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EXAMINATION OF A FAILED BOILER TUBE

by

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PHYSICAL METALLURGY DIVISION

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

SUMMARY OF RESULTS

Examination of a section of boiler tube, submitted by the New Brunswick Electric Power Commission showed that failure of the tube was due to overheating of a local area of the tube (hot-spot), combined with erosion, which resulted in reduction of the section and the development of transverse thermal-fatigue cracks.

The steel was identified as conforming to SAE-1012 composition. The tube had been manufactured from a rimming grade of steel.

The presence of copper was detected in the scale on the water-side of the failed tube by spectrographic and X-ray diffraction analysis.

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INTRODUCTION

A section of boiler tube, which failed in service, was submitted to the Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys by the New Brunswick Power Commission, Fredericton, New Brunswick, for examination to determine the cause of failure.

The covering letter (File Number 3-463, Ch. #1 boiler), dated September 14, 1960, stated that failure of the tube had occurred about mid-way between the front and back walls of the furnace in a Foster Wheeler S.A. Boiler operating at 600 psig. The side walls in this boiler are bent inward just below the mud drums to form a hopper bottom to the furnace, and it was at the centre of this sloping section that the failure occurred. (No unaffected metal was available for comparative examination).

EXAMINATION

Visual Examination

The sample of boiler tube was photographed as-received, Figure 1 (a) (b) and (c).

X 3/4

Figure 1 (a). Water-Side of Boiler Tube
Transverse cracks are visible on the water-side of the sample of boiler tube.

X 3/4

Figure 1 (b). Fire-Side of Boiler Tube
The dark area on the fire surface may be indicative of a hot-spot.

X 3/4

Figure 1 (c). Side View of Boiler Tube
A bulge in the area of the hot-spot (Figure 1 (b) is visible.

Chemical, Spectrographic and X-Ray Analysis

Chemical Analysis: Drillings for chemical analysis were obtained from the sample, as illustrated in Figure 2. The results of the analysis are shown in Table 1.

TABLE 1

Chemical Composition (per cent)

Element	C	Mn	Si	P	Cr	Mo	Cu
Boiler Tube	0.13	0.41	0.01	0.010	0.043	0.02	0.04

The boiler tube appeared to be a rimming grade, SAE 1012 steel containing residual quantities of chromium, molybdenum and copper. The composition suggests that the tube was probably manufactured by welding, followed by annealing or normalizing, prior to installation in the boiler.

Spectrographic Analysis: A specimen, for spectrographic analysis, was obtained from the boiler tube sample, as illustrated in Figure 2, and an analysis was obtained for the scale on both the water and fire-sides of the tube. The results of these analyses are shown in Table 2.

TABLE 2

Semi-Quantitative Spectrographic Analysis (per cent)

Element	Cu	Si	Ca	Sn	V
Scale, Water Surface	15.0	0.6	4	0.03	0.002
Scale, Fire Surface	0.3	5	6	Tr	0.03

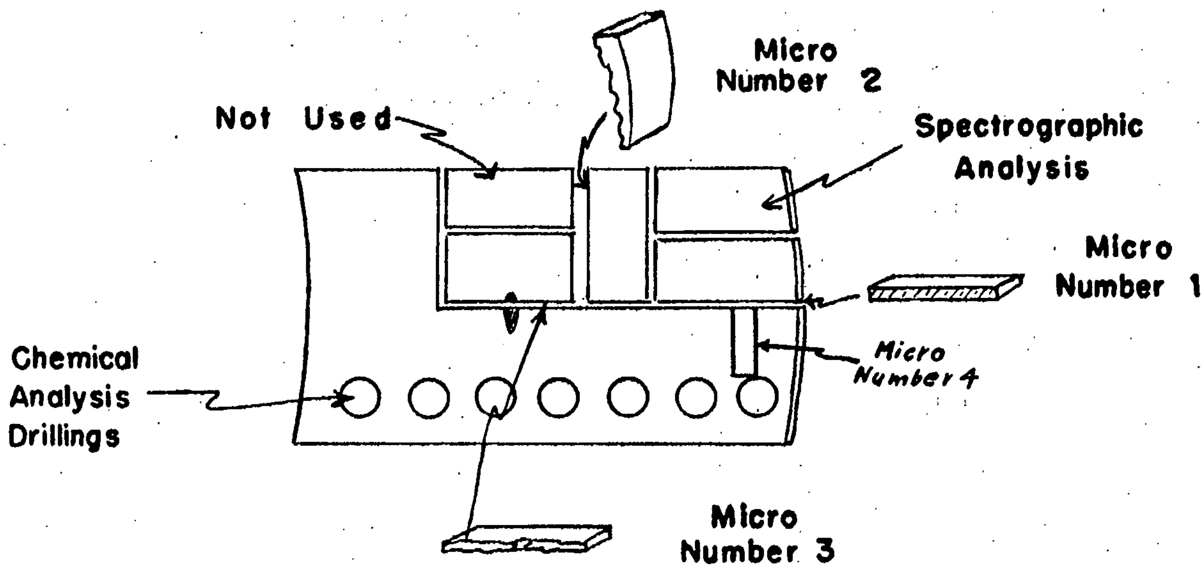
Spectrographic analysis of the scales showed concentration of copper on the water-side of the boiler tube sample.

X-Ray Analysis of the Scale

Samples of the scale on the water surface and the fire surface of the boiler tube were examined by Debye Scherrer X-ray diffraction analysis. The scale on the fire-side was identified as Fe_3O_4, Fe_2O_3, alpha Fe and possibly Cu. The scale on the water-side was identified as Fe_3O_4, Fe_2O_3, Cu_2O, alpha Fe and possibly Cu and CuO.

METALLOGRAPHY

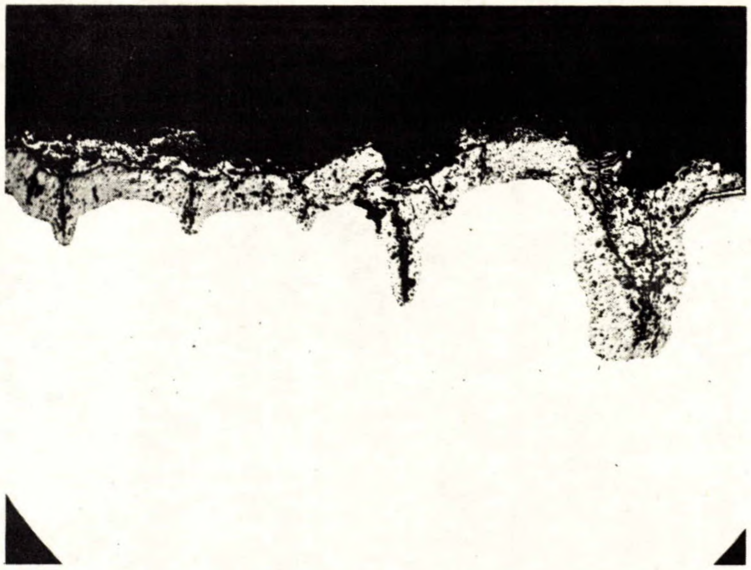
The sample of boiler tube received was sectioned, as shown in Figure 2, and four micro-specimens were examined.



Actual Size

Figure 2. Diagram of Sample of Boiler Tube.
The sample of boiler tube was sectioned as illustrated in this diagram.

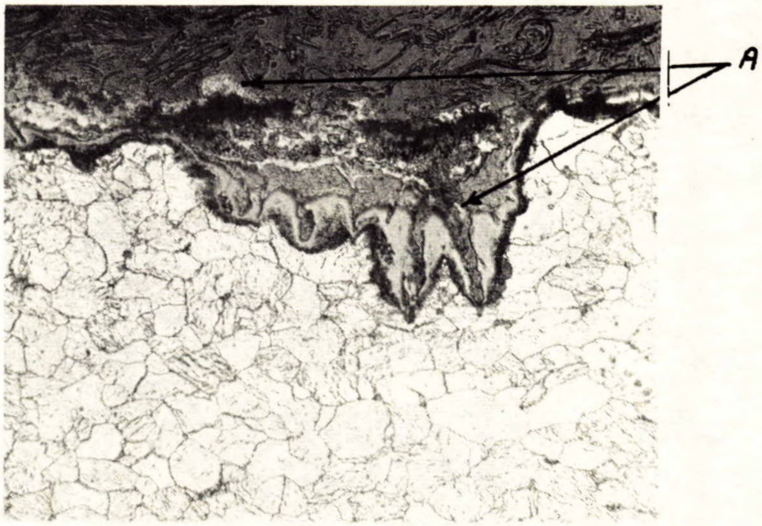
Examination of the water-side of the boiler tube (Micro Number 1, Figure 2) showed the entire surface to be covered with a uniform layer of oxide. The cracks were seen to be blunt-ended and filled with corrosion product (Figure 3).



X100 Unetched

Figure 3. Typical Section at the Water Surface of the Boiler Tube.
The uniform layer of oxide and blunt-ended cracks may be seen in this longitudinal section. (Micro Number 1, Figure 2).

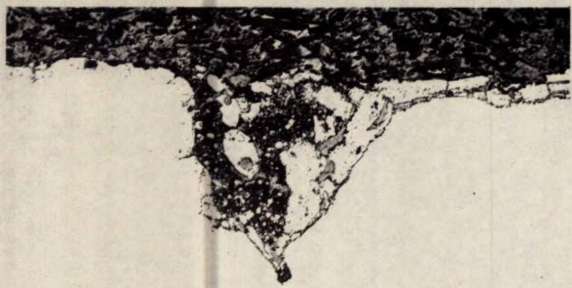
The oxide layer on the water-side of the boiler tube was seen to contain a considerable amount of copper (Figure 4, Arrows A)



X100 Etched in 2% Nital

Figure 4. Copper Contained in the Oxide Layer on the Water-Side of the Boiler Tube (A), (Micro Number 3, Figure 2) Longitudinal Section.

The fire surface of the tube (Figure 5) had a thinner oxide layer and contained fewer cracks than the water surface.



X100 Unetched

Figure 5. Typical Area on the Fire Surface of the Boiler Tube (Micro Number 1, Figure 2). Longitudenal Section.

The transverse section (Micro Number 2, Figure 2) showed a reduction in wall thickness in the darkened area of the boiler tube sample as illustrated in Figure 6.

X1-1/2

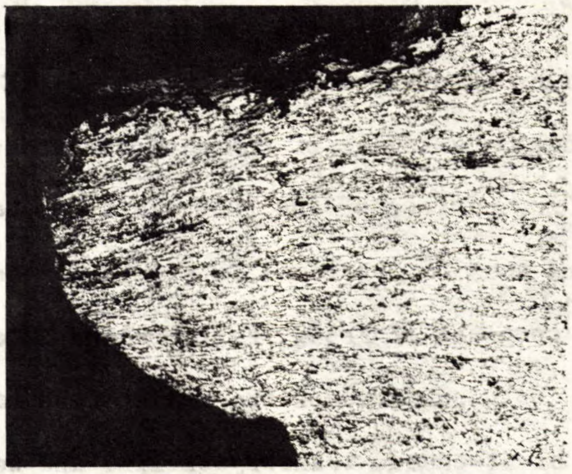
Figure 6. Micro Number 2 and Micro Number 3 (Figure 2) Transverse section number 2 (top) has a reduced section (extreme left) at a position corresponding to the dark area shown in Figure 1 (b). (The water surfaces of the two sections are closest to the centre of the specimen).

Complete spheroidization of the carbide and deposition of carbides inside ferrite grains was observed in the reduced section (Figure 7).

X1000 Etched in 2% Nital

Figure 7. Microstructure in the Area of Reduced Section.
Complete spheroidization and deposition of carbides inside ferrite grains was observed in this transverse microspecimen (Micro Number 2, Figure 2).

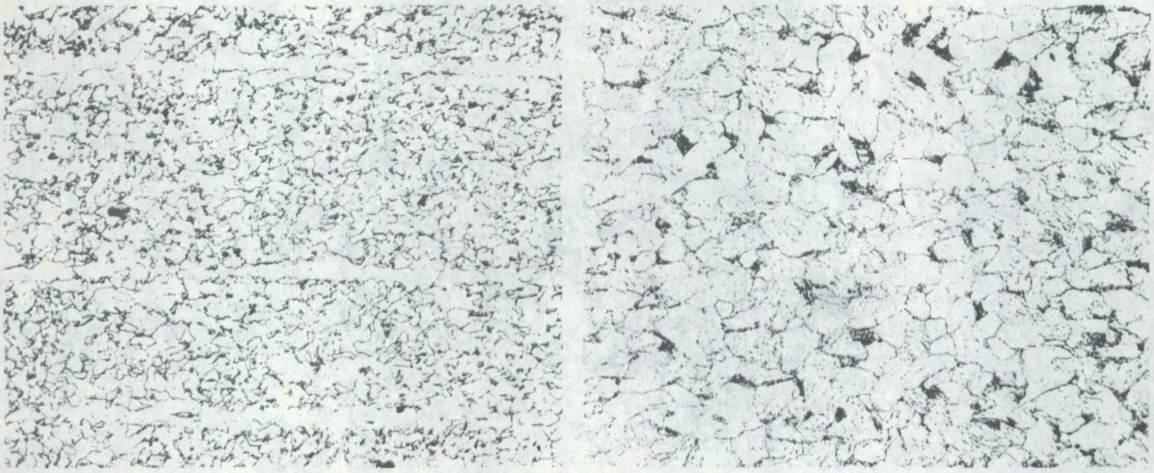
Some evidence of cold-work, as shown in Figure 8, was observed adjacent to the rupture.



X150 Etched in 2% Nital

Figure 8. Deformation at Point of Rupture (Micro Number 3, Figure 2)
The temperature at the time of failure was sufficient for complete spheroidization but did not exceed the Ac_3 temperature.

A comparison of the grain sizes in samples numbers 3 and 4 showed that recrystallization had occurred in the area adjacent to the rupture (Figure 9 (a) and (b)).



(a) X150 (b) X150

Figure 9. Recrystallization in the Area Adjacent to Rupture
(a) Microstructure adjacent to rupture (refined ferrite grain size).
(b) Microstructure $1\frac{1}{2}$ in. from the rupture (original ferrite grain size).

SUMMARY

The boiler tube was a rimming grade of SAE 1012 steel, having small residual quantities of chromium, molybdenum and copper. The scale on the fire surface of the tube was composed of Fe_3O_4, Fe_2O_3, alpha Fe and possibly residual Cu, while the scale on the water surface was composed of Fe_3O_4, Fe_2O_3, alpha Fe and a considerable amount of copper. Both surfaces of the boiler tube had transverse cracks which were blunt-ended, transcrystalline and were filled with iron oxide.

The dark area shown in Figure 1 (b) coincided with a reduction in section thickness.

Complete spheroidization of the pearlite in the area of the rupture was observed.

CONCLUSIONS

1. **The boiler tube was made from a rimming grade of SAE 1012 steel.**
2. **Copper was concentrated in the scale on the water surface of the boiler tube. This suggests the possibility of galvanic attack of copper fittings elsewhere in the boiler.**
3. **The pearlite has been completely spheroidized adjacent to rupture.**
4. **The spheroidization, evidence of cold-work and recrystallization of the ferrite suggests a temperature in the range 482°C (900°F) to 704°C (1300°F) in the region of the rupture.**
5. **Failure of the tube appeared to be due to overheating of a local area of the tube (hot-spot), combined with erosion, which resulted in reduction of the section and development of transverse thermal fatigue cracks (1).**

REFERENCE

1. **The Babcock and Wilcox Company Technical Bulletin 6 G.**

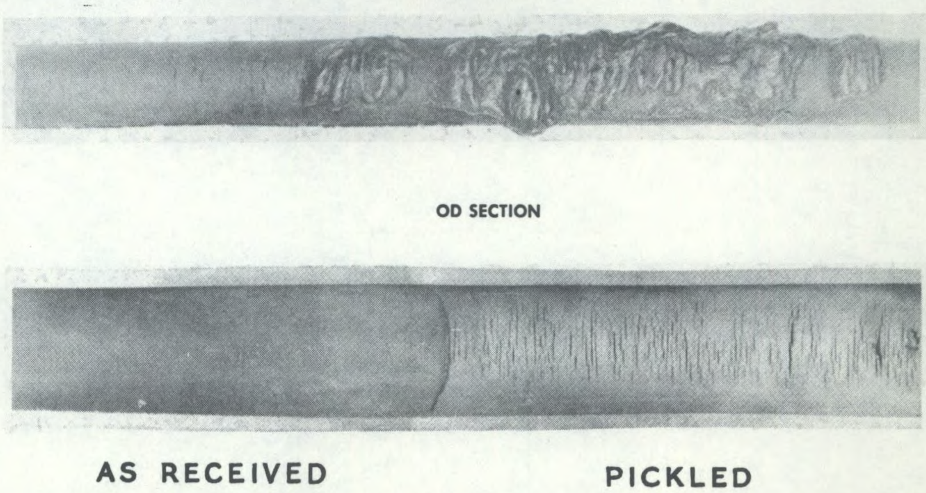


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Figure 133 – Thermal fatigue cracking in a 5%Cr–0.50%Mo superheater tube removed from a superheater control boiler. The failure was attributed to the combined action of surface corrosion – due to contact with steam and water – and a steep thermal gradient causing differential expansion during the operating cycle. The mode of operation of the equipment rather than the structural stability of the 5%Cr material was indicated as the factor responsible for the failure.