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CONFERENCE & EXHIBITION
INNOVATIVE SOLUTIONS FOR CORROSION CHALLENGES

Premature Failure of Radiant Shield Boiler Tubes in a Reformer Convection Section

A Failure Analysis Case Study

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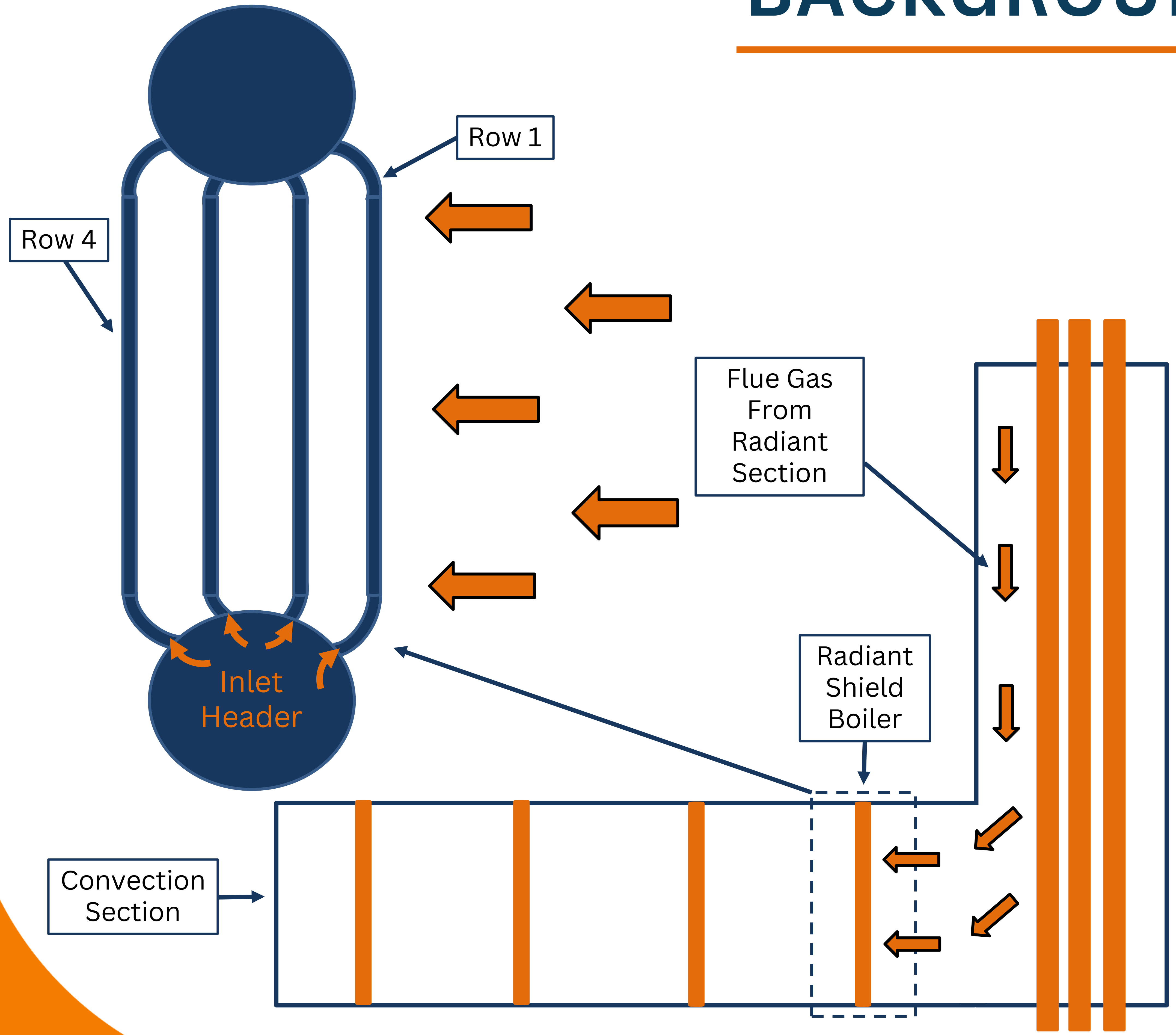
CONTENT

INTRODUCTION

- In the reformer convection section, steam leakage from radiant shield boiler tubes was observed.
- The failure of the radiant shield boiler tubes resulted in a plant shutdown.
- The failure occurred ten days after start-up following a planned maintenance shutdown.
- During planned maintenance shutdown, UT thickness checks and visual examination did not revealed any issues in the boiler tubes.
- Failure analysis was conducted to identify the reason of tube failure.

BACKGROUND

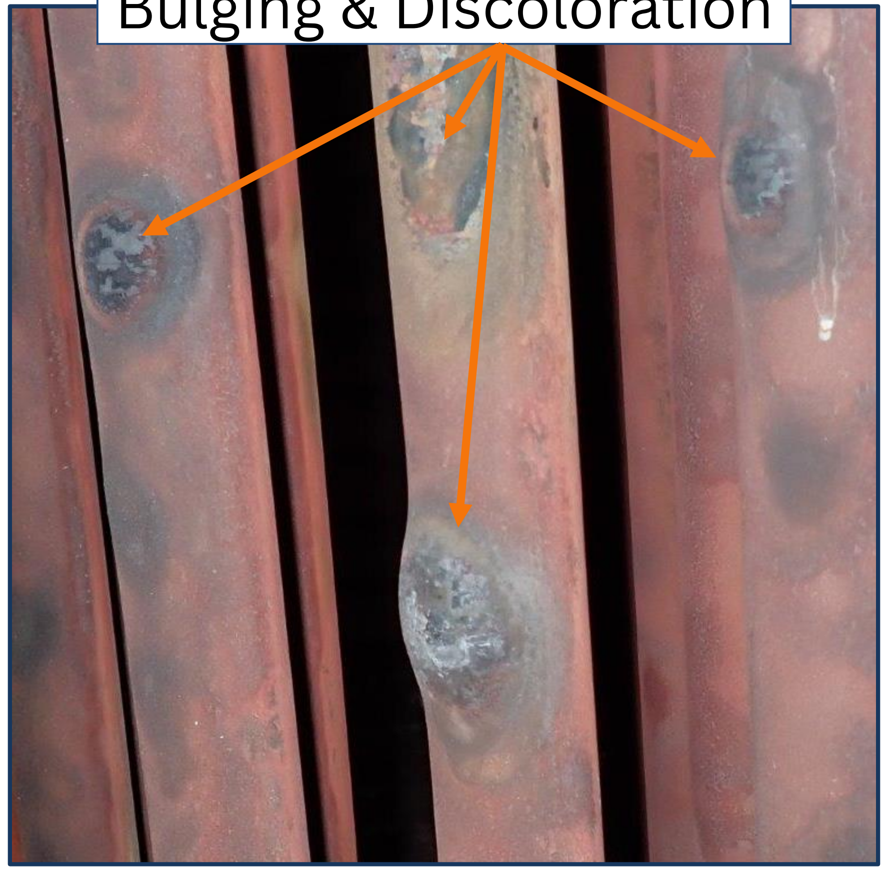


- Boiler water from the steam drum flows inside the tubes from the inlet header (bottom).
- Heating on the external surface is through flue gas from the radiant section.
- The boiler has 4 rows of tubes with Row 1 being on the upstream side (US) and Row 4 being on the downstream side (relative to flue gas flow direction)
- The failures occurred on Row 1
- The material of construction is ASME SA 210 Gr C

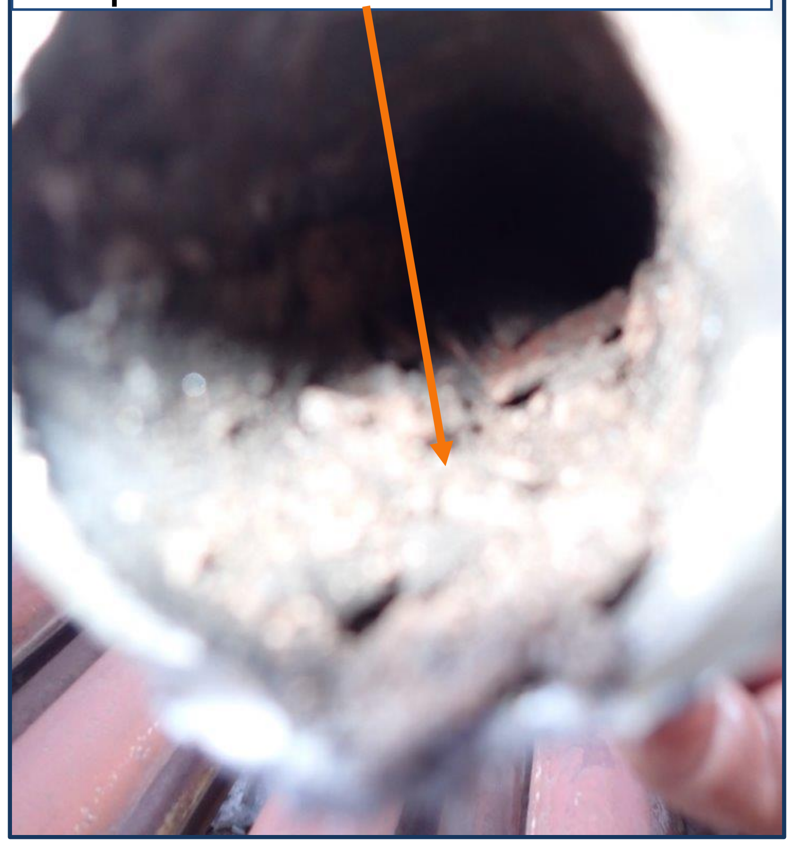
VISUAL EXAMINATION

Multiple Tubes affected with Bulges & Ruptures

Bulging & Discoloration



Deposits inside the Tubes

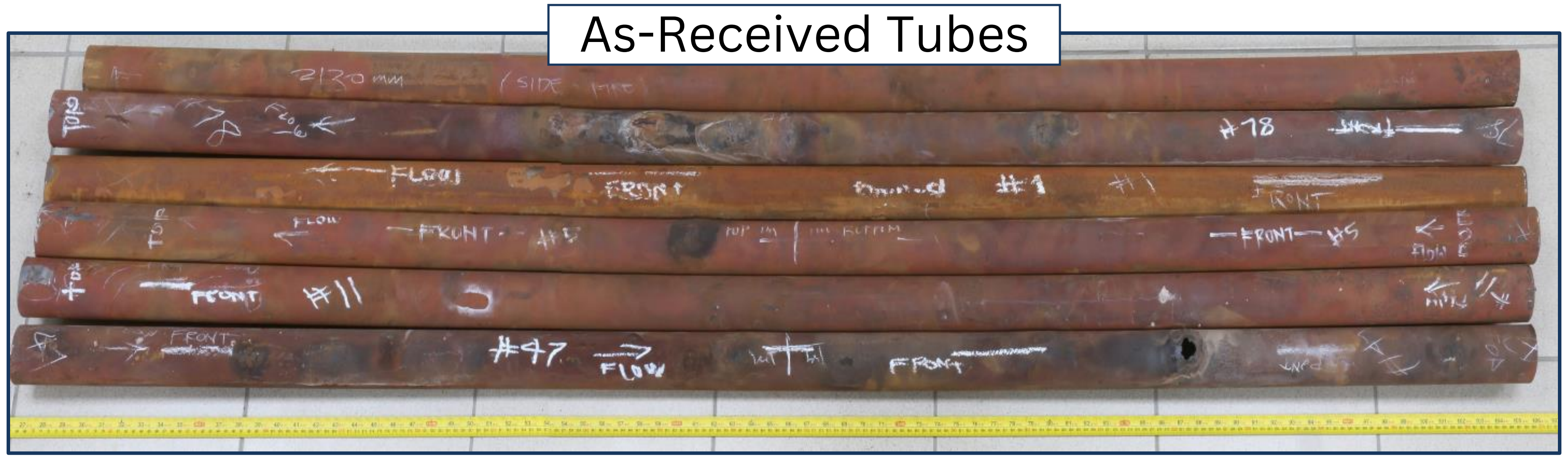


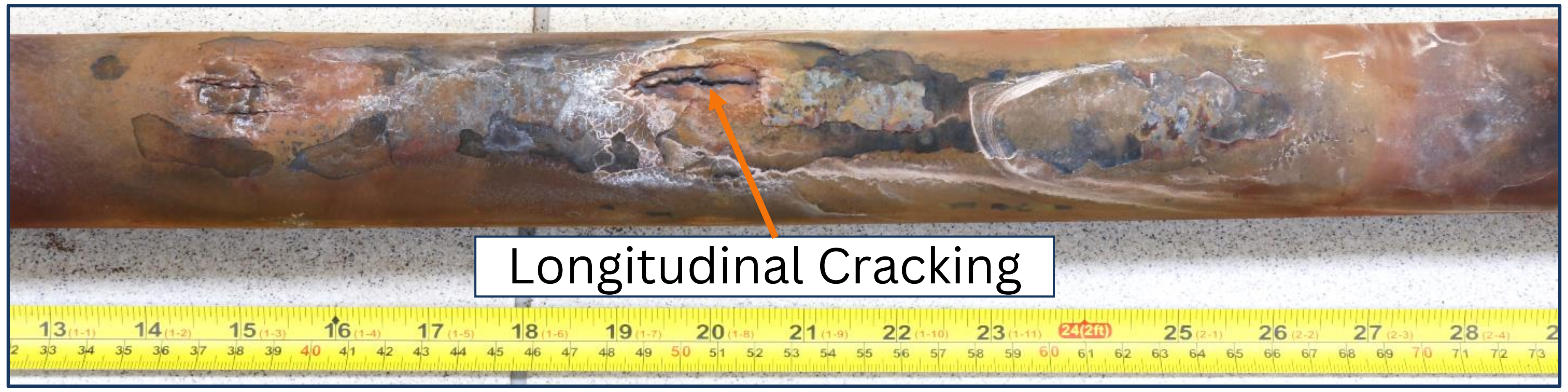
Deposits inside the Header

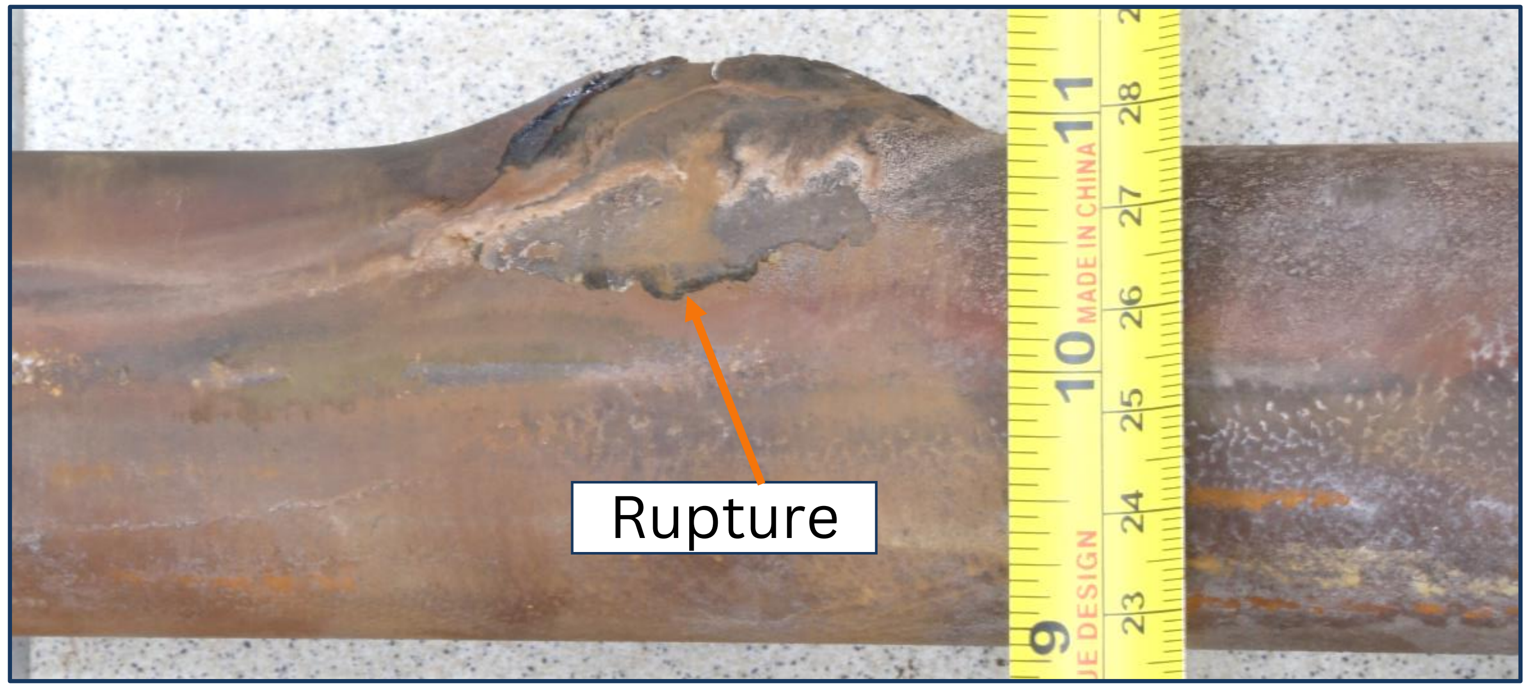
- Longitudinal cracking and bulging in multiple discolored areas along Row 1 tubes were observed
- The bulging and discoloration is typical of overheating damage
- Deposits inside the headers and tubes were observed
- Heavy deposits can block tubes leading to overheating

VISUAL EXAMINATION

- 6 tubes were selected for analysis:
  - Row 1 – 5 tubes (tubes# 1, 5, 11, 47 & 78) with varying degrees of damage (opening, cracking, bulging, no apparent damage)
  - Row 4 – 1 tube with no apparent damage was selected for reference purposes
- The damage is on the upstream side (US) of the tubes (side facing the oncoming flue gas)
- Cracking is longitudinal and multiple
- Crack direction indicates that cracking is driven by stresses due to internal pressure (hoop stresses)
- Scaling and discoloration coinciding with the bulged and cracked areas is a sign of overheating

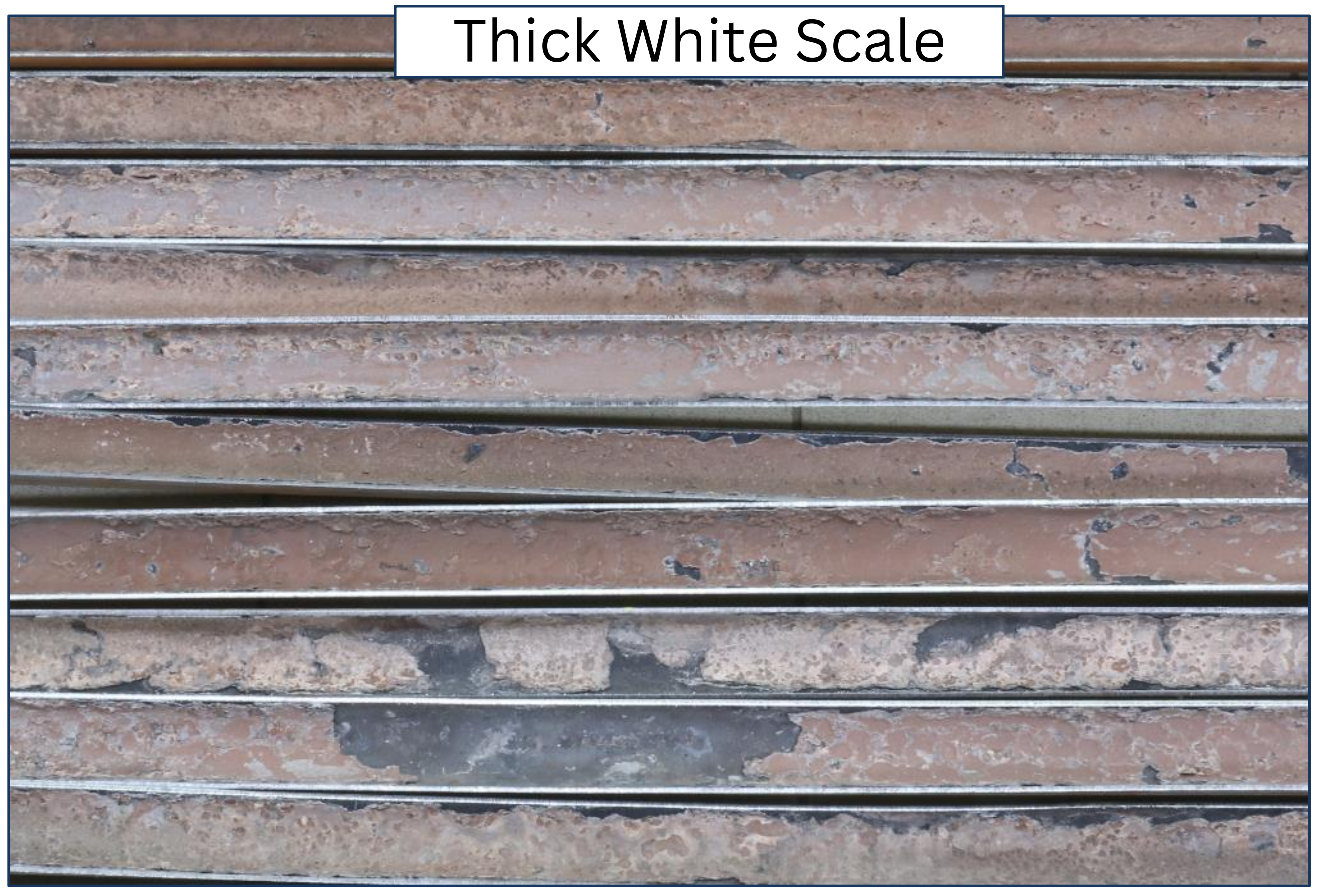


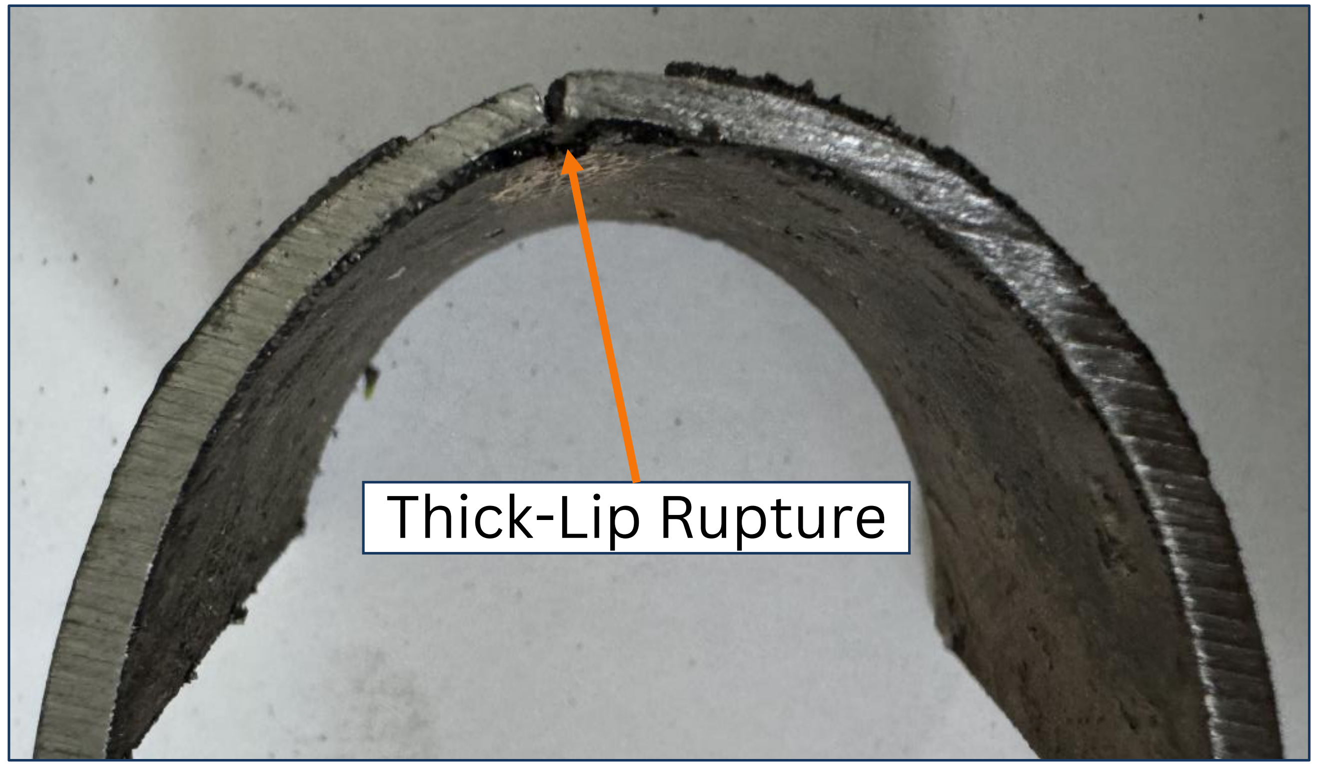




VISUAL EXAMINATION

- The internal surfaces of the tubes were covered with loose whitish scale
- Internal scales can insulate the tube from the cooling effect of the water resulting in increased tube wall temperatures.
- One of the cracks was sectioned in the middle and cross sectional views revealed a thick walled fish mouth type of rupture which is typical of creep failures.



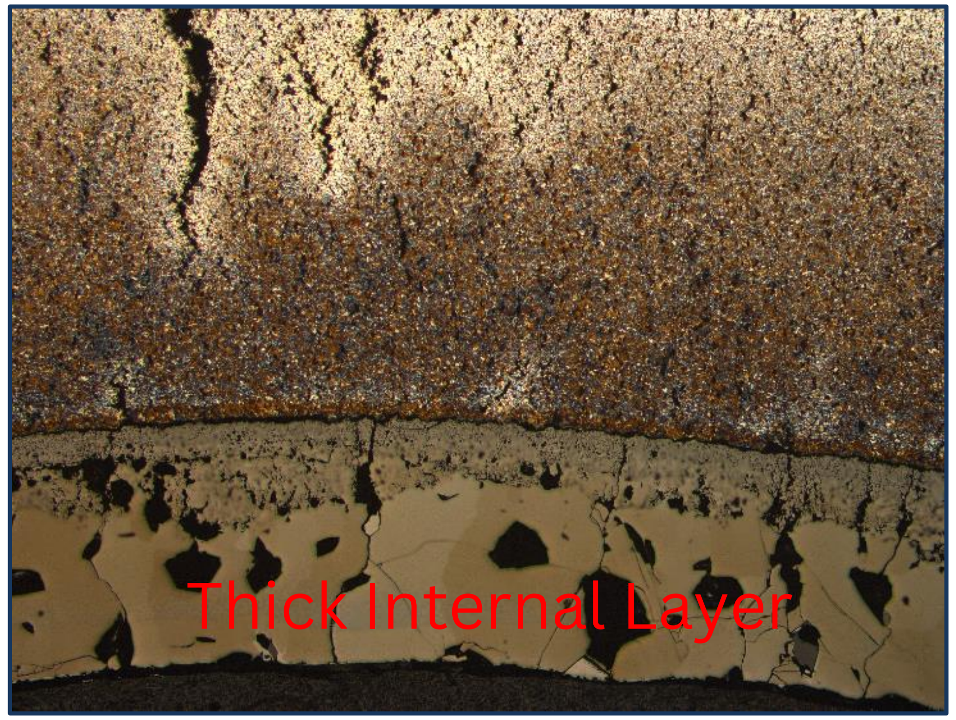


METALLOGRAPHY

Row 1 ,Tube 47 – Trans. - Crack

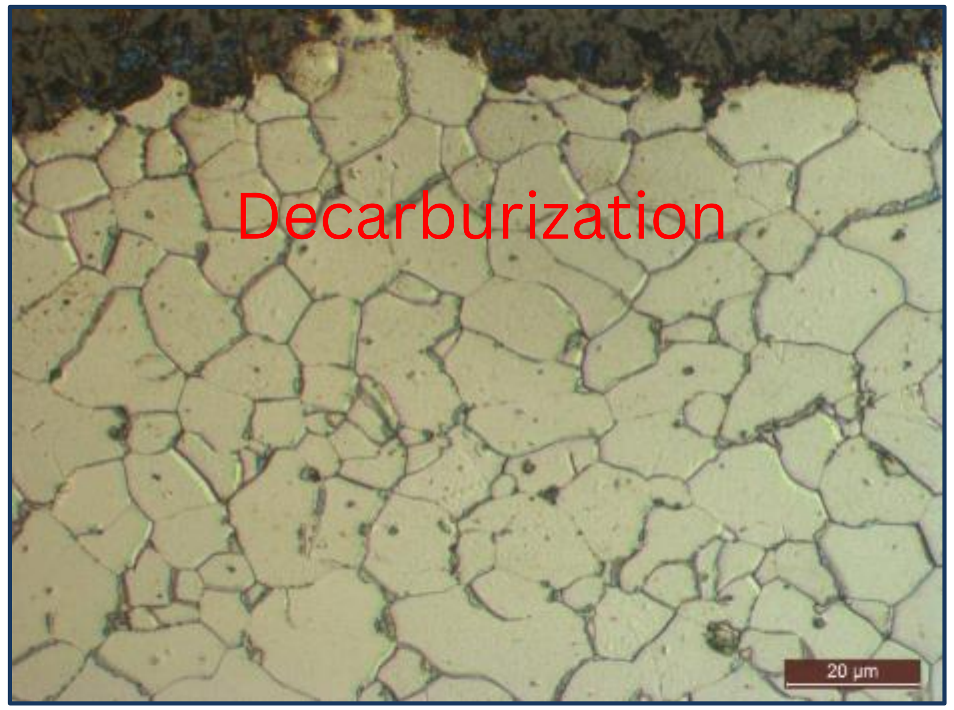
External Surface

Internal Surface

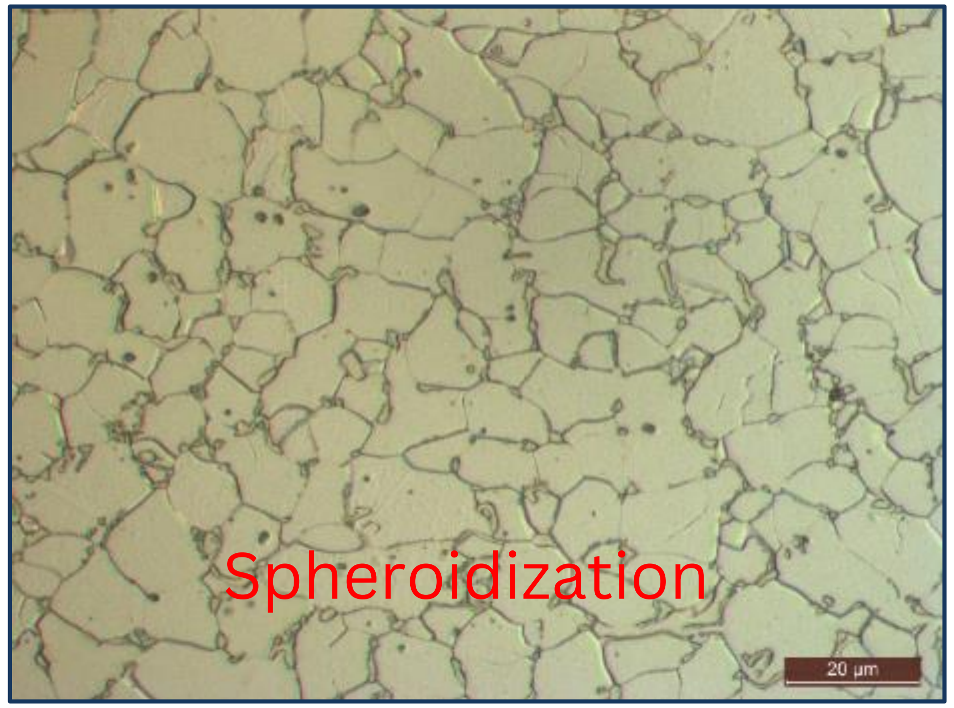


Row 1, Tube 47 – Trans. - Bulge

External Surface

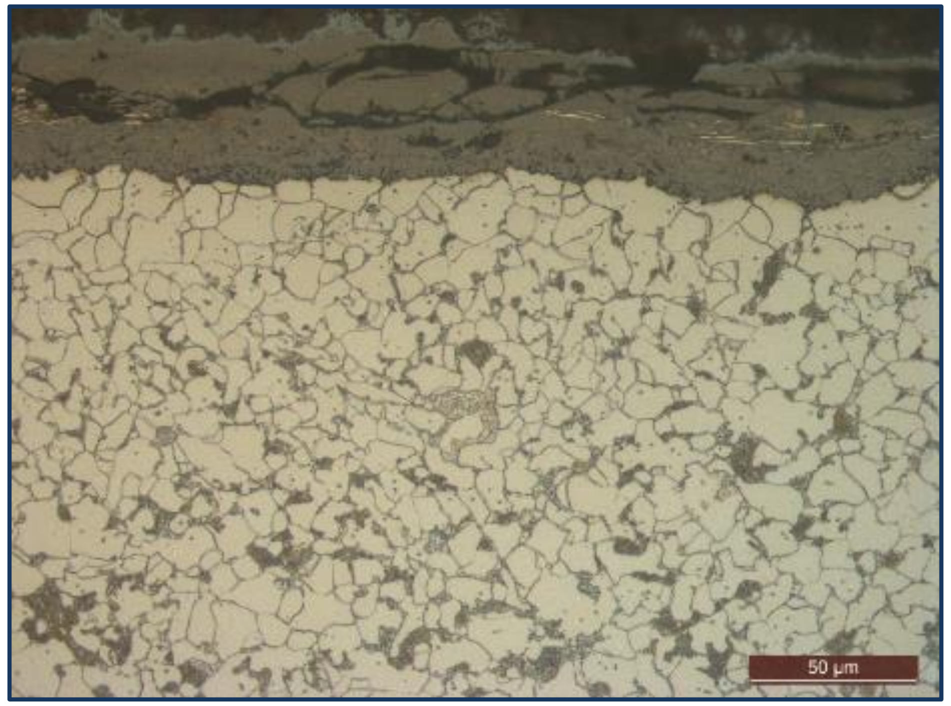


Mid-wall

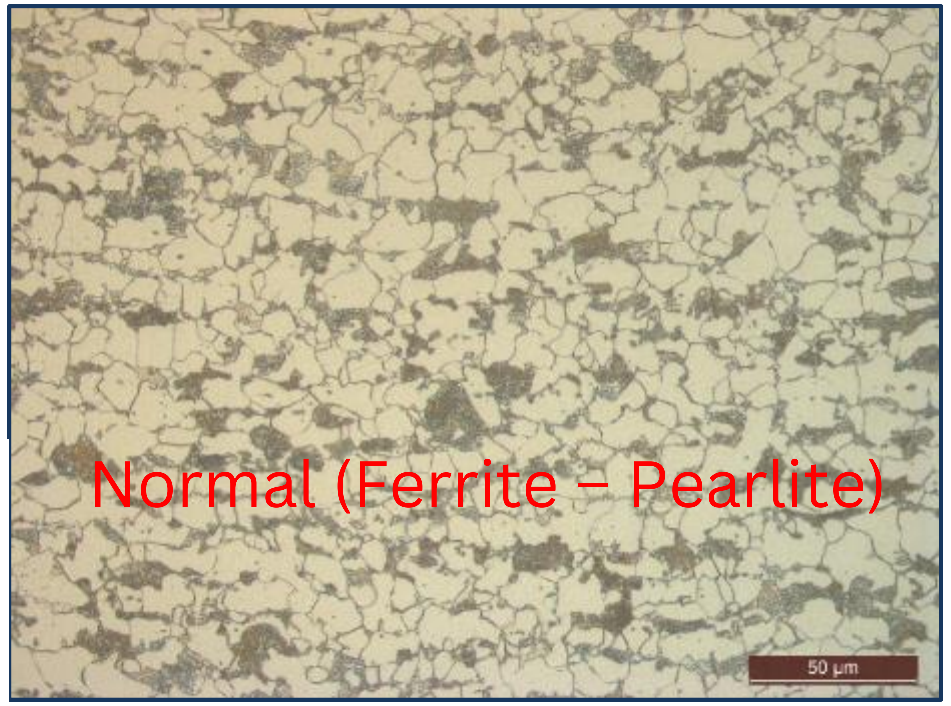


Row 4, Tube 1 – Trans. - US

External Surface



Mid-wall



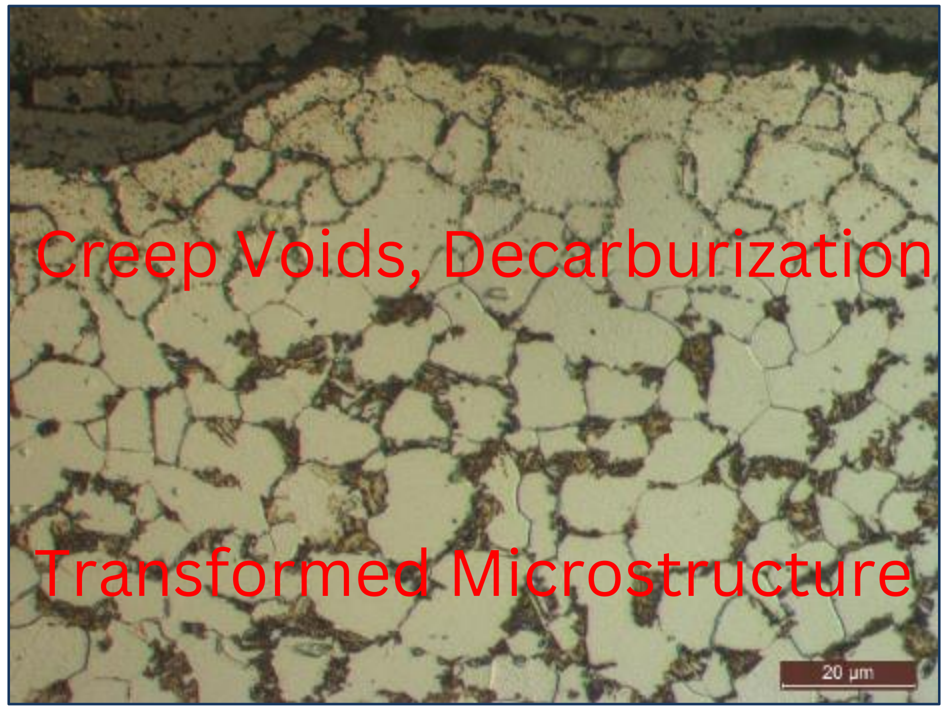
- The creep threshold temperature for carbon steel is 371°C.
- Oxidation of carbon steel becomes significant above 450°C.
- All these temperatures are above the design temperature.

- Spheroidization occurs between 440°C and 760°C. May occur within few hours at 550°C but may take several years to occur at 455°C (API 571).

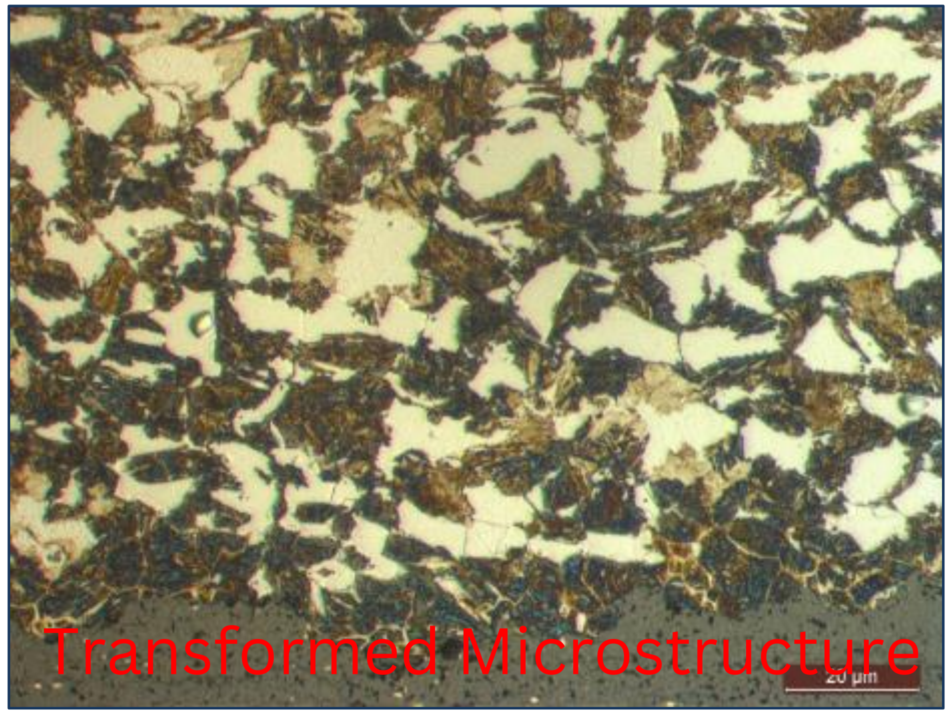
METALLOGRAPHY

Row 1 ,Tube 47 – Long. - Crack

External Surface

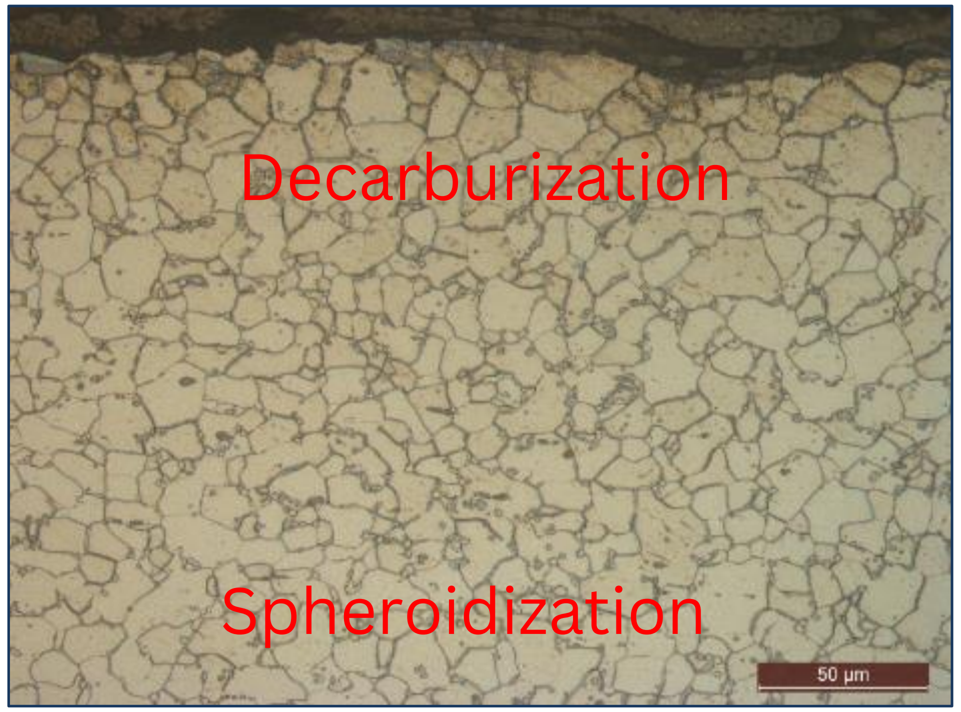


Internal Surface

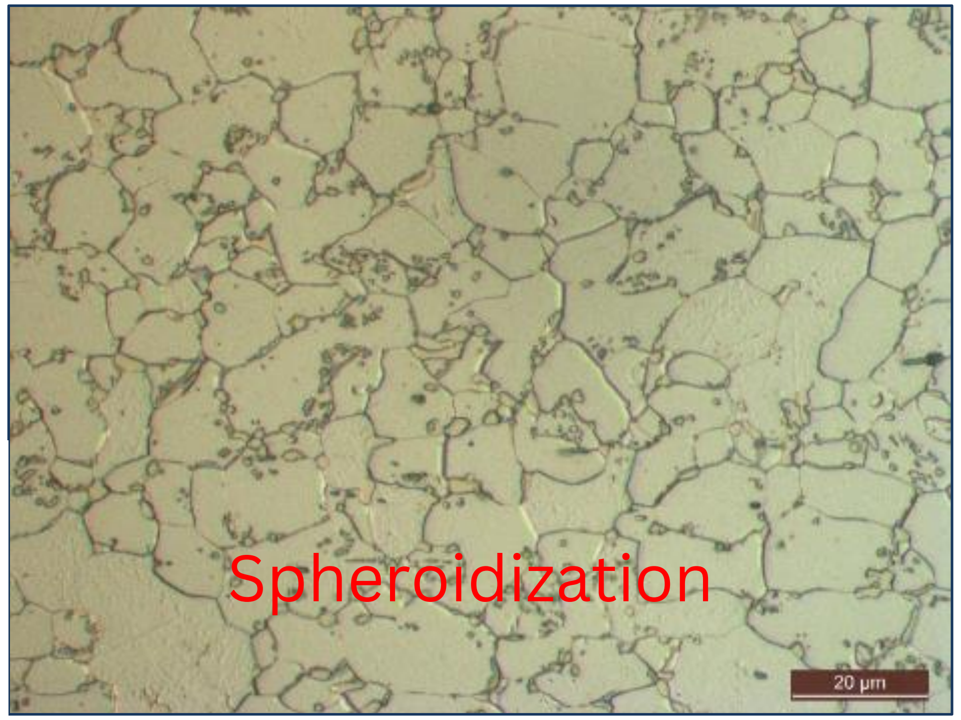


Row 1, Tube 47 – Long. - Bulge

External Surface

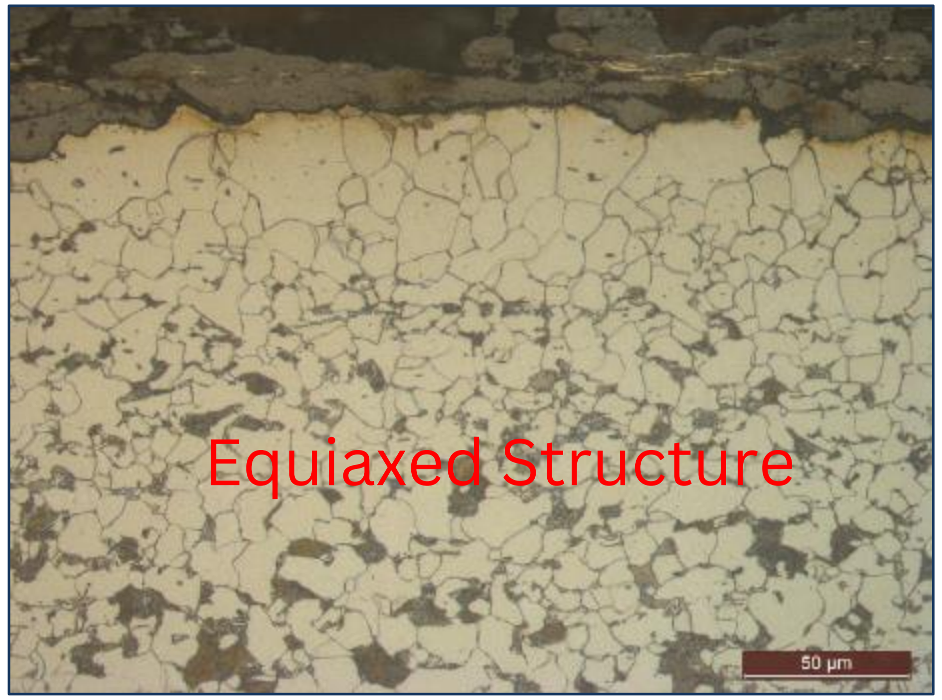


Mid-wall

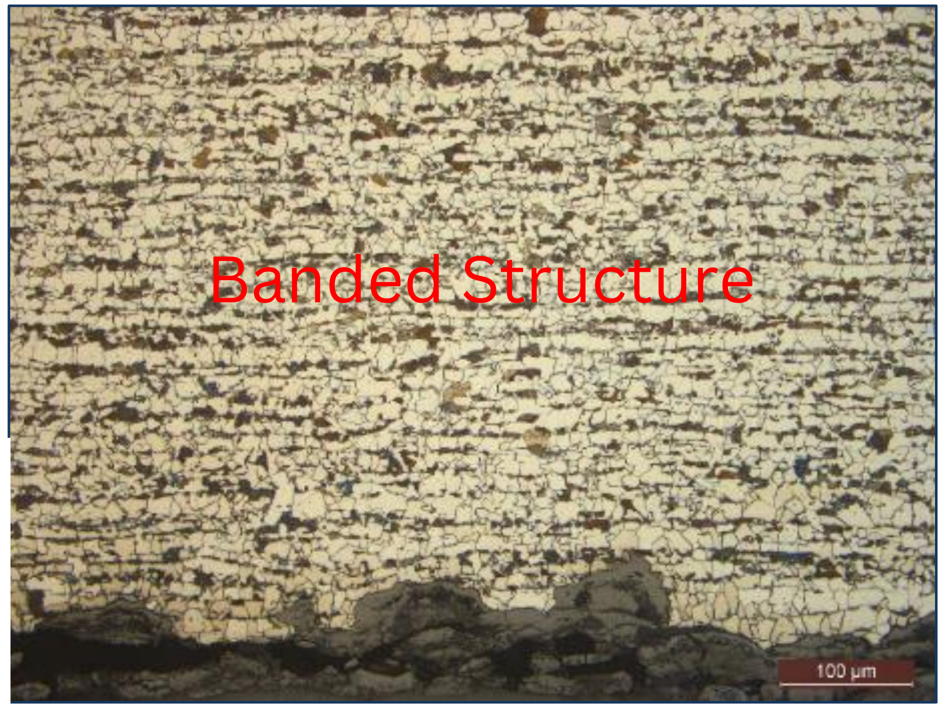


Row 4, Tube 1 – Long. - US

External Surface



Mid-wall



- Banded structure – Normal ; Equiaxed structure – recrystallization occurred
- Transformation – phase transformation occurred ; Transformation occurs above 720°C.
- The microstructure indicates overheating.

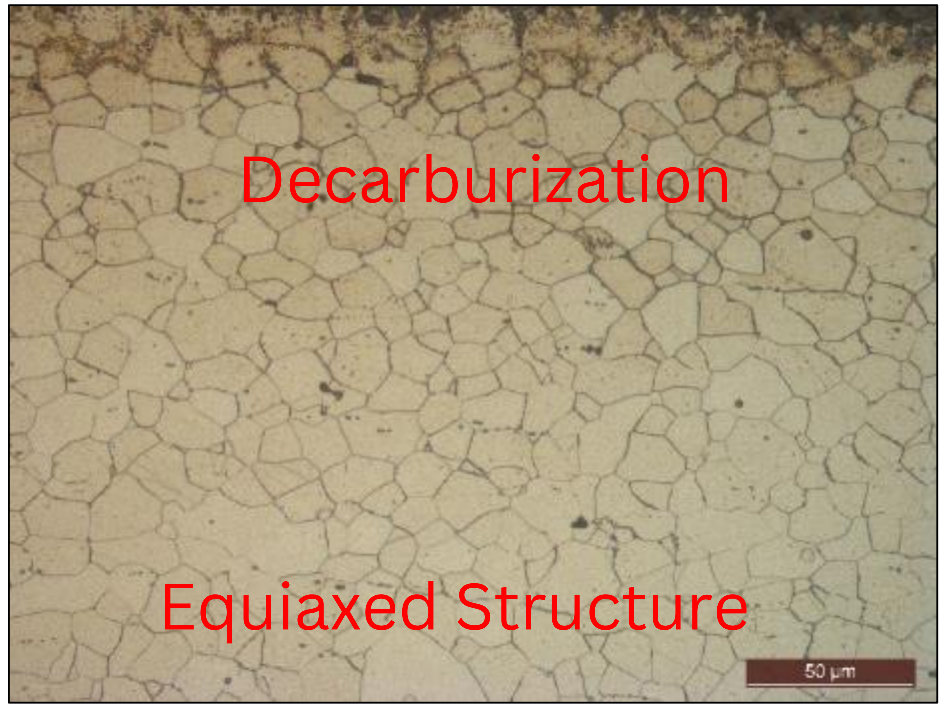
METALLOGRAPHY

Row 1 ,Tube 5 – Long. – Bulge (US)

Row 1, Tube 5 – Long. – Bulge (US)

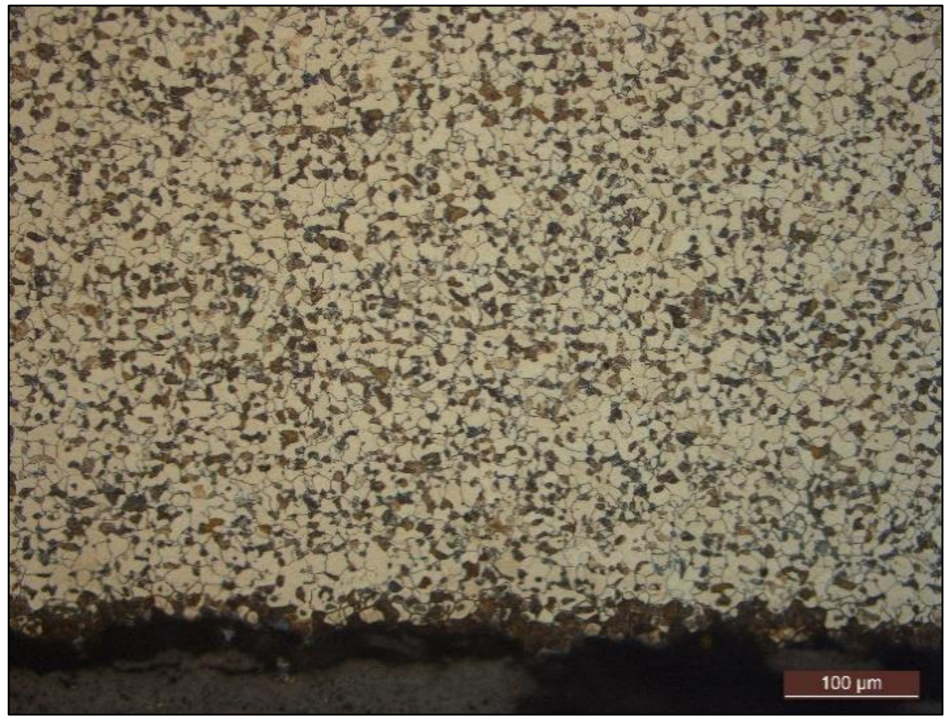
External Surface

External Surface

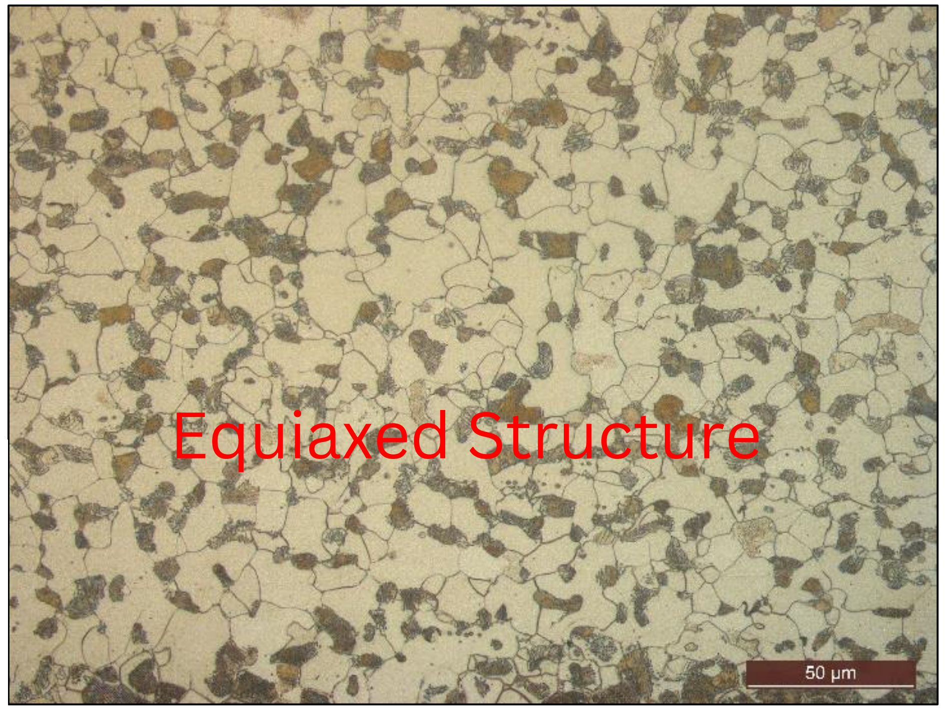


External Surface

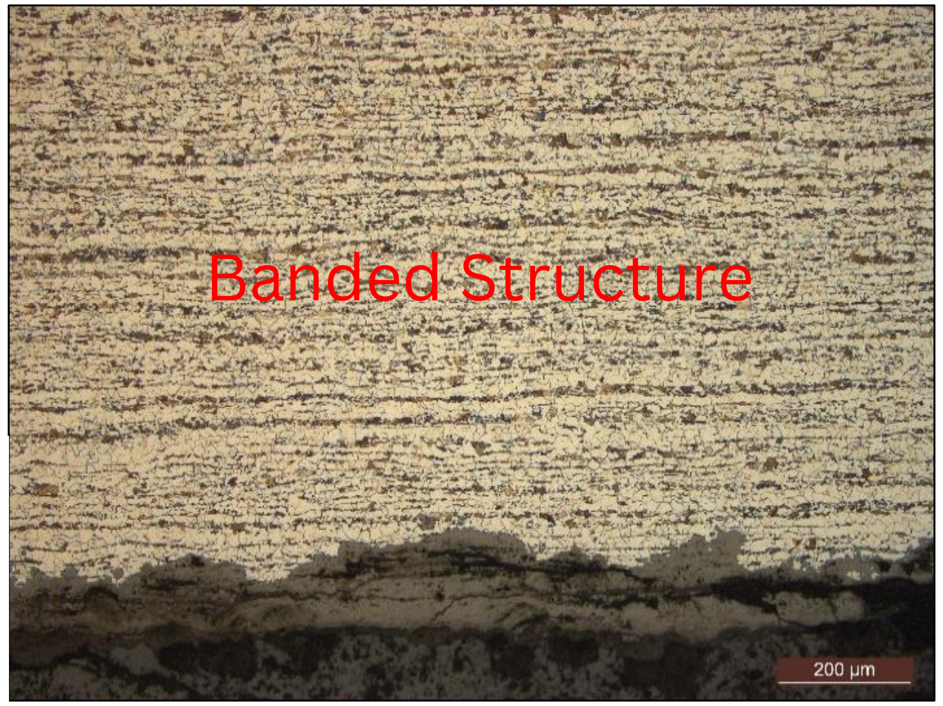
Internal Surface



Mid-wall



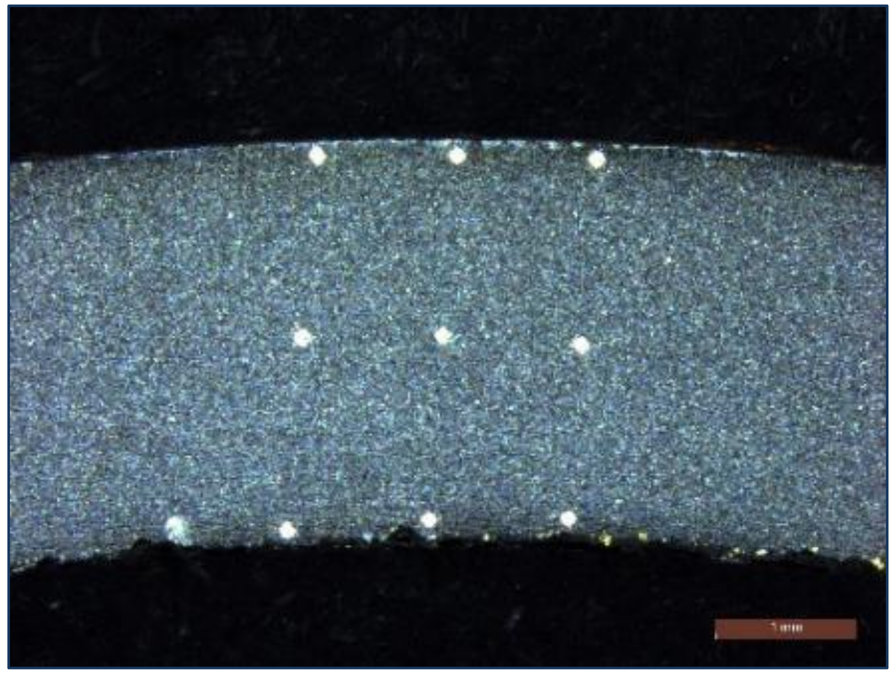
Mid-wall



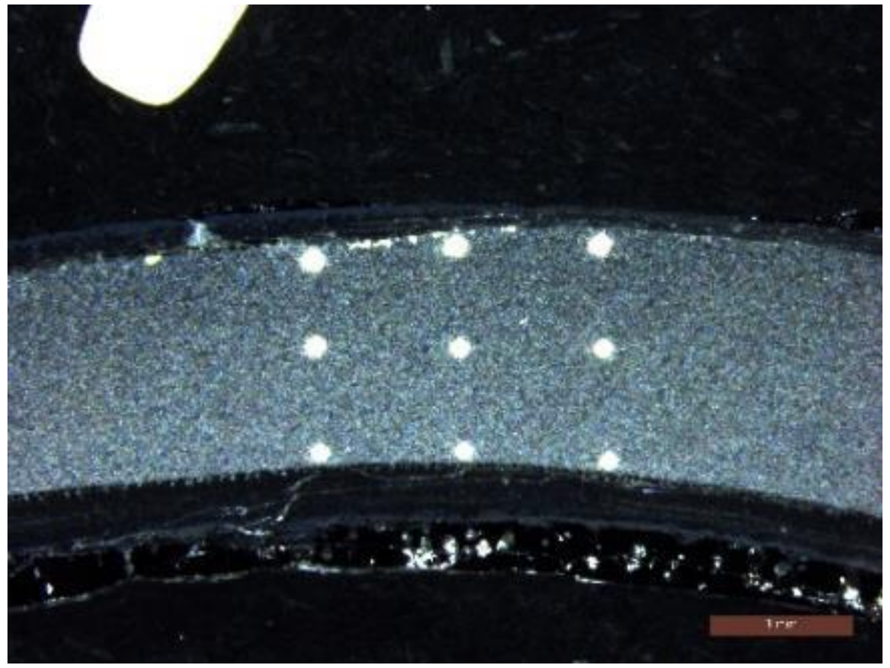
- Banded structure – Normal ; Equiaxed structure – recrystallization occurred
- The microstructure indicates overheating.

HARDNESS TEST

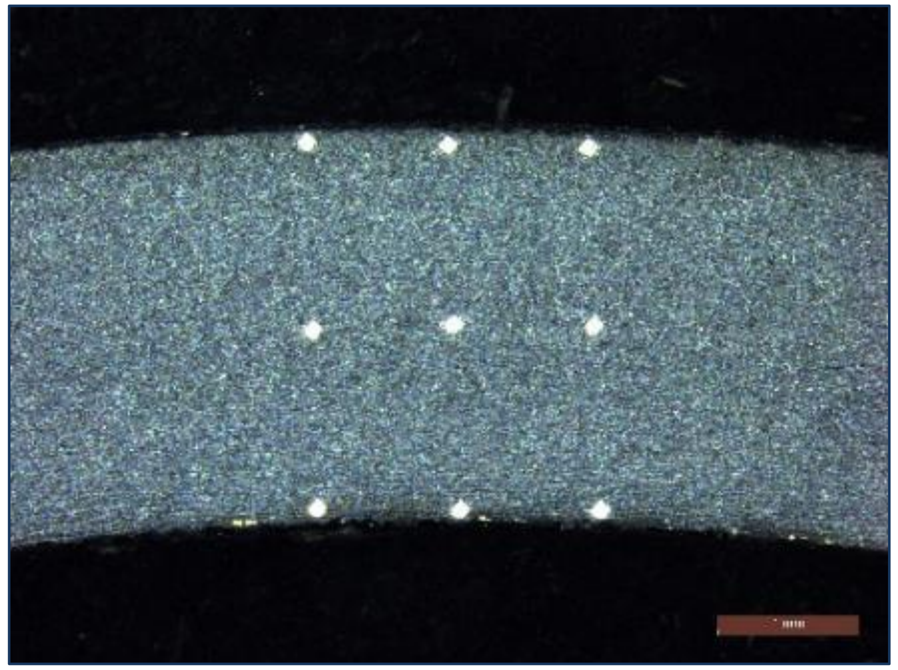
Row 4, Tube 1 – US



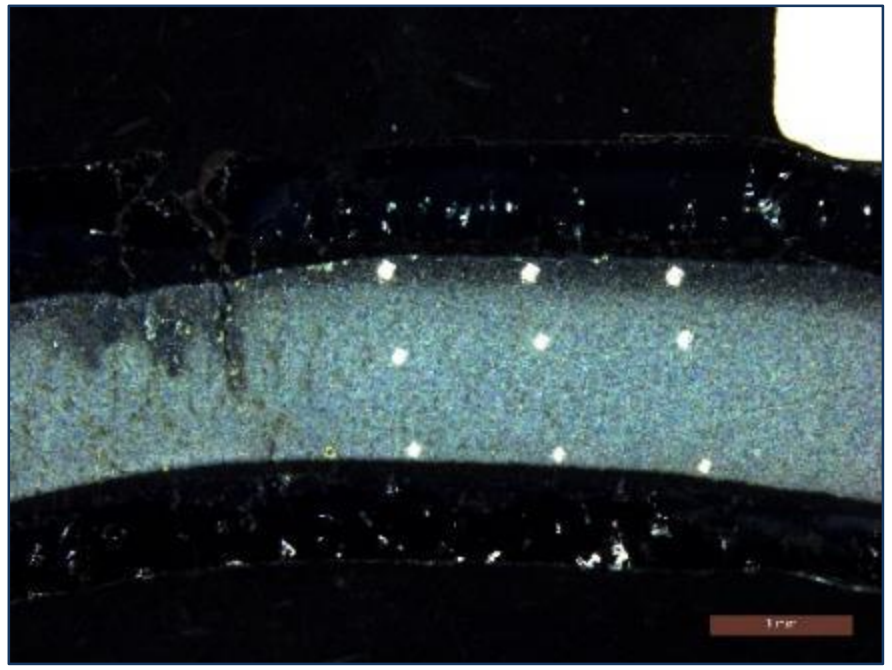
Row 1, Tube 47 – Bulge



Row 4, Tube 1 – DS



Row 1, Tube 78 – Crack



Sample/HV	ID	Middle	OD
Row 4, Tube 1, US	129	142	131
Row 4, Tube 1, DS	176	166	151
Row 1, Tube 47, Bulge	175	151	111
Row 1, Tube78, Crack	267	202	126

- The specified maximum hardness for ASME SA 210 Gr C tubes is 179HB (179HV according to the conversion table in ASTM A370).
- The hardness of tube 78 sample is higher than the specified maximum. This can be attributed to the transformation that resulted in formation of harder phases upon cooling.
- The specified minimum tensile strength for ASME SA 210 Gr C tubes is 415MPa (that's an equivalent hardness of 123HV according to the conversion table in ASTM A370).
- The hardness of tube 47 OD is below the approximate minimum hardness. This can be attributed to softening due to spheroidization.

CHEMICAL ANALYSIS / XRD

XRF: Tube Deposits

Elements	Conc. wt%
Ca	37.15
O	36
P	13.72
Fe	5.083
C	4.15
Mg	1.37
Ni	0.386
Cr	0.384
Al	0.266
Cu	0.2589
S	0.231
Mo	0.188
Mn	0.173
Si	0.0708
Zn	0.0421
Pb	0.0262
Sr	0.0159
Ti	0.012

XRF: Header Deposits

Elements	Conc. wt%
O	35
Ca	23.65
Fe	11.71
Mo	10.23
P	7.721
Mg	5.73
C	1.89
Cu	0.7932
Si	0.715
Al	0.59
Na	0.58
Ni	0.5728
Mn	0.124
S	0.105
Cr	0.091
Zn	0.0882
Sr	0.0289
Cl	0.0212
Ti	0.019

XRD: Tube Deposits

Compound Name	Formula	Semi Quant. (%)
Powellite, syn	$CaMoO_4$	33
Magnesium Iron Oxide	$MgFe_2O_4$	16
Hematite, syn	Fe_2O_3	16
Calcium Phosphate Oxide	$Ca_{10}(PO_4)_6O$	35

XRD: Header Deposits

Compound Name	Formula	Semi Quant. (%)
Hematite, syn	Fe_2O_3	79
Calcium Phosphate Oxide	$Ca_{10}(PO_4)_6O$	12
Calcium Iron Oxide	$Ca_2Fe_2O_5$	2
Siderite	$Fe(CO_3)$	7

- Chemical composition of the deposits indicates that they are mainly from the water.
- Corrosion products from upstream equipment could have also been deposited in the boiler

CONCLUSION

- Visual and metallographic examinations indicate that the cracking mechanism is creep.

- Visual, metallography and hardness testing indicate that the tubes were overheated.

- The overheating of the tubes was due to the presence of calcium-magnesium rich heavy deposits within the tubes.

- Deposits found inside the tubes restricted heat transfer between the flue gas and the water within the tubes, resulting in overheating, leading to the softening of the tube material and stress rupture due to creep.

- The nature of the deposits found inside the tubes are mostly originated from the boiler water system and indicate poor boiler feedwater treatment and monitoring.

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THANK YOU

Reach out.

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