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Case Study: Steam Coil Failure

By

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Subject

Examination of ½ inch schedule 160 steel tubing removed from a steam coil to determine the cause of leaking. The tubing was examination by visual examination, hardness testing, and metallographic examination. I had been informed that standing water was found in the tubing. This is a very good example of how basic metallurgical testing can determine the cause of failure.

Visual Examination

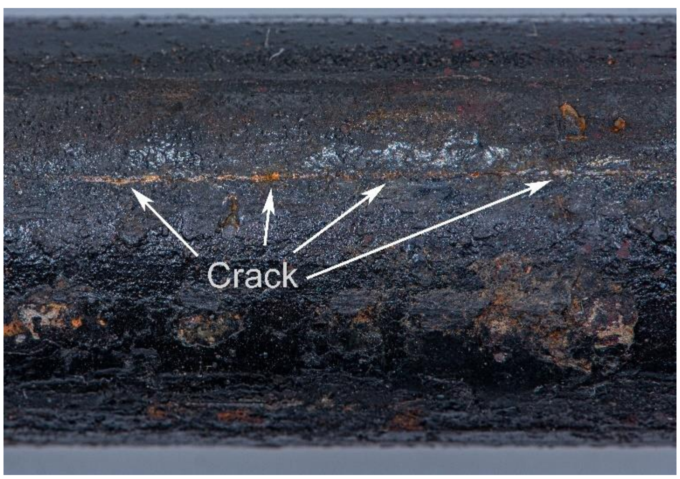

Figure 1 – Crack on Outside Diameter of Tube

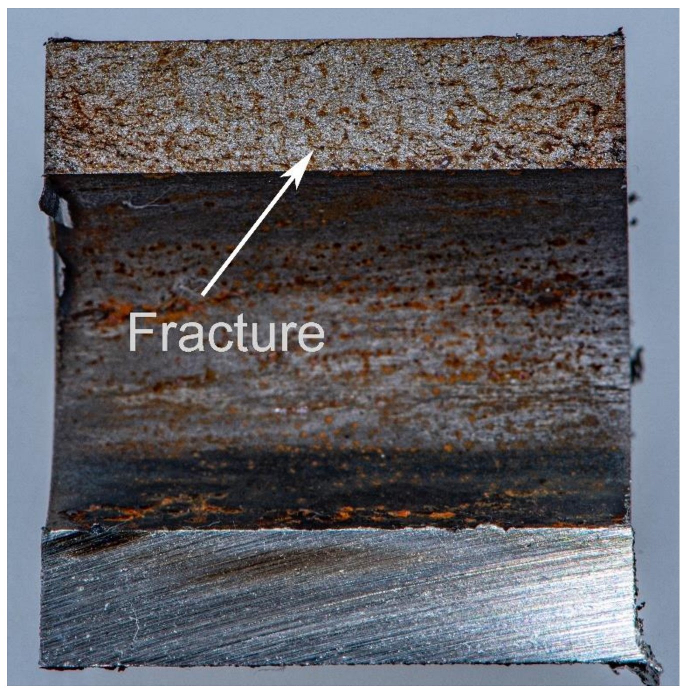

Figure 2 – Flat Fracture Surface

Figure 1 shows the barely visible crack on the tube surface. Figure 2 shows the fracture surface after the tube had been opened up. There was a small amount of rust on the fracture surface. The fracture surface was flat with no shear lips, and there were shiny specks on the surface. These two characteristics are associated with cleavage fracture, which is a brittle fracture mode typically associated with high strain rate or fracturing below the ductile brittle transition temperature.

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Hardness Testing

The hardness testing was done according to ASTM E384, using a Vickers indenter and a 500 gram load. The result of the testing is given in the table that follows.

Hardness Test Data Cracked Tube **(Brinell Hardness Number)**					
Location	Vickers	STD DEV	MAX VALUE	MIN VALUE	HARDNESS
Tube Core	222.00	5.22	230.00	216.00	222.00 BHN

The hardness reported on the mill test certification was between 162 to 165 BHN. The cracked tube tested 222 BHN. This is a significant difference that is greater than expected, even though different hardness testing methods were used. The hardness was rechecked using a Knoop indenter and was determined to be 228 BHN.

Metallographic Examination

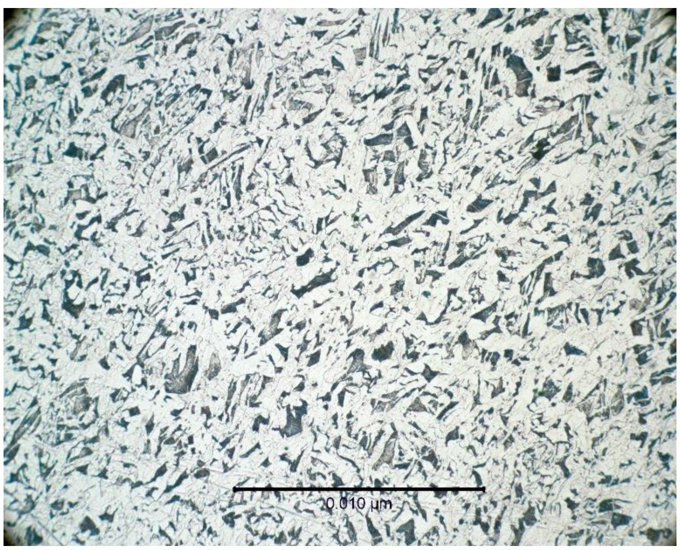

Figure 3 – 200X General Microstructure

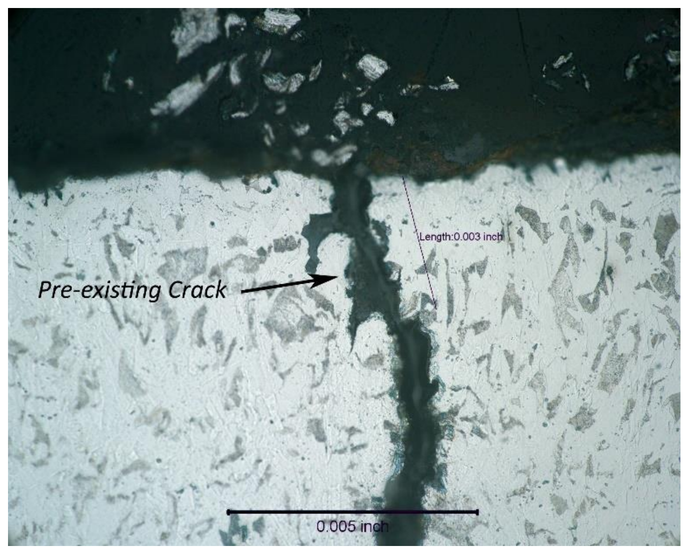

Figure 4 – 400X Fracture Origin

The general microstructure of the tube steel is shown in Figure 3. The white areas are ferrite and the dark areas are pearlite. The microstructure is 30% pearlite and pearlite is 0.627% carbon. The steel contains approximately 19% carbon, which corresponds with the composition of the steel indicated in the mill certification. The microstructure is typical of a hot finished, cold worked steel. Hot finished, cold worked steels are more susceptible to cleavage fracture than cold finished annealed steels.

The fracture origin was on the inside diameter of the tubing, shown in Figure 4. There was a seam approximately 0.003 inch deep at the location shown. There were several other locations on the inside diameter of the tubing where the failure could have begun. These location are shown in Figures 5, 6, and 7.

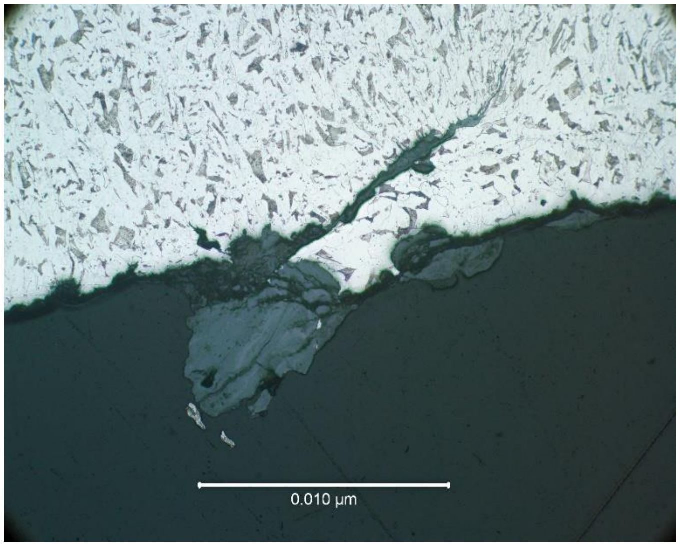

Figure 5 – 200X Seam, Tube I.D.

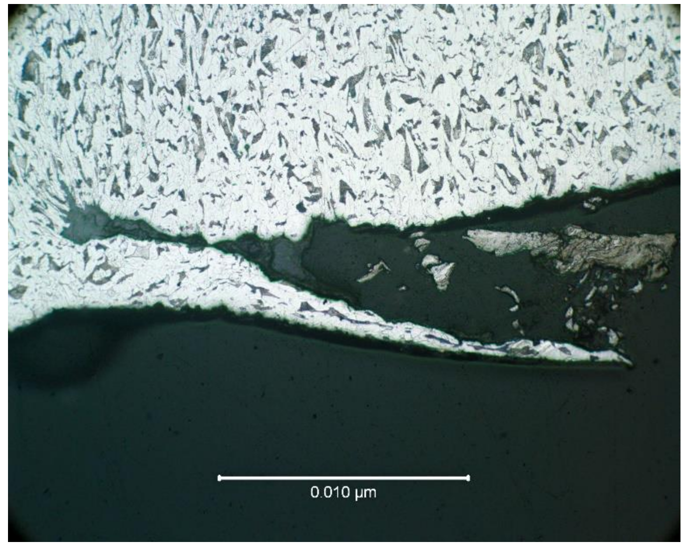

Figure 6 – 200X Seam, Tube I. D.

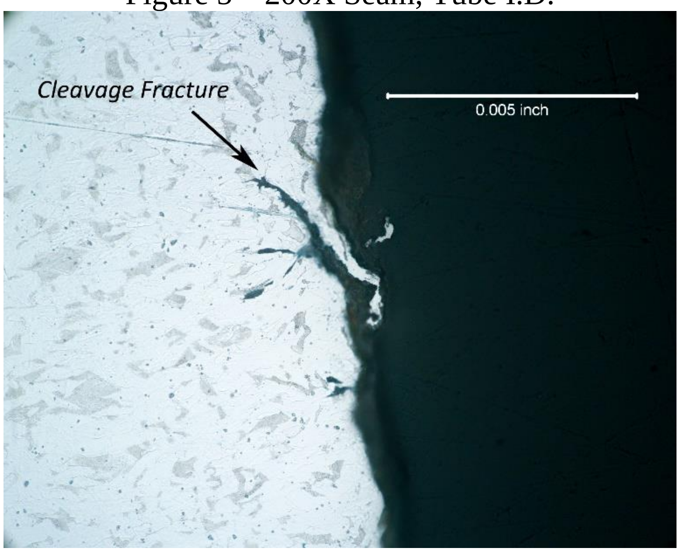

Figure 7 – 400X Seam, Tube I.D. with Cleavage Fracture

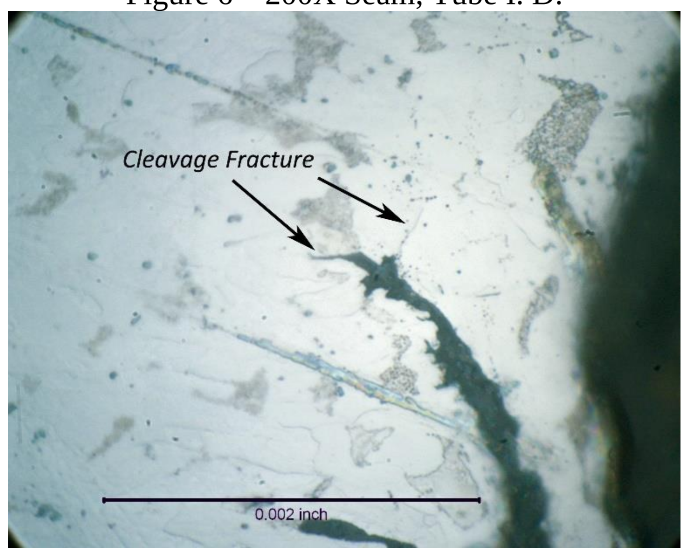

Figure 8 – 1500X Initiation of Cleavage Fracture in Seam, Tube I.D.

Figure 8 shows the seam shown in Figure 7, at higher magnification. The presence of transgranular cleavage is shown at the end of the seam. Transgranular cleavage is caused by high strain rate loading when the temperatures are below the ductile brittle transition temperature. The ductile brittle temperature in plain carbon steels is controlled by the manganese content. For this steel, manganese content was 0.758%. The ductile brittle transition temperature was approximately 32^{o} F or 0^{o} C. Freezing water would have caused cleavage fracturing of this tube. Transgranular cleavage fracture occurs at 50% of the yield strength of the steel, and shows no evidence of dimensional changes in the surrounding material. Figure 9 shows transgranular cleavage along the fracture.

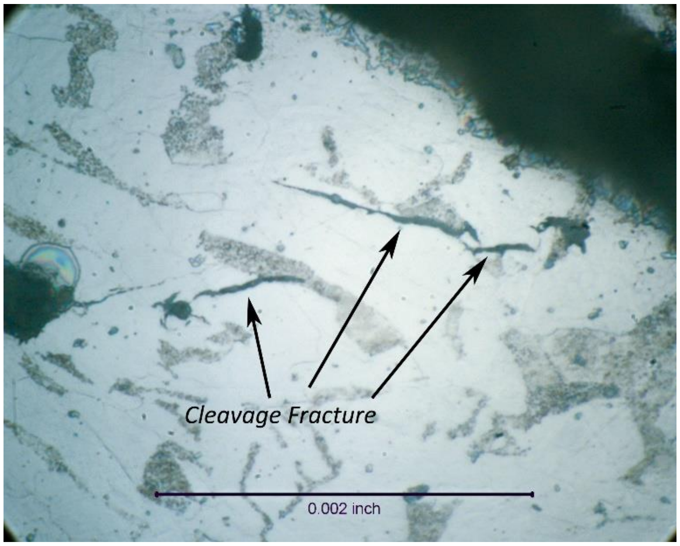

Figure 9 – 1500X Transgranular Cleavage along Fracture

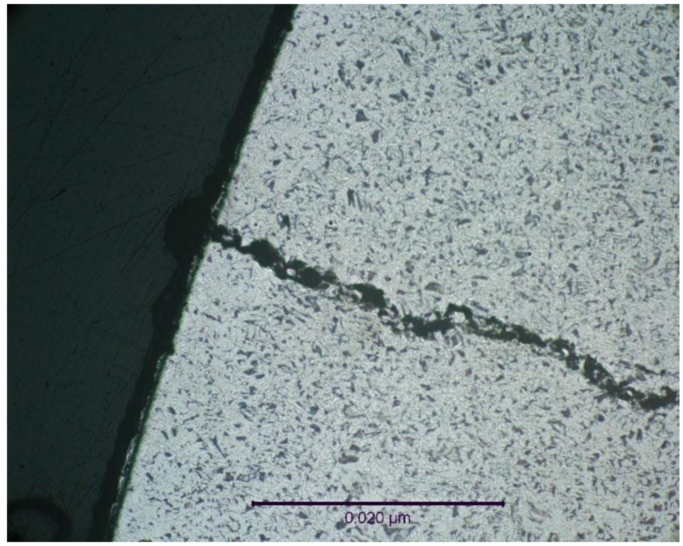

Figure 10 – 100X Fracture at Tube O.D.

Figure 10 shows where the crack in the tubing is exiting on the outside diameter of the tubing. There is no evidence of a shear lip present. The more ductile the steel, the greater the size of the shear lip. This steel had no ductility at the time of fracture.

The steel tubing used was acceptable for its intended use in a steam coil where temperatures are above the ductile brittle transition temperature.

Conclusions

1. The tube failed by transgranular cleavage at a temperature below the ductile brittle transition temperature. The failure was caused by freezing water in the tube.

2. The steel tubing was acceptable for a steam coil which is not exposed to freezing temperatures.