Steel Image Inc., Failure Analysis and Metallography
7 Innovation Drive, Suite 155, Flamborough
Ontario, Canada, L9H 7H9, (289) 895-8363

IN-SITU METALLOGRAPHY OF HEATER TUBES

EXAMPLE REPORT

Modified from Original Report

- Electronic Copy -

Shane Turcott, *P.Eng. M.A.Sc.*
Principal Metallurgist

IN-SITU METALLOGRAPHY OF HEATER TUBES

SUMMARY

Material: ASTM A106B plain carbon steel.

Pigging inspection of a furnace during the previous shutdown had found diametric growth and potential creep damage within the heater tubes. In-situ metallography was used to non-destructively assess the metallurgical condition at the sites of greatest concern (sites listed in **Table 1**). The evaluation included preparation of the tube surfaces, on-site examination, replication, hardness testing and off-site examination under an optical microscope.

Figure 1 displays examples of the sites evaluated by in-situ metallography and hardness testing. Also illustrated was deformation of a bar indicating thermal expansion from overheating (**Figure 1c**).

Inlet Tube #17 (coolest tube), selected as a reference location, comprised of a ferritic and pearlitic structure typical for as-manufactured ASTM A106 Grade B tube (**Figure 2a,b**). No notable thermal degradation had occurred at this site (Level A spheroidization, Stage 1 creep, rating chart in **Appendixes A and B**).

The other sites evaluated on the tubes, corresponding to diametrical growth, all exhibited upper bainitic structures (**Figure 2c-j**). These structures indicated that these tubes had experienced an excursion above 1600ºF (>871ºC), then cooled relatively quickly. No creep voids or cracking was observed (Stage 1 creep).

Hardness testing of each site evaluated by in-situ metallography was completed using a Krautkramer MIC-10. **Table 2** summarizes the results.

CONCLUSIONS

The bainitic microstructures found on Tubes #23, #31 and #62 indicated that they had at some point experienced an excursion above 1600ºF (>871ºC) then cooled relatively quickly. This type of thermal pattern matched well with product flow interruption during operation, causing the tubes to overheat. During re-introduction of product flow, the tubes had quenched at a moderate rate, forming the bainitic structure.

The tubes appeared to have operated without issue since the excursion. No creep damage or other life-limiting mechanisms were observed. No features were observed that would warrant immediate concern and it was likely these tubes would be fit for continued service as-is. It is recommended that the client perform a fitness-for-service evaluation to valid their suitability for continued service.

Table 1: Location of In-Situ Metallography

Tube	Coil	Description / Location
17	1	-Inlet Tube for Coil #1 -Taken near top of boiler -Expected to be coolest tube within boiler
23	1	-Mid-tube within Coil #1 -Taken ~10ft from the top (approx mid height) -Expected to be representative of Coil #1
31	1	-Diametric growth detected 10.9ft from top bend
62 (top)	2	-Outlet Tube for Coil #2 -Taken near top of boiler -Expected to be hottest tube within boiler -Deformation of bar above tubes indicated significant thermal expansion (**Figure 1**)
62 (mid)	2	-Diametric growth detected 9.8ft from top bend

Table 2: Hardness Results*

Tube	Location	Measurements (HRB)	Avg. Hardness (HRB)
Tube 17	Coil #1 Inlet	81.9, 78.1, 82.8, 78.6, 79.3	80
Tube 29	Coil #1	72.8, 73.6, 75.8, 73.7, 73.6	74
Tube 31	Coil #1 Outlet - top	81.3, 81.1, 79.9, 77.0, 79.0	80
Tube 31	Coil #1 Outlet - mid	79.6, 82.8, 81.0, 83.9, 81.4	82
Tube 62	Top	73.9, 72.4, 71.8, 73.4, 72.1	73
	9.8ft from top	76.0, 75.6, 76.6, 76.9, 75.9	76

*Hardness testing using MIC-10 hardness tester

Figure 1: (a,b) Photographs displaying examples of the sites evaluated by in-situ metallography and hardness testing. (c) Due to overheating, the tubes had experienced significant thermal expansion.

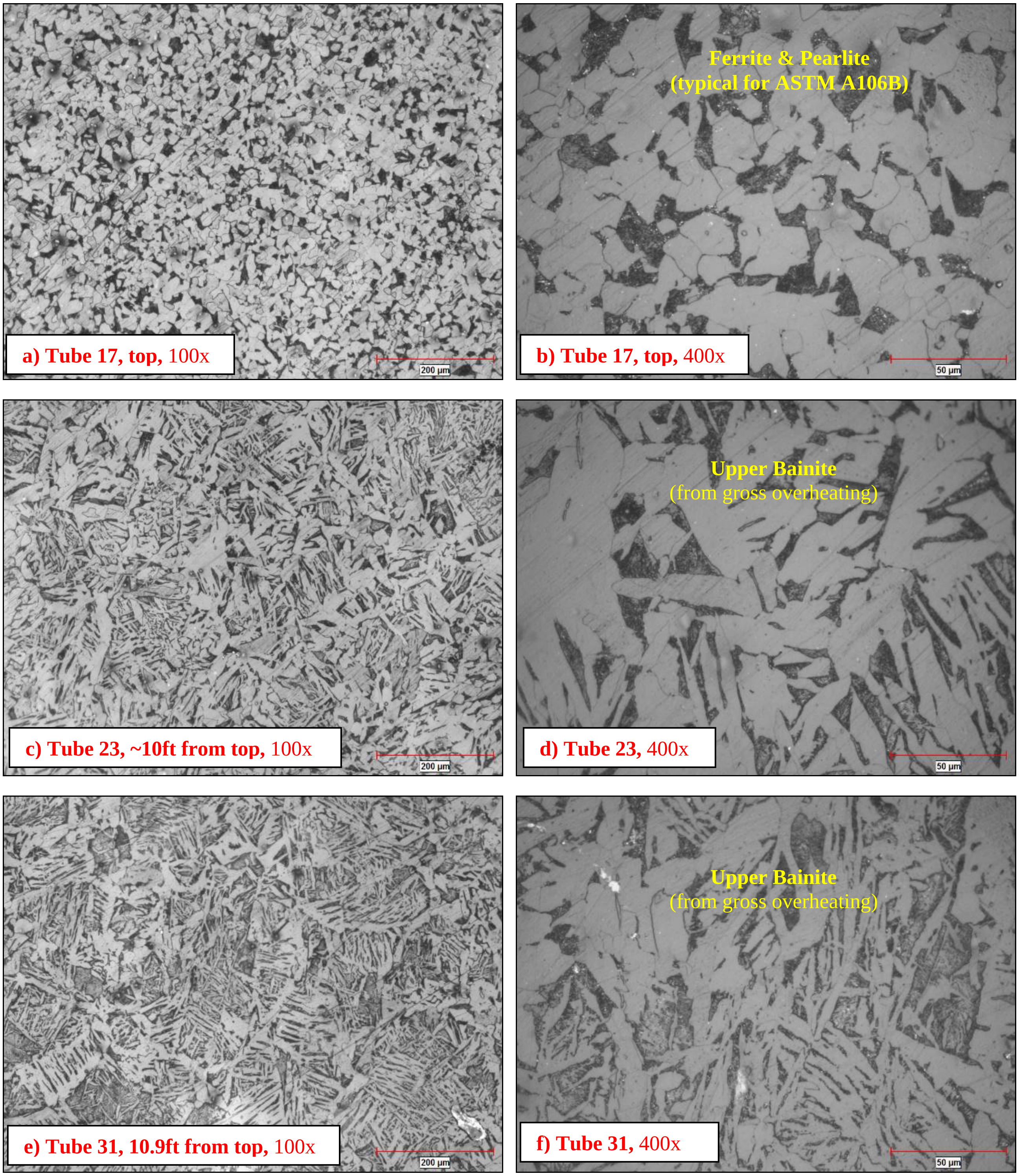
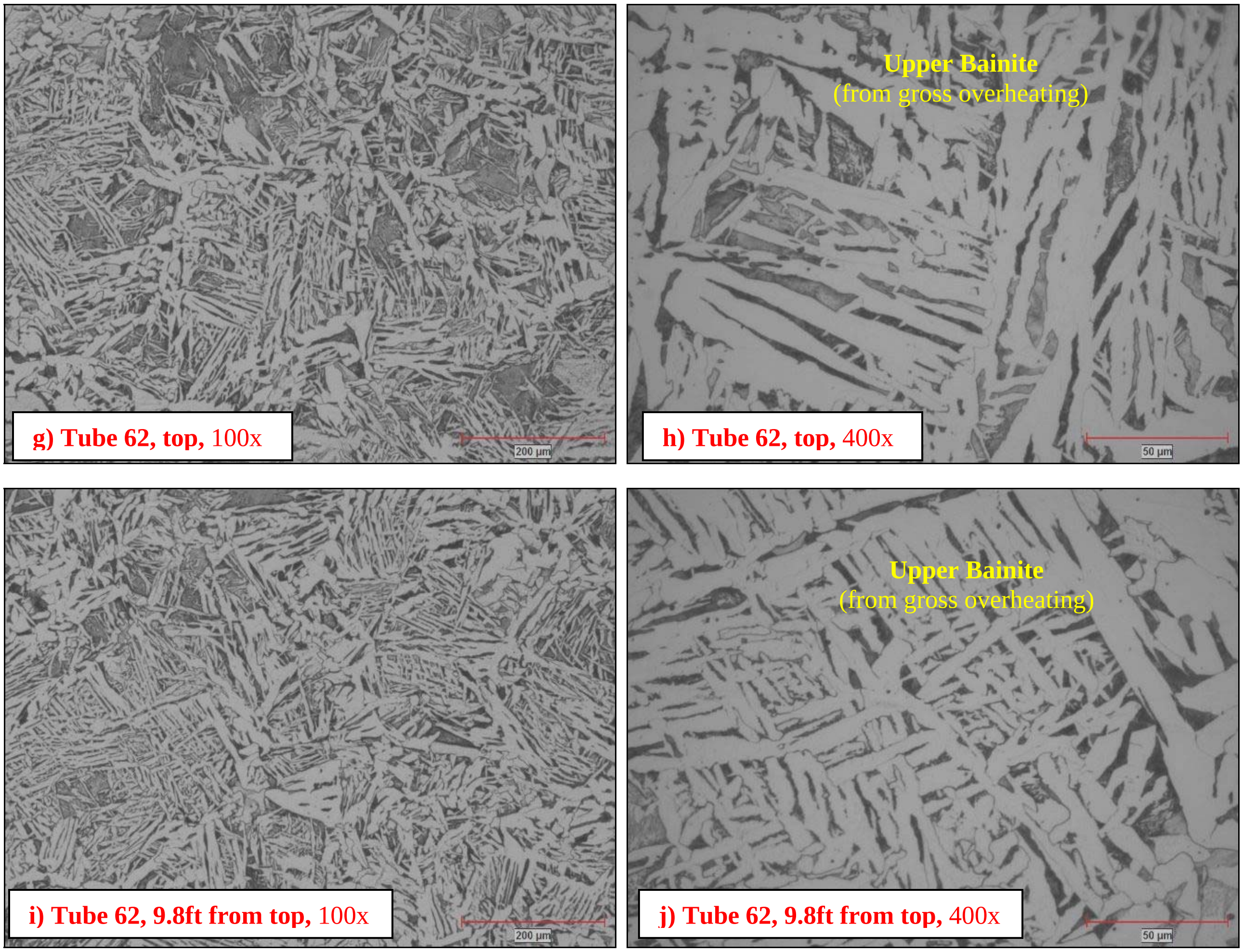


Figure 2: (a,b) The inlet Tube #17 comprised of a structure typical for an as-manufactured ASTM A106B carbon steel. No thermal degradation was observed. (c-j) The structures at the other locations, including those exhibiting diametrical growth, comprised of upper bainite. These locations had reached temperatures above >1600ºF (>871ºC). No creep voids were observed. Images taken from replications, etched on-site using 3% nital.



g) Tube 62, top, 100x

h) Tube 62, top, 400x

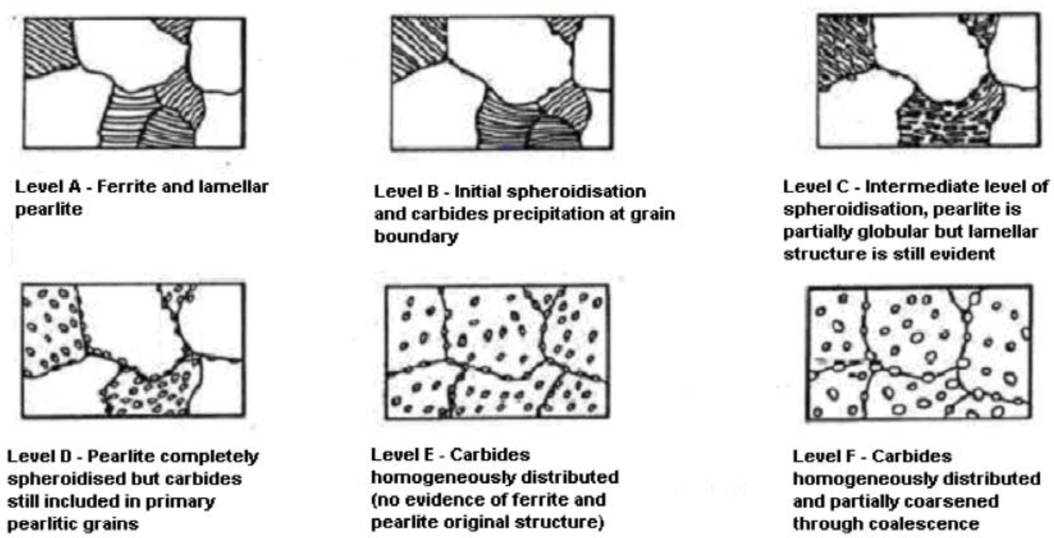
i) Tube 62, 9.8ft from top, 100x

j) Tube 62, 9.8ft from top, 400x

Figure 2 Continued.

APPENDIX A: LEVEL CLASSIFICATIONS OF SPHEROIDIZATION

Spheroidization of carbon and alloy steels is a long-term degradation mode that occurs gradually over years and decades of service (depending upon the temperature of operation). Eventually spheroidization will result in strength reduction of the steel. Advanced Levels E-F spheroidization damage often precedes creep void/crack formation. The schematics below illustrate the six stages of spheroidization.



APPENDIX B: SUMMARY OF CREEP STAGES

Table B1: Creep Damage Stages

Stage	Description	Recommended Boiler Remedial Actions*
1	No creep voids	No action
2	Intermittent creep voids	Re-inspect 3-5 years
3	Oriented, creep void strings	Re-inspect 1-3 years
4	Microcracks	Replace in 6 months
5	Macrocracks	Replace immediately

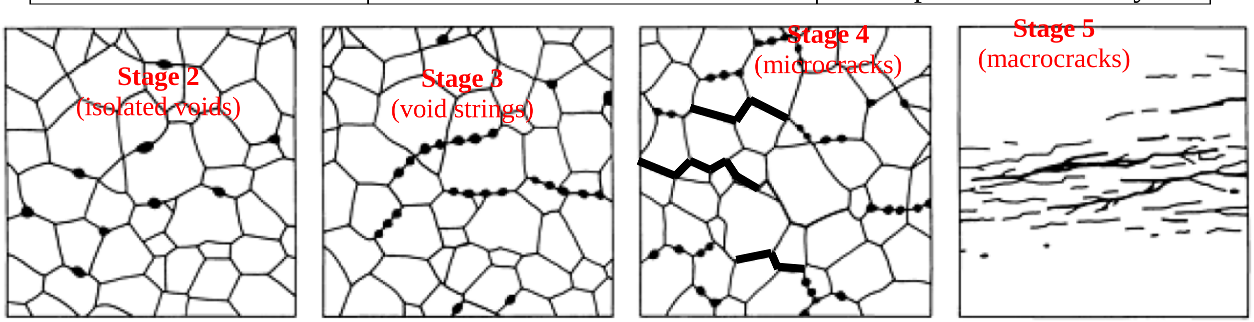


Figure B1: Schematics displaying the different stages of creep void damage.

*These remedial recommendations are for boilers. They are included to provide a reference regarding the severity of creep damage relative to their impact upon reliability. The concern of creep damage should be evaluated specific to each component/equipment design.