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Failure Analysis of Aluminum Condenser Coil

By

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Subject

Examination of a Condenser Coil Large 38mm Header to determine the cause of failure of the header port cup. The header and header port cup were a brazed aluminum assembly. This aluminum condenser coil was used as part of a mobile refrigeration unit. The header port cup was examined by visual examination, hardness testing, scanning electron microscopic examination, fracture mechanics, and metallographic examination.

Visual Examination

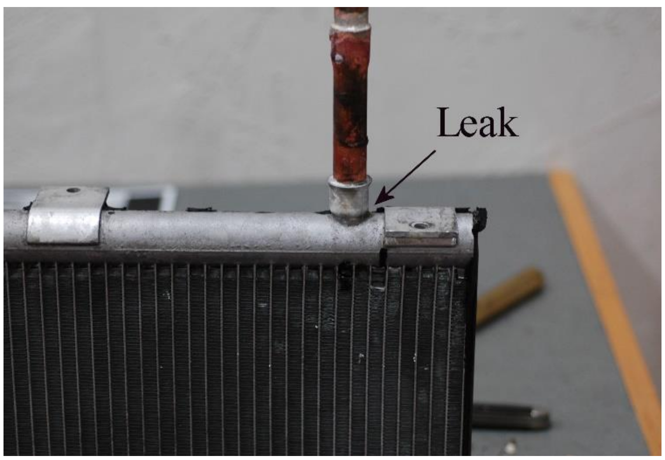

Figure 1 – Condenser Coil Leak Location

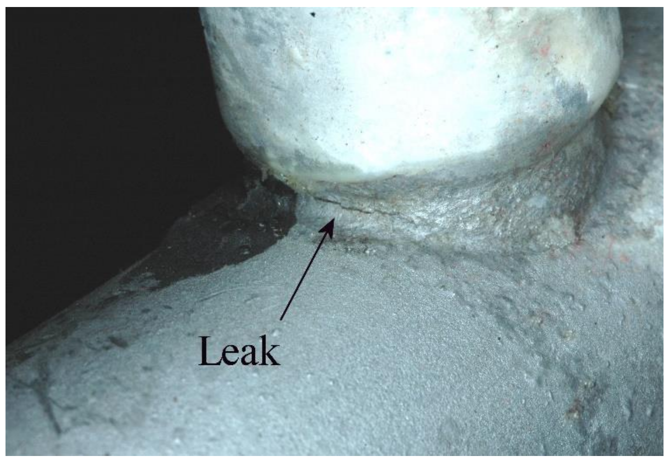

Figure 2 – Leak Location

Figure 1 shows the location of the condenser coil leak. The leak was around the brazed base of the 23mm O.D. header port cup. Figures 2 and 3 show the leak locations.

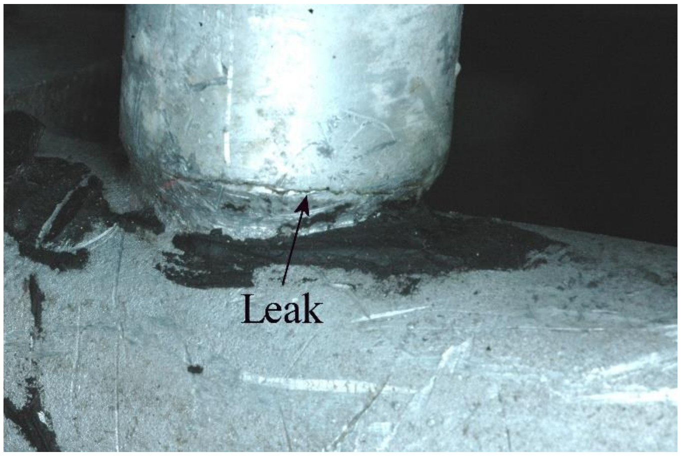

Figure 3 – Crack Associated with Leak

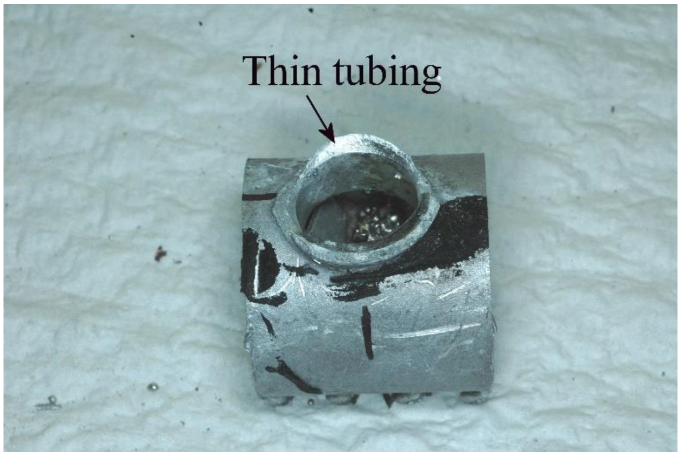

Figure 4 – Header Side of Crack

Figures 4 and 5 show the cracked port fitting opened up to show the fracture surfaces. Examination of the header port cup indicated that the tube was formed by expanding aluminum tubing from its original diameter to form a cup to accept the copper tubing. The expansion of the aluminum tubing did not appear to be uniform, and one side was thinner than the other. The thin area broke by ductile fracture.

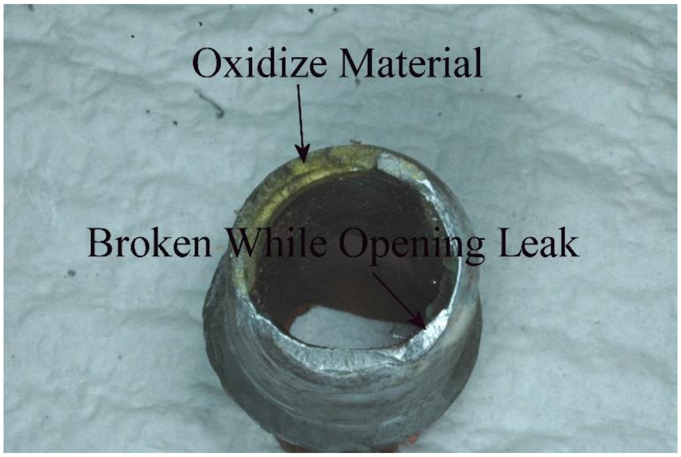

Figure 5 – Tube Side of Crack

Hardness Testing

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

Hardness Test Data				
Location	VICKERS	STD DEV	MAXIMUM	MINIMUM
Base	39.80	1.39	41.50	38.10
Thick Expanded	39.70	0.72	40.80	38.90
Thin Expanded	53.10	3.24	58.40	50.00

The testing was done to determine the hardness of the port cup material at various locations. The hardness was essentially identical in two of the locations. Hardness of ~40 Vickers indicates that the aluminum is O temper, and if the aluminum alloy was 1100, the yield strength is 5000 psi and the endurance limit is 5000 psi. The thick area is where intergranular facture and fatigue had occurred. The thin expanded location was near the ductile fracture area. There was work hardening in that location due to the ductile fracture, as indicated by the increase in Vickers hardness.

Scanning Electron Microscopic Examination

Figure 6 shows the intergranular fracture. The smoother faces appear to have been the result of localized melting. Localized intergranular melting would have reduced the strength of the header port cup even further. The presence of localized melting indicates that the brazing temperature was too high.

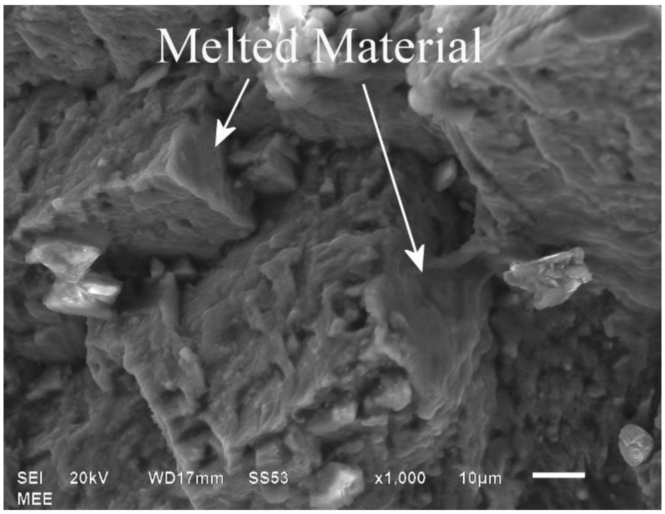

Figure 6 – 1000X Grain Boundary Melting and Intergranular Fracture

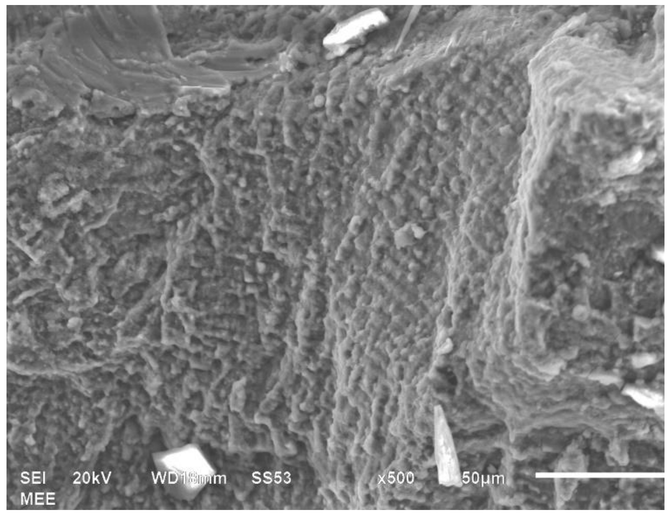

Figure 7 – 500X Fatigue Striations

Figure 7 shows fatigue striations. The spacing on the striations shown is 1.30X10^{-4} inches.

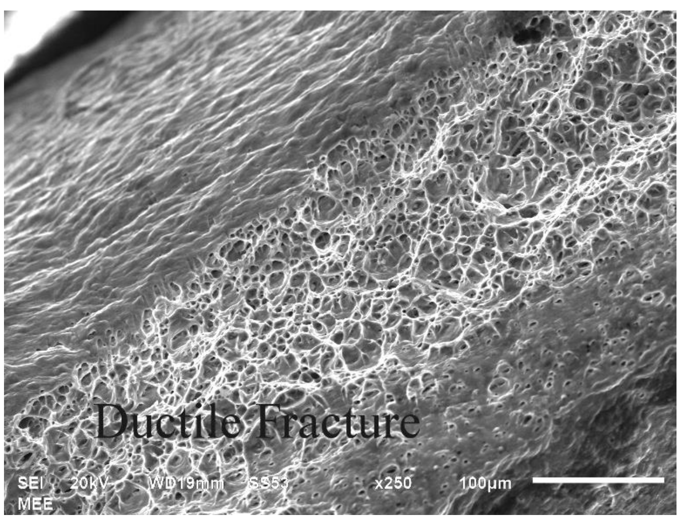

Figure 8 – 250X Ductile Fracture

The ductile fracture is shown in Figure 8. This is an excellent example of cup-cone fracture. This area was very clean, and the fracture, which occurred last, could have occurred during removal of the condenser.

The scanning electron microscopic examination showed the presence of intergranular fracture, grain boundary melting, fatigue, and ductile fracture.

Fracture Mechanics

Fracture mechanics can be used to estimate the stress levels that were on the parts at the time of fracture. Knowing the location and spacing of the fatigue striations permits the estimation of the cyclic fatigue stress by the following equation: $\Delta\sigma = \frac{E\sqrt{\frac{spacing}{6}}}{Y\sqrt{a}}$. The terms are defined below:

$\Delta\sigma$	The applied cyclic stress.
E	The modulus of elasticity equal to 10,000,000 psi for aluminum alloys.
a	The distance the fatigue striations progressed from the fracture origin.
Y	A constant equal to 2.1. It is defined by the shape of the crack.

The value for a was found to be 0.077 inches.

The estimated cyclic stress for the striations shown in Figure 7 is 54,300 psi. The aluminum used in this assembly cannot support this much cyclic stress. The actual applied stress was far in excess of the strength of the material used for the cup. Aluminum alloys are very sensitive to failure by fatigue and this sensitivity needs to be accounted for in the design and manufacturing of aluminum components.

Metallographic Examination

The magnification shown for the photos is the magnification at which the photos were taken. The photos shown in this report may be smaller or larger in size than the originals.

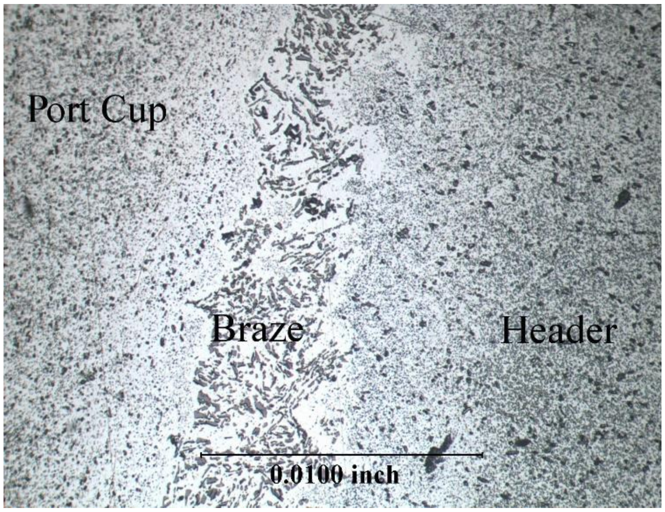

Figure 9 – 200X Braze Joint

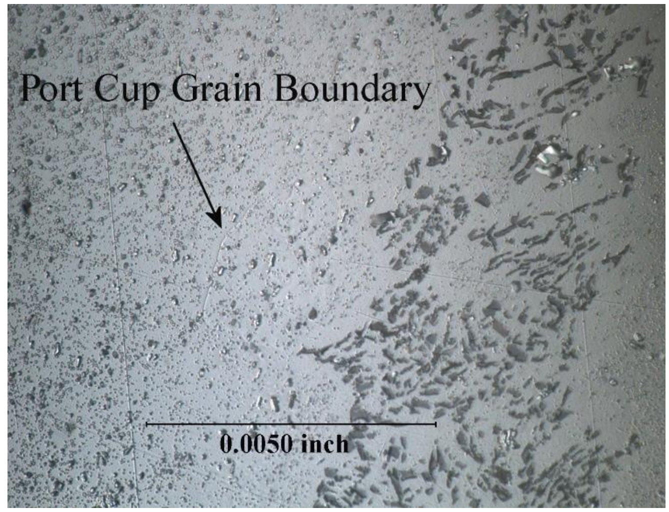

Figure 10 – 400X Port Cup Grain Boundary

Figure 9 shows the braze joint between the header port cup, to the left hand side, and the header, to the right hand side. There is a difference in alloys used for the header port cup and header tube. This is indicated by slight differences in the microstructure of the header tube and cup material.

The grain boundaries of the header port cup and header aluminum were enhanced in the area of the braze metal, Figure 10. The likely cause of the melting shown in Figure 10 was diffusion of alloying elements from the braze metal along the grain boundaries.

The minimum wall thickness of the header port cup is specified to be 1.65mm. The dimensions in each of the Figures are likely overstated because the cross sections were not exactly perpendicular to the cup port diameter. Figure 11 shows a variation of the thickness, between 1.80mm and 1.35mm, in the formed area. There was thinning of the header port cup that resulted during forming of the cup. Based on the hardness data and assuming 1100 aluminum alloy, the force required to cause failure of the header cup port was under 26 pounds.

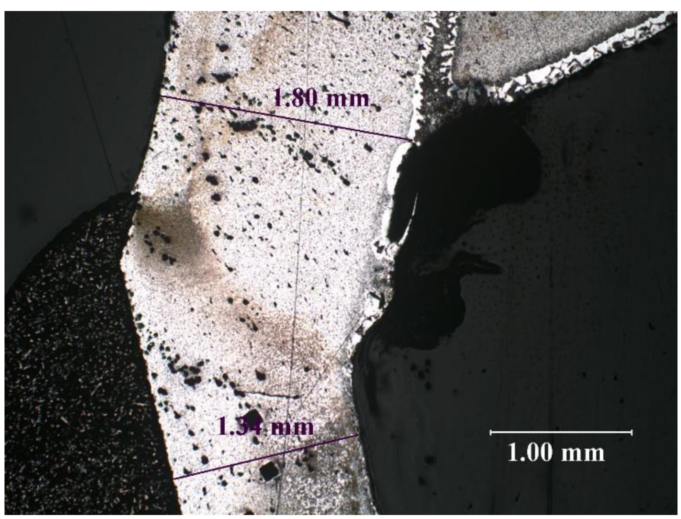

Figure 11 – 25X Wall Thickness of Header Port Cup Intergranular Fracture Area

Conclusions

1) The cause of failure was cyclic stress in excess of the endurance limit of the aluminum alloy cup. The cyclic stress that was applied to the header port cup during operation of the refrigeration unit was not considered. This was a design error.

2) The cup was also weakened by grain boundary melting, and non-uniform expansion during the forming of the cup. Failure to control material thickness and brazing temperature were major contributing factors to the failure of the condenser.