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EXAMINATION OF A FAILED HIGH-TEMPERATURE WATER DISTRIBUTION LINE

by

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PHYSICAL METALLURGY DIVISION

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D.E. Parsons* and J.G. Garrison**

SUMMARY OF RESULTS

Examination of cracked high-temperature water distribution pipe samples from the heating plant of the Central Experimental Farm at Ottawa indicated that failure occurred as a result of stress-corrosion and extension of cracks from the outside to the inside surface of the pipes.

All the pipe samples contained cold-worked metal throughout the wall section. The cold-worked metal was visible in the microstructure and was evidenced by a high ratio of yield to ultimate tensile strength and by the absence of any definite yield point when tensile specimens were broken.

In service, the pipe temperature was 180°C (360°F) and the outside surface of the pipe was in contact with sodium nitrate, ground water and insulating cement.

The pipe appeared either to have received a process-annealing treatment or to have been hot-finished at a temperature below the usual rolling temperature. However, the amount of stress-relief provided did not prevent the formation of longitudinal cracks which were mainly intercrystalline. The longitudinal direction of the larger cracks is believed to be due to the influence of the applied (250 psig) hoop stress.

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INTRODUCTION

Three lengths of high-temperature water distribution line were submitted to the Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys by Mr. A. D. Wilson, District Architect, Department of Public Works, Ottawa, Ontario. The pipe was obtained from the Central Heating Plant of the Central Experimental Farm in Ottawa. Two of the three pieces, a 7 in. and 12 in. length had been buried underground and contained longitudinal cracks which were detected by leakage of steam. The third length of pipe, 16 in. length, was taken from a location inside a building and while subjected to line temperature and pressure, 180°C (360°F) - 250 psig respectively, had not been cemented in position for underground service.

The covering letter, File Number 746-117, Department of Public Works, dated March 16, 1961, stated "the supply pipe failed over an undetermined length" and requested that the nature of the failure be determined.

Subsequently, on March 29, 1961, the results of preliminary investigation were reported by letter, pending completion of more detailed examination.

EXAMINATION

Visual Examination

The 7 in. and 12 in. lengths of pipe, when received, were partly coated with an insulating cement which was tightly bonded to the surface of the pipe. Mill marks and longitudinal cracks were visible on the outside surface of the pipe. The largest cracks extended completely through the pipe section.

Magnetic particle inspection revealed additional smaller cracks present on the outside pipe surface which did not extend to the inside surface. It was observed that some of the cracks had secondary branches or were associated with groups of parallel cracks.

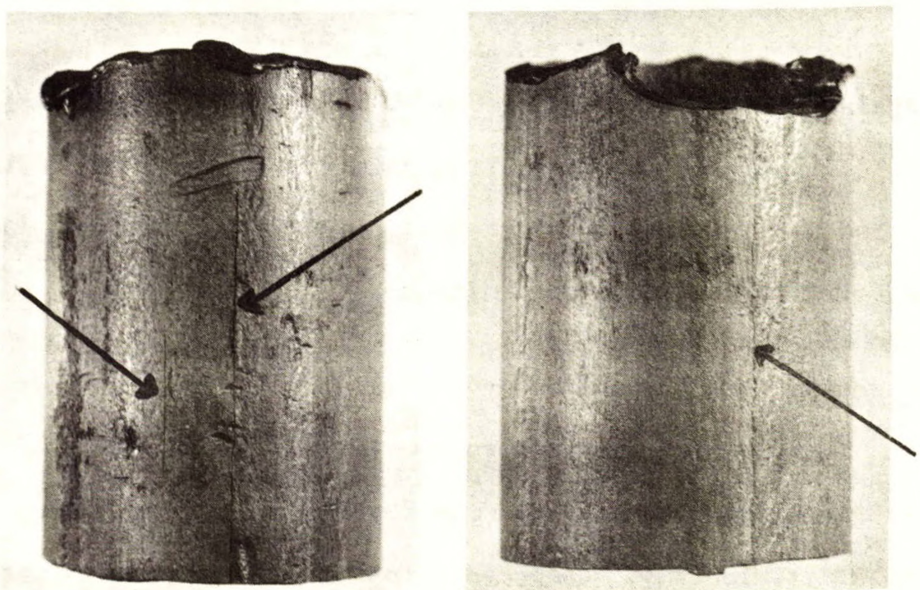
The appearance of the 12 in. length of pipe is illustrated in Figures 1 and 2.

X 1/3

Figure 1. <u>12 in. Length of Pipe</u>

Magnetic particle inspection showed the cracks to be mainly longitudinal.

A short piece of the 12 in. length of pipe was cleaned and etched in hot aqueous 50% hydrochloric acid and was photographed on two sides. The appearance of this "deep-etched" section is illustrated in Figure 2.



(a) Actual size (b)

Figure 2. <u>Deep-Etched Length of Failed Pipe</u>

Two cracks are visible (arrows) in Figure 2a. Roll marks and a lap (arrow) are visible in Figure 2b.

Chemical Examination

Drillings were obtained for chemical analyses from the 12 in. and 16 in. lengths of pipe. The results of these analyses are shown in Table 1.

TABLE 1

Chemical Composition (per cent)

Sample	C	Mn	Si	S	P	Cr	Mo	Ni
12 in. length	0.21	0.59	0.19	0.028	0.010	0.02	0.01	N.D.
16 in. length	0.21	0.48	0.12	0.026	0.011	0.06	0.01	0.08

The chemical composition conforms to the requirements for a killed AISI-1020 grade.

X-Ray Analysis of the Insulating Cement

A sample of the insulating cement on the surface of the 12 in. pipe was examined by Debye-Scherrer X-ray diffraction analysis and was found to contain sodium nitrate.

Tensile Tests

Tensile strip samples were obtained from the lengths of pipe being examined (one sample from the 12 in. length and two samples from the 16 in. length). These were tested and the results are shown in Table 2.

TABLE 2

Tensile Tests

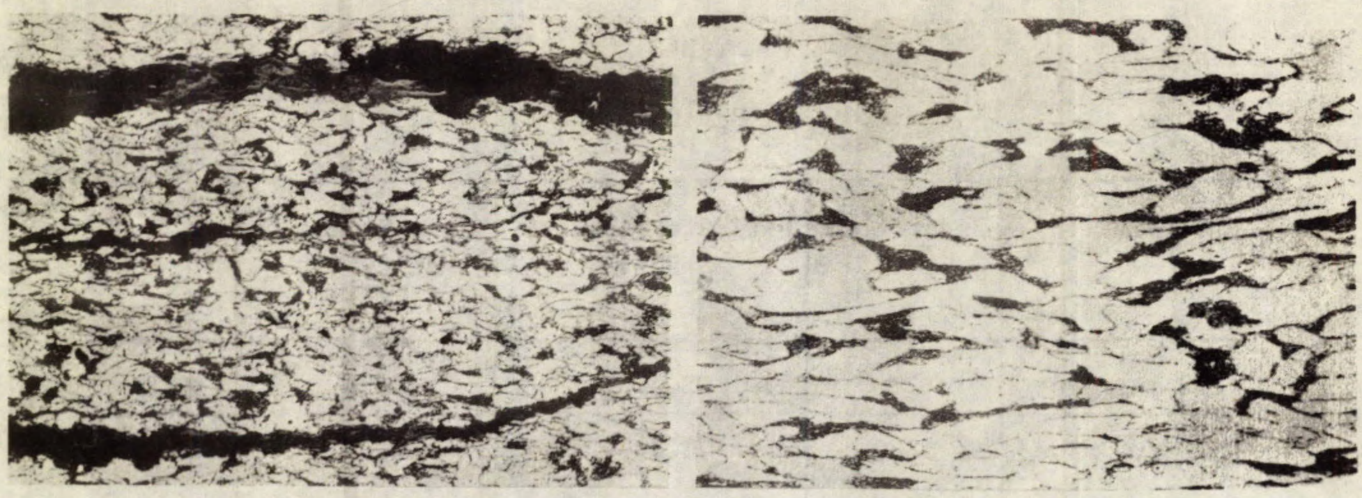
Sample	Break Load (lb)	Ultimate Strength (kpsi)	Yield Strength (0.2% offset kpsi)	% El. in 2 in.
12 in. pipe	6260	82.4	68.8	21.0
16 in. pipe	5220	75.2	66.0	28.0
16 in. pipe	5680	75.0	64.0	24.0
1020 (hot-rolled)		55.0	30.0	25.0

Neither the 12 in. nor the 16 in. lengths of pipe showed a definite yield point. The ultimate tensile strength and 0.2% offset yield strength have been increased considerably above the values obtained for hot-rolled AISI-1020 steel.

Metallography

Transverse and longitudinal micro-specimens were obtained from the 7 in., 12 in., and 16 in. lengths of pipe and these specimens were examined under the microscope.

The 7 in. and 12 in. pipes contained heavily cold-worked metal. Figure 3 illustrates the appearance of the microstucture for the failed 12 in. pipe.



(a) (b)

Etched in 2% nital; X500

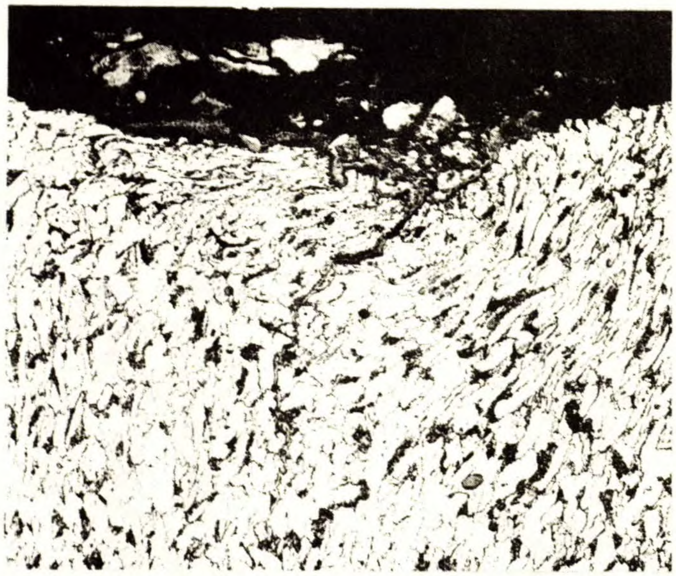
Figure 3. Microstructure of 12 in. Length of Pipe

(a) Transverse section showing cold-worked metal and intercrystalline cracks.

(b) Longitudinal section showing cold-worked metal.

The cracks in the 7 in. and 12 in. lengths of pipe were intercrystalline and were filled with corrosion product. All the cracks in these lengths of pipe originated on the outside surface of the pipe (Figure 4).

Considerable spheroidization of the pearlite is visible in the 12 in. pipe sample.

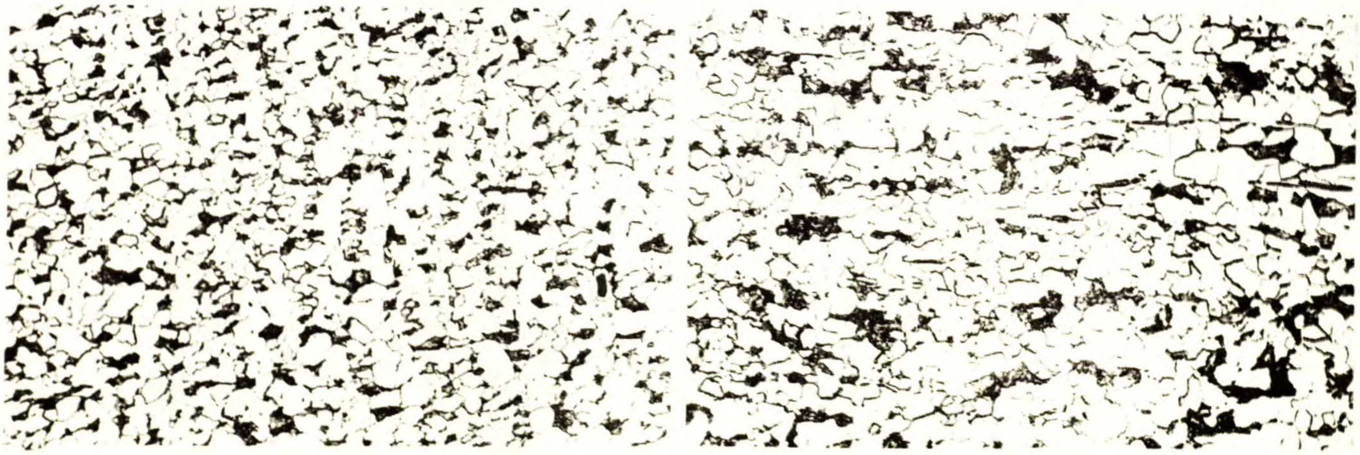


Etched in 2% nital; X500

Figure 4. Intercrystalline Crack Originating at the Outside Surface of the 12 in. Length of Pipe

The 16 in. length of pipe was found to be free of cracks, but an examination of the transverse and longitudinal micro-specimens obtained from this length of pipe showed that the steel in this sample was cold-worked and had a fine ferrite grain size.

The appearance of the microstructure for the 16 in. pipe sample is shown in Figures 5a and 5b.

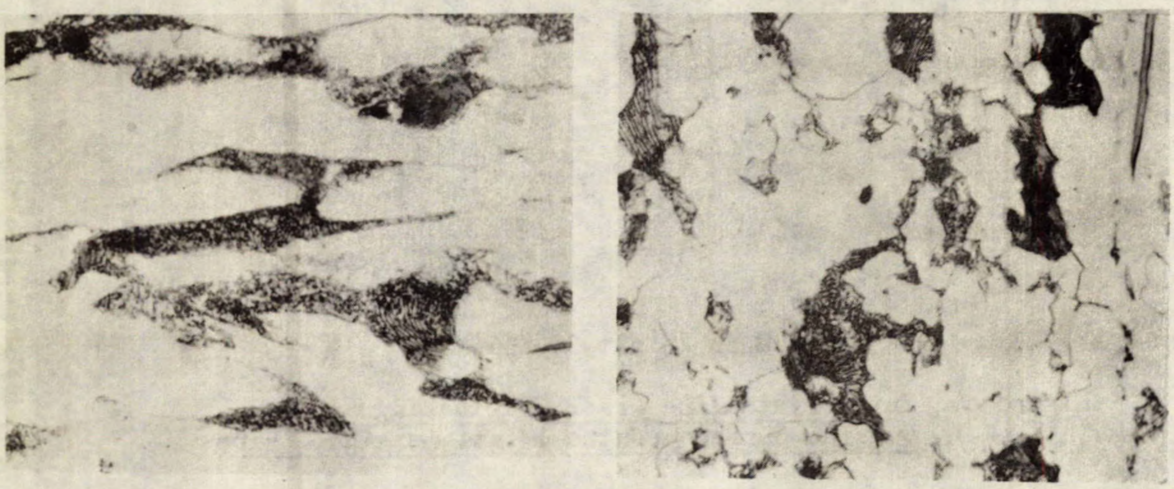


(a) (b)

Etched in 2% nital; X500

Figure 5. Microstructure of the 16 in. Length of Pipe
(a) Transverse Section.
(b) Longitudinal Section.

The pearlite in the 12 in. and 16 in. lengths of pipe was fine and partly spheroidized. Spheroidization was more advanced in the 12 in. sample than in the 16 in. specimen (Figure 6), suggesting some variation in the sub-critical annealing temperature.



(a) (b)

Etched in 2% nital; X1000

Figure 6. Pearlite Structure of the Pipes

(a) Longitudinal section of the 12 in. length of pipe.

(b) Longitudinal section of the 16 in. length of pipe.

SUMMARY

The cracks in the 7 in. and 12 in. lengths of pipe were mainly longitudinal with intercrystalline secondary cracks. These cracks progress inwards from the outside of the pipe surface and are filled with corrosion product. The longitudinal direction of the main cracks may be due to the commencement of corrosive attack at marks on the outside surface of the pipe under the influence of the applied (hoop) stress.

The failed pipes (7 in. and 12 in. lengths), in service, were buried and in contact with ground water. The insulating cement, surrounding and tightly bonded to the surface of the pipe, contained sodium nitrate. The pipes had been heavily cold-worked by the method of fabrication during manufacture and exhibited increased tensile and yield strength due to the presence of cold-work.

The 7 in., 12 in., and 16 in. lengths of pipe all appeared to have been process-annealed subsequent to cold-working. Considerable spheroidization of the pearlite was observed in the 12 in. sample. However, none of the samples had received a normalizing or full-annealing treatment subsequent to cold-working and, hence, all were in a condition susceptible to stress-corrosion attack.

CONCLUSIONS

1. The intercrystalline nature of the cracks in the failed pipes and the environmental conditions (alkaline sodium nitrate and ground water and 180°C (360°F) operating temperature) were strongly indicative of stress-corrosion.

2. The pipes contained sufficient cold-work to increase the ultimate and yield strengths and to eliminate the yield point. In this cold-worked condition (despite process-annealing) the pipes were susceptible to stress-corrosion.

3. The presence of insulating cement, tightly bonded to the surface of the failed pipes, suggests that additional stress may have been caused by restraint to thermal expansion and contraction.

RECOMMENDATIONS

1. Cold-drawn pipe should receive a full-anneal or normalizing heat treatment (in a controlled atmosphere furnace) prior to service in an environment where minimum susceptibility to stress-corrosion is required. (Allowance is necessary for the accompanying reduction in tensile strength).

2. During installation and service the drainage and chemical environment of the pipe should be carefully controlled. (Good drainage would minimize corrosive attack from ground water and prevent leaching of insulating cement).

3. The method of application of the insulating cement surrounding the pipe should ensure that the cement does not adhere and impose restraint to thermal expansion and contraction.

4. An adequate guarantee as to quality of workmanship and materials should be included in the construction contract.

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