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Case Study: Residential Heat Exchanger Failure

By

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Subject

Examination of return bends from a large residential heat exchanger to determine cause of the heat exchanger failure. The return bends were examined by visual examination and metallographic examination. A water analysis was supplied as reference information. The water analysis showed significant levels of nitrates at 3.7 mg/l, sulfates at 25.5 mg/l, and chlorides at 31.4 mg/l. The report indicated the pH of the water was 6, which is acidic. Nitrates, sulfates, and pH at the levels found are corrosive to copper and copper alloys. The presence of chlorides complicated the situation.

Visual Examination

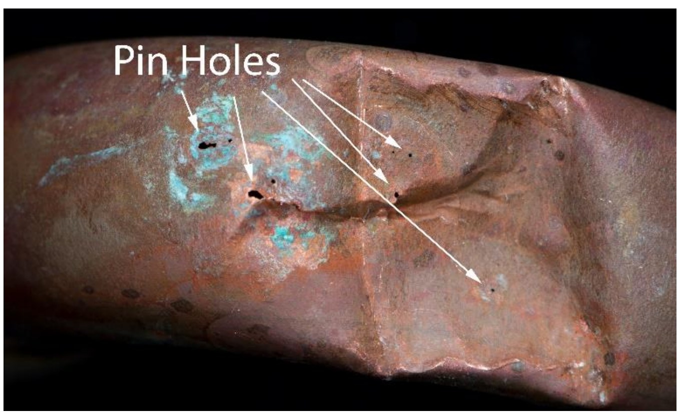

Figure 1 – Pin Holes in Return Bend

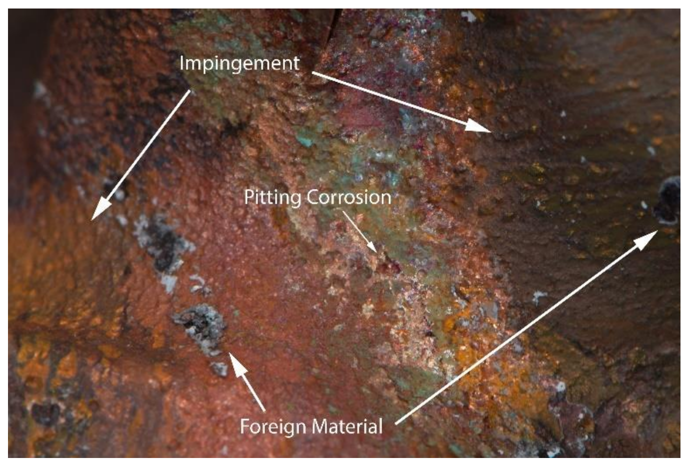

Figure 2 – Inside Diameter of Return Bend

Figure 1 shows the outer surface of a return bend. There were five pin holes present, and the wall thickness of the copper tubing had been thinned sufficiently to make it easily deformed, as shown in the photo.

Figure 2 shows the inside of a return bend that had been cut open. There were gray-black deposits of an unknown foreign material present. There was clear evidence of impingement, which is caused by a mixture of a fluid and a solid or gas when there is turbulent flow present. There was pitting corrosion present, which was likely the result of the high sulfate concentration and the acidic water conditions.

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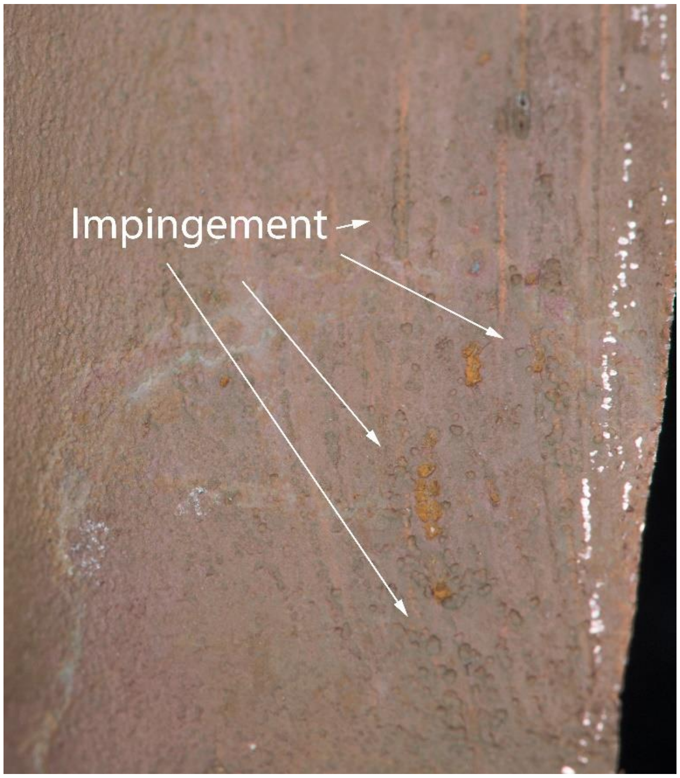

Figure 3 – Impingement on Return Bend I.D.

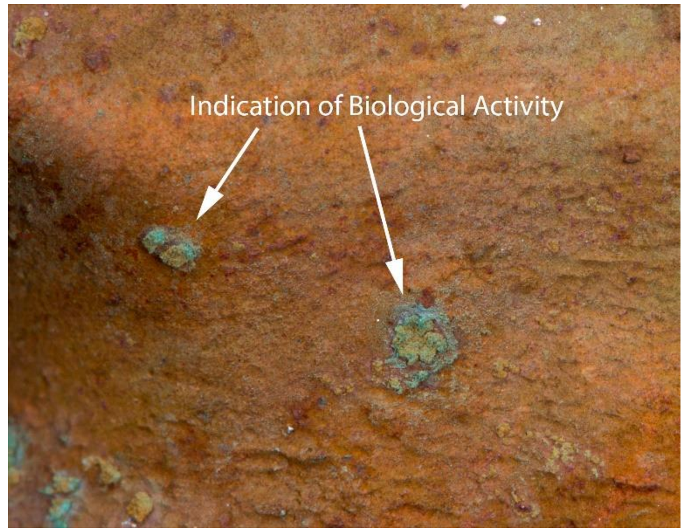

Figure 4 – Indication of Biological Activity on I.D. of Return Bend

Figure 3 shows impingement and a flow pattern in the inside diameter of another return bend.

The mounds of blue-green material, Figure 4, are typical of the mounds formed by sulfur reducing bacteria on copper tubing in an environment of cold water containing sulfates and chlorides. The mounds formed during periods of time when there was low flow or the water was stagnant in the heat exchanger.

The visual examination showed that there were at least four active corrosion mechanisms occurring in the heat exchanger: impingement (erosion corrosion), deposits of foreign material, pitting corrosion, and biologically induced corrosion. Any of these four mechanisms were likely to cause premature failure of the heat exchanger.

Metallographic Examination

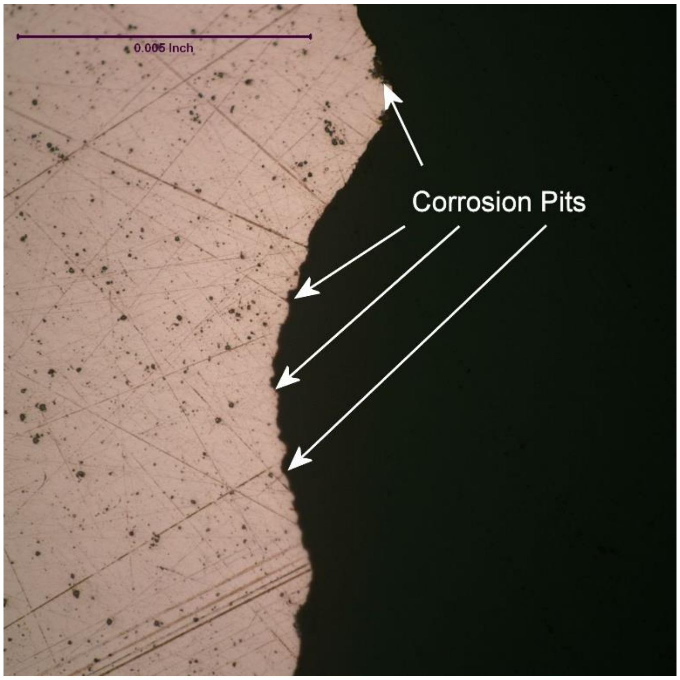

Figure 5 – 400X Erosion Pit with Pitting Corrosion

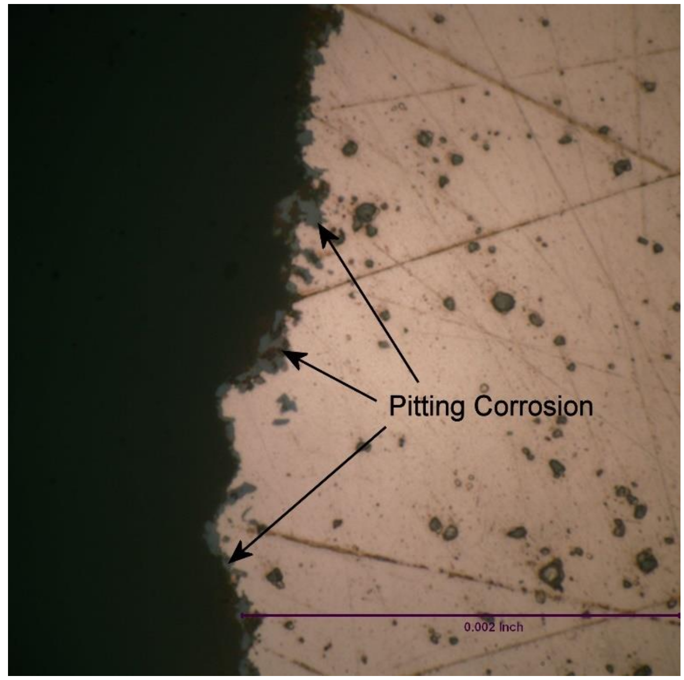

Figure 6 – 1500X Pitting Corrosion, Return Bend I.D.

Figure 5 shows an erosion pit on the inside diameter of a return bend. The shape of the pit indicates that the direction of water flow was from the top to the bottom of the photo. Besides erosion, there was pitting corrosion occurring on the eroded surface. Figure 8 shows the development of the pitting corrosion at a higher magnification.

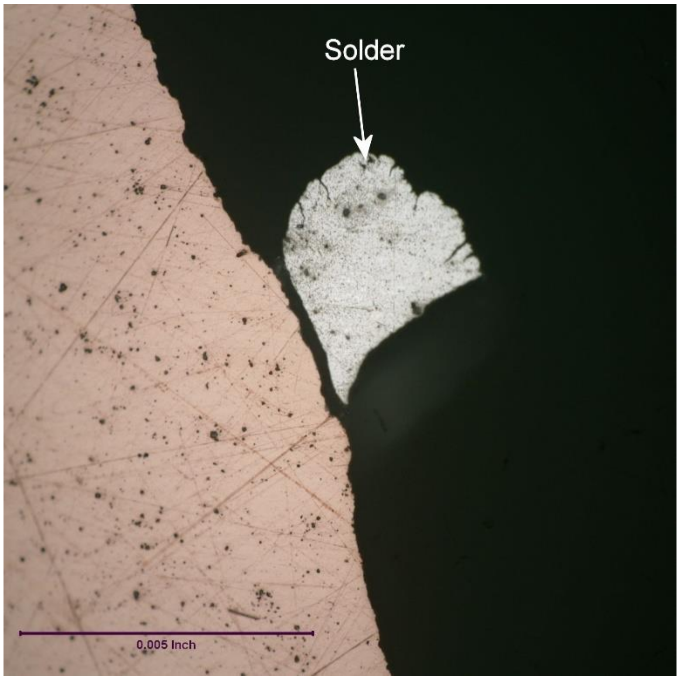

Figure 7 – 400X Solder on I.D. of Return Bend

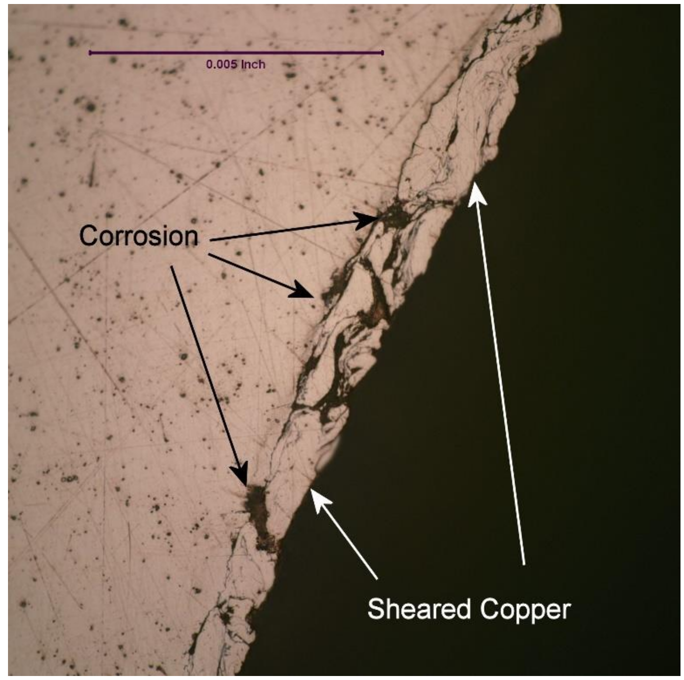

Figure 8 – 400X Sheared Copper on O.D. of Return Bend

The piece of solder, shown in Figure 8, should not have been there. Foreign materials such as solder can initiate corrosion, and are an indication of poor quality workmanship, either in the heat exchanger or elsewhere in the plumbing system.

The shear material shown on the outside diameter of the return bend tubing and the inside diameter of the return bend indicated poor quality workmanship in the forming of the return bend. The shear material trapped contaminants, and resulted in corrosion starting on the outside diameter of the return bend tubing.

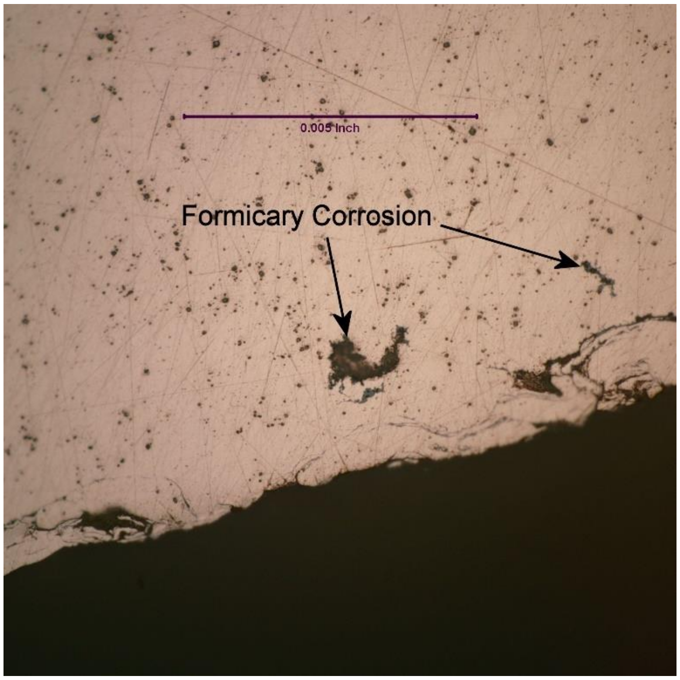

Figure 9 – 400X Formicary Corrosion Return Bend Tube O.D.

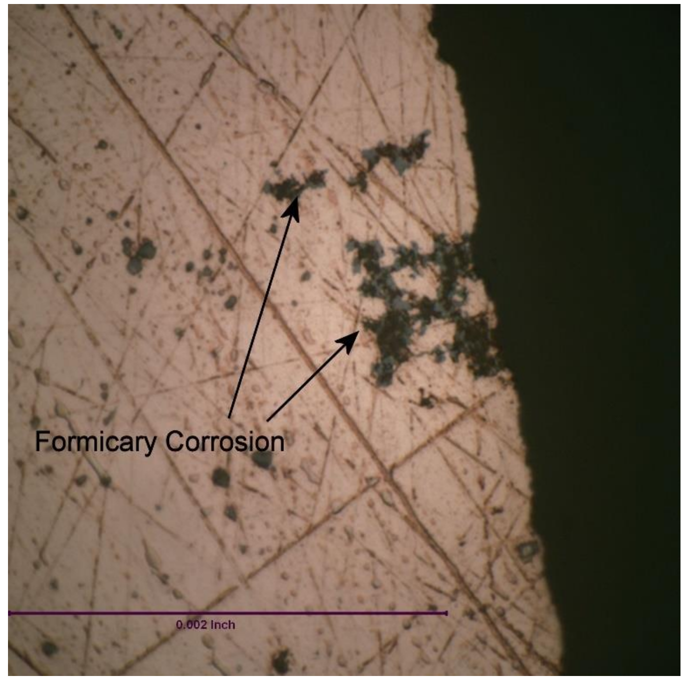

Figure 10 – 1500X Formicary Corrosion Return Bend Tube O.D.

There were clear indications of formicary corrosion on the outside diameter of the return bend tubing. Figures 9 and 10 show the beginning of formicary corrosion on the outside diameter of the return bend. There was a significant number of locations where formicary corrosion was observed, indicating some of the leaks in the heat exchanger were the result of formicary corrosion. The most likely cause of the formicary corrosion was the decomposition products of a POE oil used in the forming process of the return bends. This heat exchanger was defective at the time of manufacture.

The metallographic examination revealed that there was pitting corrosion associated with the impingement on the outside diameter of the return bend tubing; there was shear material associated with corrosion on the outside diameter of the tubing used for the return bend; there was formicary corrosion on the outside diameter of the return bend tubing; and there was solder on the inside diameter of the tubing.

Conclusions

1. The water used in the heat exchanger was corrosive to copper and copper alloys because of the high levels of nitrates, sulfates, chloride, and the acid pH. The water also contained
2. particulate matter, as shown in Figure 3, which contributed to impingement, or erosion corrosion. If no other factors were involved, the water problems were sufficient to cause premature failure of the heat exchanger.
3. The visual examination showed the presence of impingement (erosion corrosion), foreign material, pitting corrosion, and biological activity, most likely in the form of sulfur reducing bacteria. The impingement was the result of particulate matter in the water, combined with turbulent flow. The turbulence was the result of excessive velocity of the water in the heat exchanger. The blue-green mounds formed during periods of low flow rates and stagnant conditions.

4. The metallographic examination confirmed that both impingement and pitting corrosion were occurring on the inside diameter of the heat exchanger tubing. The examination also showed that there were manufacturing defects associated with the failed heat exchanger. The manufacturing defects were shearing of tubing material on the inside diameter of the return bends, and the apparent use of POE oil during manufacturing of the heat exchanger. These defects resulted in pitting corrosion and formicary corrosion starting on the outside diameter of the heat exchanger tubing.
5. The metallographic examination confirmed that there were solder particles in the system. These particles could have trapped materials that resulted in corrosion.

Recommendations

Based on the findings of this evaluation, I recommended that this heat exchanger be replaced with a heat exchanger fabricated from 316L stainless steel. There are potential problems even with 316L stainless steel, and these are: (1) the chloride levels are high enough to result in stress corrosion cracking, and (2) deposits of foreign material are likely to cause oxygen depletion corrosion. A heat exchanger with at least one cleanout header would help to reduce oxygen depletion corrosion.