Failures of High Alloy Expansion Bellows in Refinery Catalytic Cracking Units

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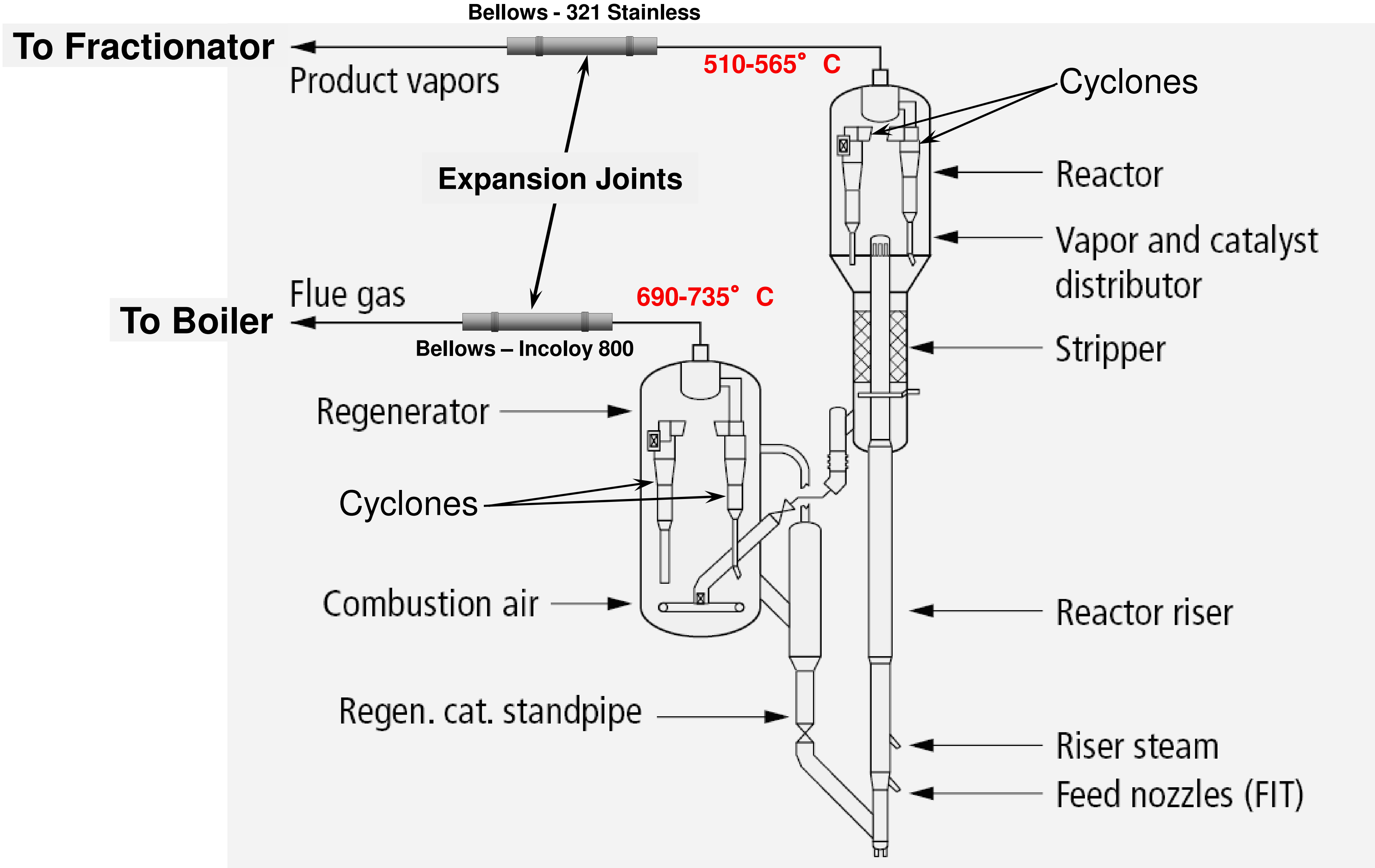
Presentation Summary

- What a Catalytic Cracking Unit Does
- Where Expansion Bellows Are Used
- Bellows Failure Mechanisms
- The Reactor Overhead Line Failure
  - Failure Description
  - False Indication of Sensitization
  - Weld Geometry Problems
  - Field Repairs vs. Shop Repairs
- The Regenerator Off Gas Line Failure
  - Failure Description
  - Cracking during the turnaround.
  - Cracking after start-up
  - Long term plans

Expansion Joints in the Reactor and Regenerator

The unit uses heat and catalyst to break large molecules into smaller molecules.



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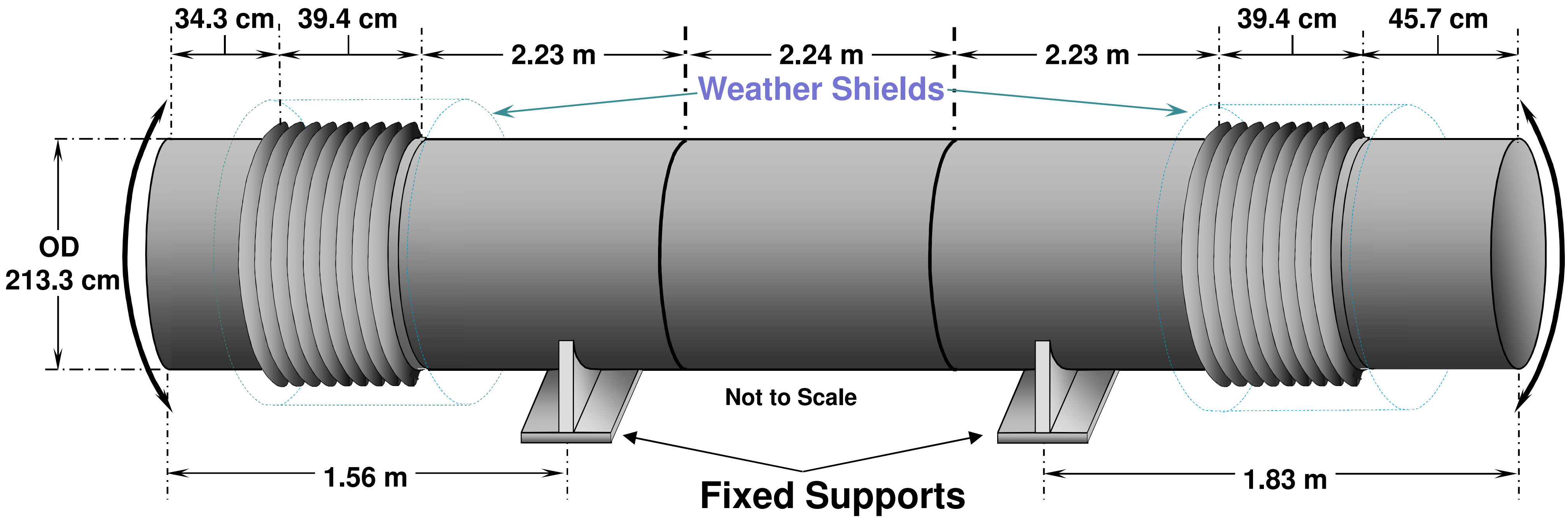
What an Expansion Joint Looks Like

The dimension shown are for the off gas system joint.



The expansion joint accommodates movement of the upstream and downstream piping by compression and rotation of the bellows. On some expansion joints the center pipe between the expansion bellows is fixed and on others it can tilt to help deal with the pipe elevation changes. At the operating temperature the expansion joint is straight and it is distorted when the joint is cooled for shut down.

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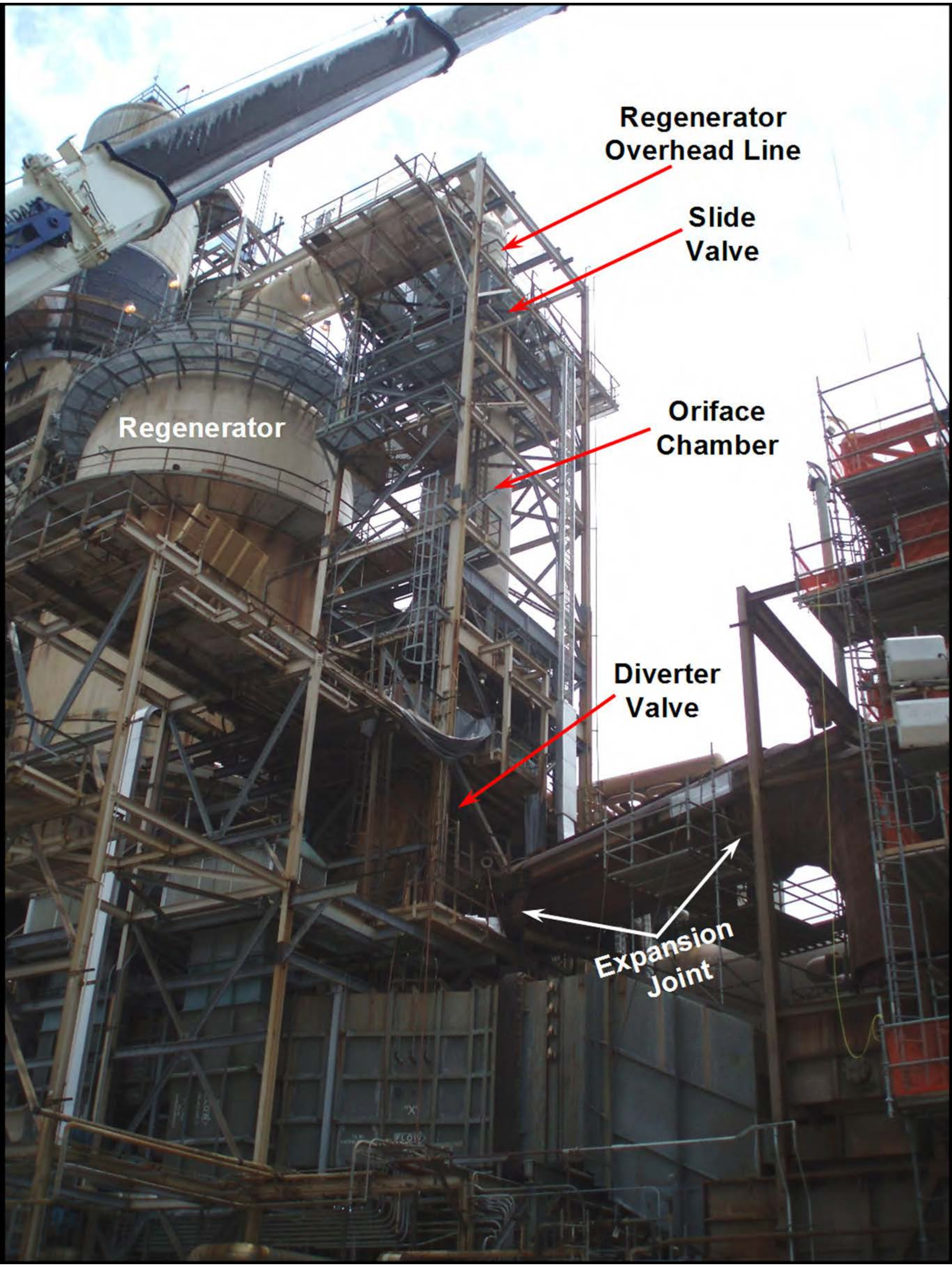
FCC Regenerator Overhead System



Failure Mechanisms for Expansion Bellows

➢ ***Creep:***	High temperatures due to purging failure or insulation failure. Operations with higher than design pressure – higher stress. Long-term deformation and rupture.
➢ ***Fatigue:***	High stress and cyclic loading.
➢ ***Dew Point Corrosion:***	H_2SO_4 condensing in the bellows.
➢ ***Sensitization:***	High temperatures lead to chromium carbides forming in the alloy grain boundaries making the surrounding alloy non-stainless.
➢ ***Polythionic Stress Corrosion Cracking:***	Metal sulfides form during operations and react with air and moisture when the unit cools to form polythionic acids that can attack sensitized stainless steels.
➢ **Pressure Overloads:**	High internal pressure leading to rupture.
➢ ***Temperature Upsets:***	High temperature leading to short term bulging and rupture.

Failure Mechanisms for Expansion Bellows

- ***Chloride Cracking:*** Alloys with more than 32% nickel content are more or less immune. Some high Mo stainless steels are immune.
- ***Alloy Embrittlement:*** Nickel alloys and stainless steels embrittle at elevated temperatures due to the formation of brittle phases: sigma, alpha prime, etc.
- ***Wet H2S Cracking:*** More than 50 ppm H_2S and liquid water must be present - unlikely for higher alloys.
- ***Caustic Cracking:*** Nickel alloys are immune and stainless steels have some resistance. Liquid water must be present.
- ***Erosion:*** Gas and catalyst flow impacting the bellows surface causing wall loss. This is usually the result of failure of internal shrouds.

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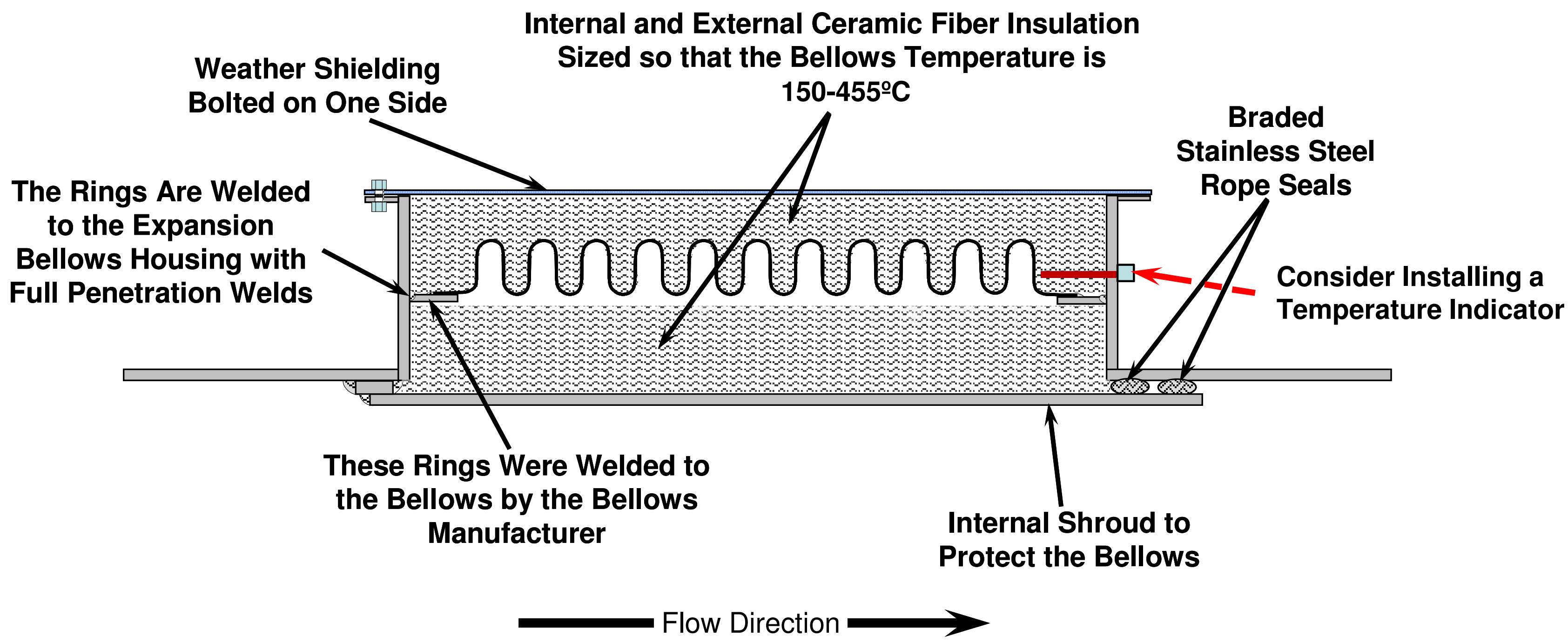
Failure Mechanisms for Expansion Bellows

- ***Expansion Joint Design:***
  - The temperature of the bellows needs to be maintained below the range where long term degradation occurs – below 455ºC.
  - The in Regenerator off gas systems the temperature needs to be above the temperature at which H_2SO_4 dew point corrosion occurs – above 150ºC.
  - Weld designs should allow thorough inspections of the welds.



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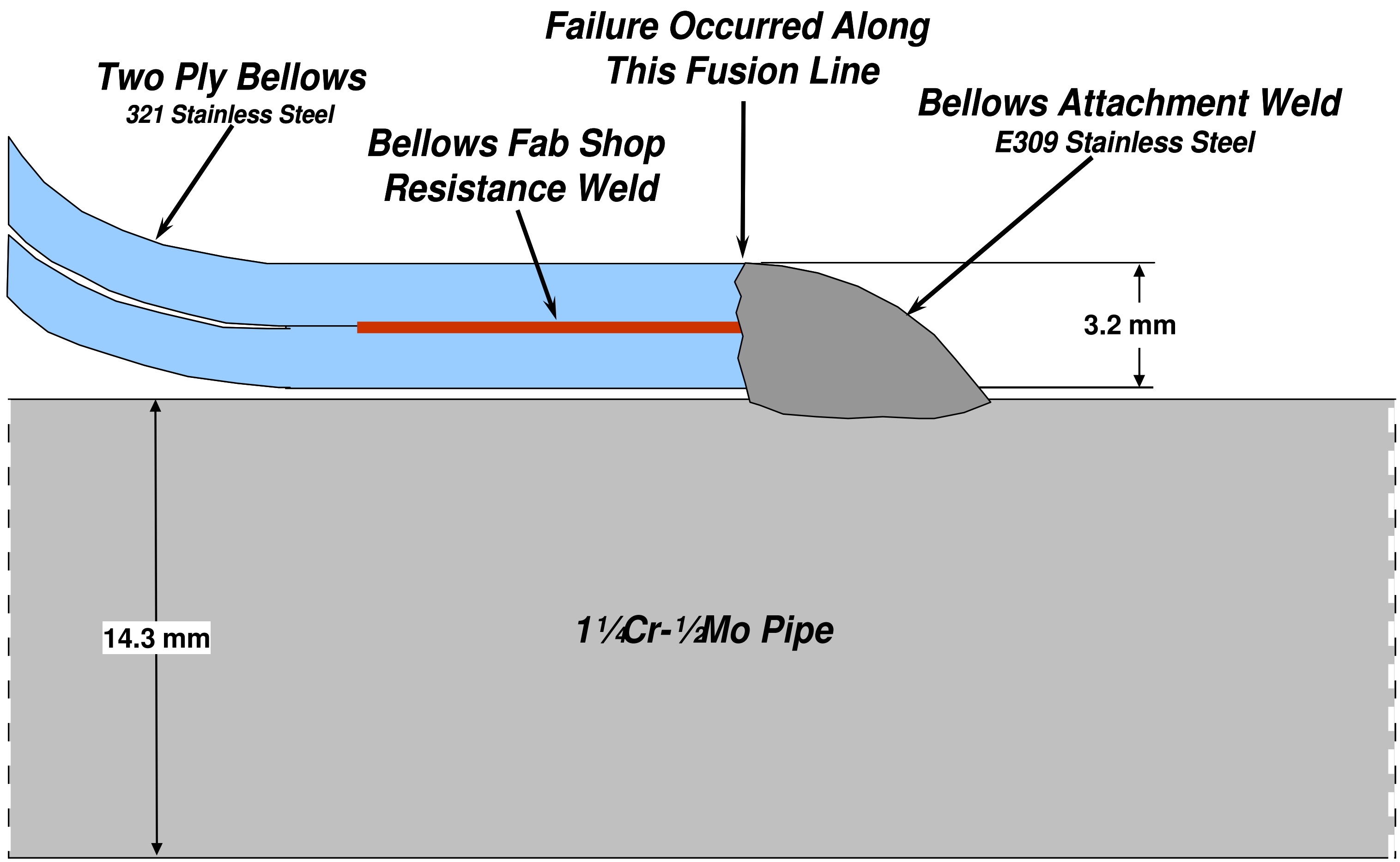
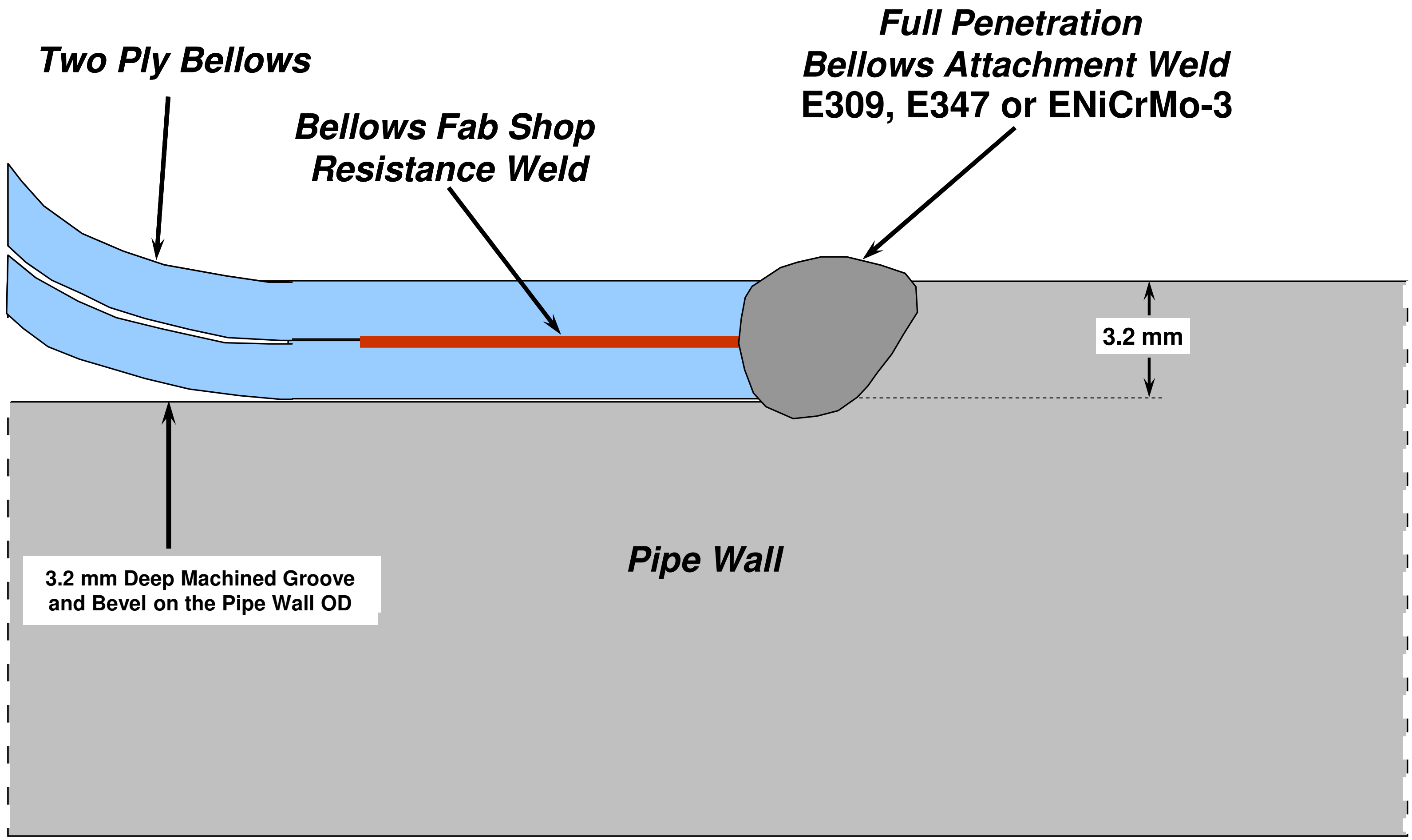
The Reactor Overhead Line
Previous Bellows Attachment Weld Design

Bellows Attachment Weld Joint Geometry

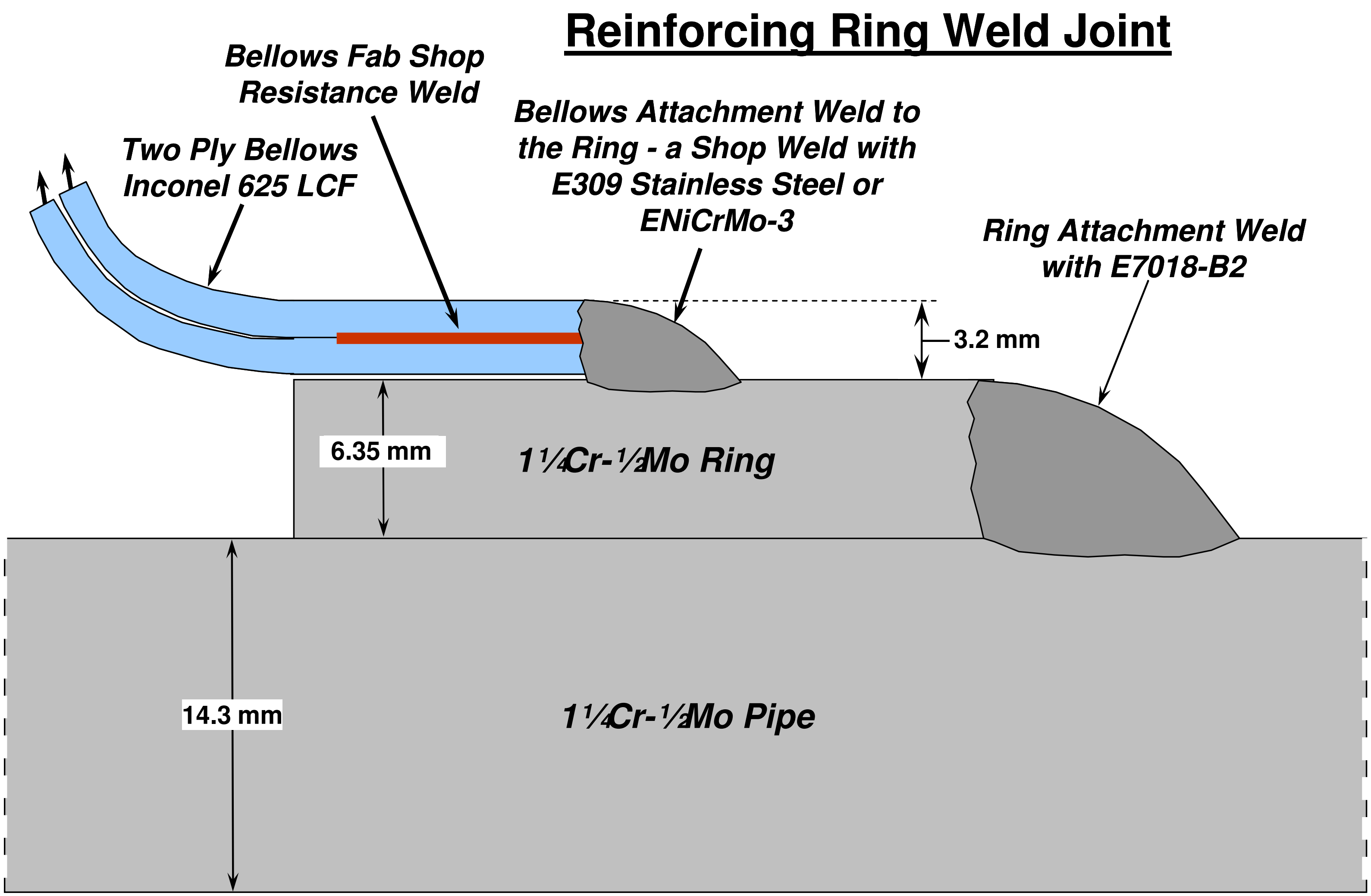


Improved Attachment Weld Design

Bellows Attachment Weld Joint Used in the Nuclear Industry



Another Improved Attachment Weld Design



The bellows attachment weld is made in the shop improving weld quality.
The ring attachment welds do not involve mixed metallurgy and are larger welds.

The Reactor Overhead Line Bellows Failure

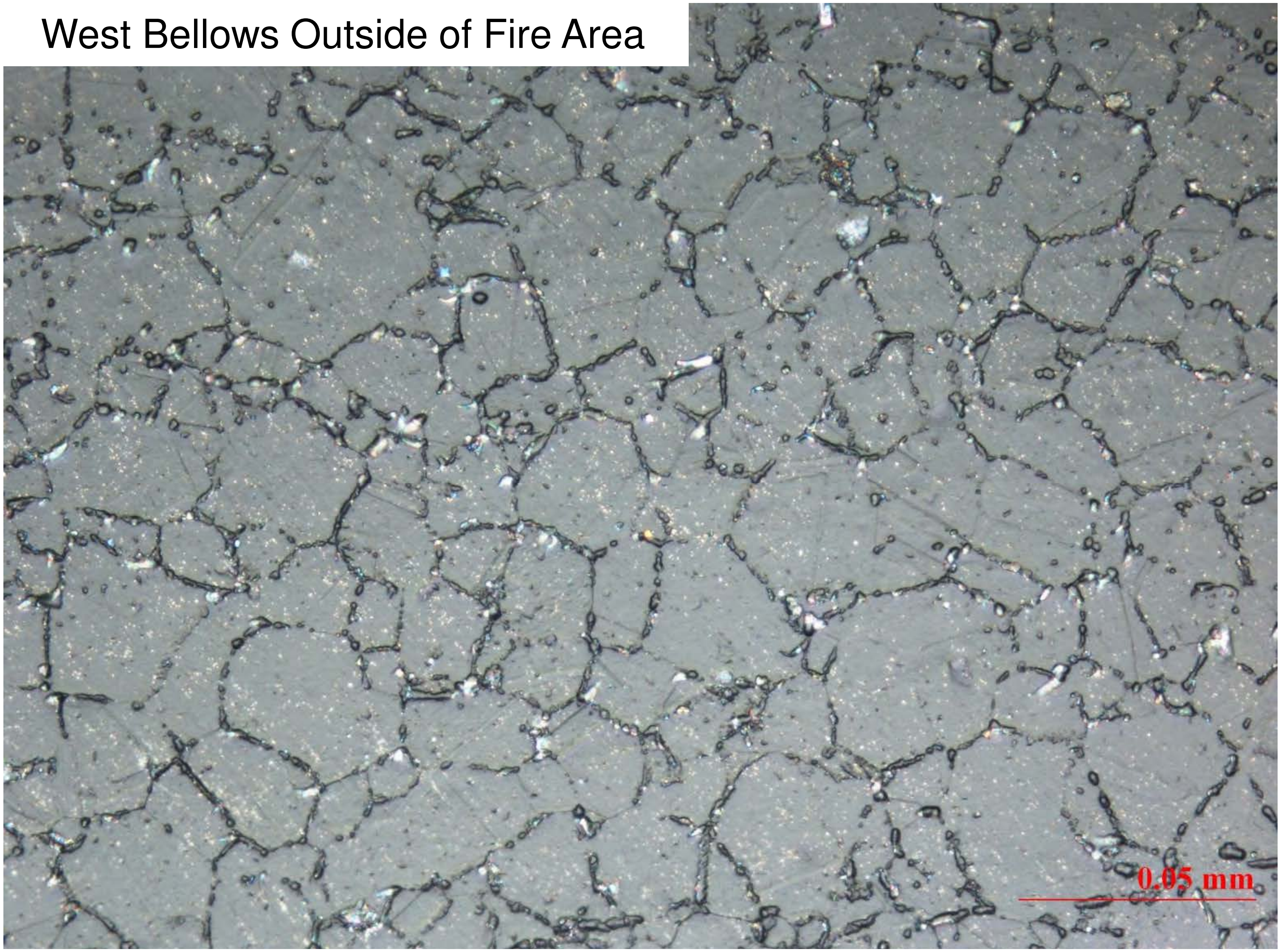
Fire Damaged Area of the Bellows

Insitu Metallography of the Reactor Bellows

This indicated the steel was sensitized.

Insitu Metallography of the Reactor Bellows

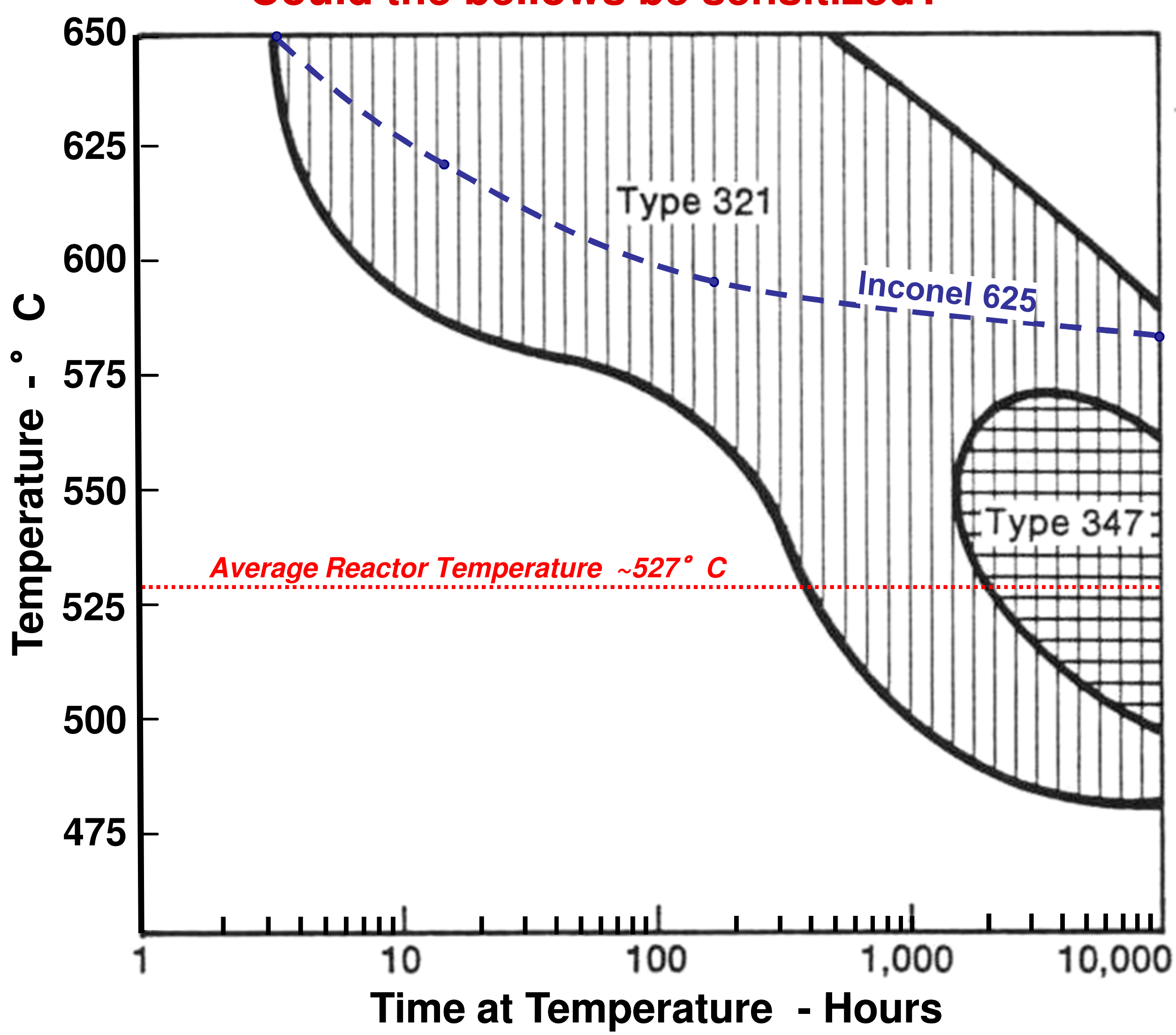
West Bellows Outside of Fire Area



Electrolytically Etched with Oxalic Acid   Original Magnification - 500X
This indicated the 321 was sensitized.

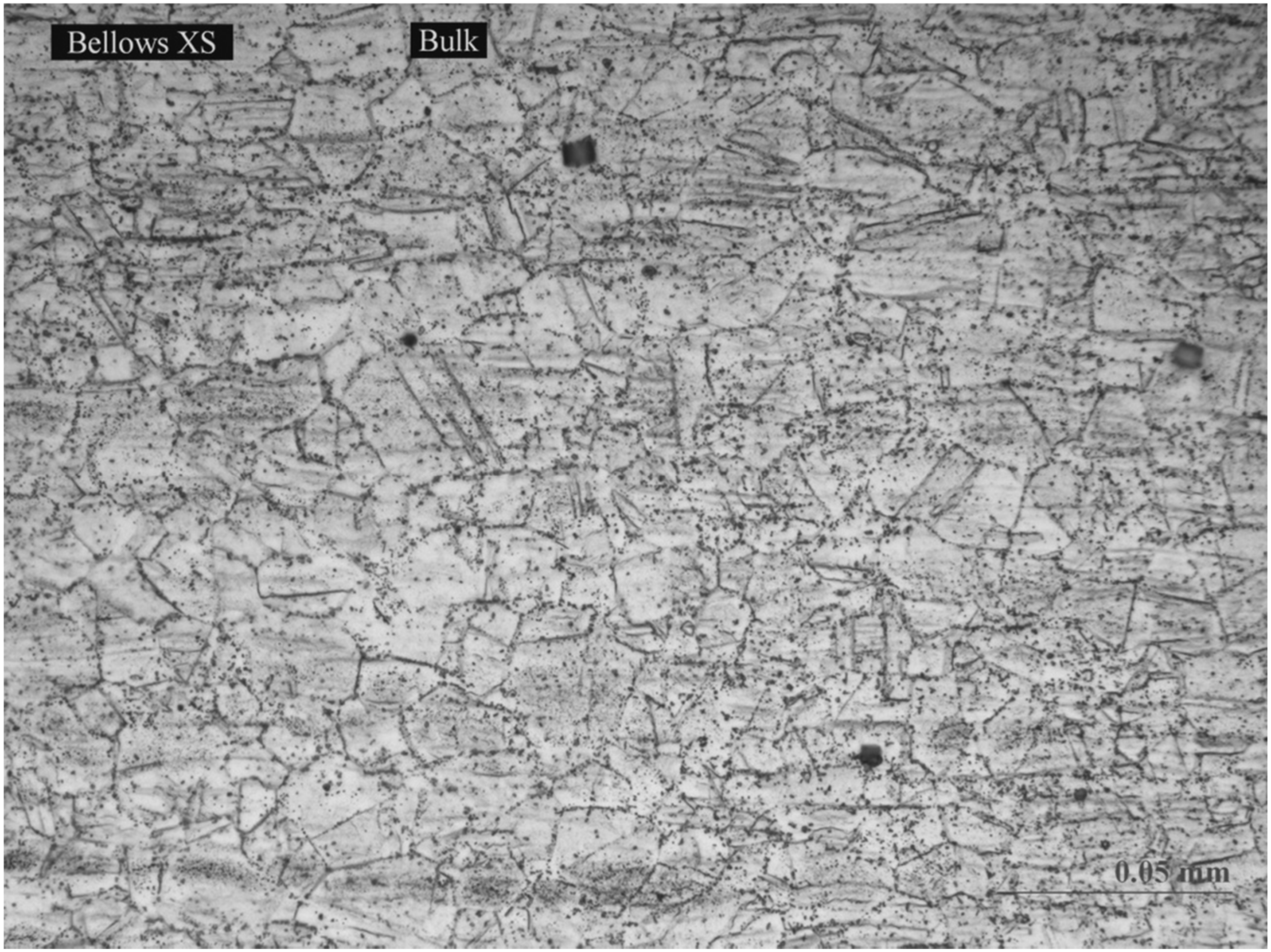
Sensitization of Stainless Steels and Inconel 625

Could the bellows be sensitized?



Laboratory Testing Results

Metallography of the Cross Section of the Bellows

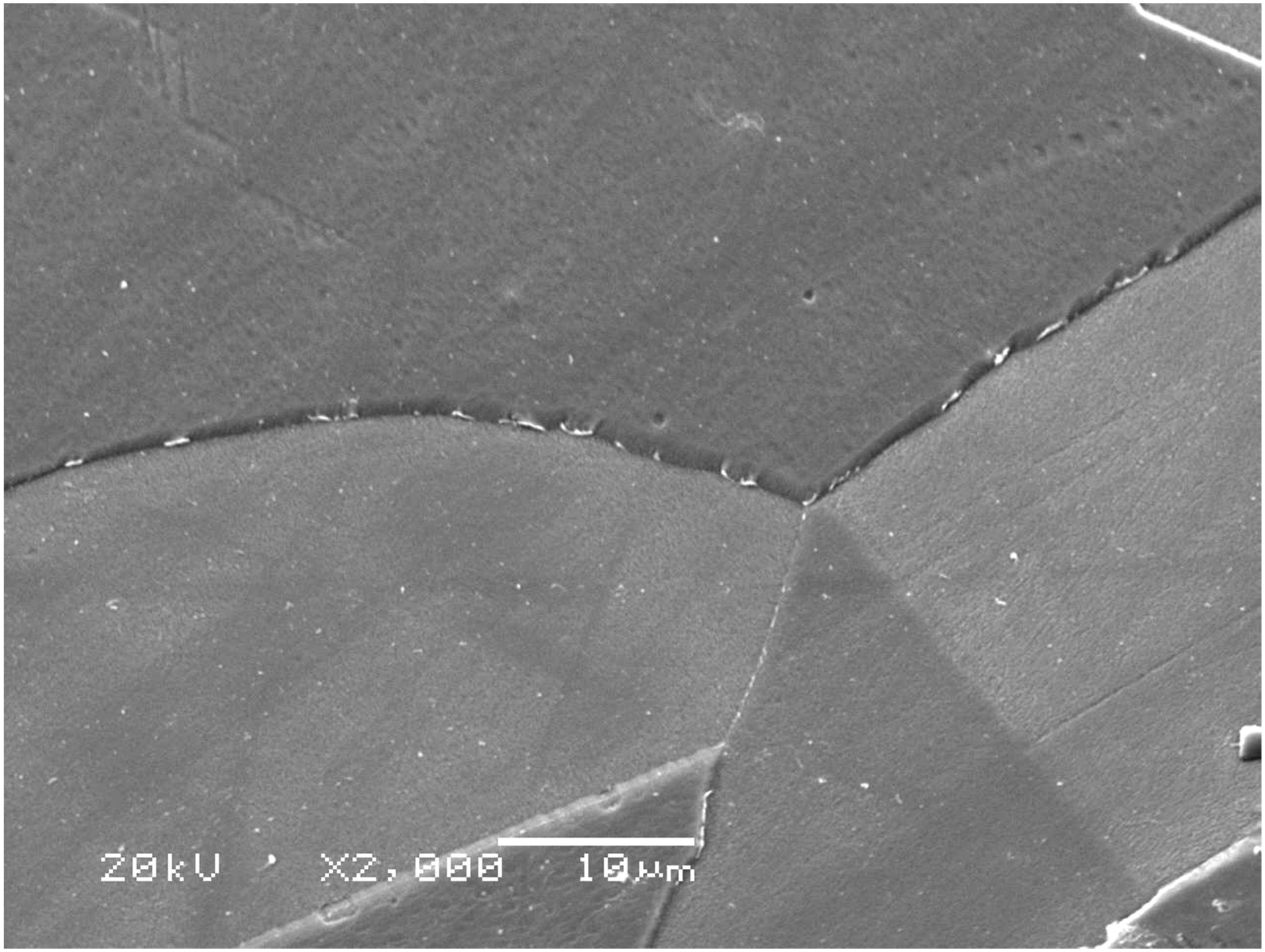


Electrolytically Etched with Oxalic Acid Original Magnification 500X

No indication of sensitization was detected in the laboratory.

Sensitization Did Not Occur

There was some chromium carbide precipitation, but it wasn't sensitized.



Why the 321 Stainless Appeared to be Sensitized

Polishing led to a surface with pits outlining the grain boundaries so it looked sensitized after electrolytic etching with oxalic.

Etched with Glyceregia

Original Magnification 50X

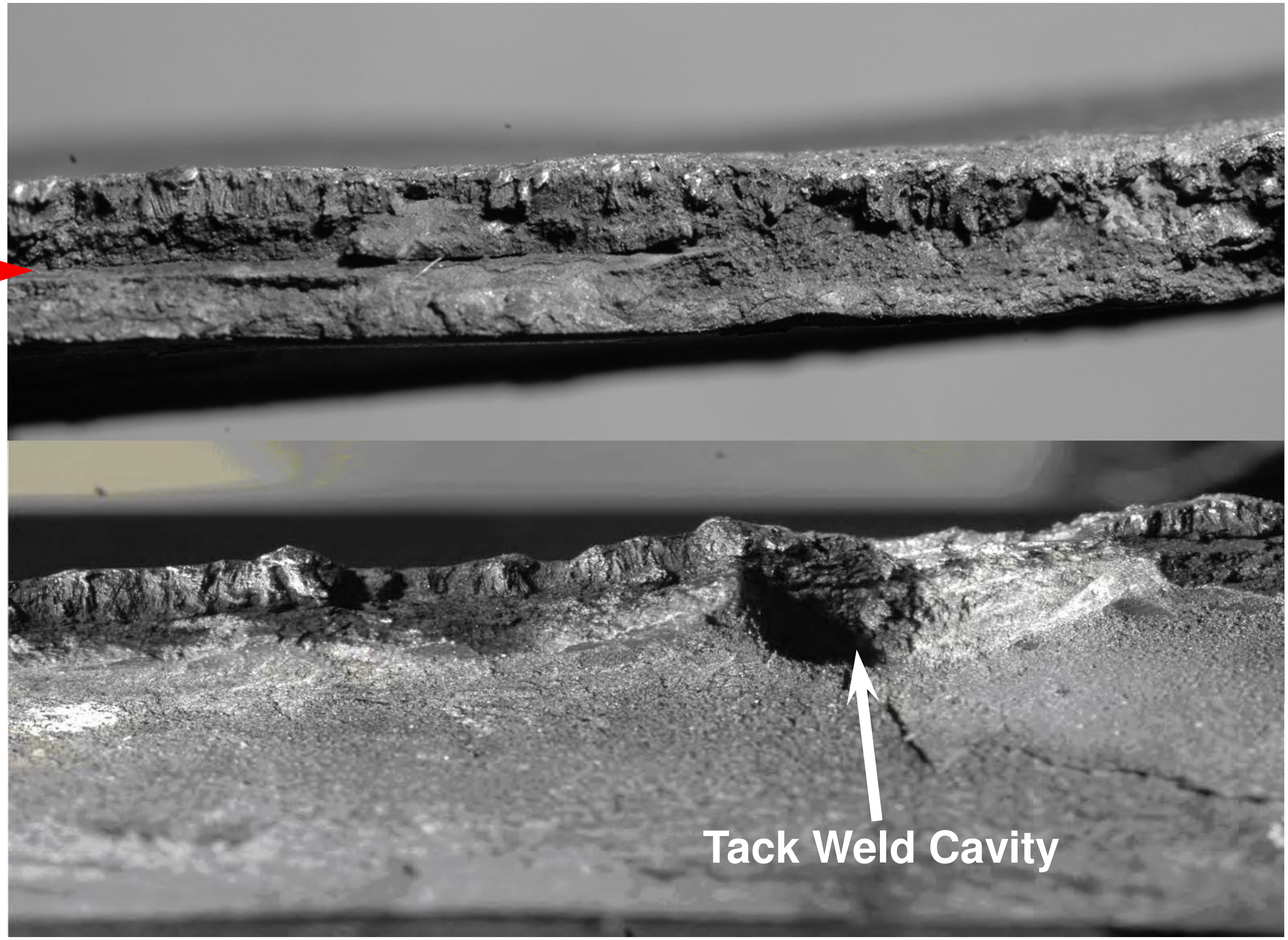
Unusual Weld Features

Tack Welds that Weren't Melted by the Attachment Weld

Weld Fracture Surface Features

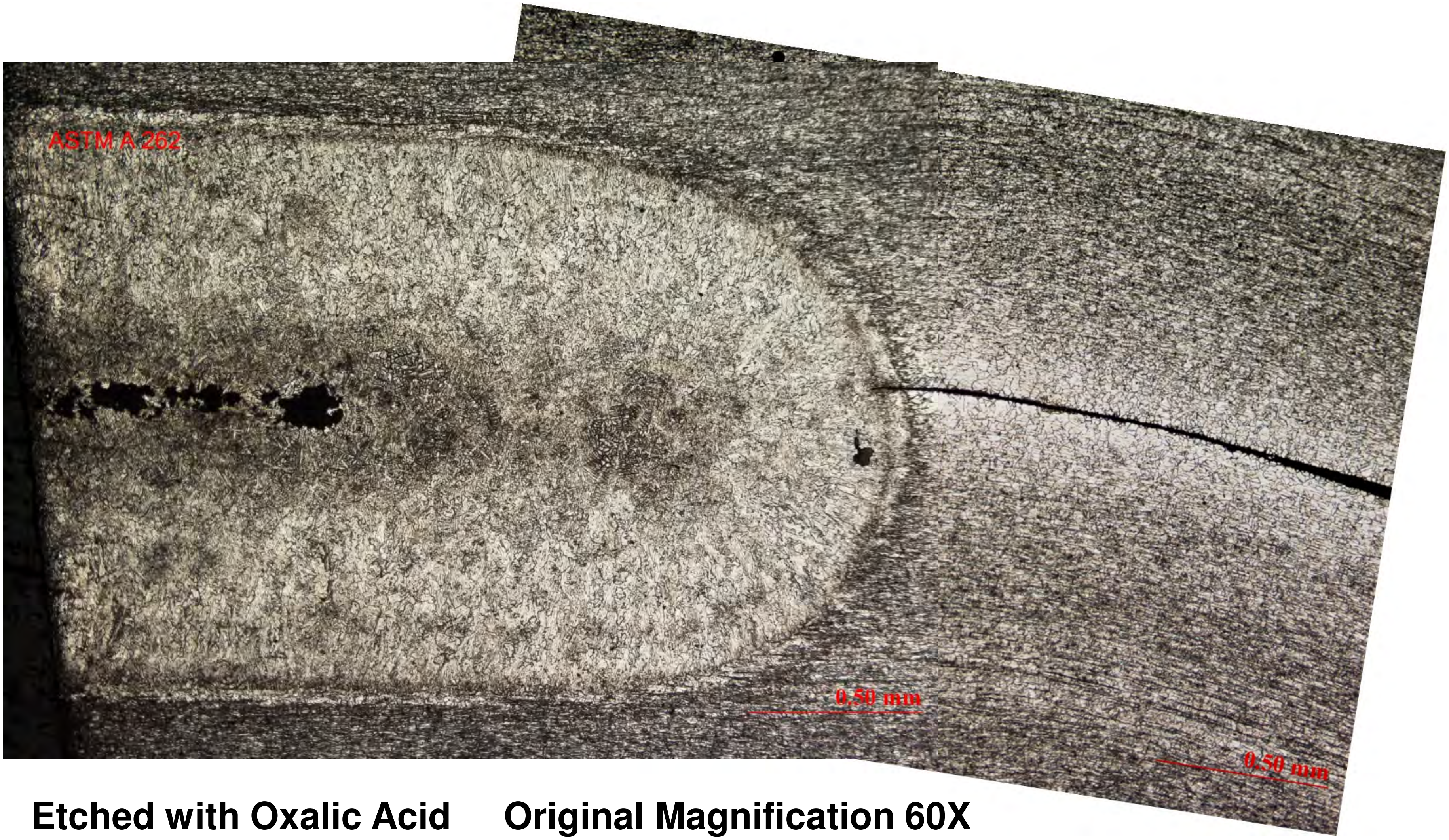
Two Views of the Fracture

Split Between Plies



Resistance Weld Defects

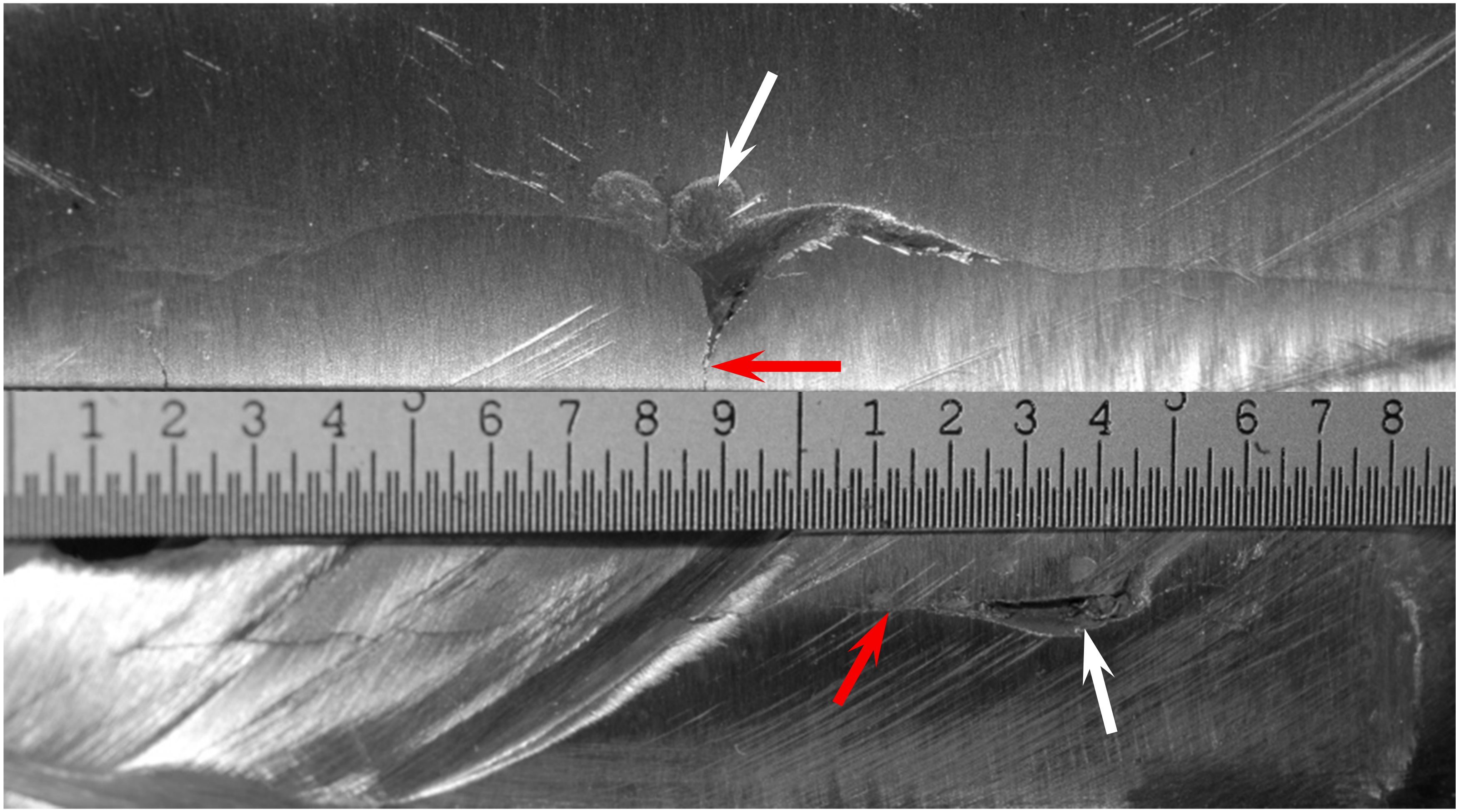
Lack of fusion defects across the resistance welds.



Etched with Oxalic Acid   Original Magnification 60X

Weld Defects – Large Inclusions in Welds

Some cracks were found near inclusions – red arrows.



Original Magnification - Near Actual Size

Reactor Overhead Line Bellows Failure

- Primary cause was attachment weld defects.
  - Unmelted tack welds
  - Lack of fusion at tack welds and along weld joint.
  - Attachment welds couldn't be thoroughly inspected with ultrasonic testing due to fillet weld geometry
  - The attachment welds were dirty – field installation.
- Secondary cause was the defects in the resistance welds – relatively large defects at the attachment welds.
- Sensitization of the 321 stainless had not occurred.
- Bellows replaced with Inconel 625 bellows.
- Weld geometry improved.

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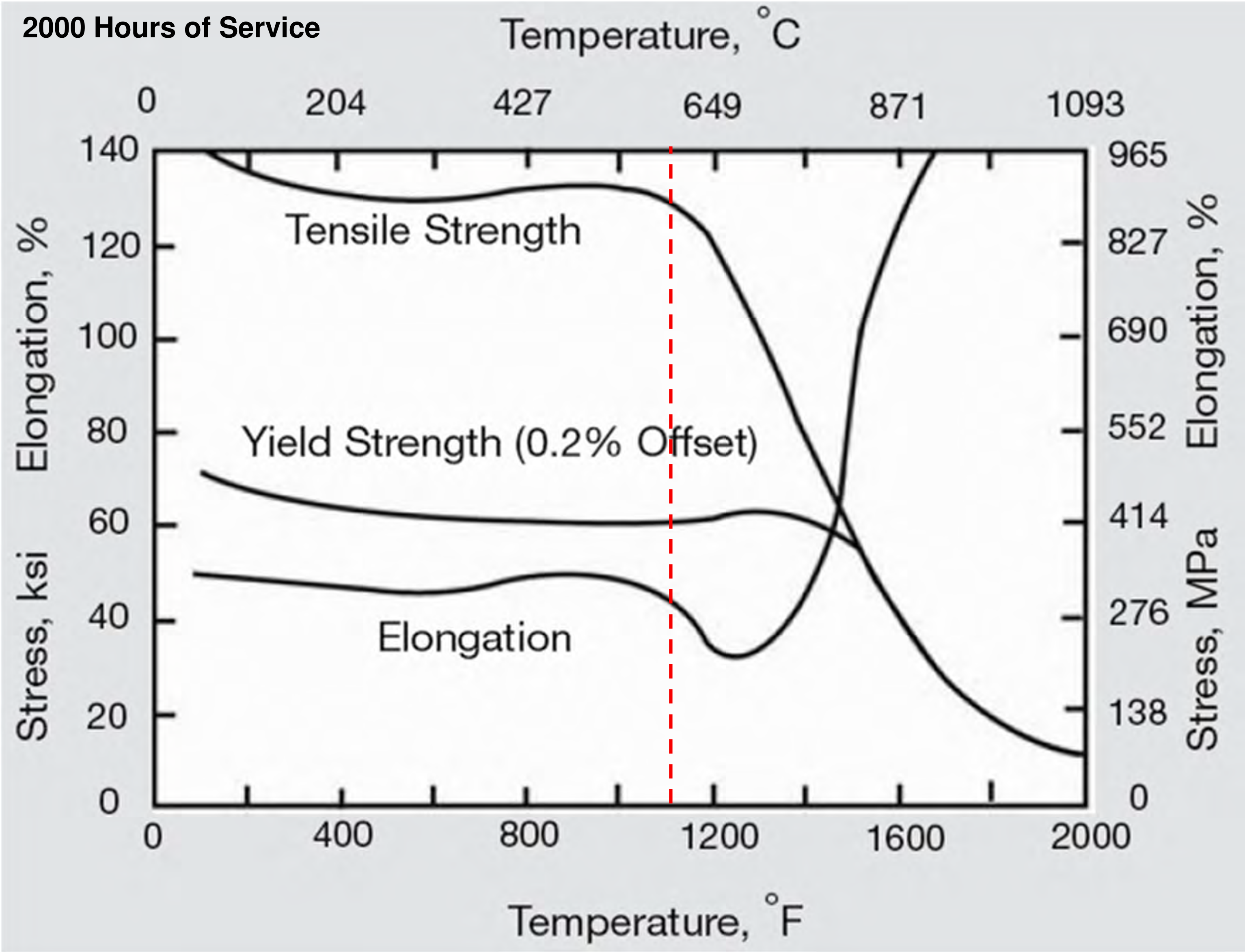
Inconel 625 Embrittlement Above 610° C

This is a possible problem for Inconel 625



The Regenerator Off Gas Bellows Failure

Multiple Jagged Cracks Throughout the Incoloy 800 Bellows

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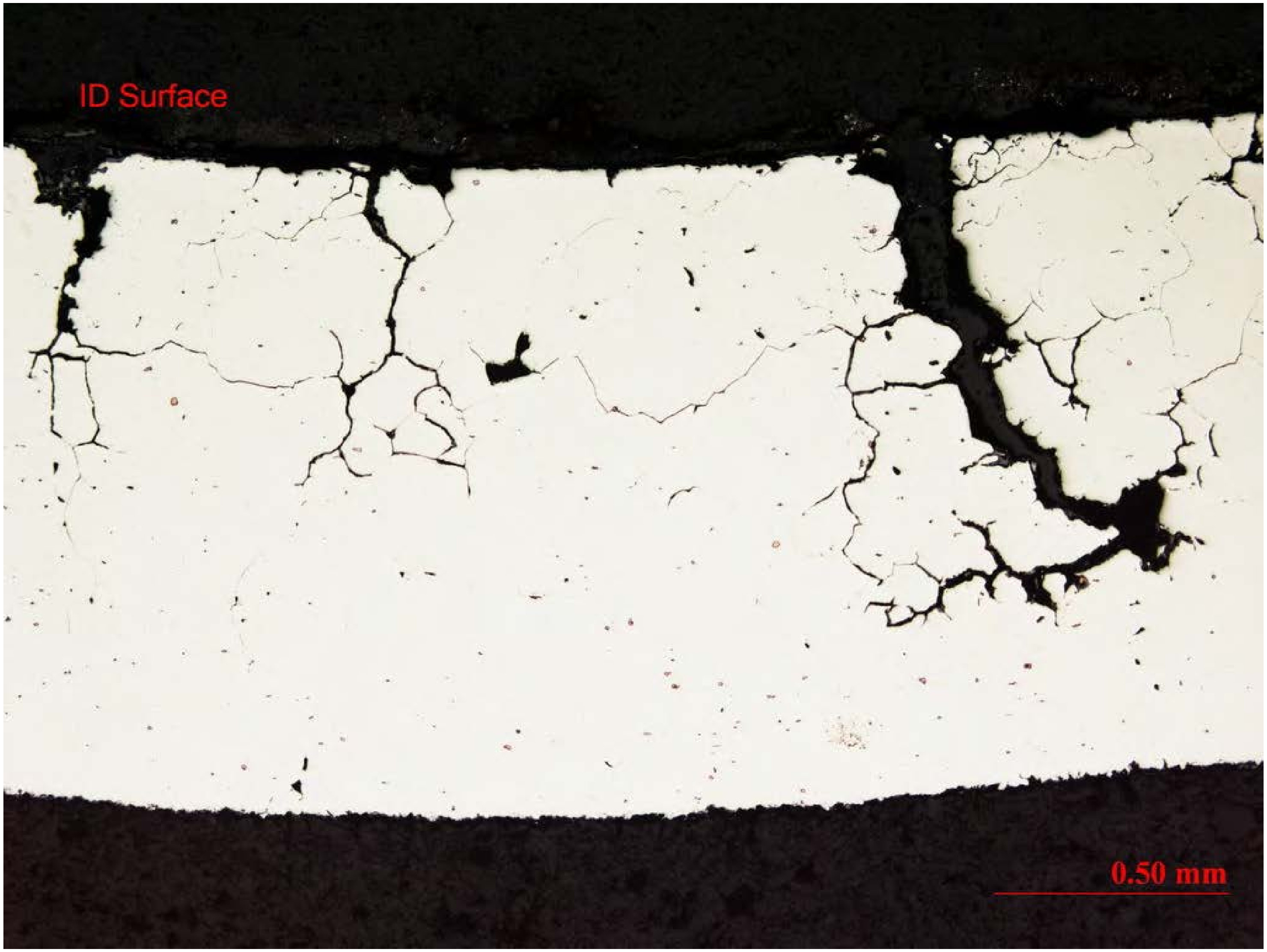
Cross Section of the Regenerator System Bellows

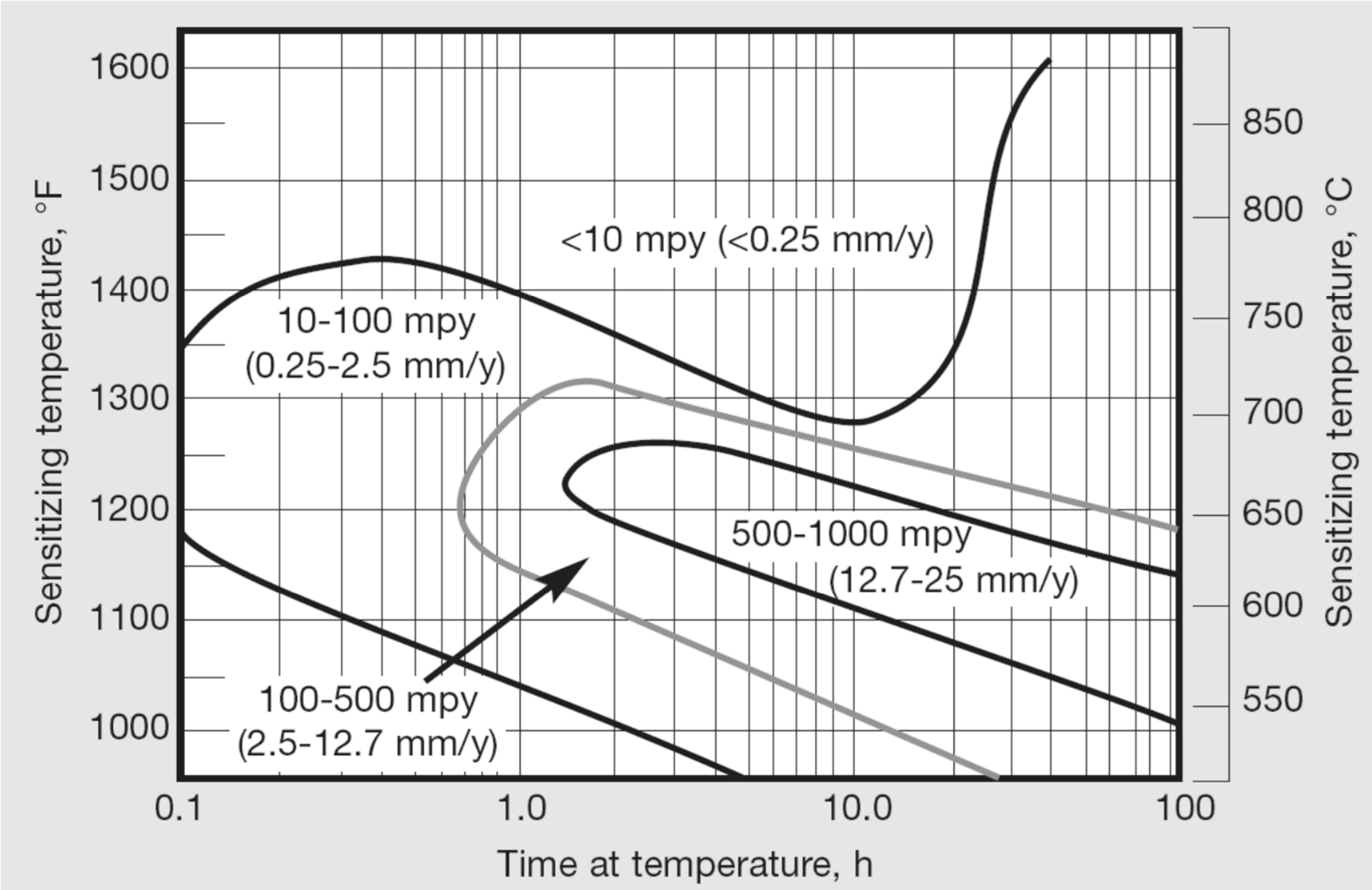
Cracks running in all directions – not stress driven.



Original Magnification – 20X

Sensitization Curves for Incoloy 800

This alloy sensitizes over a wide range of temperatures.



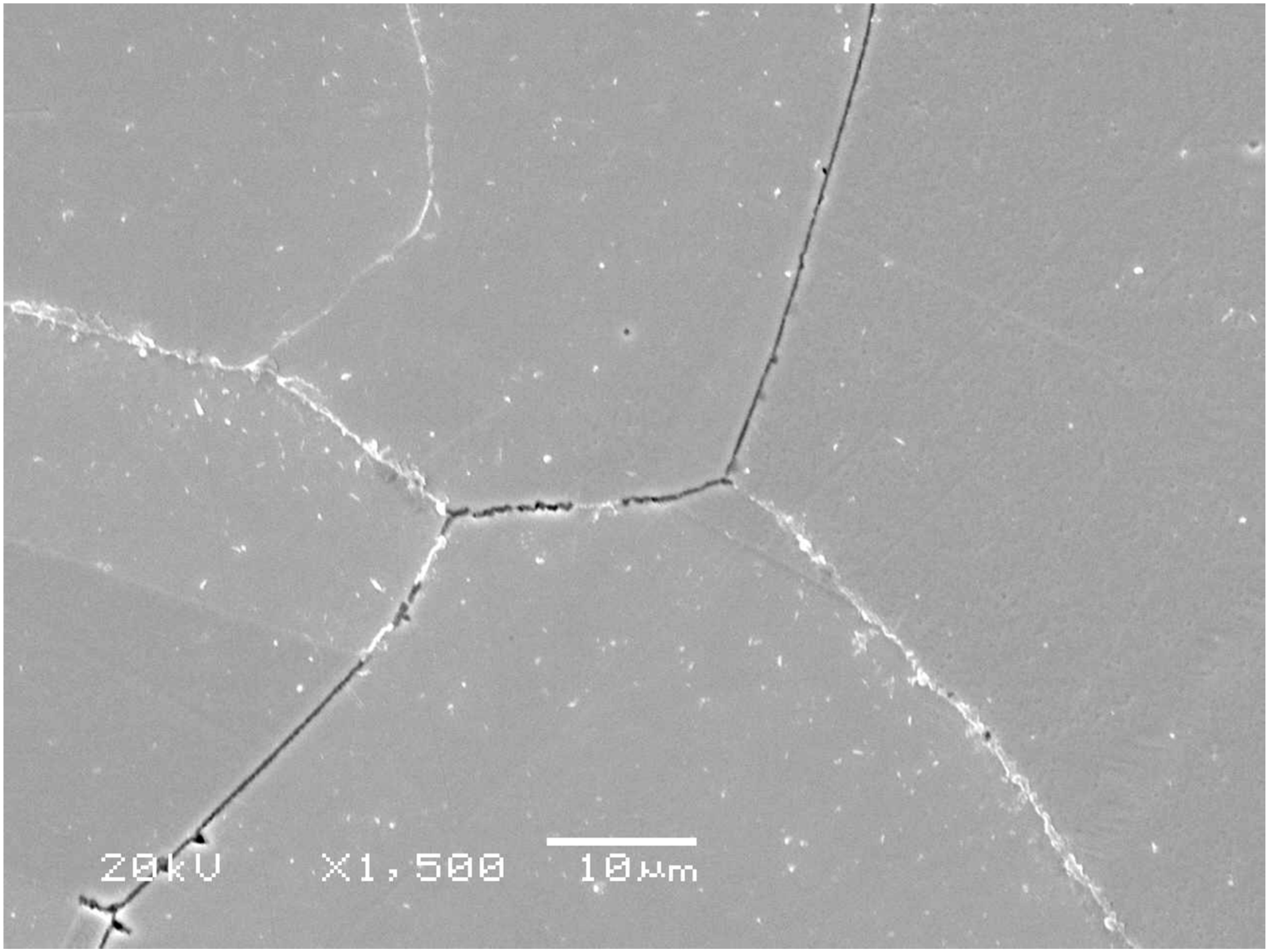
Metallographic Test for Sensitization

The corroded boundaries indicate it was sensitized.

Electrolytically Etched with Oxalic Acid **Original Magnification – 200X**

Carbides Fill Grain Boundaries

The grain boundaries are corroded indicating sensitization.



Etched with Glyceregia   Original Magnification 1500X

The Regenerator Off Gas Bellows Failure

- Sensitization was identified as the cause of the failure.
- Systems upgraded to keep the bellows cooler – more purge steam and more internal insulation.
- Bellows replaced with Inconel 625 LCF bellows:
  - Reduced chance of sensitization.
  - Increased resistance to H2SO4 corrosion.

Questions?