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30 May 2007

Our File: 02454

Baywest Management
300 – 1770 Burrard Street
Vancouver, B.C.
V6J 3G7

Attention: David Parsons
Property Manager

Subject: Metallurgical Examination of Failed 4 inch Diameter Copper Pipe

Dear Sir:

Please find attached our report on our analysis of your failed copper water pipe. We have documented our findings in some detail, considered justified in view of the potential magnitude of the problem.

We draw your attention to the final part of the report: we are exploring methods of identifying and segregating flawed pipe. Etching is one of the methods we are investigating.

Do no hesitate to call if you wish to discuss the above further.

Thank you for this assignment.

Yours very truly,

Victor T. Baker, P.Eng.

/jt

Enclosure

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Metallurgical Examination of Failed 4 inch Diameter Copper Pipe

Our File: 02454

For

David Parsons
Property Manager

Baywest Management
300 – 1770 Burrard Street
Vancouver, B.C.
V6J 3G7

Prepared by: Victor T. Baker, P.Eng.

30 May 2007

Phone: **(604) 879-3585** Fax: (604) 879-6323 E-mail: info@bakereng.ca www.bakereng.ca

1.0 REQUIREMENT

On 11 May 2007, we received for examination one 84 inch (213 cm) and one 114 inch (290 cm) lengths of 4 inch (10 cm) diameter copper pipe. Leaks had developed after a limited period of service. The requirement was to determine the cause.

2.0 ANALYSIS PROCEDURE

a) After initial inspection of the two supplied pipe sections (Figure 1), a detail survey of the surface of each was carried out. The technique was visual supplemented by dye penetrant tests. Photos were prepared of representative discovered flaws.

b) Sections were then cut from the pipe to allow the flaws to be examined in detail. Cracks were broken open and separation surfaces studied using low power stereo microscopy.

c) Sections were prepared for metallographic examination and evaluated on a metallurgical microscope.

d) Qualitative chemical analysis was carried out on a representative specimen sawn from the pipe.

e) Experimental etch tests were carried out.

3.0 OBSERVATIONS

3.1 Surface Features

Figure 2 shows the identification on the failed pipe, "Hong Tai L China ASTM B88" (plus Warnock Hersey stamp, a Canadian testing company). Surface examination of the two pipe samples revealed at least 14 crack flaws*. All displayed similar character: long, irregular and lying generally parallel to the axis of the pipe. Figures 3 to 7 reveal the typical crack features boldly displayed by dye penetrant test technique. Figures 8 to 11 are representative crack surfaces without crack enhancing application.

* Comprehensive recording of all fine scale crack would be a time consuming task which did not appear justified at this time.

The surface manifestation of the cracks revealed a narrow ridge displaying some necking, i.e., ductile elongation of the metal under hoop stress. Evidence that the pipe wall had however been completely perforated by the crack at some locations for a long time is found by the thick build-up of copper oxidation products at two locations (Figures 10 and 11).

3.2 Fracture Features

Representative cracks were selectively broken open, preserving the crack features intact. Figure 12 is representative. Except for a thin strip of tensile failed copper, the entire section is a series of long facets, displaying a faint herringbone surface texture. These are actually the surfaces of hugely elongated grains where normally drawn copper pipe is a fine equiaxed grain structure. Figure 13 shows the same features, much degraded at one of the old corroded crack surfaces.

3.3 Cross Sections

Cross sections revealed under the microscope, jagged cracks penetrating most of the pipe wall (Figure 14).

3.4 Composition

Qualitative chemical analysis gave the results shown in Appendix A. No unusual tramp elements are present. Of primary importance is the complete absence of phosphorous in either analysis of the supplied pipe.

4.0 DISCUSSION

Emerging from our examination is a failure phenomenon which we have previously investigated and analyzed in considerable detail. Huge elongated grains have formed during the manufacturing process of this pipe and these grains are spreading along their interfaces, destroying the integrity of the pipe wall. Every case we have investigated so far has revealed:

- The product is manufactured in China.
- The residual phosphorus level is zero or nearly zero.

- We have been unable to identify any tramp element assignable as causing the huge grains and the separation along the grain boundaries.

Most copper water pipe sold in North America would be specified under ASTM** B88-03, "Standard Specification for Seamless Copper Water Tube." This document is exceedingly limited as regards the composition requirements. Three grades of copper may be used interchangeably under this specification:

- C10200 "Oxygen free without residual deoxidants."
- C12000 "Phosphorus deoxidized, low residual phosphorus."
- C12200 "Phosphorus deoxidized, high residual phosphorus."

There is no explanation by ASTM as to why three grades should exist. For air conditioning (ASTM B280-03), the same three grades are listed, again without discrimination as to application.

The phosphorus is added to react with oxygen in the copper and remove it. Its relevance to preventing the cracking problem is known only from what has been revealed during our analysis work, i.e. where some phosphorus is present the cracking is absent. The copper industry is silent on this pipe cracking phenomenon, in spite of the emerging problems it is creating.

6.0 DEALING WITH THE PROBLEM

It is unlikely that any measure other than removal of the flawed pipe is feasible. Reducing the costs would depend on identifying defective material and removing only these sizes. The following would be worth exploring:

a) Tracing the mill certificates of the suppliers of the various size pipes installed*** and determine if any are non-Chinese.

** American Society for Testing and Materials. A very widely cited institution when materials are specified.

*** We have found the cracking in Chinese copper pipe of all sizes.

b) A non-destructive test of accessible locations to identify defective product. We are working on an etch test which might serve this purpose. Figure 15 is the surface of the defective pipe (your samples). Figure 16 is from a known sound copper pipe, both having the same experimental etch process applied to the pipe surface.

/jt

Report Distribution:
1 client copy

Figure 1.

Figure 2.

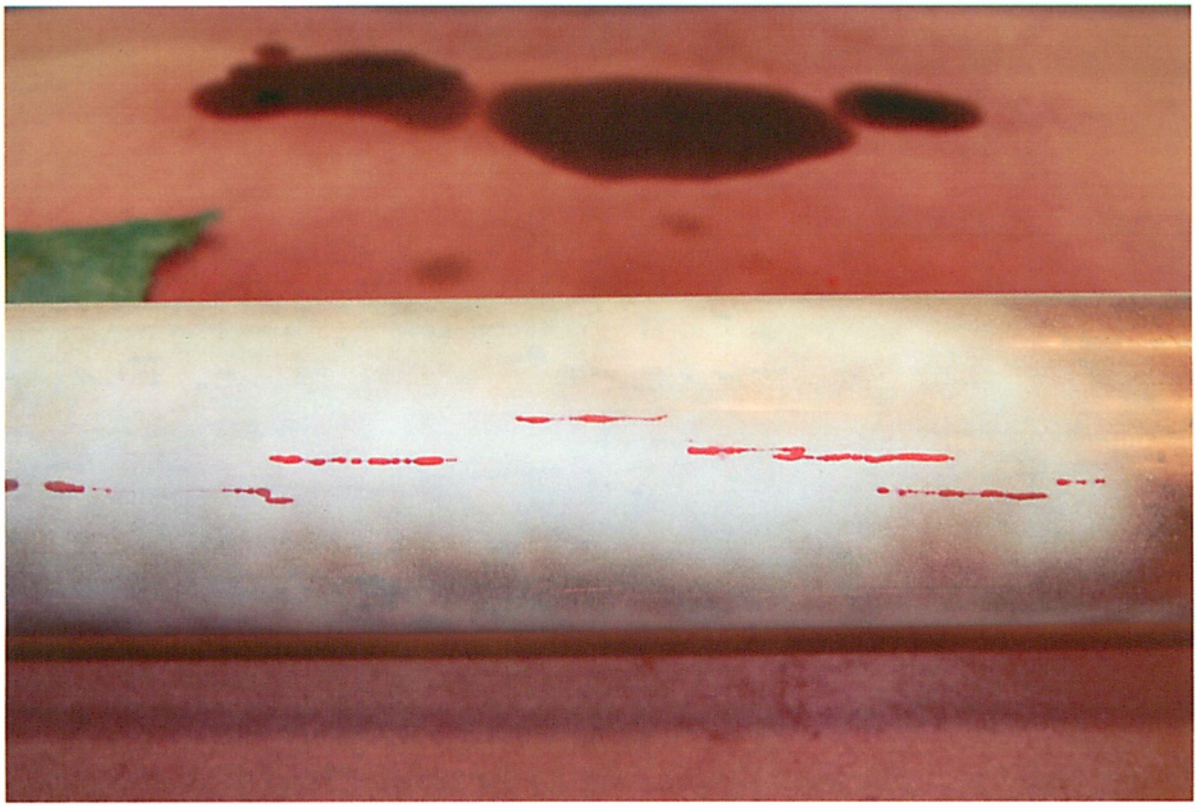


Figure 3.

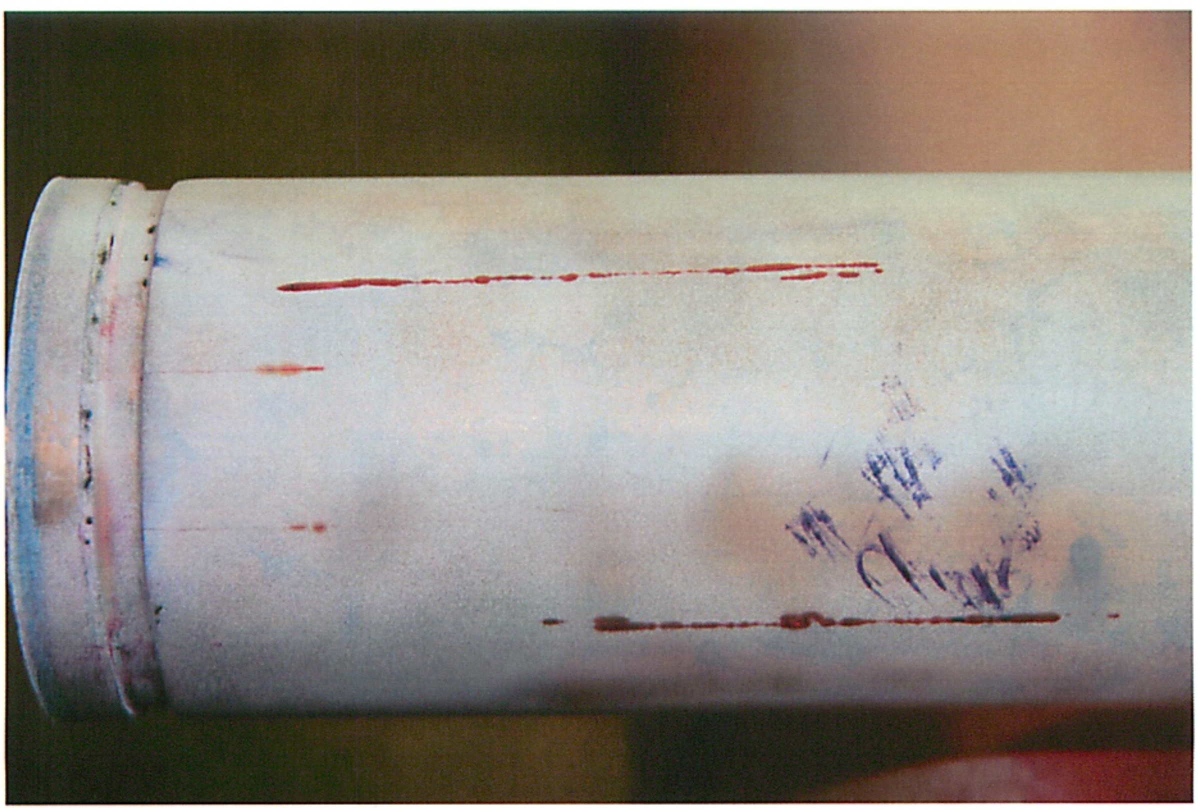


Figure 4.

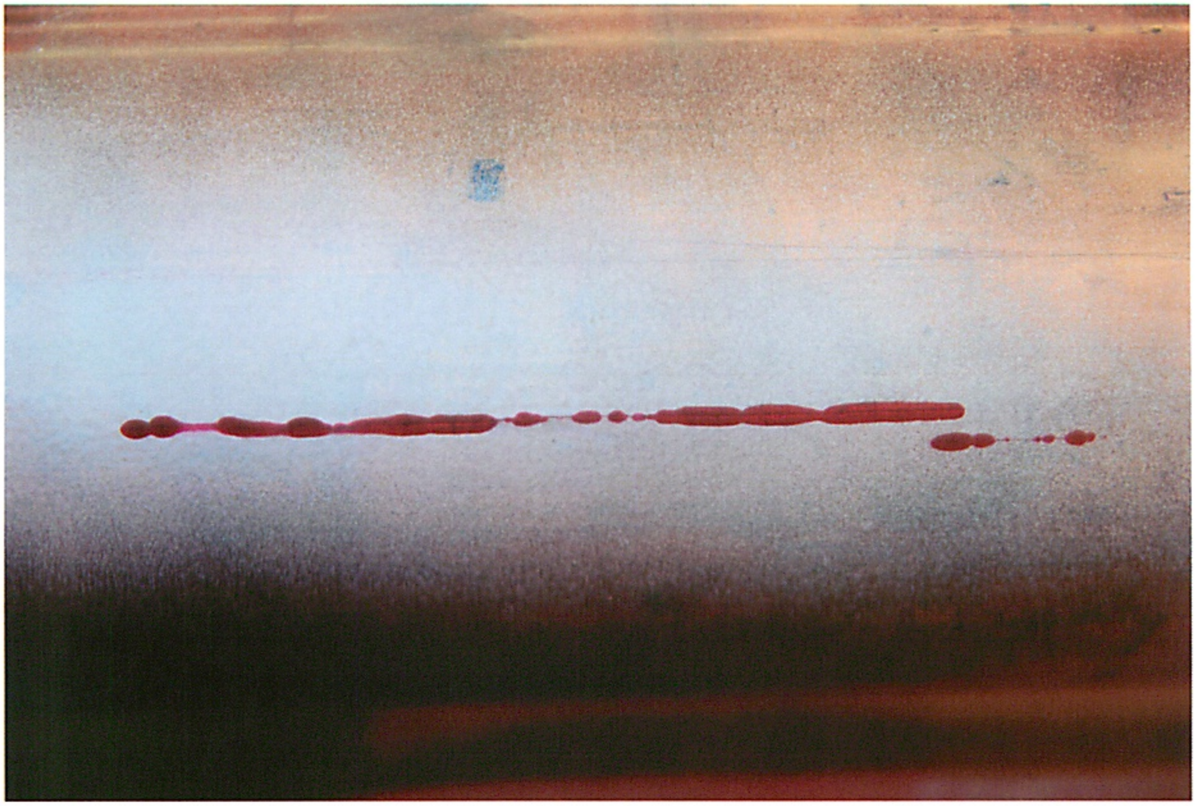
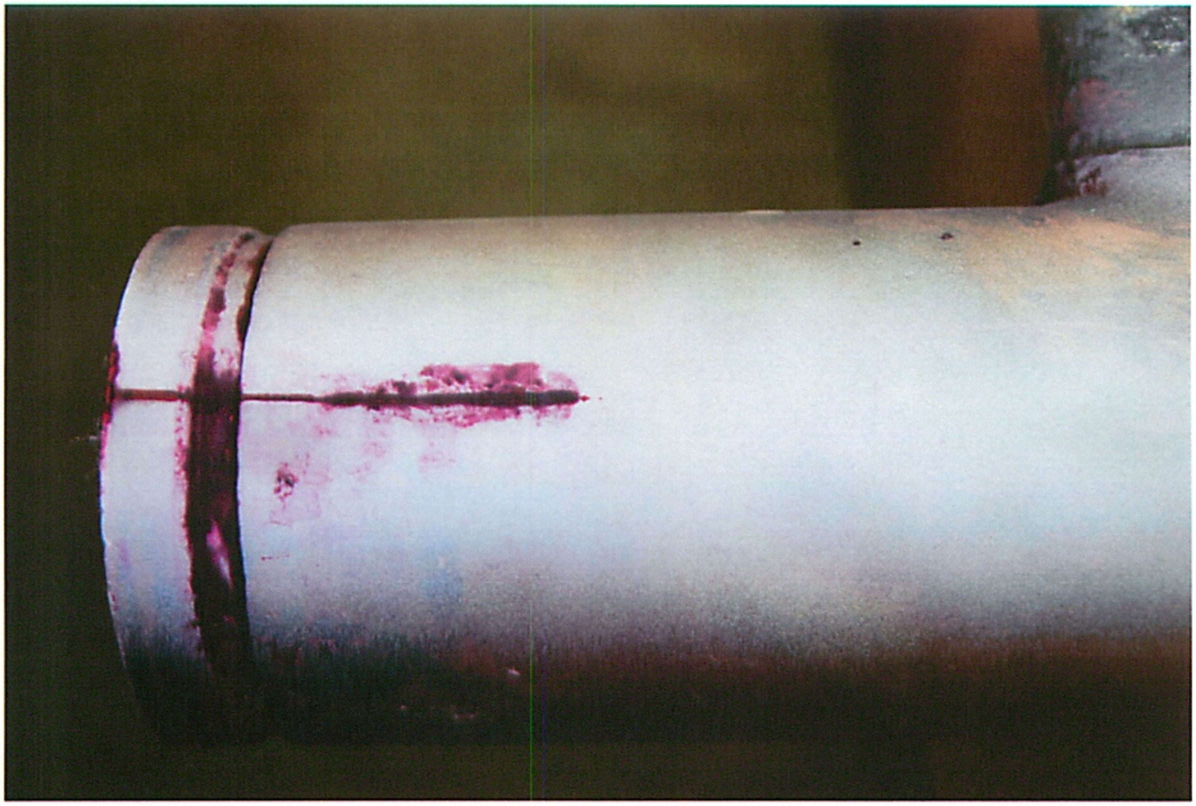


Figure 5.

Figure 6.



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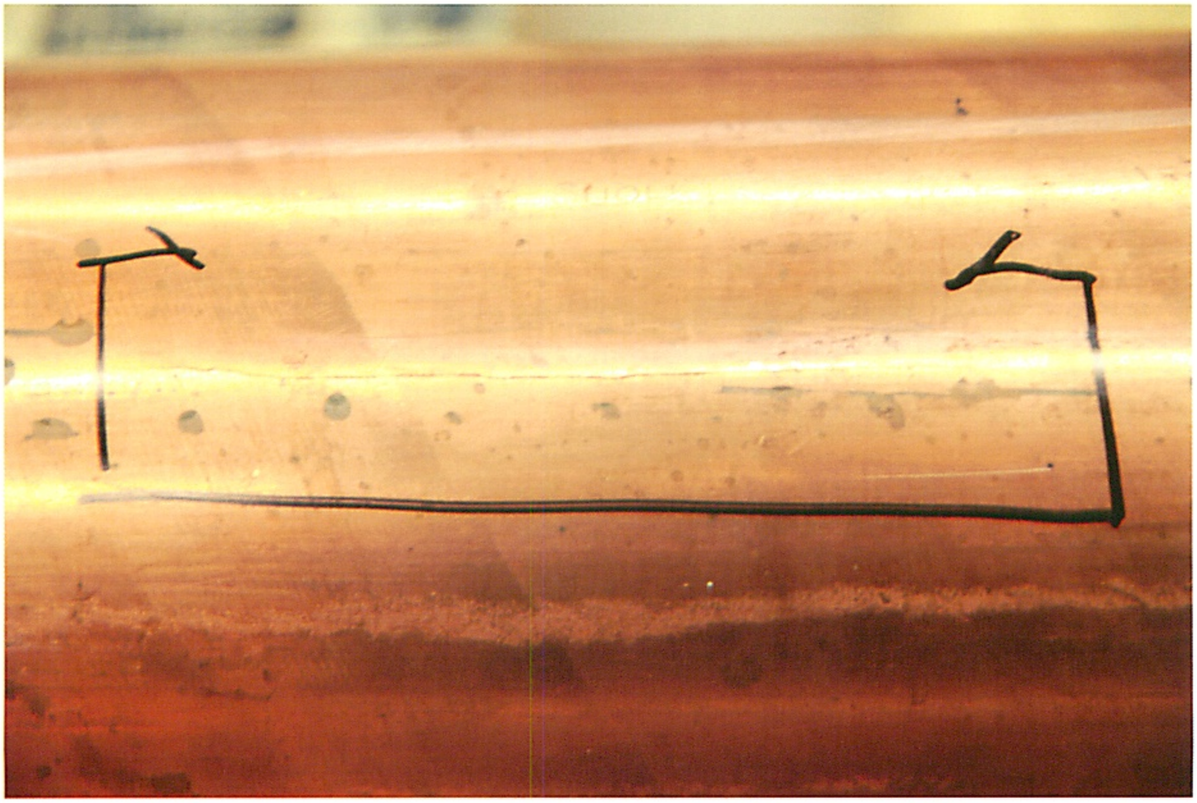

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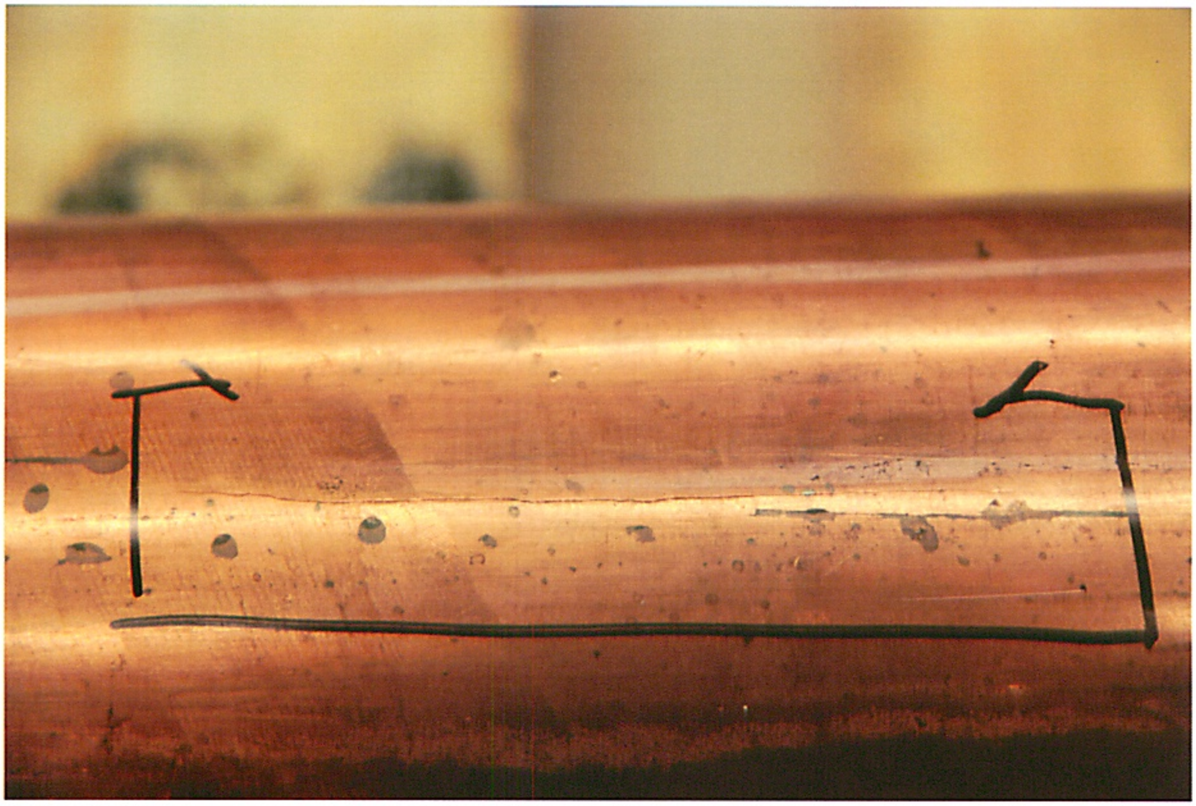

Figure 9.

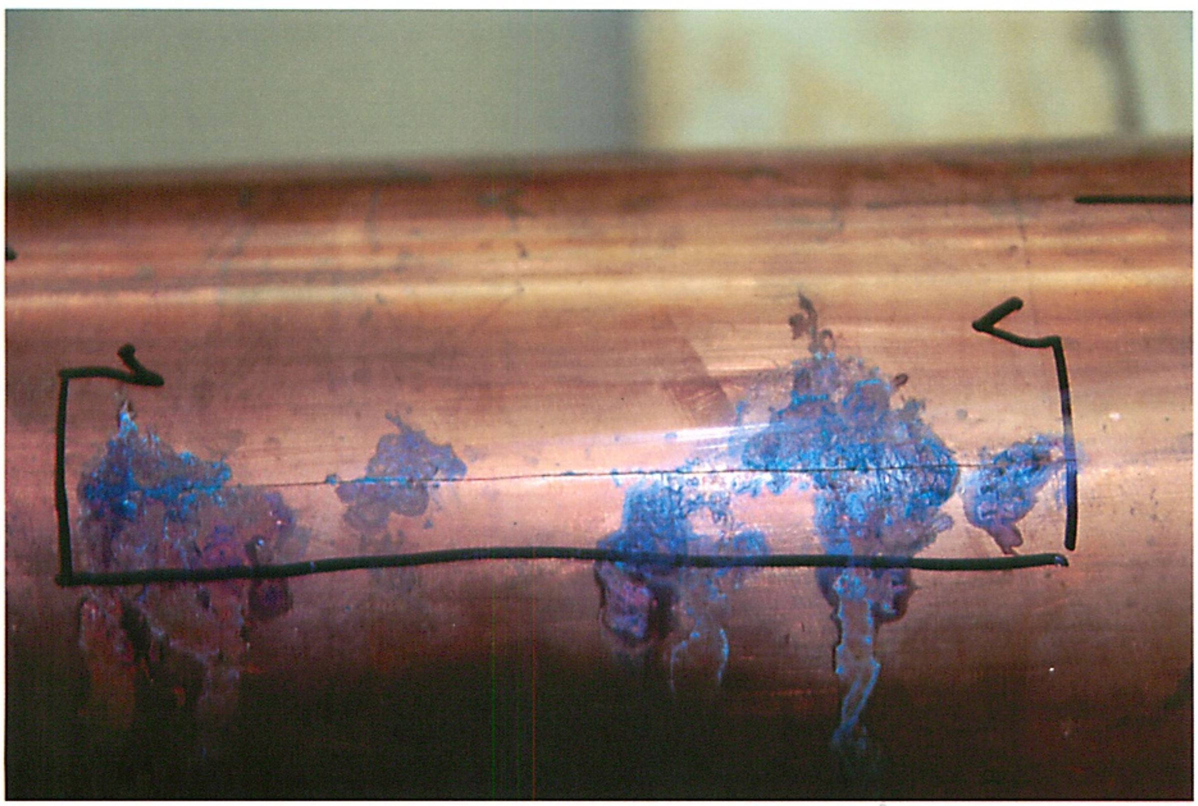

Figure 10.

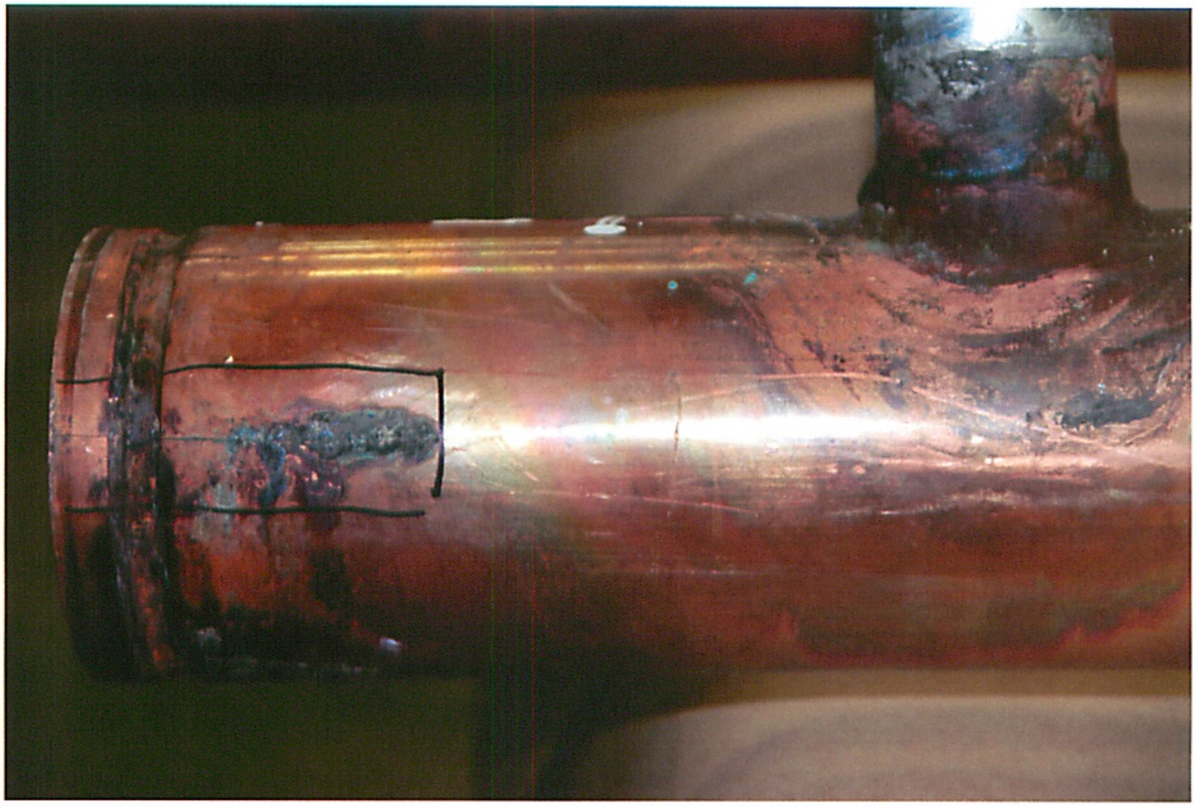

Figure 11.

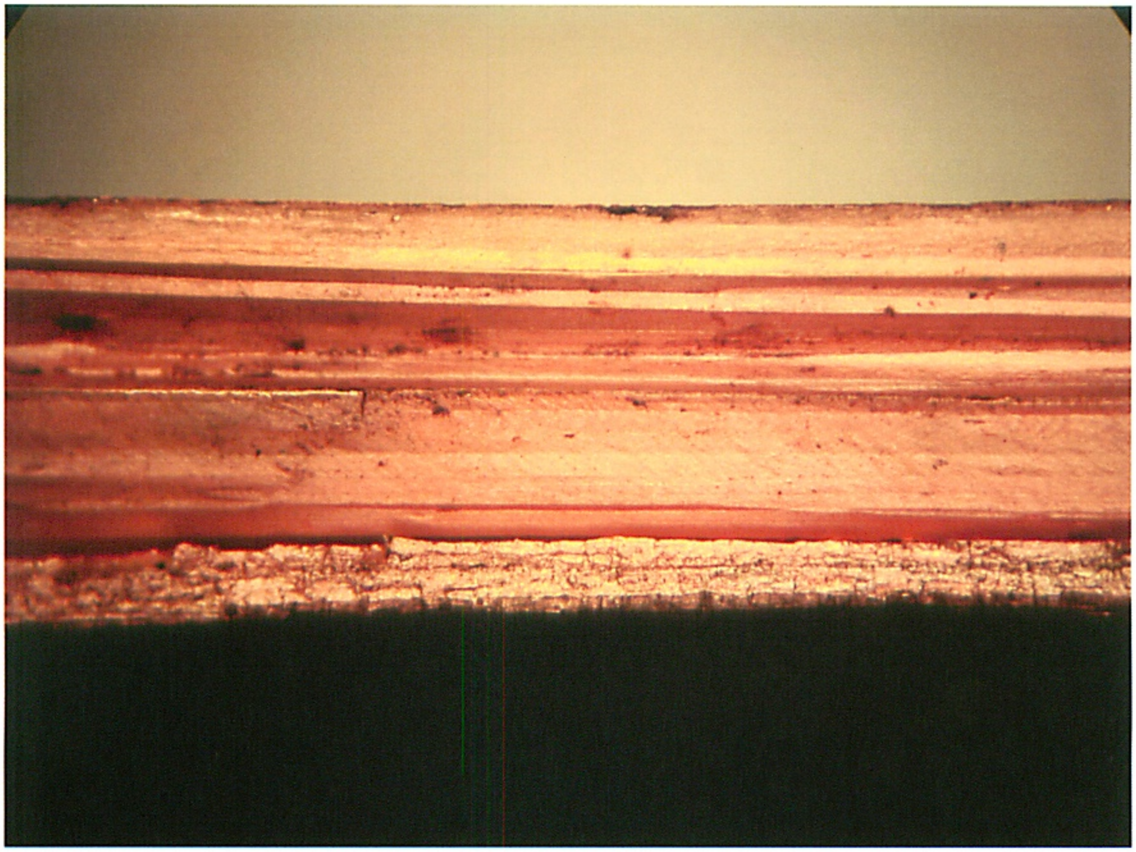

Figure 12.

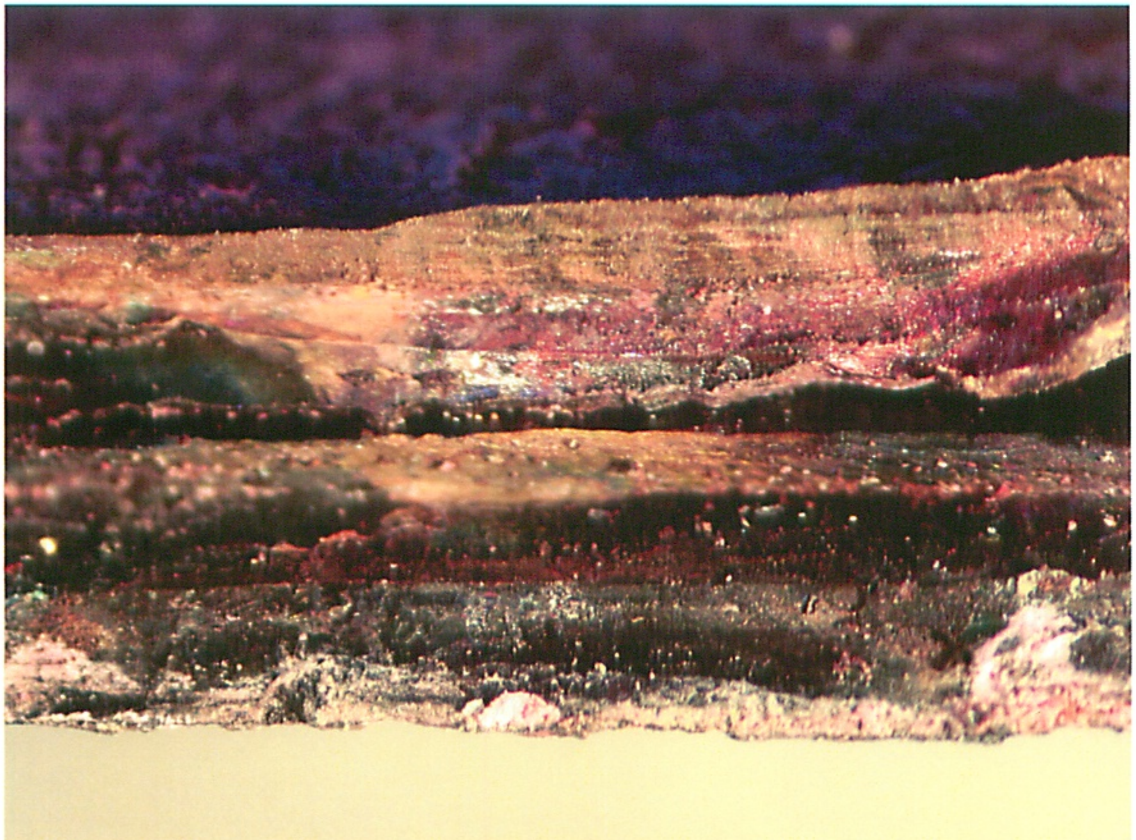

Figure 13.

Figure 14.

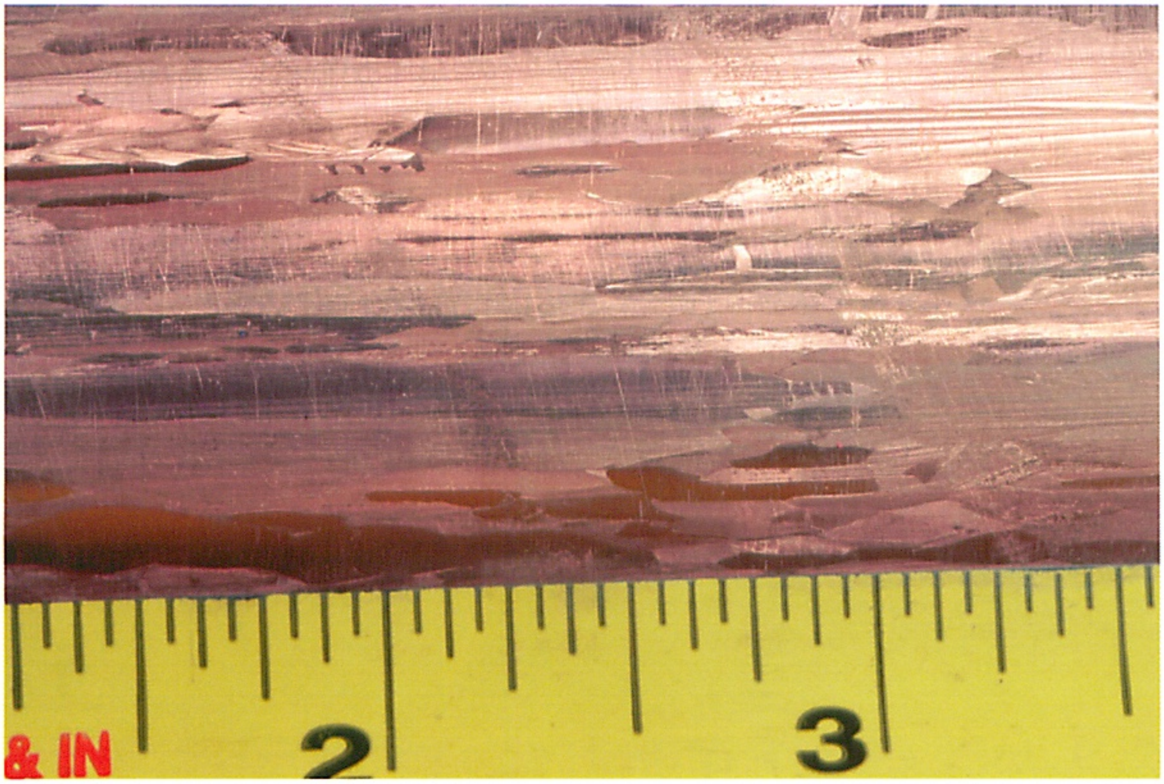

Figure 15.

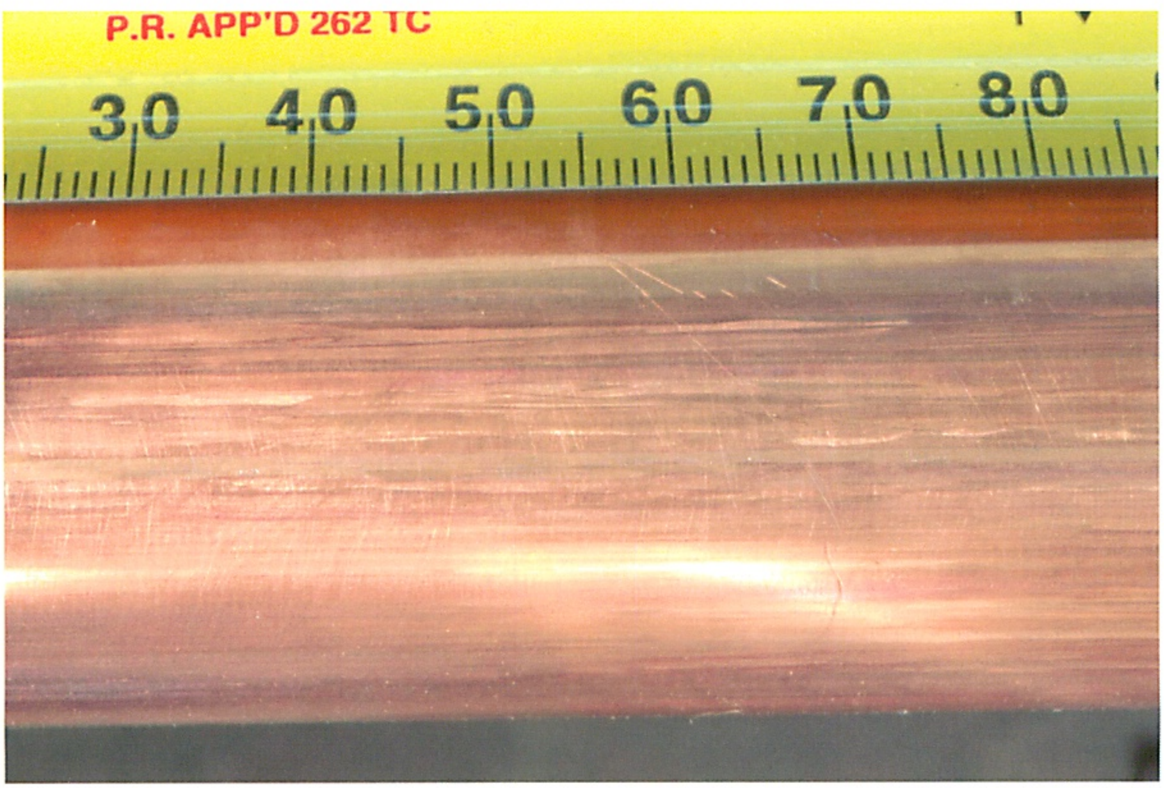

Figure 16.