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FAILURE ANALYSIS OF A RUPTURED BOILER TUBE

EXAMPLE REPORT

OVERVIEW & OUTCOME

Tube rupture had resulted in a forced shutdown of a critical boiler. To better understand the cause of damage, a failure analysis of the tube was conducted.

Tube rupture had occurred due to short-term overheating yet the tube had experienced prolonged, elevated temperatures. As the damage appeared isolated to this tube only (supported by on-site evaluation), tube failure had been the result of a tube blockage. Boroscope inspection by the refinery had found a suspected blockage at the base of the tube, matching well with this theory. The ruptured tube section was replaced and the boiler put back into service.

The following report was provided within 24 hours of receipt of the sample. This short-report style is used to quickly communicate results when time is critical.

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FAILURE ANALYSIS OF A RUPTURED BOILER TUBE

SUMMARY

A refinery boiler had experienced a rupture failure on Tube #69 of the east water wall near the roof tubes. The tube material was ASTM A192 plain carbon steel and had been in service for approximately thirty years.

The ruptured section of Failed Tube #69, and a sample from the fire side of Tube #65 at approximately the same elevation as the rupture, were provided for analysis (**Figure 1**). Optical examination found Tube #65 to exhibit a microstructure typical of as-manufactured ASTM A192 steel (ie. no service degradation, **Figure 2**). Therefore, this tube had not experienced the same elevated service temperatures later found on the Failed Tube.

The rupture of Failed Tube #69 exhibited a mild fish-mouth morphology (**Figure 3**). The full tube perimeter was cut at the location of failure and examined by optical microscopy. The fireside wall, remote from the failure, exhibited significant thermal degradation in the form of spheroidization from long-term overheating (prolong exposure at temperatures up to 727ºC / 1340ºF, **Figure 4d,e**). The region of failure itself exhibited a partially bainitic structure, indicating this region had reached a maximum temperature of approximately 800ºC / 1475ºF at the time of failure (**Figure 5**). At this high temperature, the steel would have been partially austentic and had significantly reduced strength, resulting in overload from the internal pressure. Once ruptured, the steam flow would have increased, quenching the steel to form bainite.

Hardness testing was conducted in the transverse orientation on Tubes #65 and #69. **Tables 1 and 2** list the obtained results. The hardness along the fireside of Failed Tube #69 varied significantly due to the alteration of the microstructure from (a) long-term overheating and (b) reaching temperatures above 727ºC.

CONCLUSIONS

Tube #69 rupture was due to overheating. The tube had experienced long term overheating well above its rated temperature, causing thermal damage to the tube. Yet failure had not occurred until a small portion of the tube had reached temperatures in the order of 800ºC / 1475ºF. This short-term spike in temperature resulted in strength loss, causing rupture. **Figure 4a** provides a diagram with the thermal profile of the tube indicated.

This sequence of failure matched well with the theory that a blockage specific to this tube had reduced steam flow, reducing the cooling of the tube. It was likely that a partial blockage had resulted in long-term overheating and, from continual worsening of the blockage, the temperatures had increased until rupture.

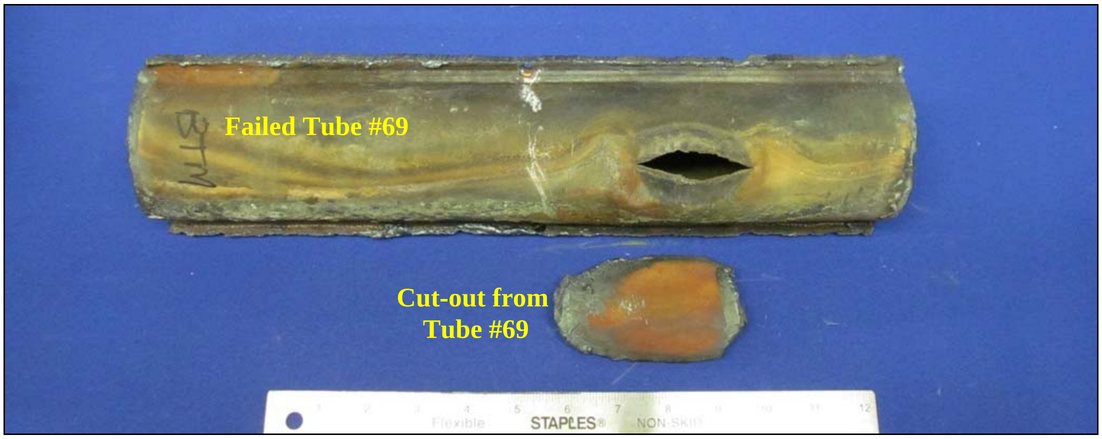

Figure 1: Photograph displaying the samples submitted for analysis including (1) the Failed Tube #69 and (2) a segment from Tube #65, at the height of failure.

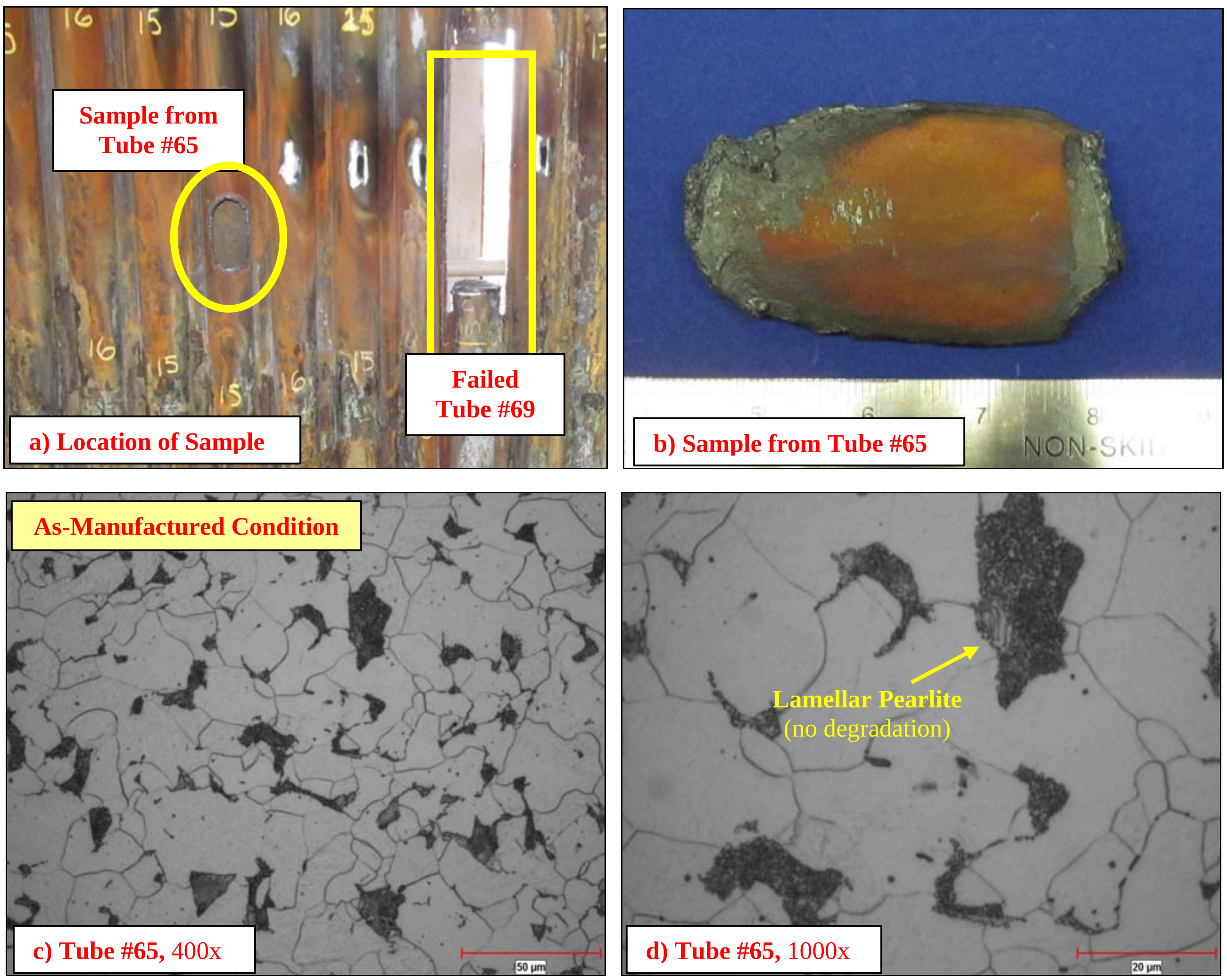

Figure 2: Photographs and micrographs of the sample taken from Tube #65. The core structure at this location was typical for the as-manufactured condition of ASTM A192 steel (ie. no service degradation). Etched using 3% nital.

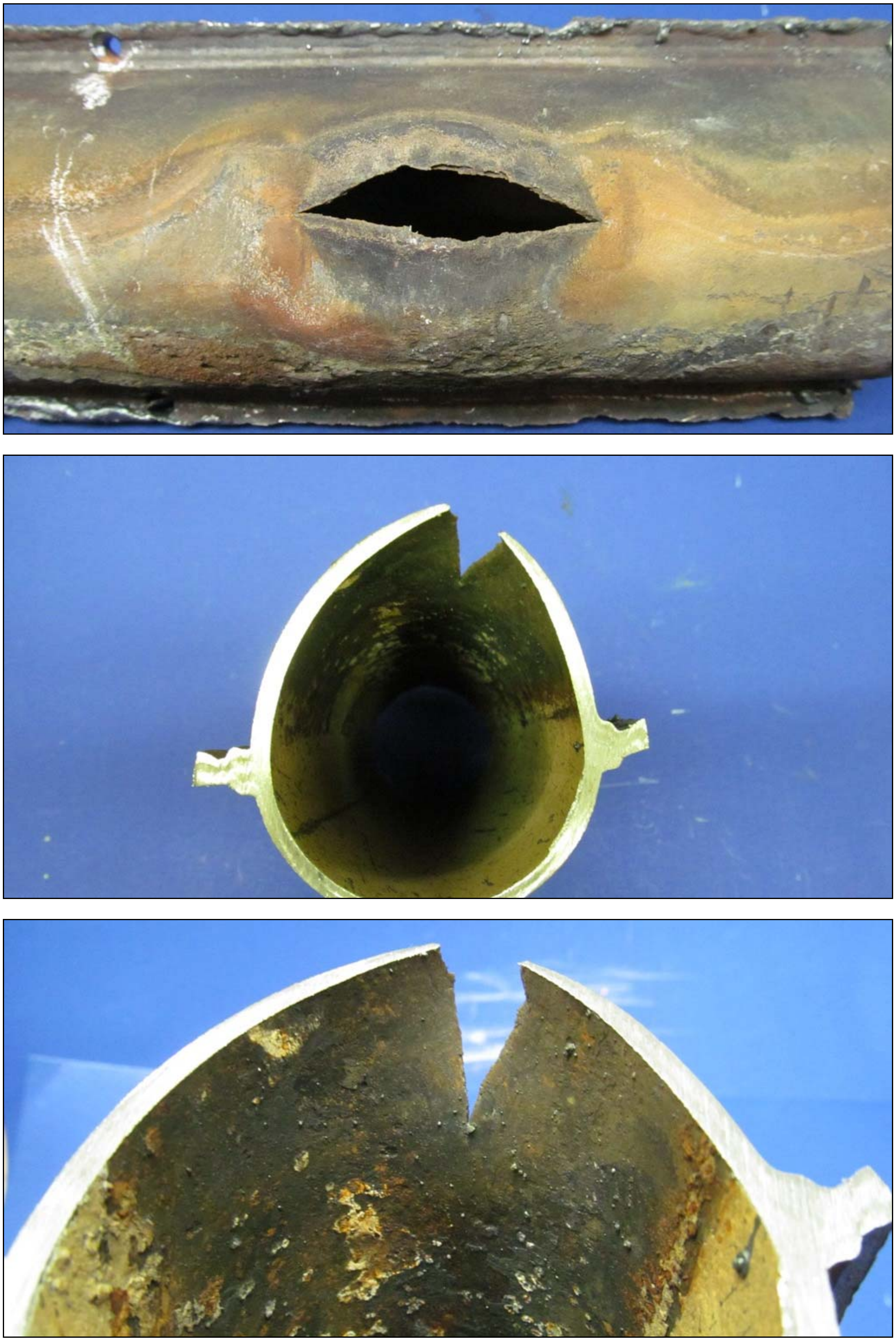

Figure 3: Photograph displaying the failure of Tube #69. The failure exhibited a mild fish-mouth morphology. Further analysis would find that the failed region had been overheated at the time of failure.

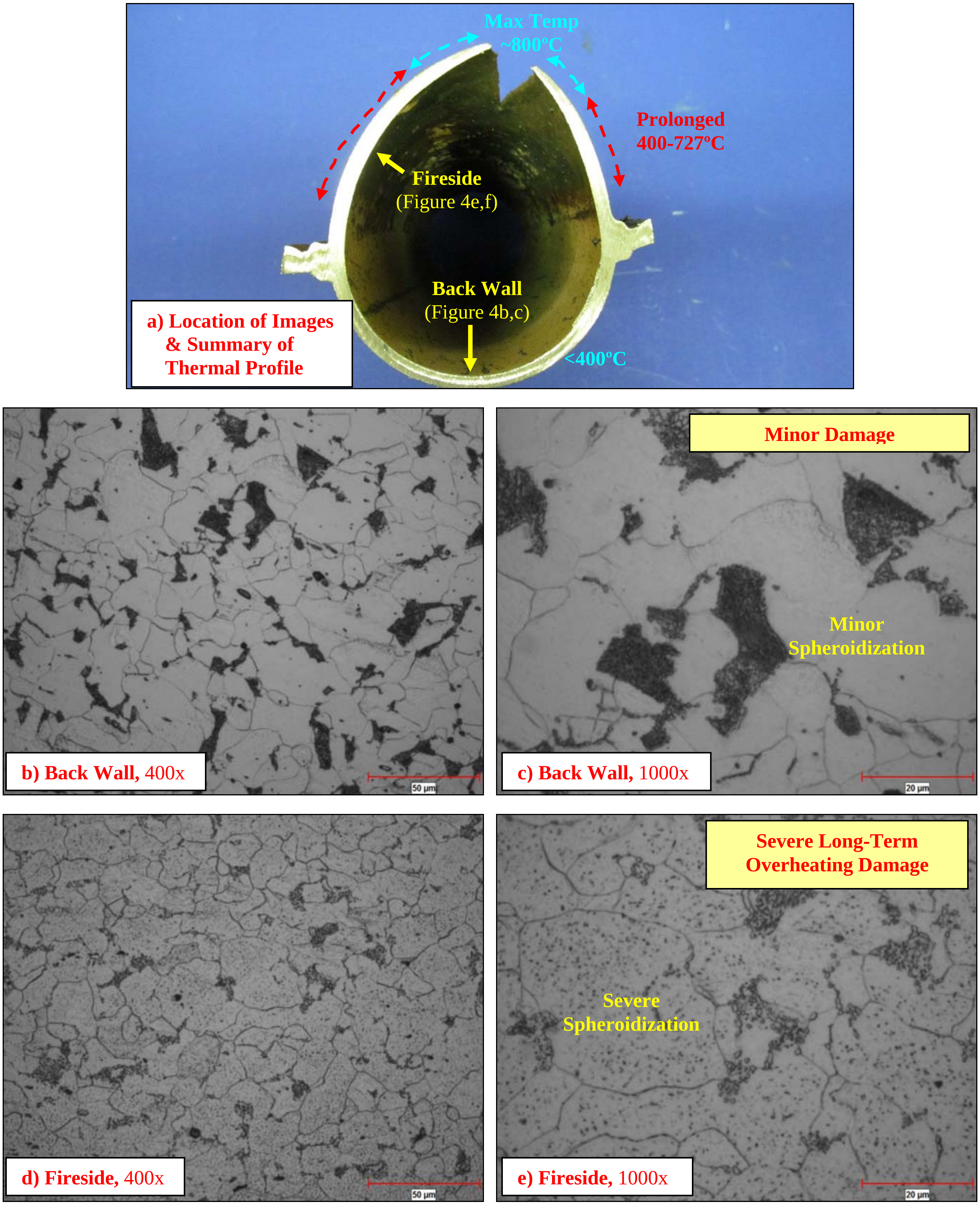

Figure 4: (b,c) The back wall of Tube #69 exhibited only minor spheroidization/thermal degradation from service. (d,e) Portions of the fireside exhibited significant spheroidization/thermal degradation from long-term overheating (<727ºC / 1340ºF). Etched using 3% nital.

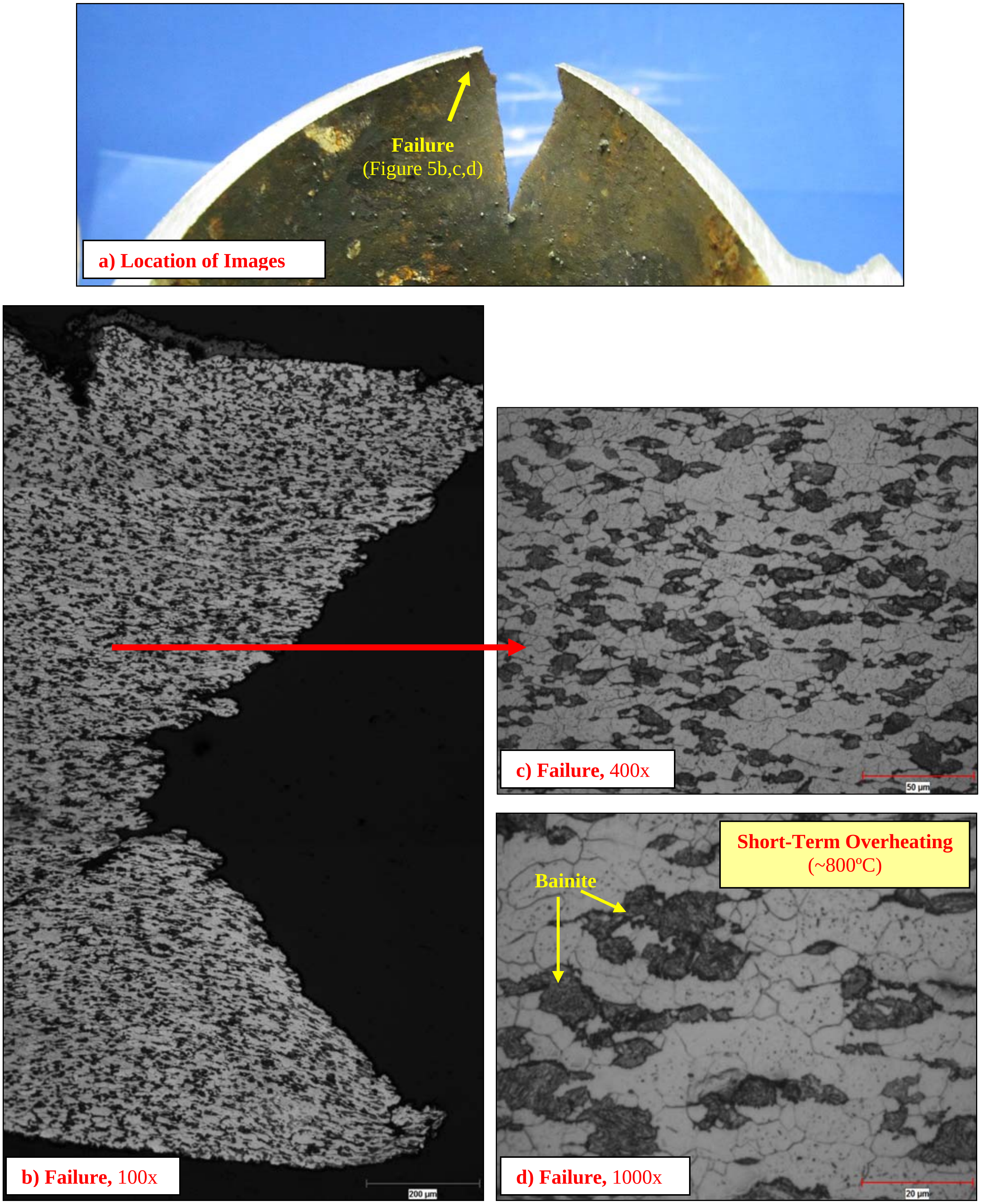

Figure 5: Micrographs displaying the initiation region to comprise of deformed ferrite and bainite. The bainite indicated that this region had reached an approximate maximum temperature of 800ºC (~1475ºF) at the time of failure. The elevated temperature resulted in reduced material strength, causing rupture failure.

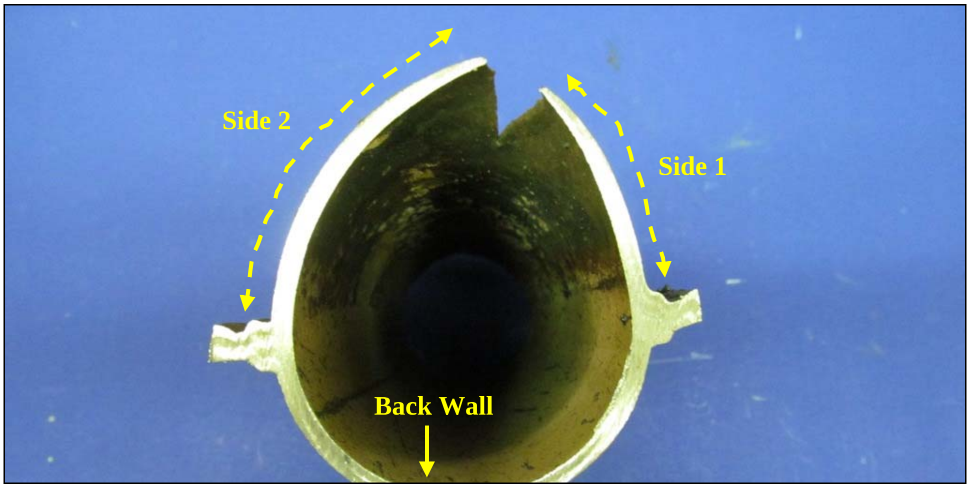

Table 1: Microhardness Test Results of the Failed Tube #69*

Distance from Failure (mm)	Side 1		Side 2	
	HV_{500gf}	HRB	HV_{500gf}	HRB
1	149	80	148	79
2	150	80	140	76
3	145	78	145	78
4	161	84	154	81
5	156	82	165	85
10	151	80	160	83
15	151	80	153	81
20	133	73	145	78
25	134	74	144	78
30	134	74	129	72
35	140	77	128	71
40	147	79	128	71
45			134	74
50			124	70
55			121	68
60			127	71
65			125	70
70			133	73

Location	Measurements (HV_{500gf})	Avg. Hardness	
		HV_{500gf}	HRB
Back Wall	130, 129, 118, 123, 127	125	70

*Hardness testing conducted in the transverse orientation around the tube perimeter as illustrated in the picture above.

Table 2: Microhardness Test Results of Tube #65

Location	Measurements (HV_{500gf})	Avg. Hardness	
		HV_{500gf}	HRB
Tube 65	117, 119, 114, 117, 119	117	66