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FRACTURE OF HEAT EXCHANGER COPPER TUBES

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

A fractured copper tube from an air liquefier was received to determine the cause of failure.

Examination showed that the fracture gave indications of both fatigue and corrosion damage. While corrosion fatigue is proposed as a fracture mechanism, there are certain anomalies, and the possibility of corrosion damage after fatigue fracture cannot be ruled out.

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INTRODUCTION

In September, 1964, L'Air Liquide Canada Ltée provided samples of failed copper tube from an air liquefier for examination. These tubes had failed at the point where they were brazed onto a manifold, and it was suspected that the failure was related to the brazing operation, in particular, hydrogen embrittlement.

Examination of these tubes, which was carried out in the presence of the L'Air Liquide representatives and not reported formally, indicated that the failures were in fact due to fatigue, and were not associated with the brazing operation. It was suggested that because of vibration in the tube bundle and the possibility of certain sections developing resonant frequency, failure would occur at the points of maximum flexure, in this instance where the tube is joined to the stiff manifold.

Subsequent to this, in April 1965, additional failed tubes were supplied for examination. These failures had been produced deliberately on a machine designed to simulate the possible flexure in the tube bundle, so that these failures were known to have been caused by fatigue. Examination of these fractures showed that they had the same general characteristics and occurred in the same place as those experienced in the air liquefier. This supported the conclusion that the original failures were due to fatigue.

On August 20, 1965, yet another failed tube was received for examination, together with a covering letter which stated that this came from a heat exchanger (air liquefier) that had been operating at -300°F for four years with a warm-up period every three weeks. The failure had occurred in 3/8 in. OD x .035 in. wall copper tube to ASTM specification B111, and was located at the first solder tack attaching the tube to the wound bundle. The other end of the tube was held in the tube sheet, giving an unsupported length of about 14 in.

VISUAL EXAMINATION

The general region of the fracture is shown in Figure 1. It will be seen that the fracture is of the brittle type and that, at least in the "as-received" condition, there had been considerable bending in the unfractured portion, as shown by the wide spacing between the outer edges of the fracture surfaces. The fracture faces were relatively flat and at right angles to the main axis of the tube. A small discoloured lip was present on the fracture surface at a point which could have been the origin of the failure, i.e., diametrically opposite the still unbroken section of the tube.

METALLOGRAPHIC EXAMINATION

A number of longitudinal sections were cut from the tube in such a way as to study various stages of the fracture and also the appearance of the tube behind the fracture. It was found that the fracture appeared more intercrystalline in nature than had been observed with the previous fractures. In order to check this point, specimens from the first failed tubes submitted in September 1964 and from the tubes which were known to have failed by fatigue, were re-polished and re-examined. In general, as noted in the Introduction, these previous fractures showed similar characteristics and, therefore, only the fracture that was known to have been caused by fatigue is considered below.

Two areas of this fatigue fracture are shown in Figures 2 and 3. It is seen that, in general, the fracture appears to be transcrystalline and that there is some crack damage approximately parallel to the main fracture surface.

By comparison, the fracture of the tube supplied in August 1965 is mostly intercrystalline as in Figures 4 and 5. The latter shows a long intercrystalline crack running parallel to the main fracture. This tube fracture also contains intercrystalline cracks at right angles to the main fracture (Figure 6). It should be mentioned that the grain size of this tube is considerably smaller (0.035 to 0.045 mm) than in the previous material (0.035 to 0.090 mm) so that it is more difficult to determine whether the fracture path is intercrystalline or transcrystalline. A further disturbing feature is the fact that there are a number of cracks on the inside wall of the tube a short distance from the main fracture in the region which was taken to be the origin of the failure. These cracks, one of which is shown in Figure 7, are mostly intercrystalline, although they may be transcrystalline along some part of their length.

It will be appreciated that the internal intercrystalline cracks shown in the above photomicrographs may have been widened somewhat by the etching procedures used. However, they were quite apparent in the as-polished condition.

CHEMICAL COMPOSITION

A ring specimen, cut approximately 2 in. from the main fracture, was analysed by the Analytical Chemistry Subdivision of the Mineral Sciences Division, Mines Branch, Department of Mines and Technical Surveys, and reported in Internal Report MS-AC-65-1029 as containing 0.041% phosphorus. The alloy, therefore, complies with ASTM Designation B 111 as mentioned in Mr. Schneller's letter of August 20, 1965.

DISCUSSION

Because of certain anomalies in the appearance of the fracture, it is not possible to define the cause of failure in terms which will satisfactorily account for all the observed phenomena. However, certain points have been established:

(a) The failure occurred at the first solder tack of the wound tube bundle, thus giving an unsupported pipe length of approximately 14 in.

(b) The heat exchanger was operating at -300°F for four years with warm-ups every three weeks.

(c) Tubes failed by fatigue showed similar superficial fracture characteristics to the one under examination.

(d) The main fracture and cracks located in the inside wall of the tube seem to be mainly intercrystalline in this instance, whereas, in the previous cases, cracks were mainly transcrystalline.

(e) The chemical composition of the pipe indicates that it could be susceptible to stress-corrosion cracking in certain media.

It would appear at first that the failure under investigation is a simple fatigue failure caused by vibration of the unsupported length of pipe; failure would then take place where the pipe is rigidly held at the brazed joint, the tube sheet, or at the solder tack at the other end. Examination of failures, which are known to have been caused by fatigue, indicates that the fatigue failures and the fracture under examination are not dissimilar, thus supporting the proposal that the failure is due to fatigue. However, there are several factors against this simple fatigue failure hypothesis.

(a) the fracture appears to be predominantly intercrystalline while previous fatigue failures were predominantly transcrystalline - a more likely mode for fatigue failure.

(b) the sample contained intercrystalline cracks in one area which appeared to start from the inside of the tube.

(c) some areas of the main fracture showed intercrystalline cracks which progressed at right angles to the main fracture, i.e., along the proposed direction of stressing instead of at right angles to it.

While none of these factors are completely inconsistent with fatigue failure, they do suggest that some other mechanism - particularly corrosion - played a part in the failure, and that corrosion fatigue was a possible mode of failure. Thus, a corrosive attack could be intercrystalline, and, in combination with fatigue, could give a failure which had both the intercrystalline fracture and cracks, and the general configuration of a fatigue failure. Against this corrosion hypothesis is the fact that there appears to be no general corrosion on either the inside or outside surfaces of the tube, and the fact that the cracks observed on the inside were only present in one of the ten or so sections prepared from the same tube.

It is also possible, but perhaps unlikely, that the apparent intercrystalline path of the main crack and all the subsidiary cracks were caused by surface contamination subsequent to the fracture. The high phosphorus deoxidized tube which was used is susceptible to stress corrosion cracking in media such as ammonia, so that the highly worked areas in the region of the fracture could show preferential attack. Similarly, solder flux left on the surface of the tube could become moist during warm-up periods and contribute to the attack. The highly local cracks on the inside of the tube cannot be accounted for unless there was some unforeseen spot contamination on the inside of the tube, or some seepage of corrosive media through the crack, which it is assumed propagated from the outside.

In summary, therefore, it may be said that the general form, appearance and location of the fracture are indicative of fatigue failure. The microstructures, while not inconsistent with fatigue failure, strongly suggest a corrosion factor leading to intercrystalline failure. Thus, it is suggested that, in this instance, the failure was due to some form of corrosion fatigue. This assumes that the fracture surfaces were not exposed to strong cleaning solutions or other strongly corrosive media between the time of fracture and the time of examination. If such exposure did in fact occur, then of course the corrosion effects noted could be from this cause, and the failure could be straightforward fatigue as proposed for the previous fractures.

JOE/AC/gm

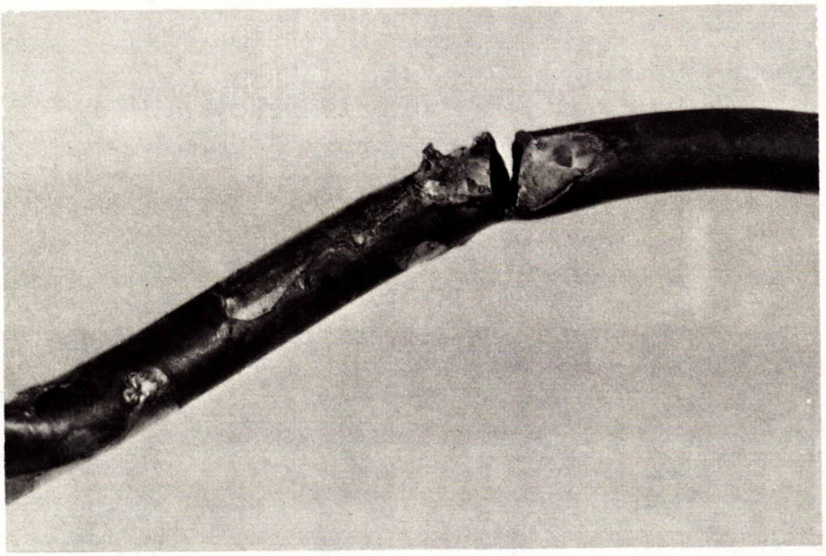
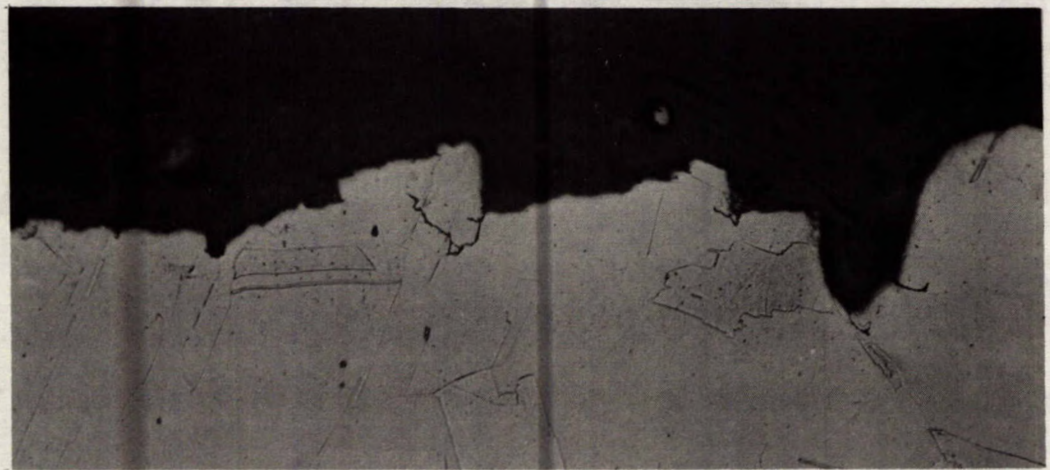


Figure 1. As-received broken pipe.

X 400

Figure 2. Fatigue failure, mainly transcrystalline
Etched in alcoholic ferric chloride.



X 400

Figure 3. Fatigue failure, mainly transcrystalline and
crack damage in adjacent material.
Etched in alcoholic ferric chloride.

X 400

Figure 4. Fracture in last tube is mainly intercrystalline with transcrystalline components. Etched in alcoholic ferric chloride.

X 400

Figure 5. Intercrystalline crack running approximately parallel to main fracture in last tube. Etched in alcoholic ferric chloride.

X 500

Figure 6. Fracture area - main fracture parallel to top of picture. Note intergranular voids. Etched in alcoholic ferric chloride.

X 500

Figure 7. Intercrystalline crack originating in inside wall of pipe and running parallel to main fracture. Etched in alcoholic ferric chloride.