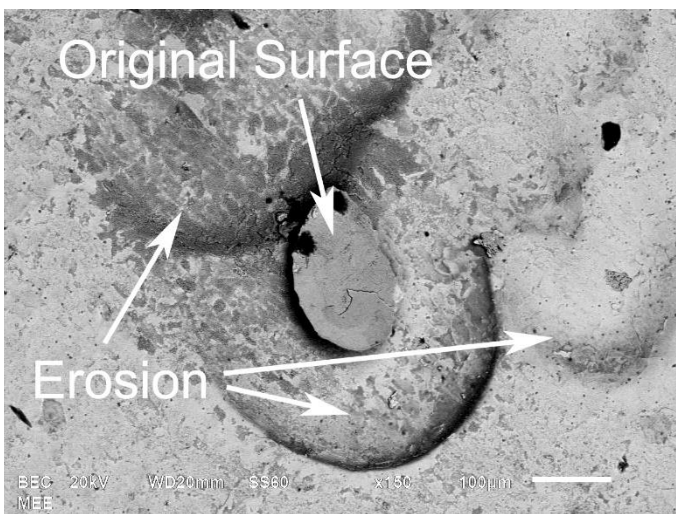

Figure 11 – 150X Tube 2 Erosion

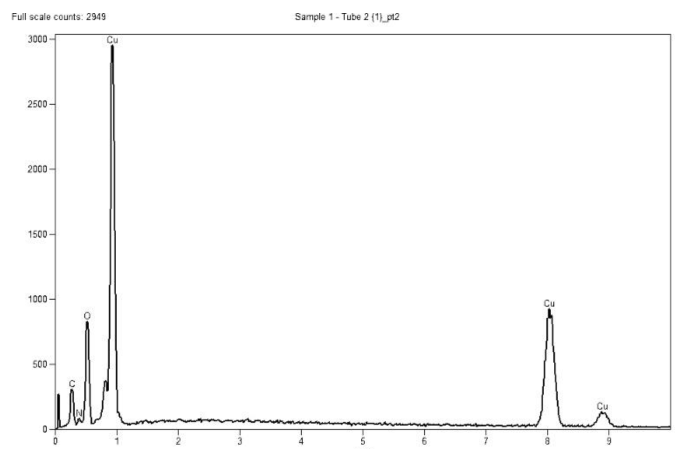

Figure 12 – EDS of Black Material Tube 2

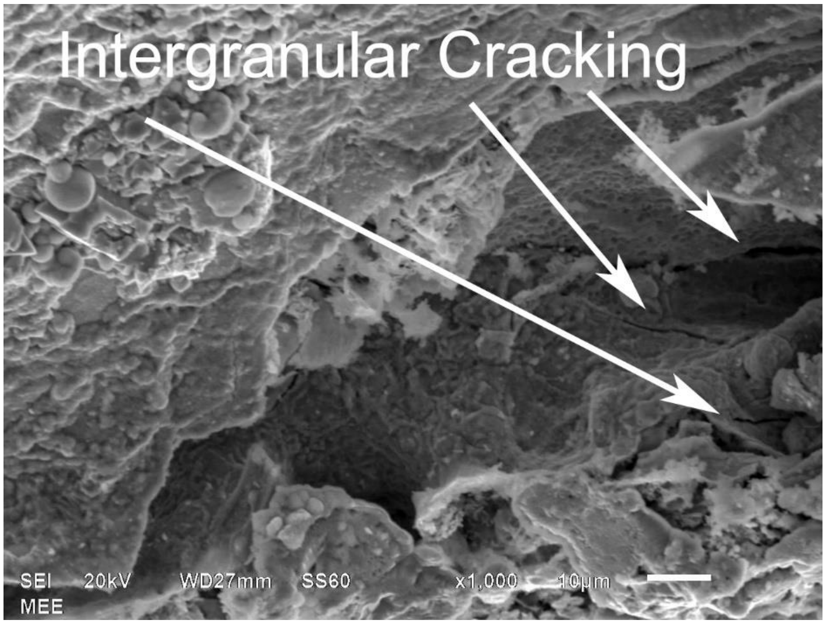

Figure 13 – 1000X I. D. Braze Joint

The Pinhole Leak location from Figure 5, and shown in the SEM photo in Figure 13, was likely the source of the leak in the braze joint. The opening shown was at the interface of the copper tubing and braze metal. There were indications of corrosion and of intergranular cracking. Nitrogen compounds cause intergranular cracking in copper and copper alloys. Sulfur compounds are associated with pitting corrosion of copper and copper alloys.

Metallographic Examination

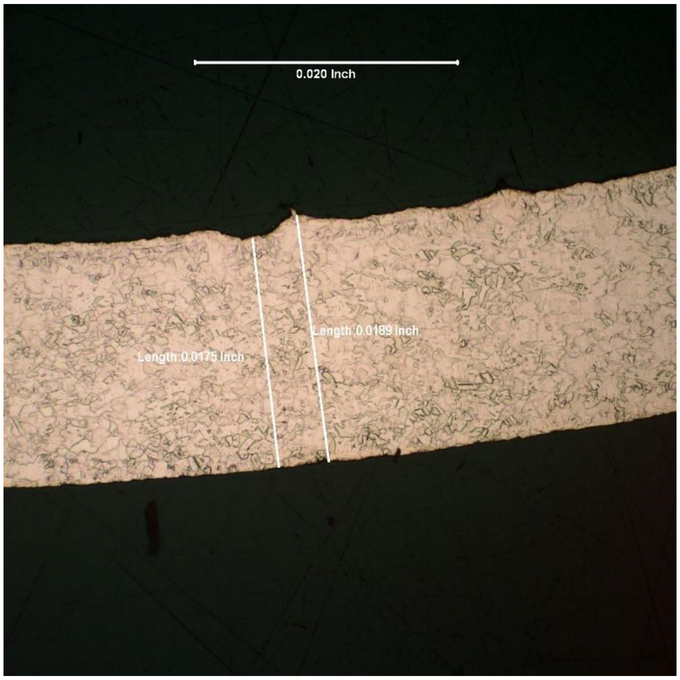

Figure 14 – 100X Sheet Tube

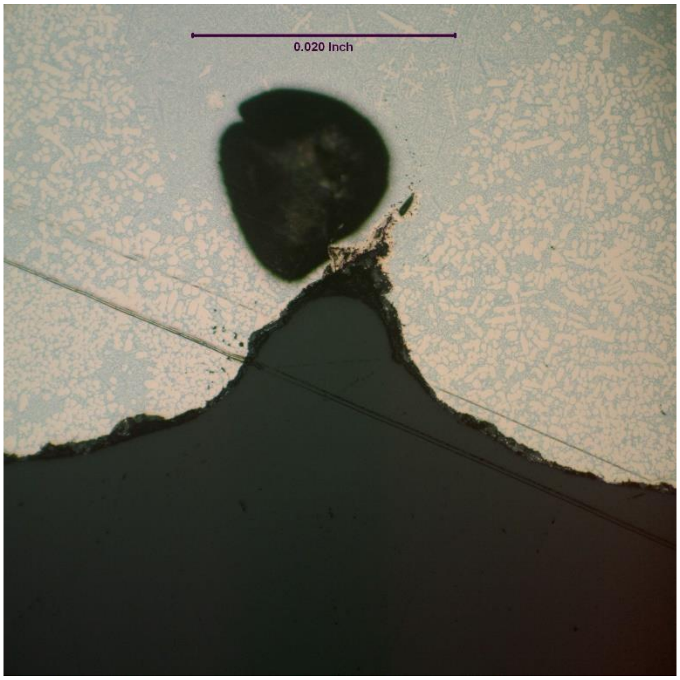

Figure 15 – 100X Pinhole Leak

The thickness of the sheet tubes was 0.020 inches. Figure 14 shows the wall thickness of a sheet tube removed from the coil. The thickness of the ridge was 0.0189 inches, and the thickness of the eroded location was 0.0175 inches. This was a significant amount of erosion.

Figure 15 shows the cross section of the Pinhole Leak shown in Figure 7. This leak is typical of many leaks found in heat exchangers and does not go straight through the metal, or, in this case, the braze joint. The large porosity next to the leak location is typical of braze material. Occasionally leaks will develop along lines of porosity, but that did not appear to be the case here.

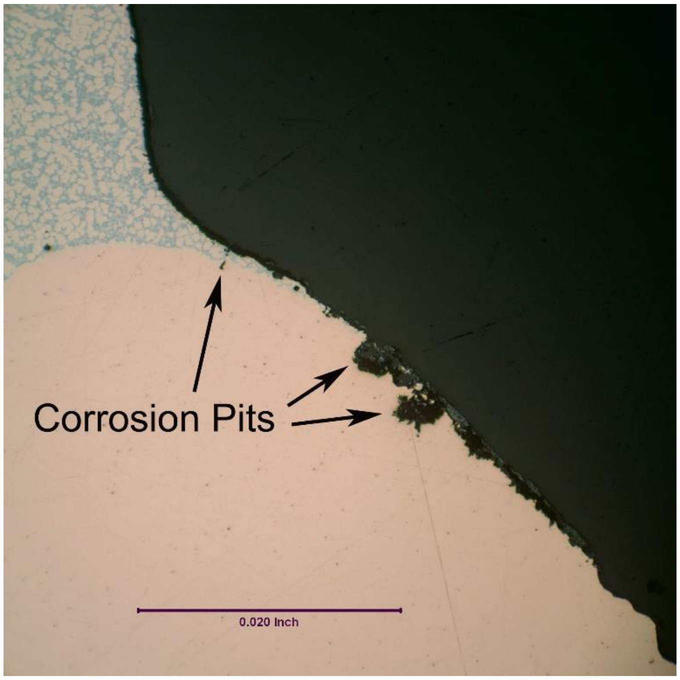

Figure 16 – 100X Corrosion Pits

The inside diameter of the braze tube section is shown in Figure 16. There were corrosion pits at the interface of the braze metal and copper tubing. These pits were likely the result of galvanic corrosion, where the copper is the anode to the cathodic braze metal. This means that the water in the system was electrically conductive, indicating that the water was very contaminated.

Conclusion

In following the evidence, the cause of failure was determined to be extensive erosion, corrosion, and some cavitation on all of the internal surfaces. These types of failures can occur in very short periods of time. Nitrogen and sulfur compounds were associated with the corrosion of the copper tubing and fittings. This heat exchanger failed because of high velocity water flowing in the system which resulted in erosion and cavitation, and the presence of nitrogen and sulfur compounds that were corrosive to copper. No evidence of any manufacturing defects was found.