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EXAMINATION OF RUPTURED NEW BRUNSWICK HYDRO PIPE

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

Metallurgical examination of a ruptured pipe, which had been removed from a boiler after service at 538°C (1000°F) and 1450 psig, showed that the pipe did not conform to ASTM Standard A335-P11, Schedule 160 with respect to chemical composition and wall thickness.

The failed tube was a seamless, carbon steel grade having a nominal wall thickness of 0.188 inch. The wall thickness was further reduced by the presence of internal seams and lack of section uniformity.

Failure occurred by stress-rupture mechanism due to pressure and temperature conditions, which were too severe for carbon steel pipe.

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INTRODUCTION

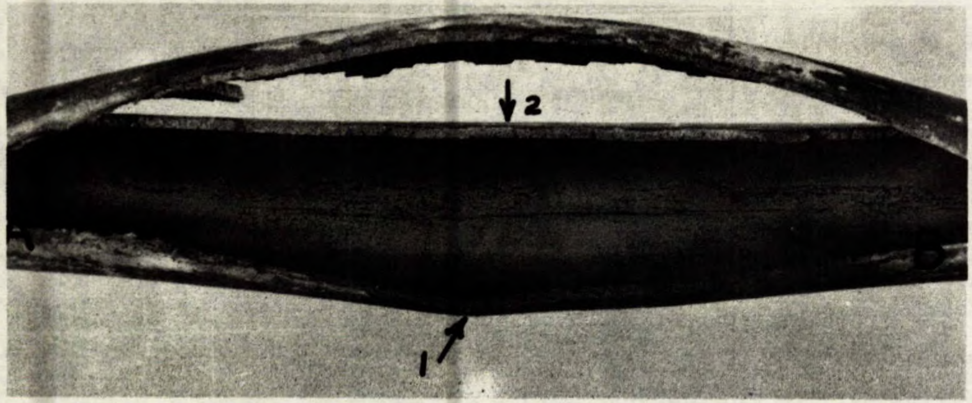
On December 31, 1963, Mr. J.R. Dean, Assistant Manager of Production, The New Brunswick Electric Power Commission, submitted a 3 ft length of burst, 1½ in. boiler pipe to the Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys with the request that the steel be examined to determine whether the failed pipe conformed to the specification requirements of ASTM A335-P11, Schedule 160, for 1½ in. diameter pipe.

The covering letter, December 18, 1963, File Number: 3-463g E.S.J. #1 Br, stated: - "The 1½ in. pipe failed under pressure of 1450 psig at 538°C (1000°F).

Specifications called for 1½ in. Schedule 160-A335-P11 pipe. However, the portion in question is off standard with respect to outside diameter and wall thickness. We suspect that a substitution was made.

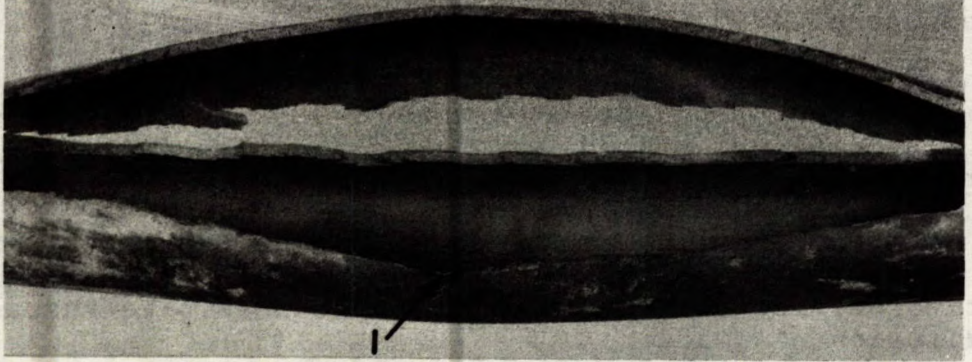
We would appreciate having your people examine this pipe with a view toward determining its source."

The appearance of the ruptured pipe viewed in three positions is shown in Figure 1.



(a)

The origin of the rupture appears to be at the position marked by arrow 1. The fracture propagated from the origin to A and B. A final rupture occurred along the surface marked, arrow 2.



(b)

The fracture is of the high pressure type with the final stages occurring in brittle fashion. The origin of the crack at arrow 1 appears to be stained, possibly indicating leakage prior to rupture.

(c)

Figure 1. Ruptured Pipe. Three Views Illustrate the Appearance of the Fracture Surfaces. (All 1/3 actual size).

METHOD OF EXAMINATION

Metallurgical examination was carried out as follows:-

(i) Visual examination and measurement of the pipe dimensions.

(ii) Chemical analysis of drillings taken from a grit-blasted section.

(iii) Deep etch and sulphur print of pipe sections.

(iv) Metallographic examination.

RESULTS

(i) Visual Examination and Pipe Dimensions

Visual examination showed a small shear lip in the region where rupture appeared to start. The remainder of the fracture appeared to be of the high velocity type, resulting in brittle fracture without reduction of section.

The wall thickness approximated 0.188 in. except for three zones that were approximately 0.156 in. thick. The failed pipe was seamless and appeared to conform to the requirements of ASTM A53-61T, grade A, Type S, Schedule 80 (XS) "Specification for Steel Pipe", or to ASTM A83-61T, grade A "Seamless Carbon Steel and Open Hearth Iron Boiler Tubes".

Measurement of the outside diameter of the failed tube gave results of 2.020 to 2.065 in. with wall thickness varying between 0.188 and 0.156 in.

The governing specification was stated to be ASTM A335-P11, Schedule 160. In this specification, reference is made to ASA B36.10-1959, Standard for Wrought-Steel and Wrought-Iron Pipe published by the ASME. Dimensional requirements for $1\frac{1}{2}$ in. pipe having an outside diameter of 1.900 in., according to ASA B36.10-1959, are listed in Table 1.

TABLE 1

Dimensions and Weights of Welded and Seamless Steel Pipe*

Size — Nominal (Outside Diameter in.)	Wall Thickness in.	Plain End Weight lb/ft	Identification		
			API Standard	Standard X-Strong XX-Strong	Schedule Number
1½ (1.900)	.145	2.72	5L	STD	40
	.200	3.63	5L	XS	80
	.281**	4.86	-	-	160**
	.400	6.41	5L	XXS	-

*Table 2, p. 8, ASA B36.10-1959

**Note that Schedule 160 requires a wall thickness of 0.281, subject to the variation allowed by ASTM A335.

(ii) Chemical Analysis

The results obtained by wet chemical analysis of drillings are shown in Table 2.

TABLE 2

Results of Chemical Analysis (Per Cent)

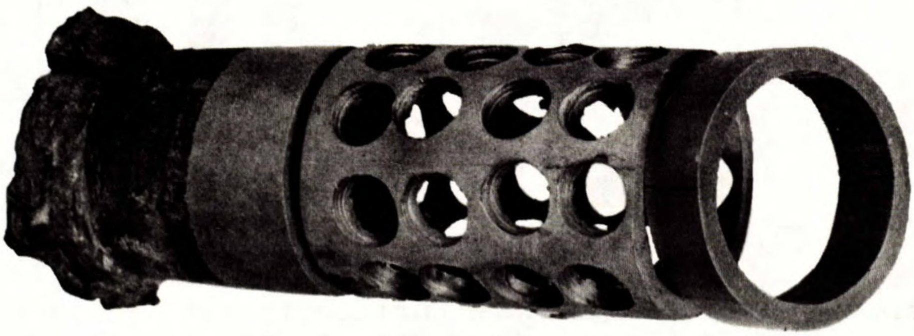
Element	Ruptured Pipe 3.463 E.S.J. #1 Br.	ASTM A335-P11 Schedule 160
Carbon	0.13	0.15 max
Manganese	0.58	0.30 to 0.60
Silicon	0.28	0.50 to 1.00
Sulphur	0.019	0.030 max
Phosphorus	0.024	0.030 max
Chromium*	0.12	1.0 to 1.5
Molybdenum*	0.02	0.44 to 0.65
Nickel	0.08	

*Note that the chromium and molybdenum contents of the failed tube were 0.12% and 0.02% respectively, and failed to meet the composition requirements of ASTM A335-P11.

(iii) Deep Etch and Sulphur Print of Pipe Sections

The appearance of approximately 6 in. of the failed pipe, taken adjacent to the weld, and including the drilled section used for chemical analysis, is shown in Figure 2 after deep etching for 15 minutes in 1:1 HCl:water at 77°C (170°F).

Seams were visible on both surfaces of the pipe, particularly on the inside surface. The seams were not continuous and, although undesirable from the viewpoint of reduction of section, would probably be acceptable in terms of ASTM A53. None of the internal seams was observed to coincide with the thinnest 0.156 in. section, nor did the location of rupture appear to be affected by the presence of the longitudinal seams.



X3/4

Figure 2. Deep Etched Pipe Sections Adjacent to Weld and Including Portion Drilled for Chemical Analysis.

Both external and internal seams are visible in the drilled and in the ring sections.

A sulphur print was taken on the ring section shown at the right in Figure 2. The sulphur content of this steel was low. No concentration of sulphur was observed in the metal section or in the associated scale.

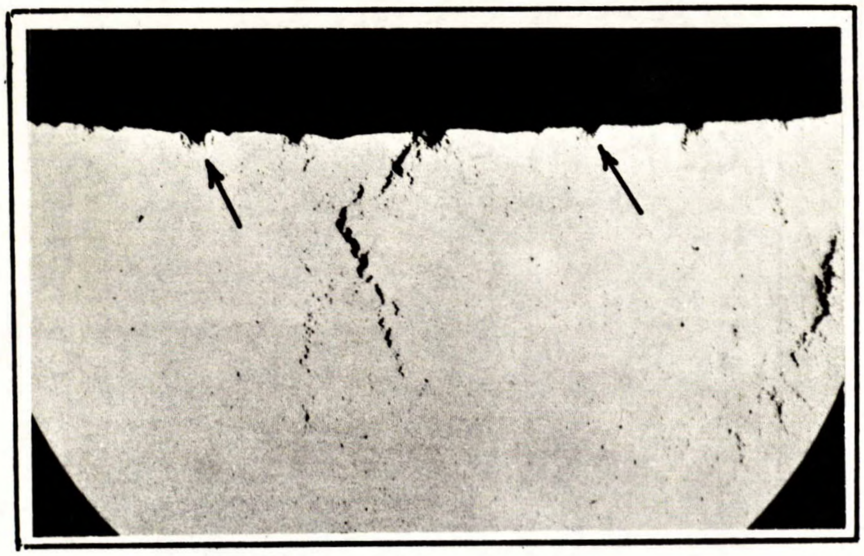
(iv) Metallographic Examination

The appearance of the fracture and the inside (steam) side of the pipe is illustrated in Figure 1. This transverse section was taken at the location marked by arrow 1, Figure 1.

X36 As-polished

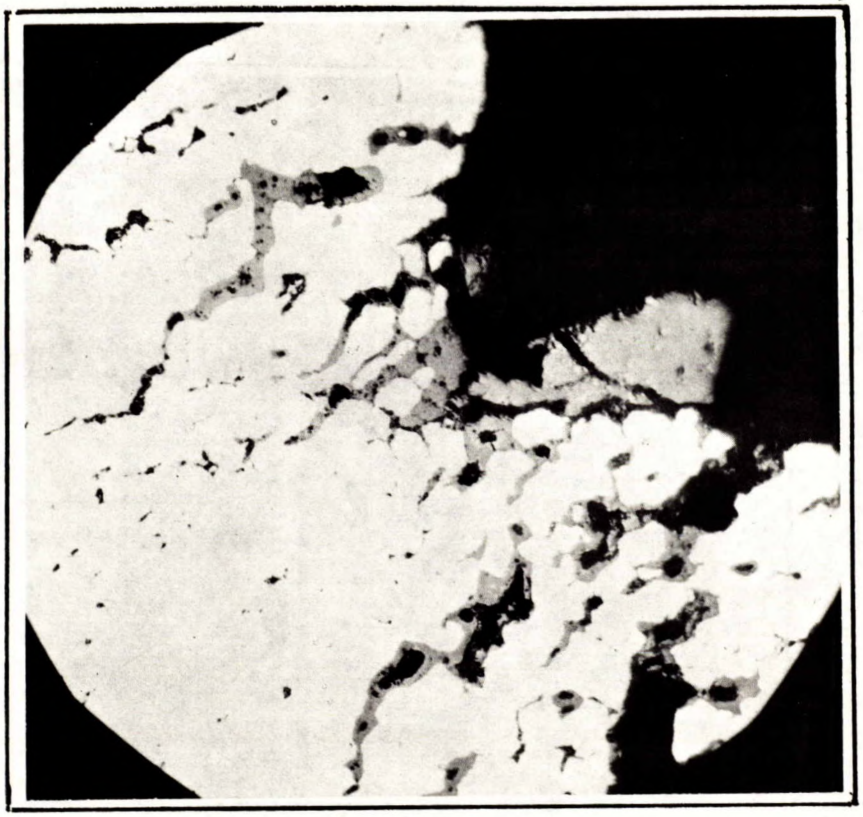
Figure 3. View of Fracture Surface in Bulged Area. (Steam side at top, fracture at right of photomicrograph).

This transverse section intersects regularly spaced longitudinal stress cracks, one of which appeared to have acted as an origin for rupture. Intergranular oxidation typical of stress rupture, extending from the steam surface through 2/3 of the section adjacent to the fracture, is visible.



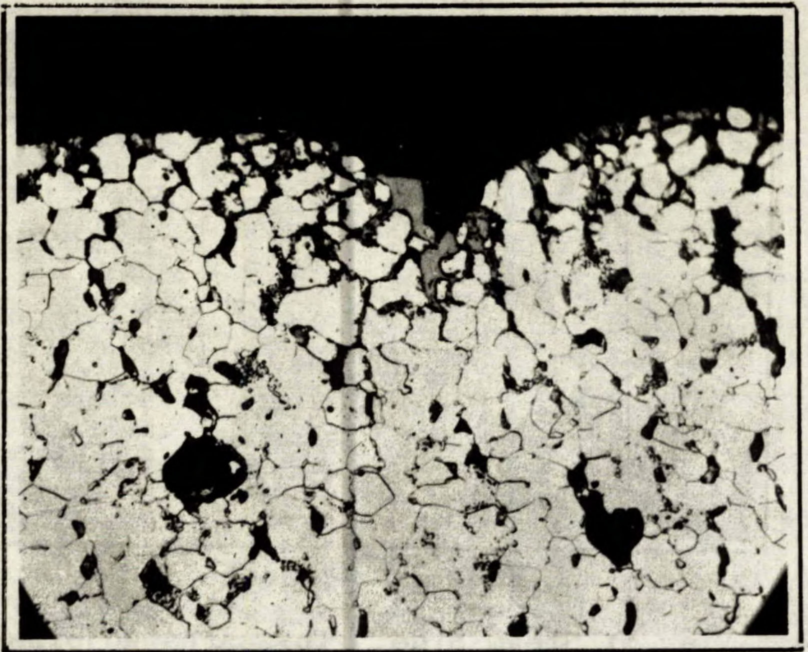
X36 As-polished

Figure 4. View of Steam Side. This area adjoins the surface illustrated in Figure 1 and contains a typical (stress rupture) oxidized intergranular crack viewed in transverse section. The intersection of this section with regularly spaced longitudinal cracks at the steam surface is illustrated, (arrows).



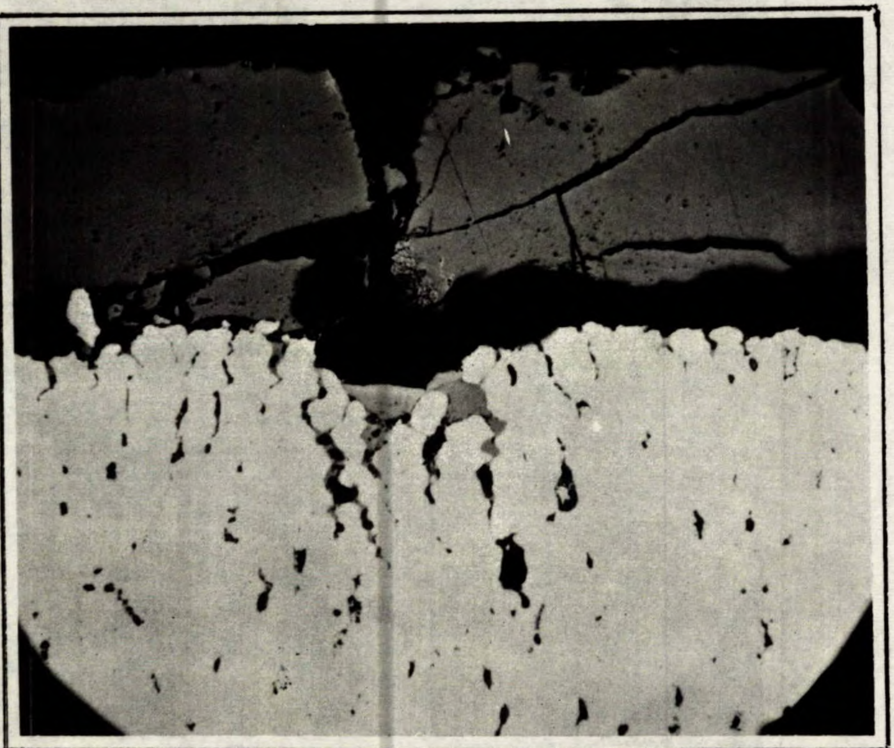
X500 As-polished

Figure 5. View of Oxidized (Stress Rupture) Fracture Surface. Severe intergranular oxidation, indicating failure by stress rupture, is shown.



X500 Etched in 2% Nital

Figure 6. View of Steam Side. (Inside Surface). Transverse Section. Scaling and oxidation had occurred on the steam surface. No evidence of grain coarsening was observed. The pearlite was spheroidized but had not coalesced.



X500 As-polished

Figure 7. View of Cracked Side and Oxide Roots on Steam Side. Cracks in the thick layer of scale coincide with regularly spaced longitudinal stress-cracks.

DISCUSSION AND SUMMARY

The failed "tube" contains only 0.12% chromium and has a wall thickness of 0.188 in. with thin zones of 0.156 in. thickness. The pipe did not meet ASTM A335-P11 requirements with respect to chemical composition or wall thickness. (The failed pipe appeared to conform to ASTM A53-61T, grade A, type S, Schedule 80-XS; "Specification for Steel Pipe") or to (ASTM A83-61T, grade A, "Seamless Carbon Steel and Open Hearth Iron Boiler Tubes".)

Measurement of the outside diameter of the failed tube gave results of 2.020 to 2.065 in. with the wall thickness varying between 0.187 in. and 0.156 in. The allowable hoop stress, at 538°C (1000°F) for pipe (ASTM A335-P11) is 7800 psi, which corresponds to a minimum wall thickness of 0.187 in. at 1450 psi. The allowable temperature for carbon steel, having adequate wall thickness, is restricted to 482°C (900°F), hence, the carbon steel pipe would be overstressed and liable to stress-rupture failure.

Seams were observed on both surfaces of the pipe and, although these were not continuous and did not coincide with the thin zones, they did effect a 10% reduction of wall section. This reduction is allowable by ASTM and European specification unless agreement is reached between manufacturer and purchaser.

The microstructure of the pipe consisted of fine grained, equiaxed ferrite and spheroidized but non-coalesced carbide.

The metal in the vicinity of the origin of rupture showed severe intergranular oxidation. A thick layer of heavily rooted scale was observed on the steam side and to a lesser extent on the fireside. Failure appeared to be of the stress-rupture type, starting from oxide roots at the steam surface. The appearance of the scaled surface indicated that the metal did not have adequate oxidation resistance for a service requirement of 538°C (1000°F).

No evidence of grain growth, solution of carbide or excessive coalescence of carbide was observed to indicate service temperature in excess of that specified, 538°C (1000°F), in this pipe sample.

The initial pipe rupture appeared to be due to stress-rupture followed by tearing of the carbon steel at 1450 psig.

CONCLUSIONS

1. The failed pipe did not conform to the requirements of ASTM A335-P11 with respect to chemical composition or wall thickness.

2. Failure was by stress-rupture at service temperature and at high pressure.

3. The pipe contained discontinuous external and internal seams, which caused a reduction of at least 10 per cent of nominal wall thickness.

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