Dr. J. Convey

~~RESTRICTED—GOVERNMENT USE ONLY~~

Declassified Sept. 18/79

IR64-28

CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

OTTAWA

MINES BRANCH INVESTIGATION REPORT IR 64-28

FAILURE OF LOW PRESSURE BOILER TUBE

by

D. E. PARSONS

PHYSICAL METALLURGY DIVISION

COPY NO. 6

MARCH 20, 1964

01-7989049

2

Restricted Government Use Only

Mines Branch Investigation Report IR 64-28

FAILURE OF LOW PRESSURE BOILER TUBE

by

D.E. Parsons*

- - - - - -

SUMMARY OF RESULTS

Metallurgical examination of a burst tube from a low pressure Foster-Wheeler boiler at Kingston Penitentiary showed that the coal burner flame had impinged on the tube raising the metal temperature to 538°C (1000°F) approximately, and forming a molten (eutectic) sulphur-rich slag, having a melting point of the order of 1000°C (1832°F). The volatile content of the coal was high, resulting in a long burner flame and in deposition of sulphur on the outside tube surface.

The water side deposit, while relatively thick, had not contributed to the localized hot spot and appeared to be removable by mechanical cleaning.

Use of protective flame baffles, control of combustion conditions and extent of corrosion were discussed.

---

*Senior Scientific Officer, Ferrous Metals Section, Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada.

INTRODUCTION

On February 5, 1964 a 14 in. length of burst boiler tube, removed from a Foster-Wheeler, low pressure, water-tube boiler installation at Kingston Penitentiary was submitted to the Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, by Mr. W.J. Gorman, Department of Public Works. The covering letter, reference 820-3560, requested that the cause of rupture of the tube be determined.

The affected area had a diameter of about 2 in. and showed deformation with a short split progressing inwards from the fire side of the tube. Examination showed that failure was due to flame impingement aggravated by attack of the outside tube metal surface by FeO.FeS slag. The appearance of the tube is illustrated in Figures 1 to 4 inclusive.

Damage to the tube appeared to be restricted to the local overheated flame area. Removal of the water deposit on the inside tube surface did not reveal any unusual pitting or wastage of section; hence, mechanical cleaning and removal of water scale appeared to be feasible.

EXAMINATION

The results of chemical analysis of the tube are shown in Table 1.

Chemical Analysis

TABLE 1

Results of Chemical Analysis (Per Cent)

Sample	C	Mn	Si	S	P	Ni*	Cr*	Mo*	Cu*
Burst Tube	0.11	0.45	Tr.	0.035	0.012	0.01	0.02	0.01	0.02
AISI-C-1010	0.08 0.13	0.30 0.60	-	0.050 max.	0.040 max.				

*Residual quantities.

The tube is a rimmed steel, conforming to the chemical requirements of AISI-1010 and contains an electric resistance weld.

X-ray Diffraction

X-ray diffraction tests were made on scale samples removed from the outside surface adjacent to and remote from the burst. Samples were also obtained from the water deposit on the inside surface. The results of these tests are shown in Table 2.

TABLE 2

X-ray Diffraction Results

Description	Location	Constituent
Outside scale at hot spot	Outside of tube	FeO and FeO.FeS*
Outside scale remote from hot spot	" " "	Fe_2O_3
Inside scale	Inside of tube	Ca.Mg carbonates

*fused sulphur-rich slag - contains eutectic sulphide phase. The melting point of the FeO.FeS eutectic phase is approximately 1000°C(1832°F).

Metallography

The microstructure of the steel tube consisted of ferrite and fine lamellar pearlite (Figures 5 to 7 inclusive). Spheroidization of the pearlite had commenced in the heat-affected zone (beneath the fused slag) but had not proceeded to the stage where pearlite lamellae were eliminated or carbide had coalesced. This suggested that the metal temperature beneath the fused slag had not exceeded 538°C (1000°F), but that the metal had been heated above 454°C (850°F). No grain growth was seen in any of the pipe. No change in microstructure was observed except in the 2 in. diameter affected zone.

DISCUSSION

The slag temperature at the hot spot was estimated to have been 1000°C (1832°F), and the metal temperature to have been 454°C-538°C (850°F-1000°F).

The melting point of the slag was reduced by the presence of sulphur and by formation of a low-melting FeO.FeS eutectic phase (Figure 8).

The tube contained a relatively thick water scale deposit on the inside tube surface. This material has been identified as alkaline carbonate and has been deposited despite use of water conditioning apparatus (Figure 9).

Tests were also made to determine if the water scale could be removed from the inside surface of the tube and to observe whether pitting corrosion had occurred beneath the deposit on the inside tube surface. The water scale appeared capable of removal by mechanical cleaning and was easily removed by laboratory pickling treatment in HCl-Sb2O3. No pits or damage were observed on the inside tube surface, indicating that attack was localized in the small area (approx. 2 in. diameter) caused by direct flame impingement.

The presence of sulphur (due to deposition under reducing conditions) on the outside of the tube was observed along the full length of the tube sample, but had only fused and reacted with the steel in the local overheated area of the burst. Formation of corrosive sulphur-rich eutectic slag in the area of flame impingement on the outside of the tube caused severe intergranular attack and reduction of section at this surface contributing to subsequent failure by high temperature stress-rupture in the presence of notches.

SUMMARY

In summary, the following observations can be made:-

1. Tube damage was restricted to the localized area of direct flame impingement.

2. The cause of failure was fusion of deposited sulphur into slag in the area of impingement and corrosive slag attack from the fire side inwards followed by stress-rupture failure of metal heated to approximately 538°C (1000°F).

3. The water scale was not the main cause of overheating, since this deposit was also present in unaffected areas remote from the hot spot.

4. Sulphur was visible as a deposit on the outside surface of the tube, indicating that combustion conditions tended to be reducing in this area.

5. Indications are that the tubes can be cleaned mechanically and that elimination of direct flame impingement should avoid burst tubes. (Reduction of the sulphur deposit might be a worthwhile precaution, even if protective baffles are used).

6. The quality of the steel was satisfactory for service at normal temperature. The service temperature for this grade of steel is usually limited to 454°C (850°F) maximum.

RECOMMENDATIONS

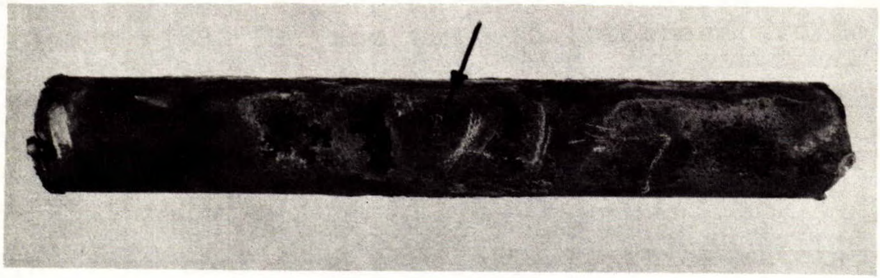
1. Avoid direct flame impingement on tube surfaces. Possibly this can be done by use of protective baffles --- although the possibility of change in the location of the flame with change in fuel or combustion conditions should be noted.

2. Avoid deposition of sulphur (reducing conditions) especially in hot zones.

3. Improve the efficiency of the water conditioning plant to control deposition of water scale.

4. Consideration should be given to the choice of a chromium-molybdenum alloy, seamless tube, with wall thickness based on allowable stress if service temperature of the steel is above 454°C (850°F).

DEP/ls

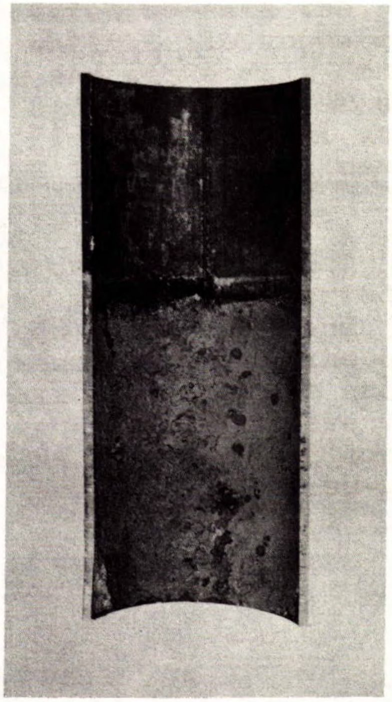


X 1/4

Figure 1. Tube Sample, as-received - Affected Area (arrow).

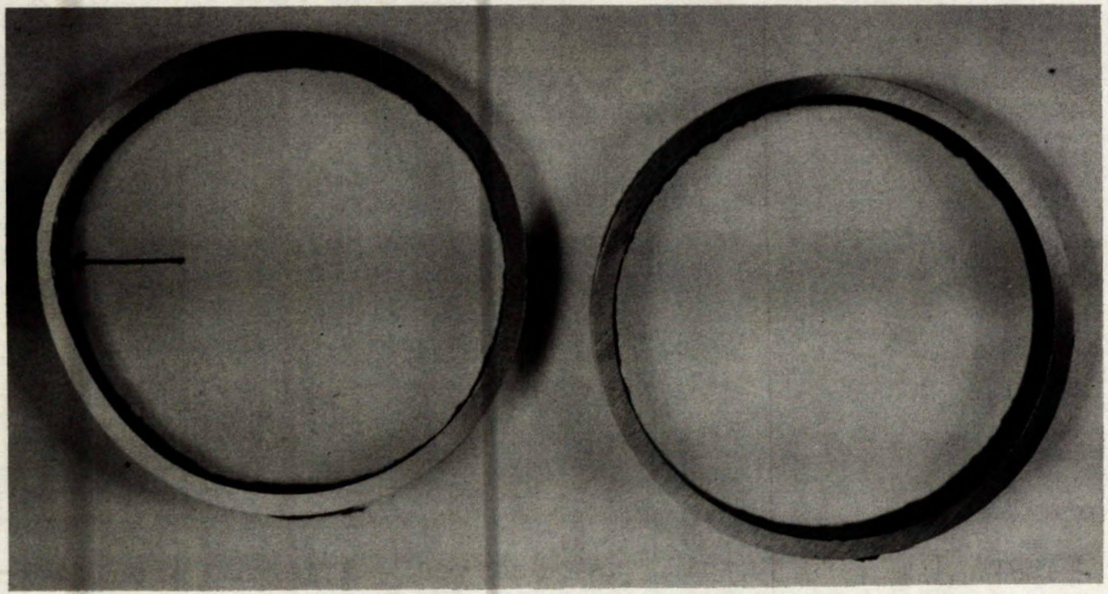
X 1/2

Figure 2. Illustrates Deposit on Inside Tube Surface and Sulphur Deposition on Outside of Tube.



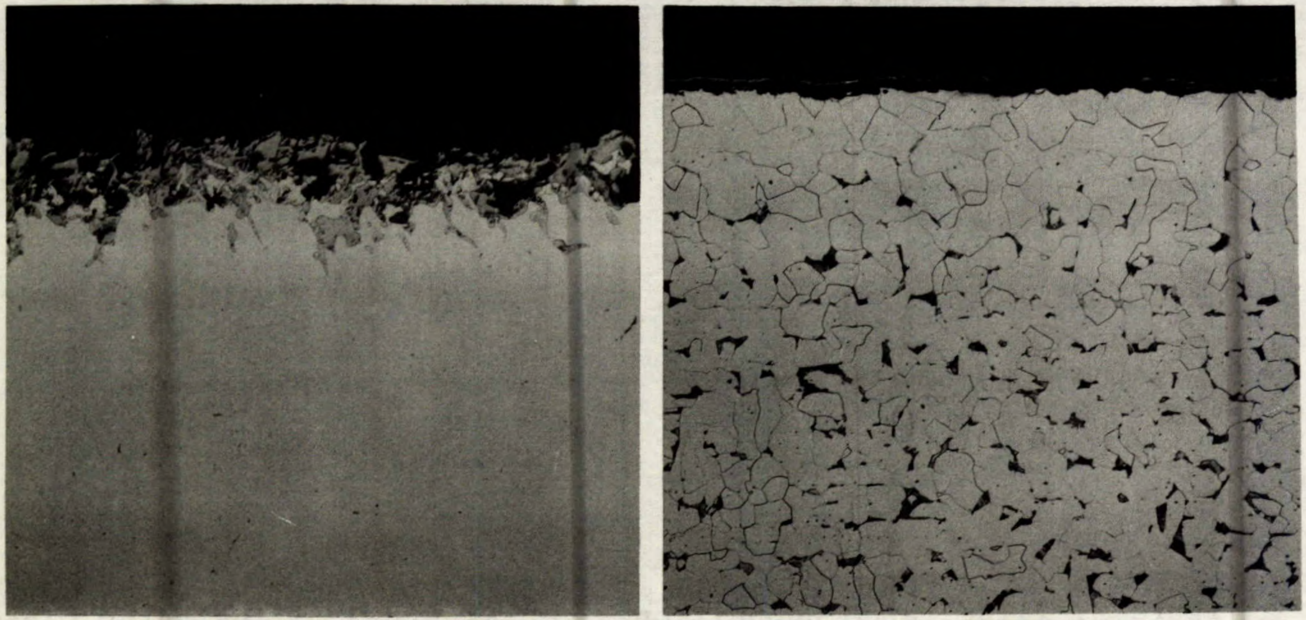
X 1/2

Figure 3. Illustrates Cleaned Area of Inside Tube (Top) after Laboratory Pickling in $HCl:Sb_2O_3$ Solution. This water side scale is loose and can probably be removed mechanically.



X 1

Figure 4. Sections Through Tube at Burst (Bulge and reduced section, arrow, extreme left of picture) - 10 in. from Burst (section at right).

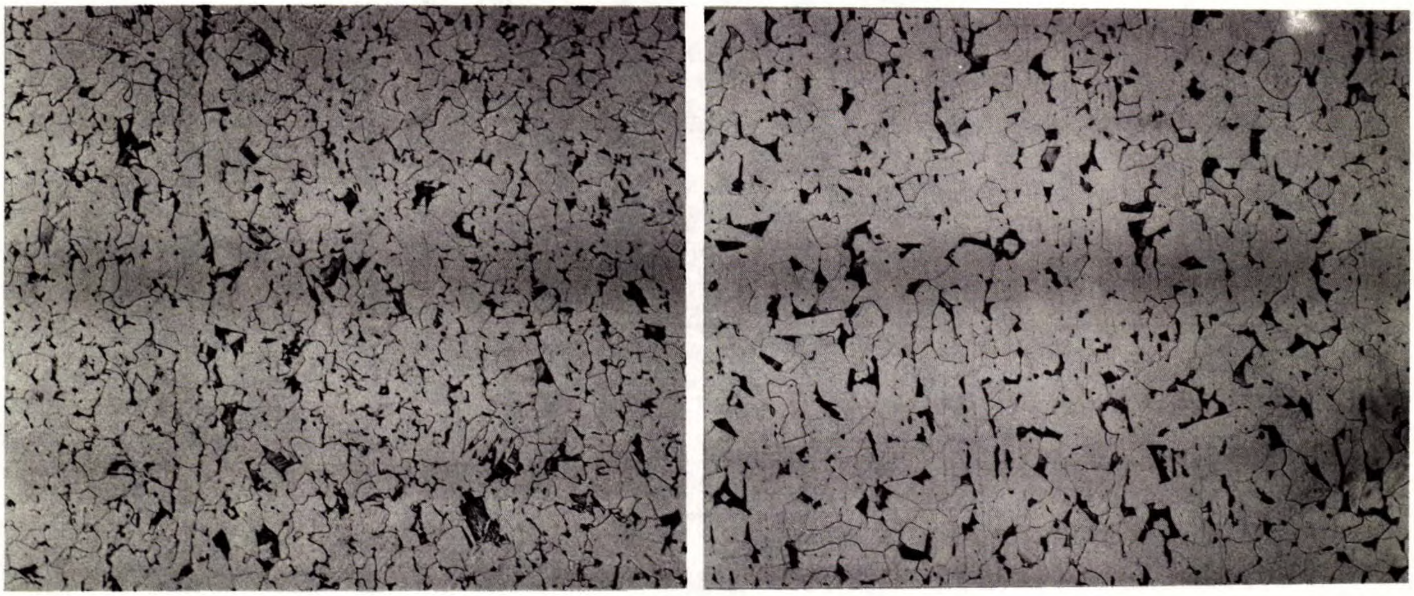


(a) as polished

X100

(b) etched 2% nital

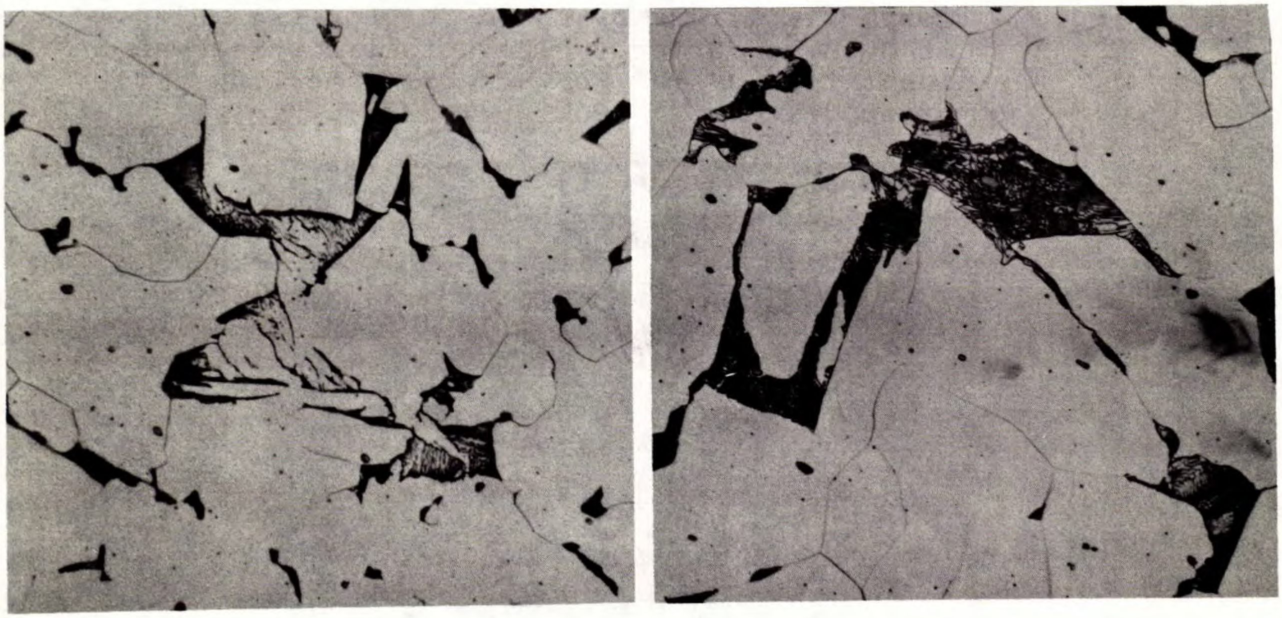
Figure 5. Outer Tube Surface at Bulge (a) - 10 in. from Bulge (b). Corrosive attack by eutectic slag is visible at the outside surface of the hot spot (a).



(a) X100 (b)

etched 2% nital etched 2% nital

Figure 6. Etched Microstructure at Bulge (a) - 10 in. from Bulge (b).



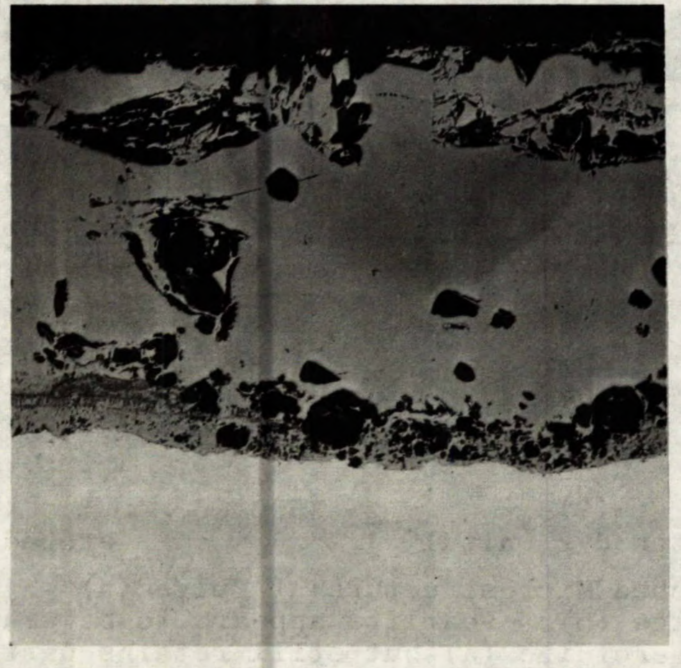
(a) X500 (b)

etched 2% nital etched 2% nital

Figure 7. Etched Microstructure at Bulge (a) - 10 in. from Bulge (b). Pearlite appears to be starting to spheroidize (a) but still retains partial lamellar form. The pearlite in areas other than the 2 in. diameter hot spot is lamellar and is unaffected (b). No coalesced carbide was observed.

as polished X500

Figure 8. Corrosive Attack by Fused Sulphur-rich Slag at Outside Surface. The eutectic phase was identified as FeO.FeS and has a melting point of approximately 1000°C (1832°F).



as polished X100

Figure 9. Illustrates Thick Water Scale on Inside Surface. This scale is relatively non-adherent.