Damage Occurring in FCC Hexmesh Systems

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Damage Occurring in FCC Hexmesh Systems

- **Reactor Hexmesh Damage**
  - Hexmesh that separated from the vessel wall
  - Brittle fracture of the welds
  - Corrosion and cracking of the hexmesh steel at the attachment welds
- **Regenerator Hexmesh Damage**
  - Examples of failures
  - Sigma embrittlement of FCC Regenerator welds
  - Carburization of hexmesh steel and welds
  - Test sample cut from FCC cyclone crossover piping
  - Damage found at the interface

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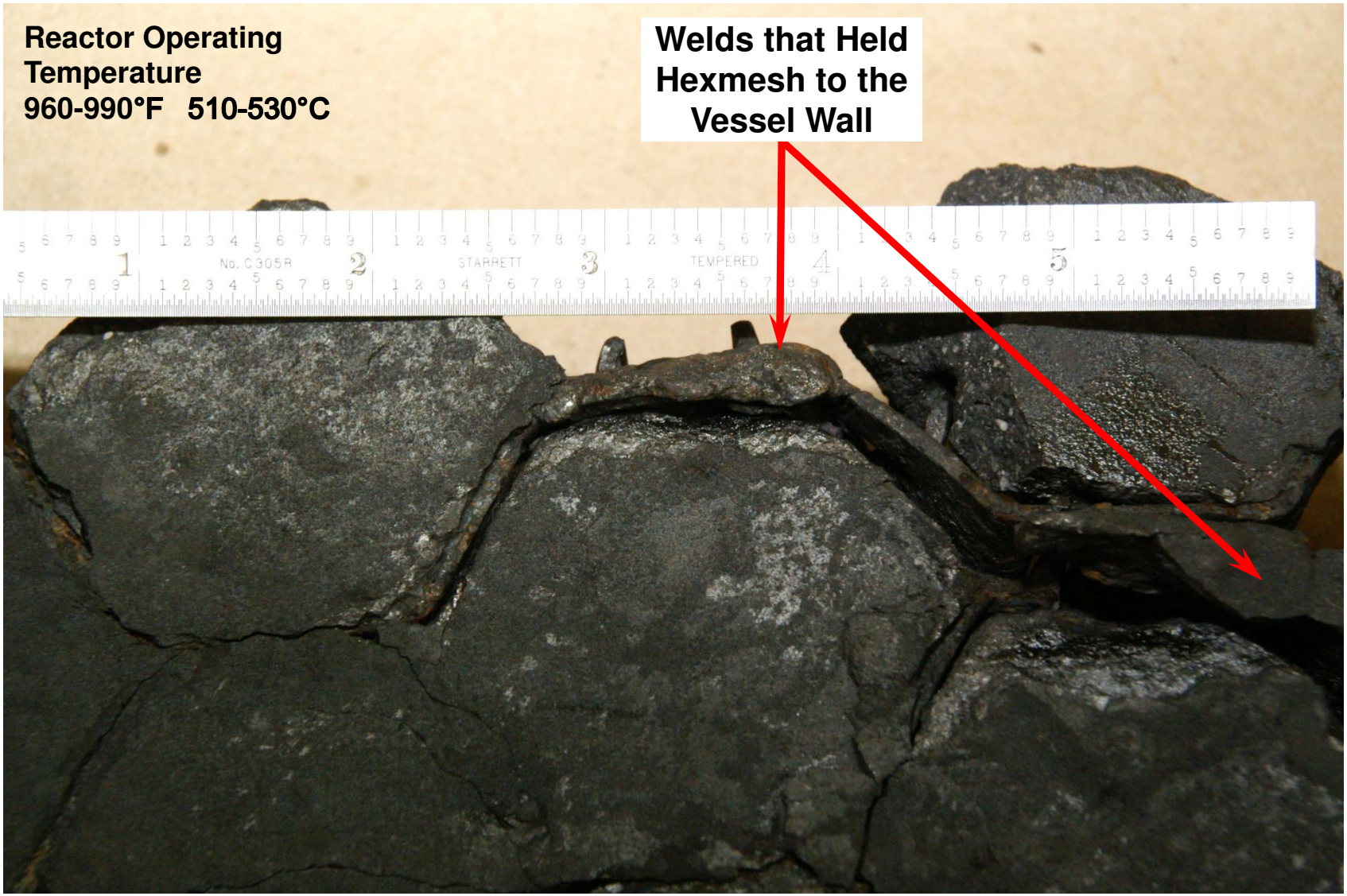
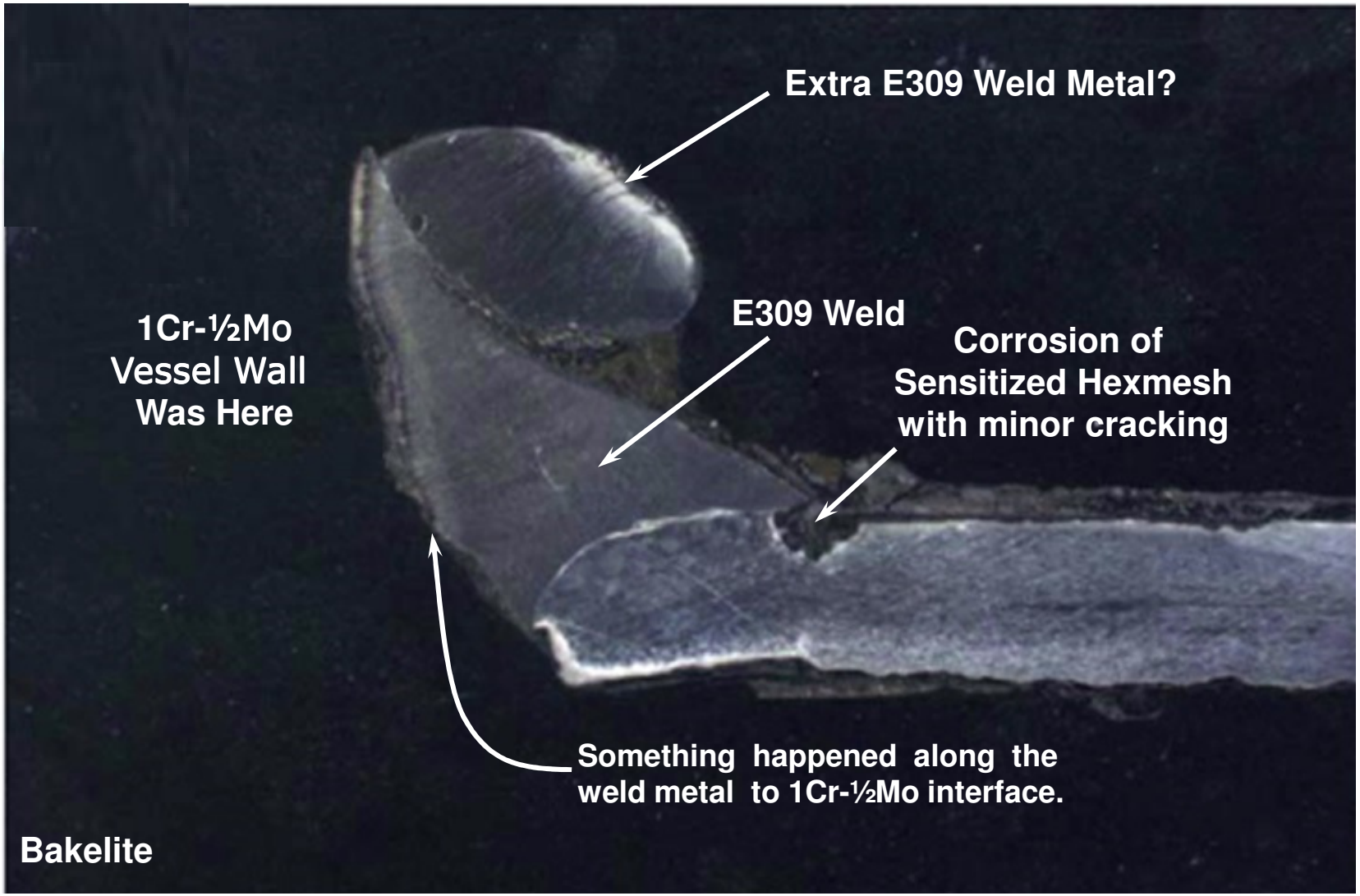
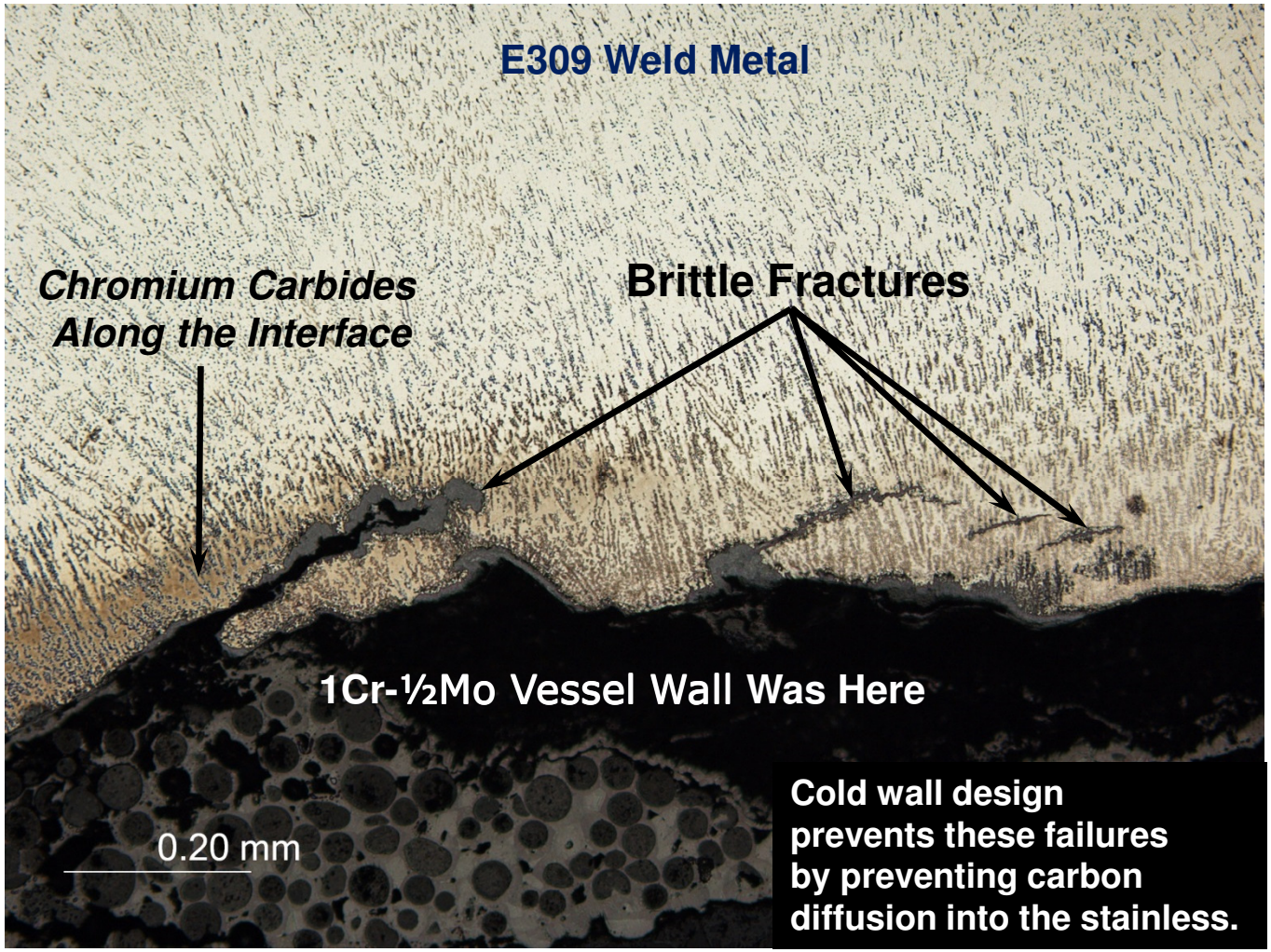
Hexmesh that Separated from the Reactor Wall



Why the Welds Holding the Hexmesh Failed



Weld Metal at the Vessel-to-Weld Interface



Carbon from the 1Cr-½Mo diffused into the stainless steel forming chromium carbides and lowering the fracture toughness of the weld metal. Refer to NACE Paper 626 from NACE Corrosion 1993 for examples of this phenomenon.

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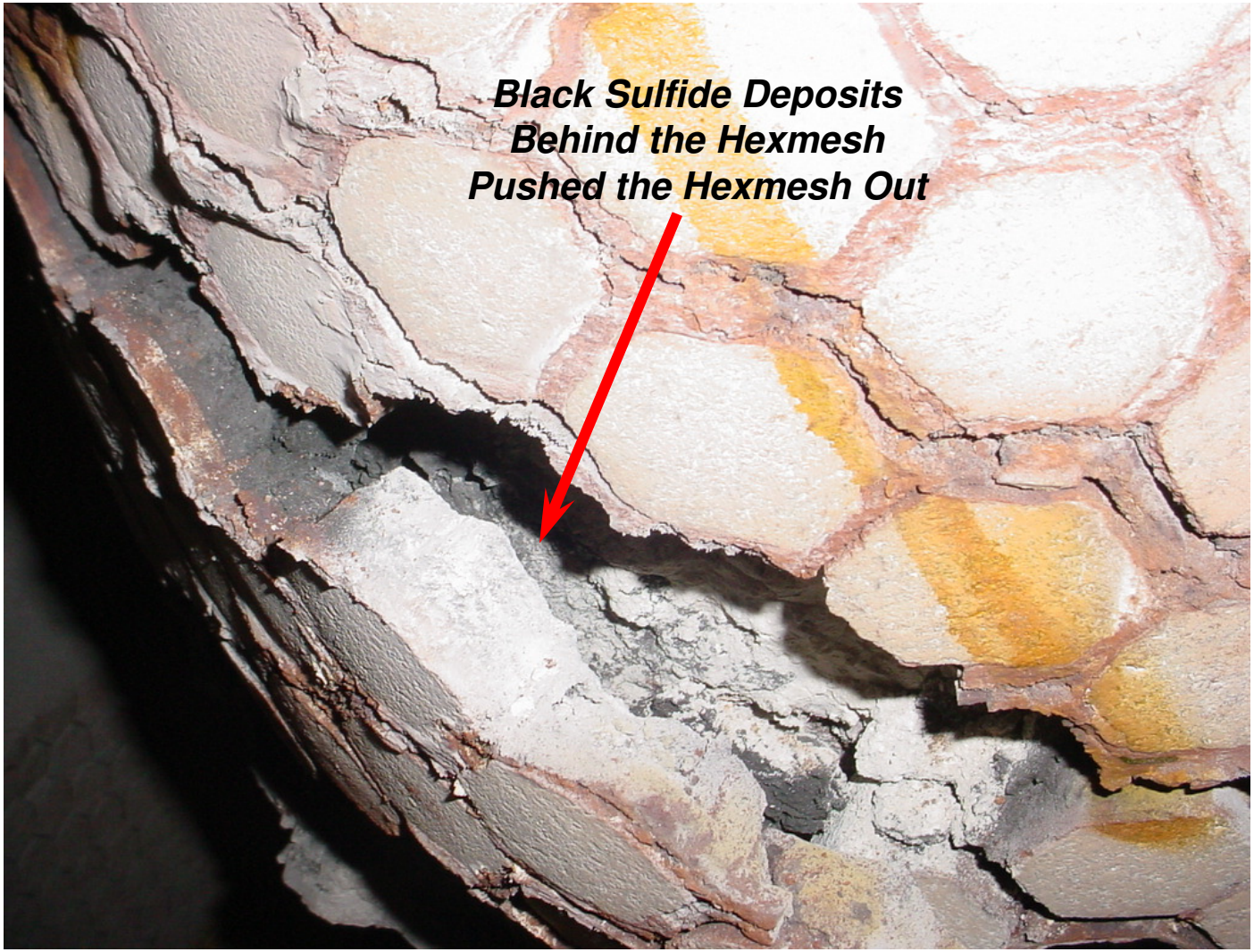
Example of Regenerator Hexmesh Failures

Inside of a cyclone



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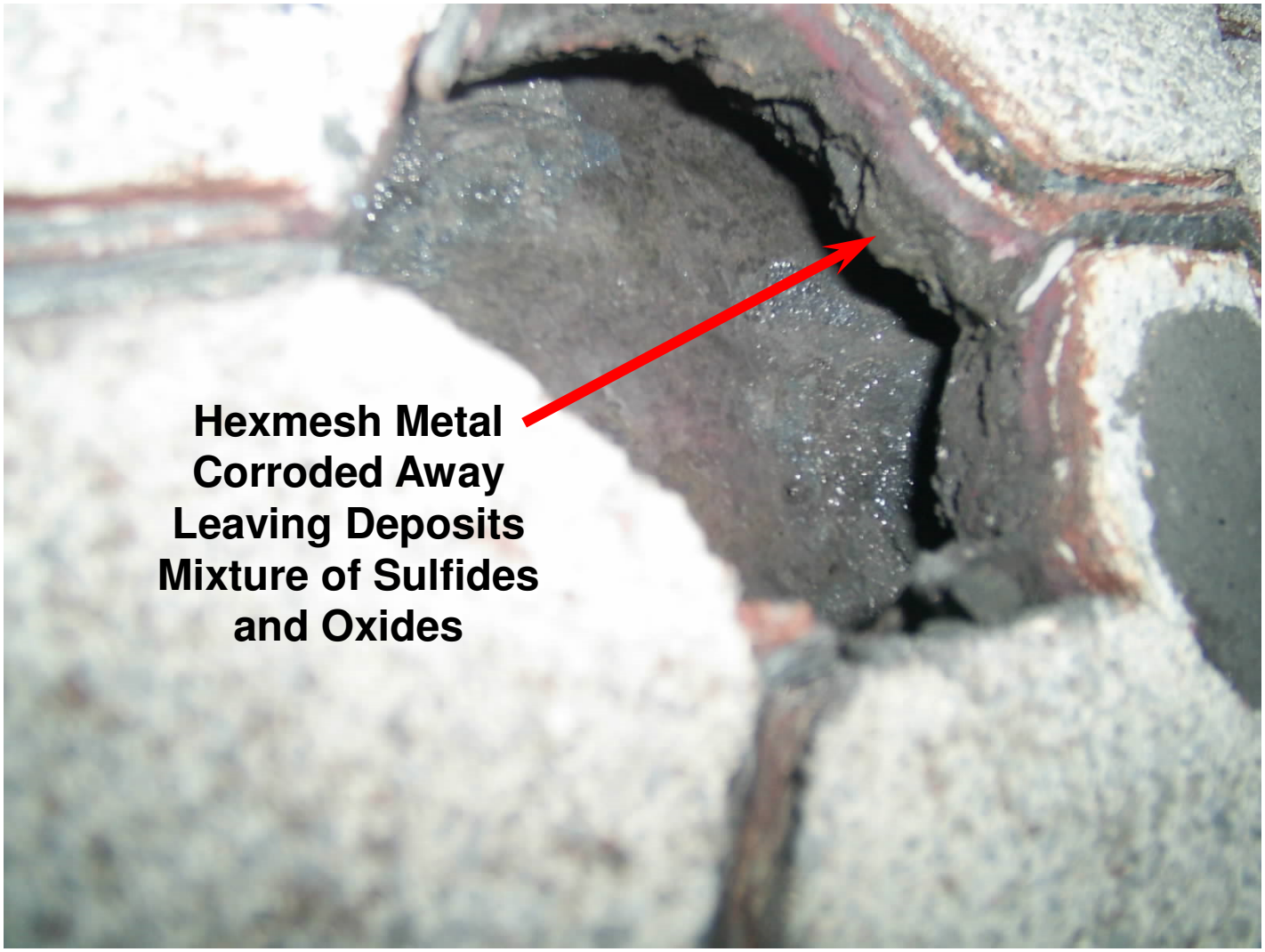
Hexmesh Metal Completely Corroded Away



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Results of Corrosion Deposit Analysis

Corrosion Product from the Hexmesh		
Element	**Atomic %**	**Weight %**
Oxygen	35.6	16.6
Iron	23.0	37.3
Chromium	14.4	21.8
Sulfur	10.9	10.2
Carbon	8.3	2.9
Nickel	4.2	7.2
Manganese	1.6	1.3
Other Elements	2.62	1.54

Metal sulfides convert to oxides when exposed to air, so while in-service the deposits contained more sulfur.

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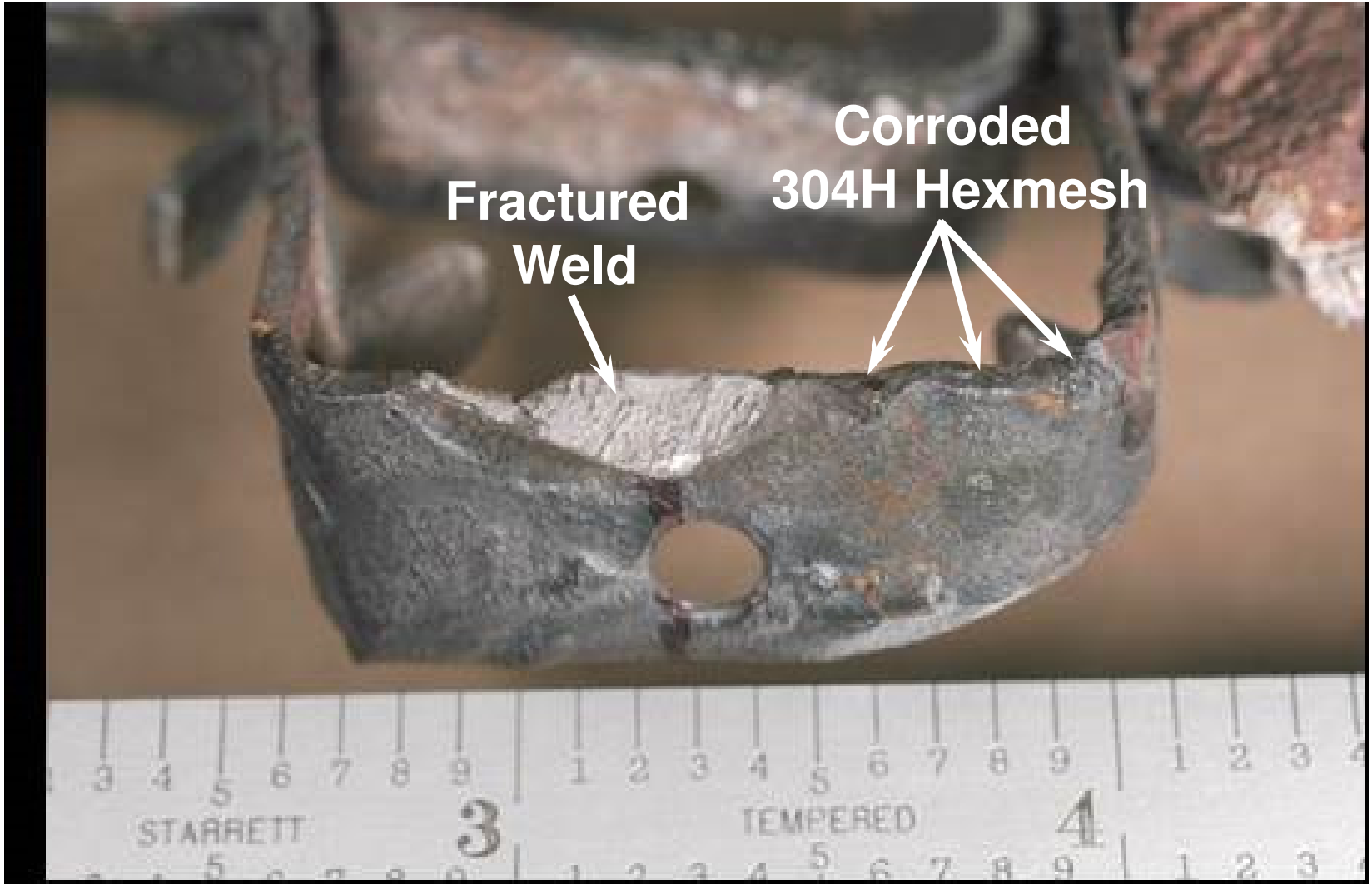
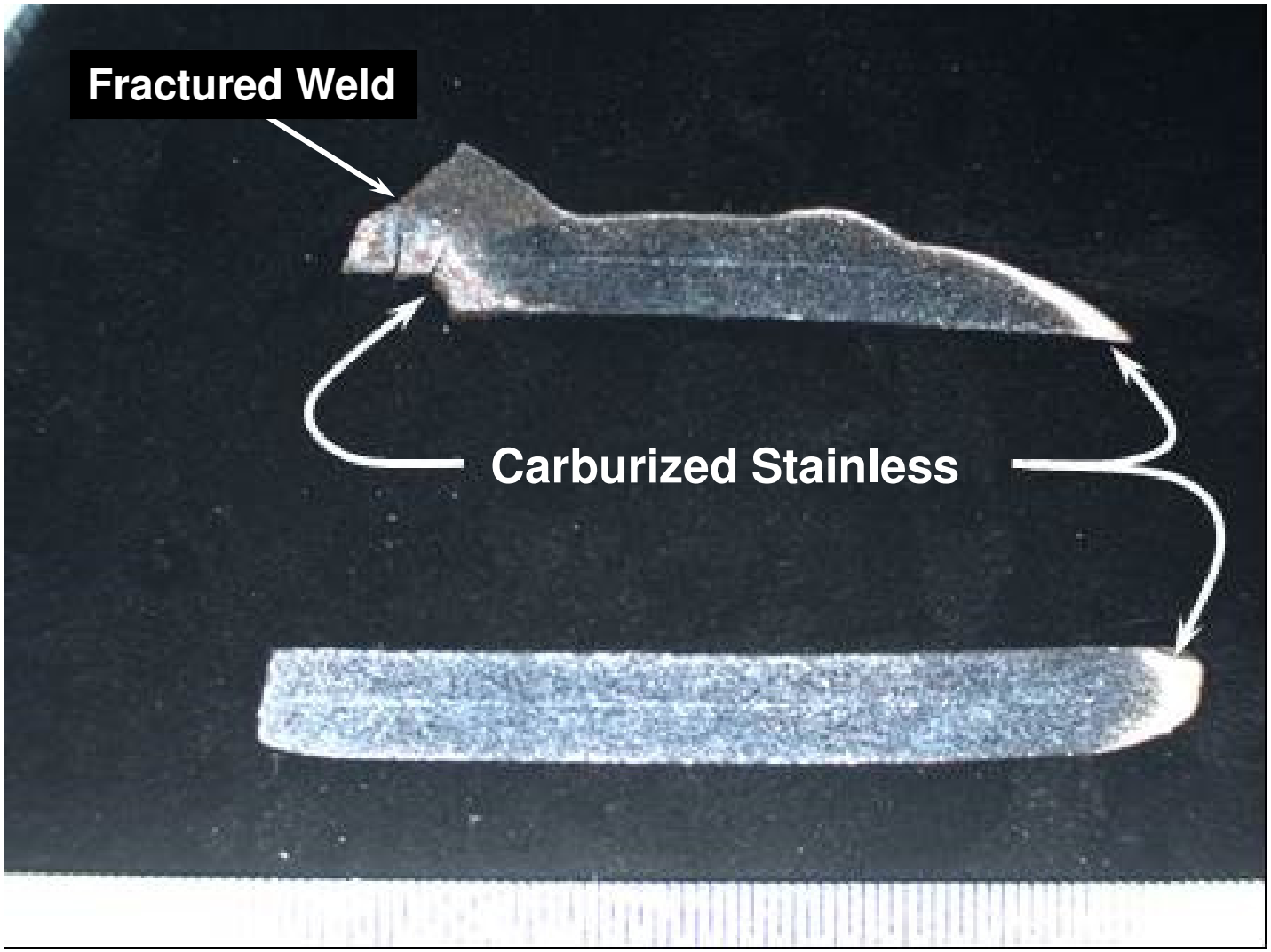
Areas Where Welds Fractured and Hex Corroded

Red arrows point to fractured welds. White arrows point to corrosion damage.

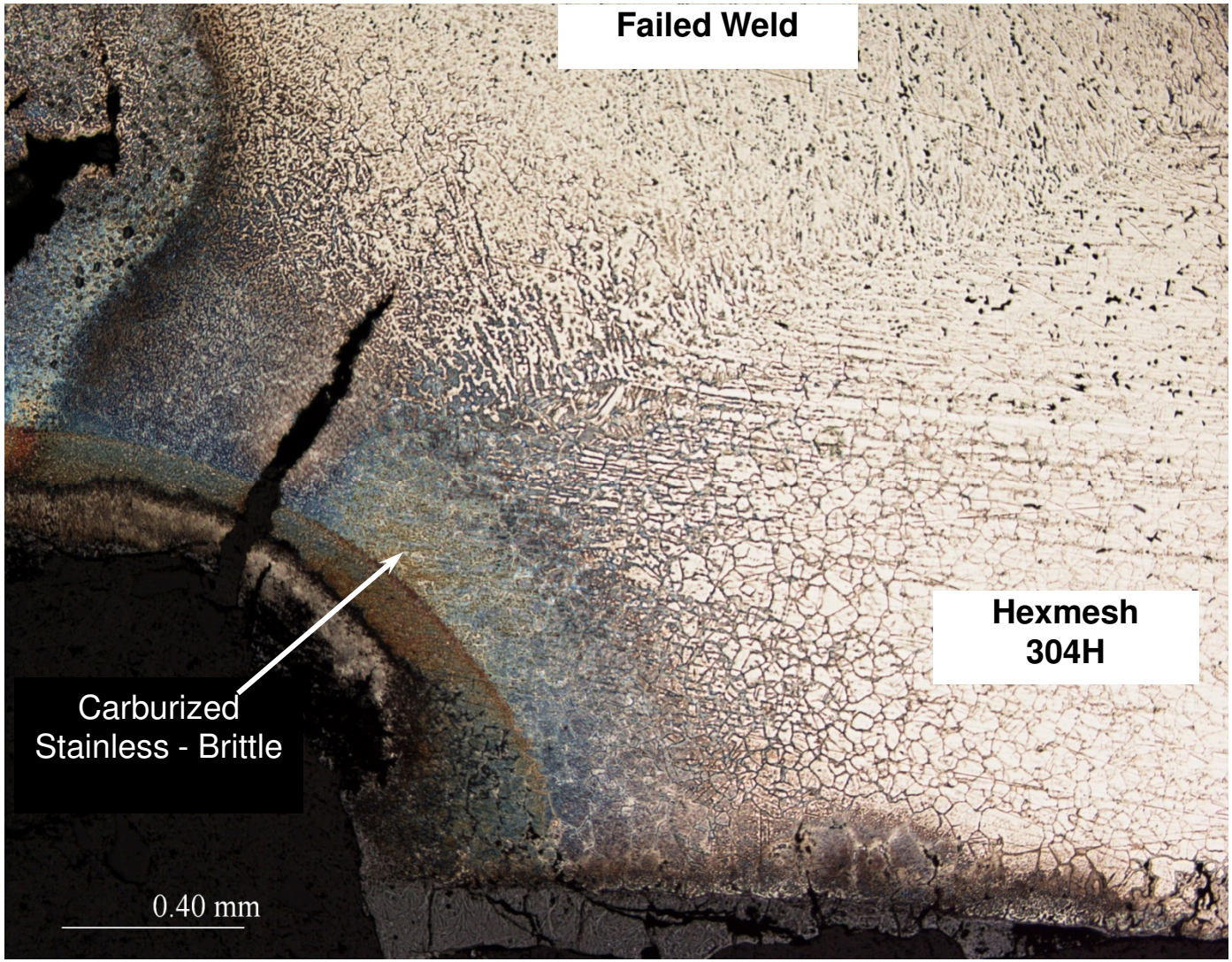
Close-up of the Weld Fracture and Corroded Hex



What's Happening to the Stainless Steel?

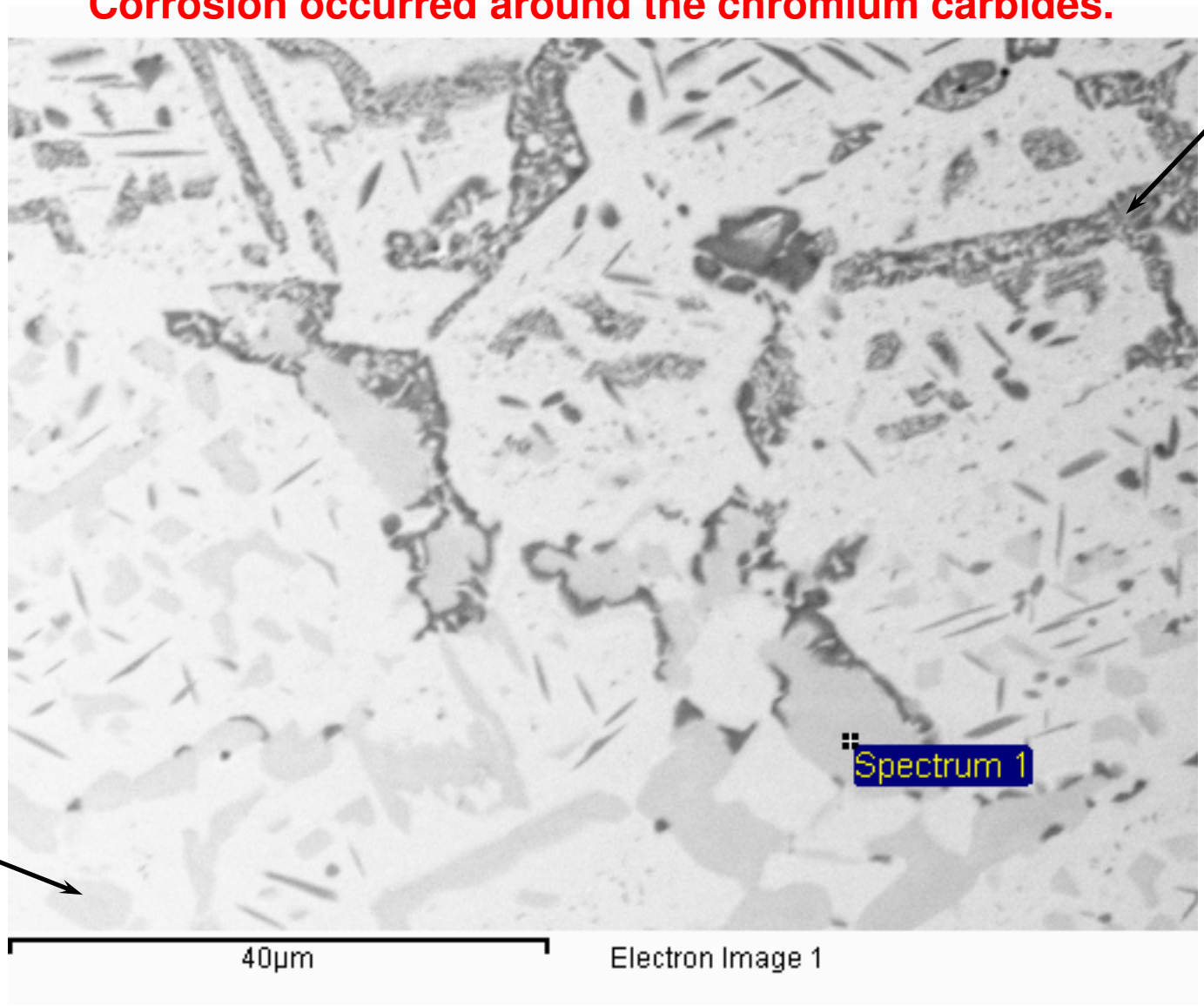


Carburization of 304H Stainless Steel



Carburized Stainless at Higher Magnifications

Corrosion occurred around the chromium carbides.



Oxides & Sulfides

Chromium Carbides

Composition of the Chromium Carbide in Hexmesh

Analysis of Chromium Carbides in 304H		
Elements Present in Order of Descending Atomic %	**Atomic %**	**Weight %**
Chromium	47.94	61.03
Carbon	27.00	7.94
Iron	17.58	24.04
Nickel	2.02	2.90
Oxygen	2.00	0.79
Sulfur	1.39	1.09
Manganese	1.06	1.42
Silicon	0.82	0.57
Other	0.17	0.22

The exact formula for pure chromium carbide is $Cr_{23}C_6$, but the composition of metal carbides typically varies with some Fe, Mn, and Ni in place of Cr atoms. When chromium carbides form, the surrounding stainless becomes non-stainless.

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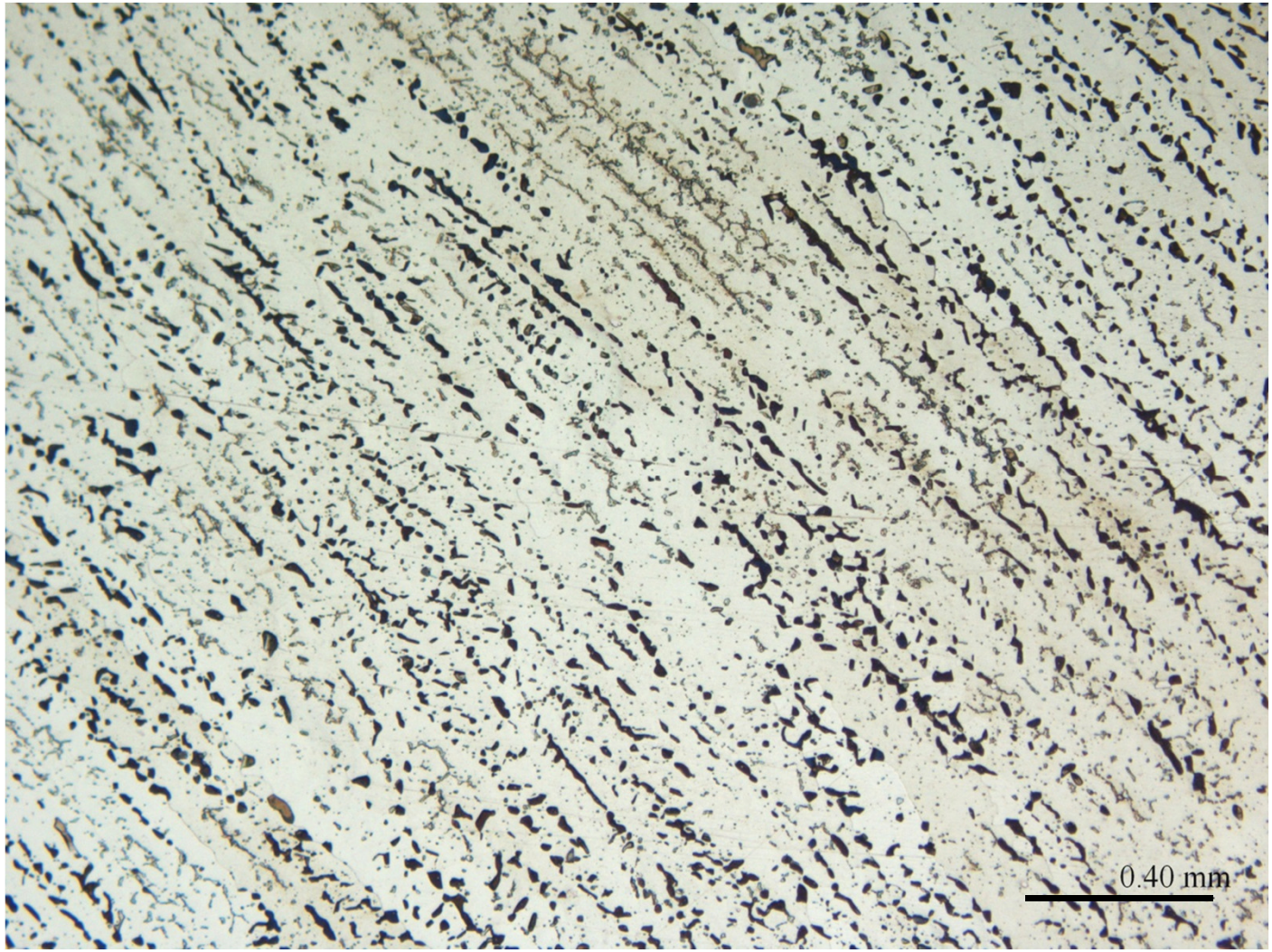
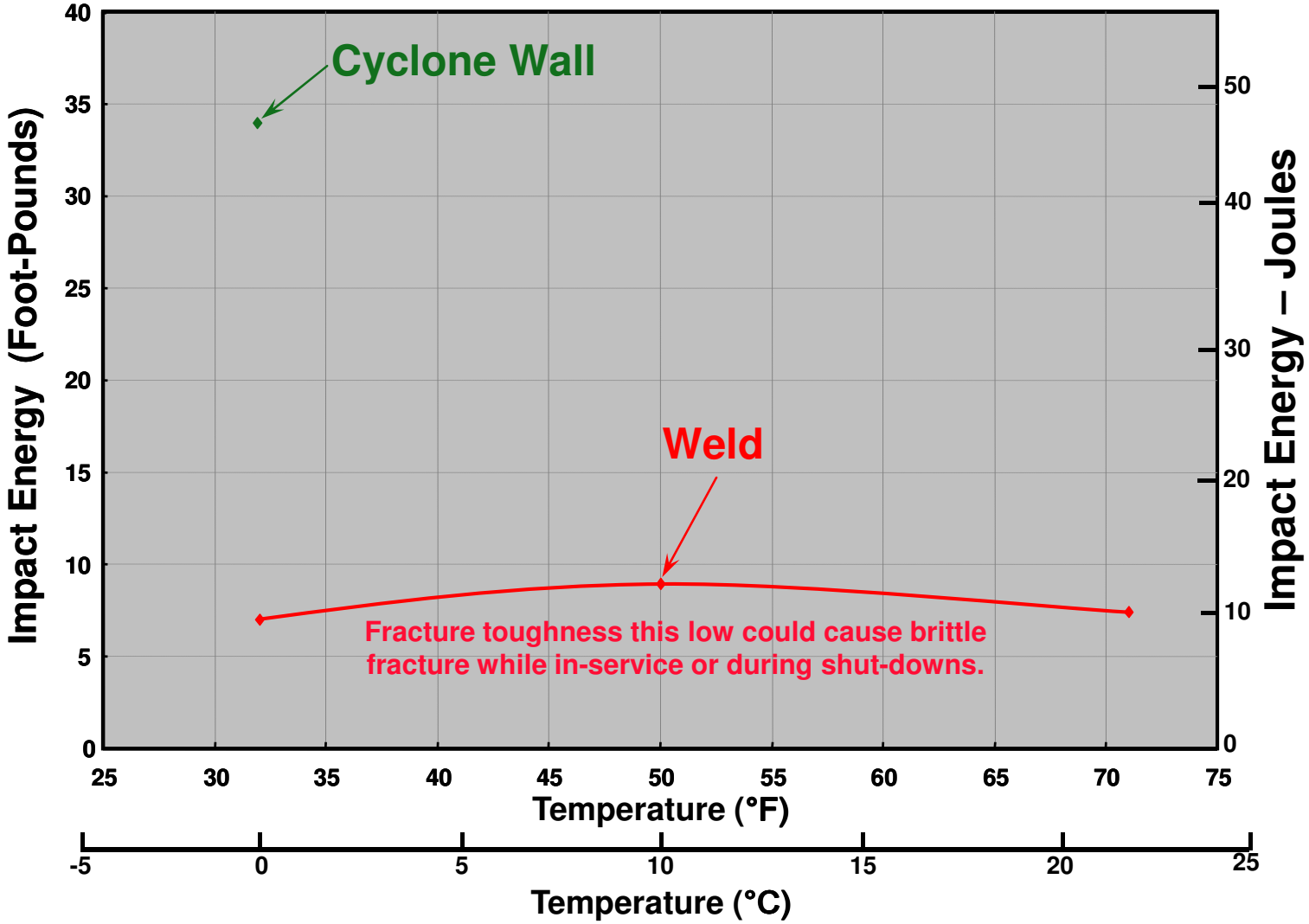
Sigma Formation in Weld Metal Causing Brittle Weld Fractures



The dark phase is sigma in E309 weld metal – it creates aligned weak interfaces.

Regenerator Cyclone Welds vs. Wall Test Results

Results of Charpy Impact Testing of Regenerator Cyclones



CITGO's 2015 Investigation of Hexmesh Damage in a Regenerator after 5 Years of Service

- Test sample cut from FCC Regen crossover duct
- Early in the degradation so mechanisms can be seen
- Specimens dry cut from the sample to avoid contamination
- The interface between refractory and steel was inspected and damage was found at the interface
- Analysis of corrosion deposits and phases present to identify the corrosion mechanism

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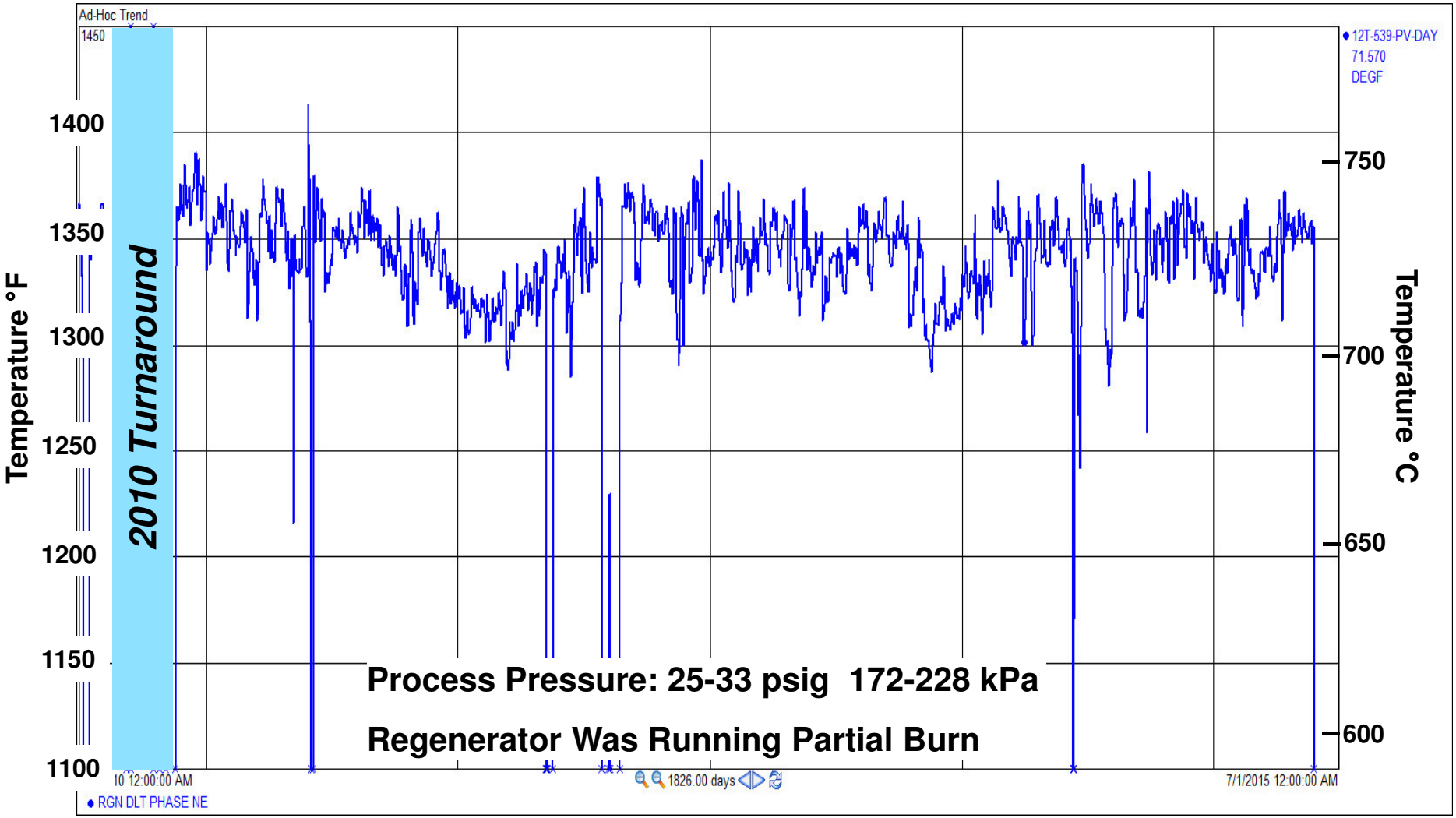
Process Temperature During the 5 Year Run



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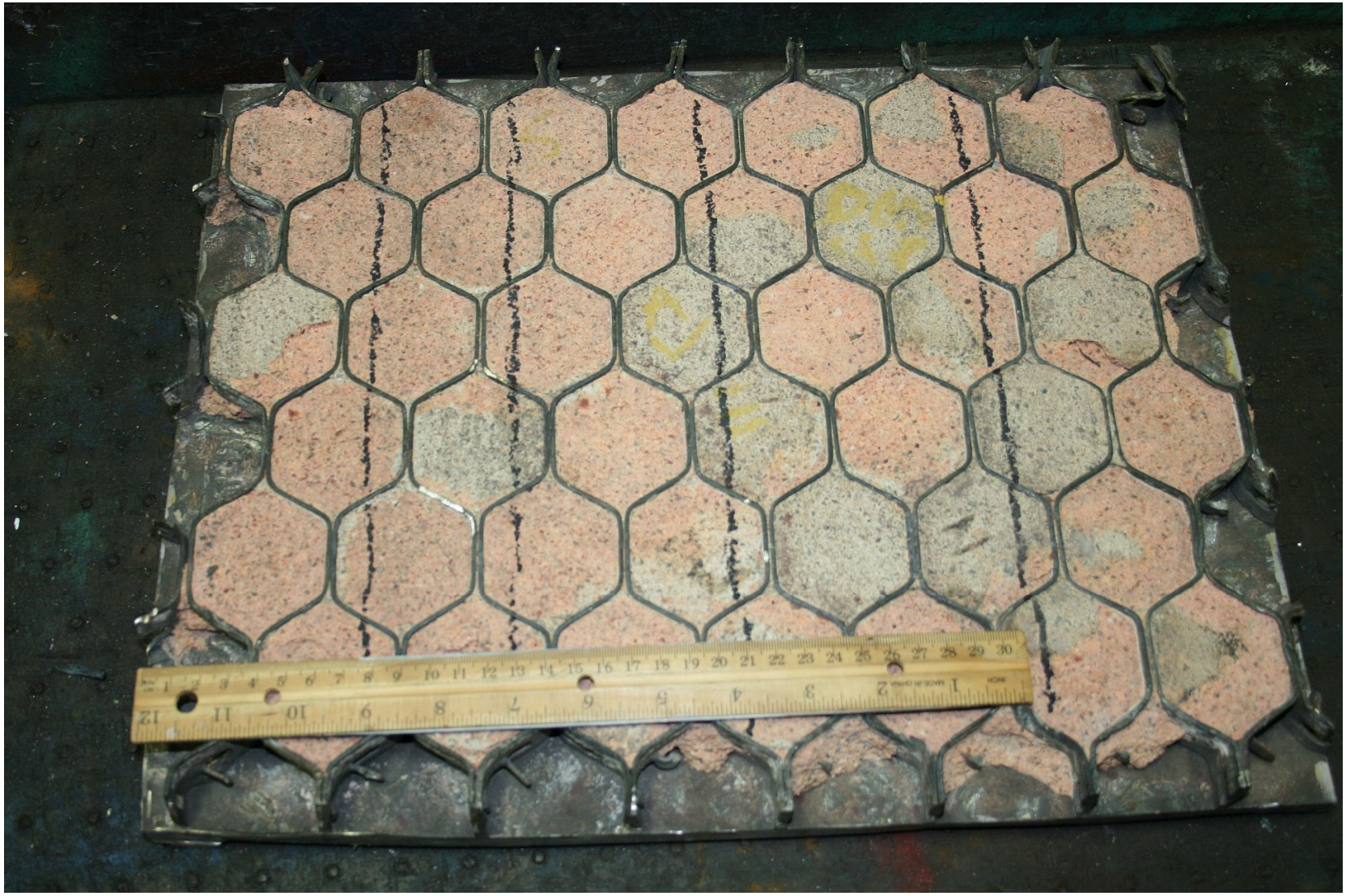
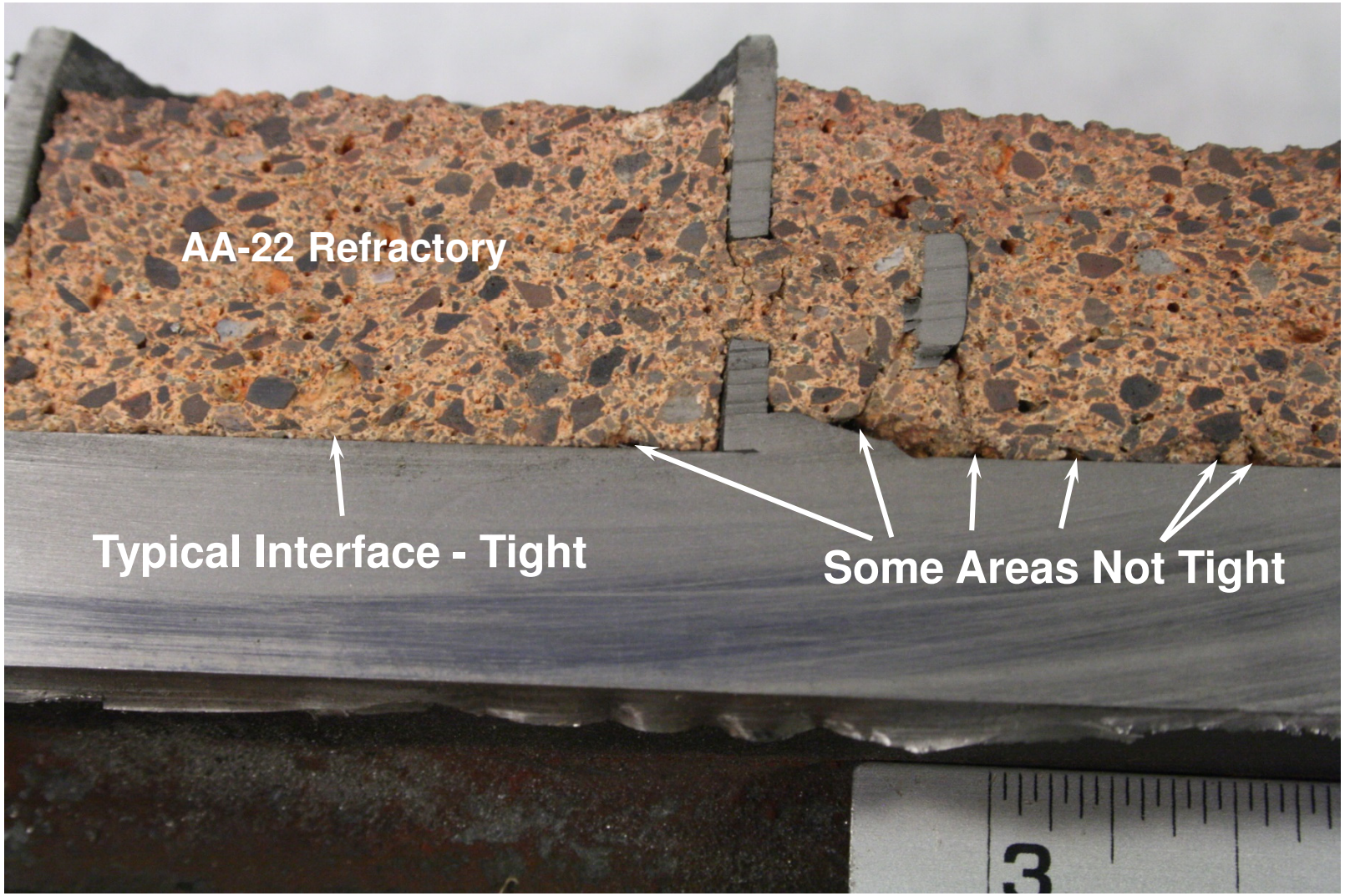
2015 Sample Cut from the Lemont Regenerator

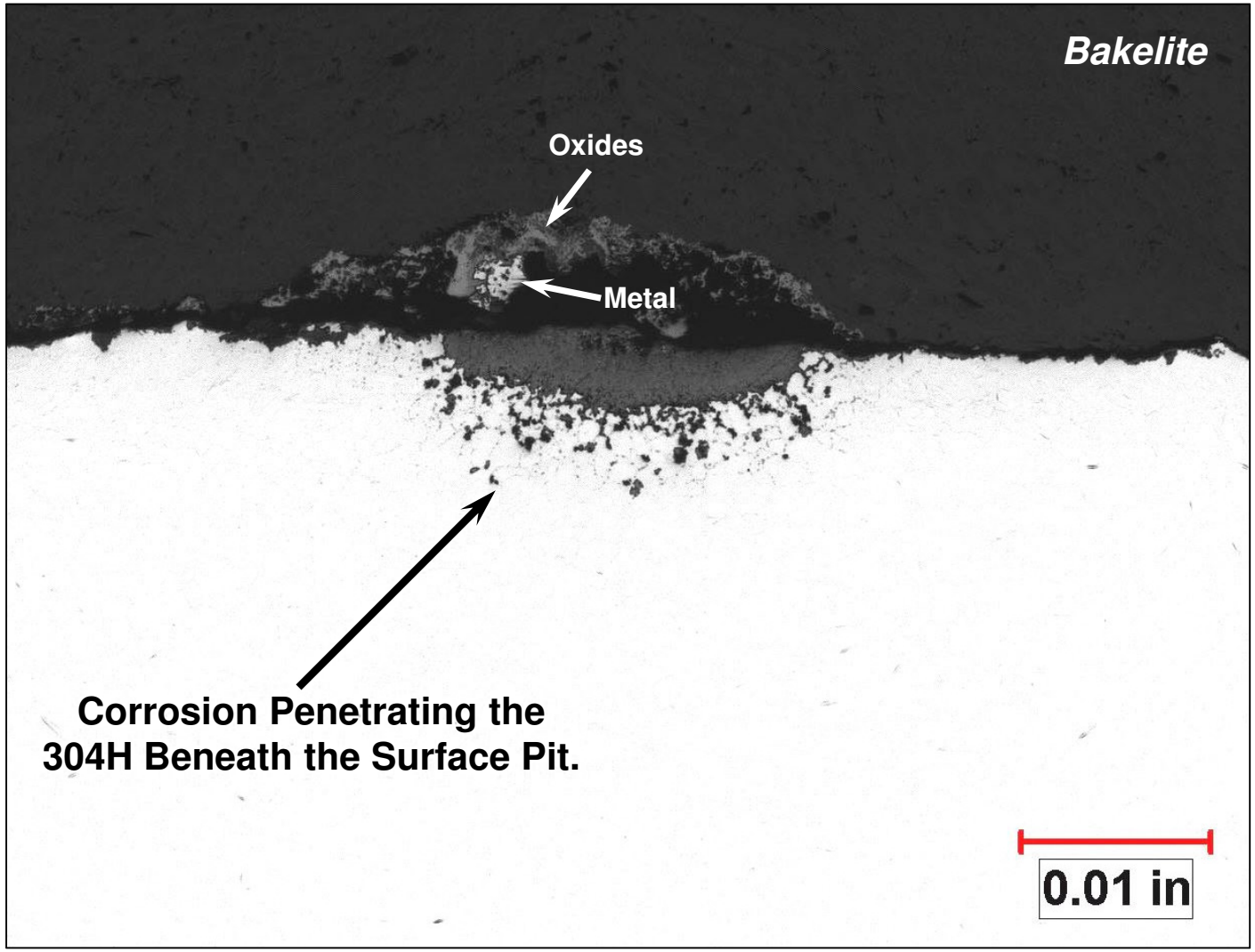


Specimens Cut from the Sample

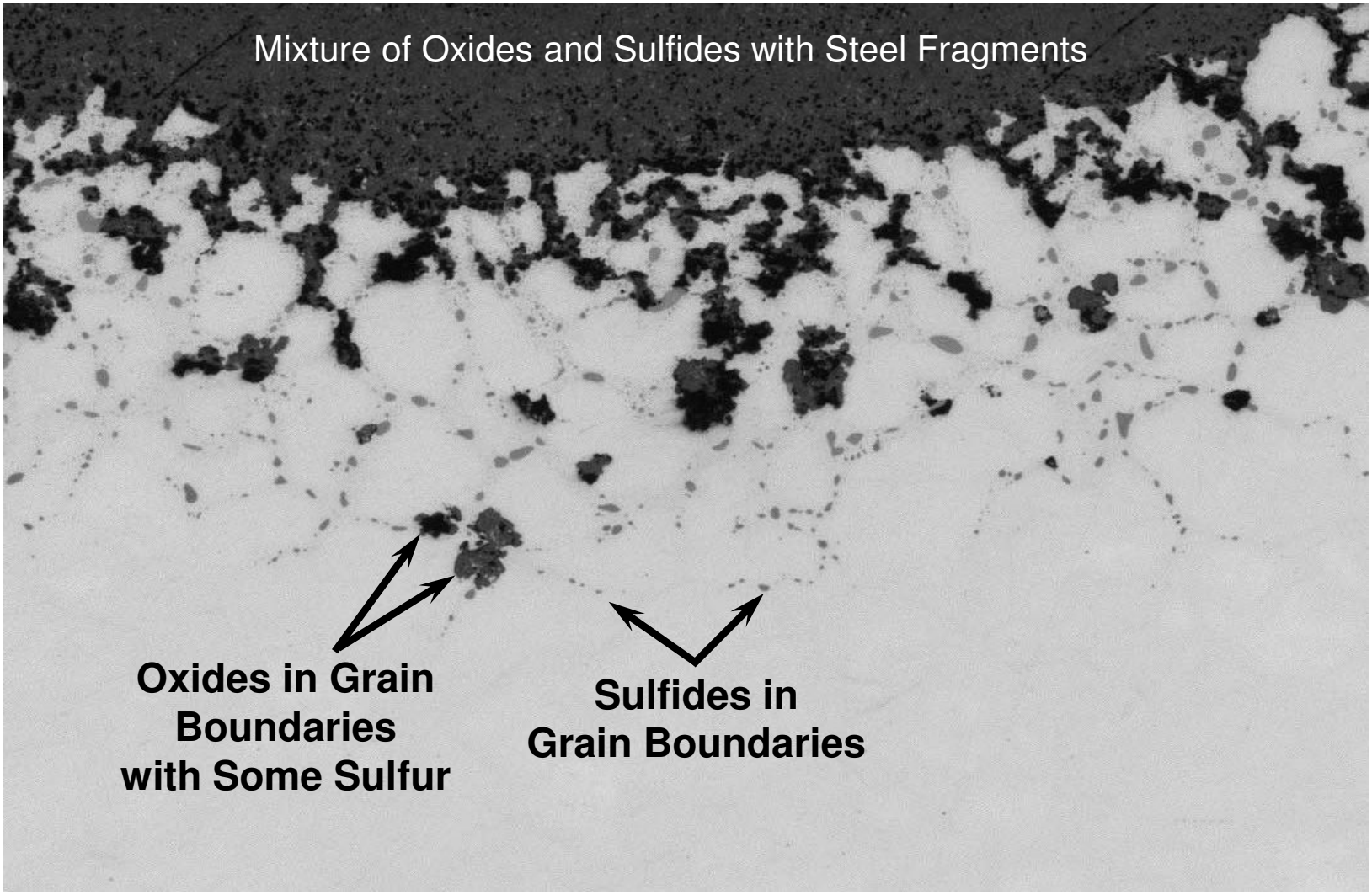
Close-up of the Refractory-Steel Interface



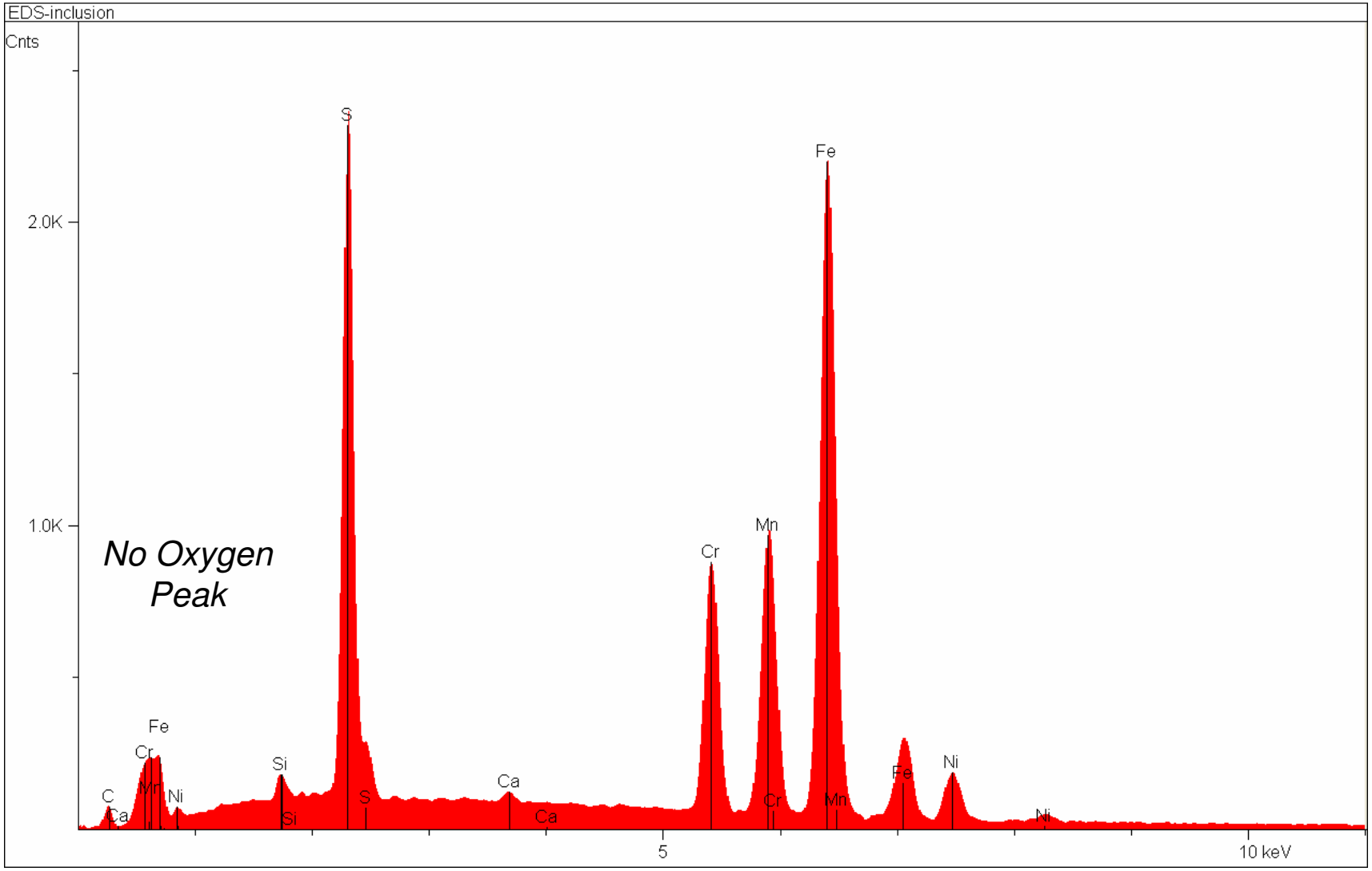
Damage Found at the Refractory-Steel Interface



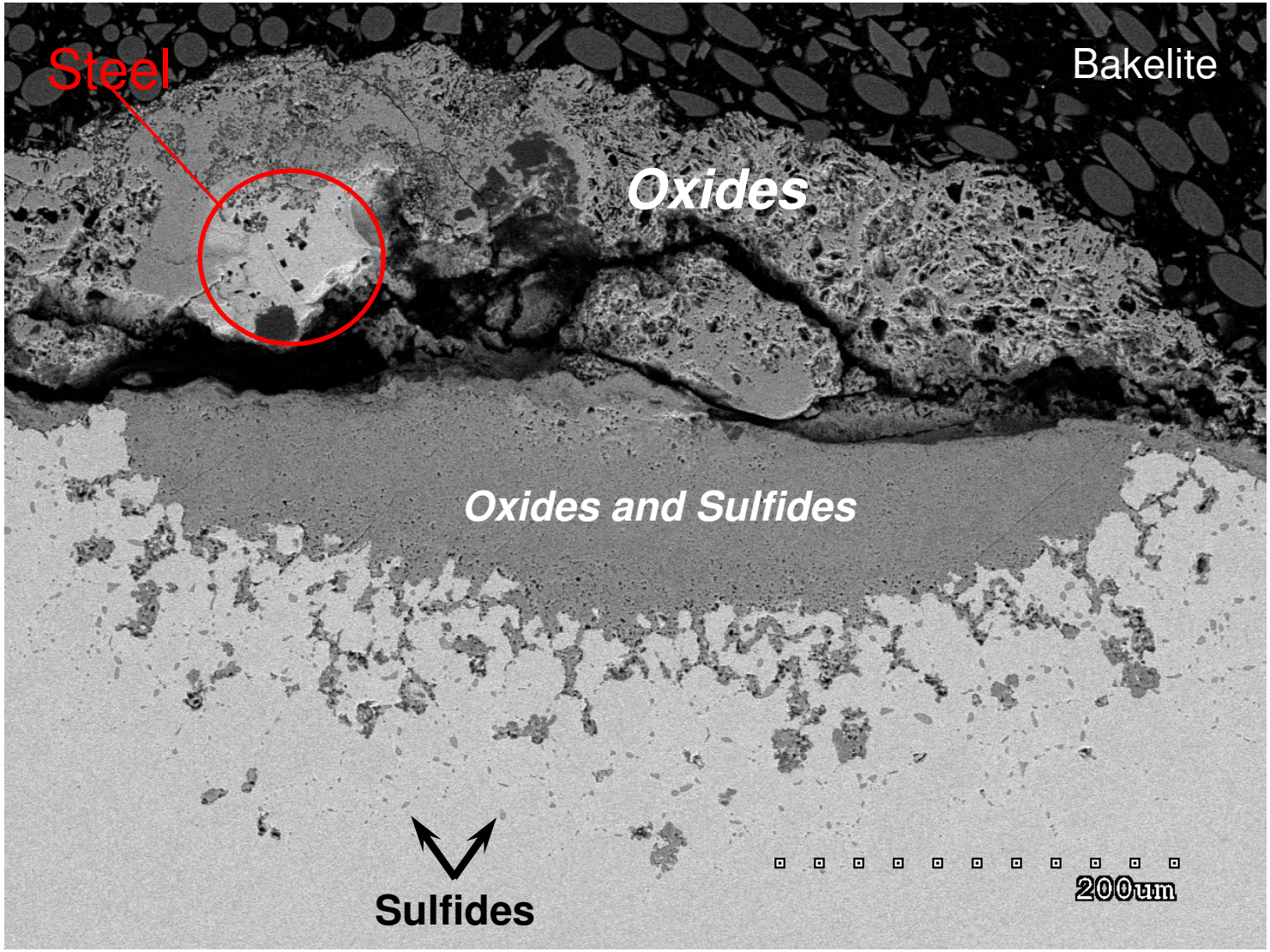
A Closer Look at the Corrosion Damage



X-Ray Analysis Results for Light Grey Deposits

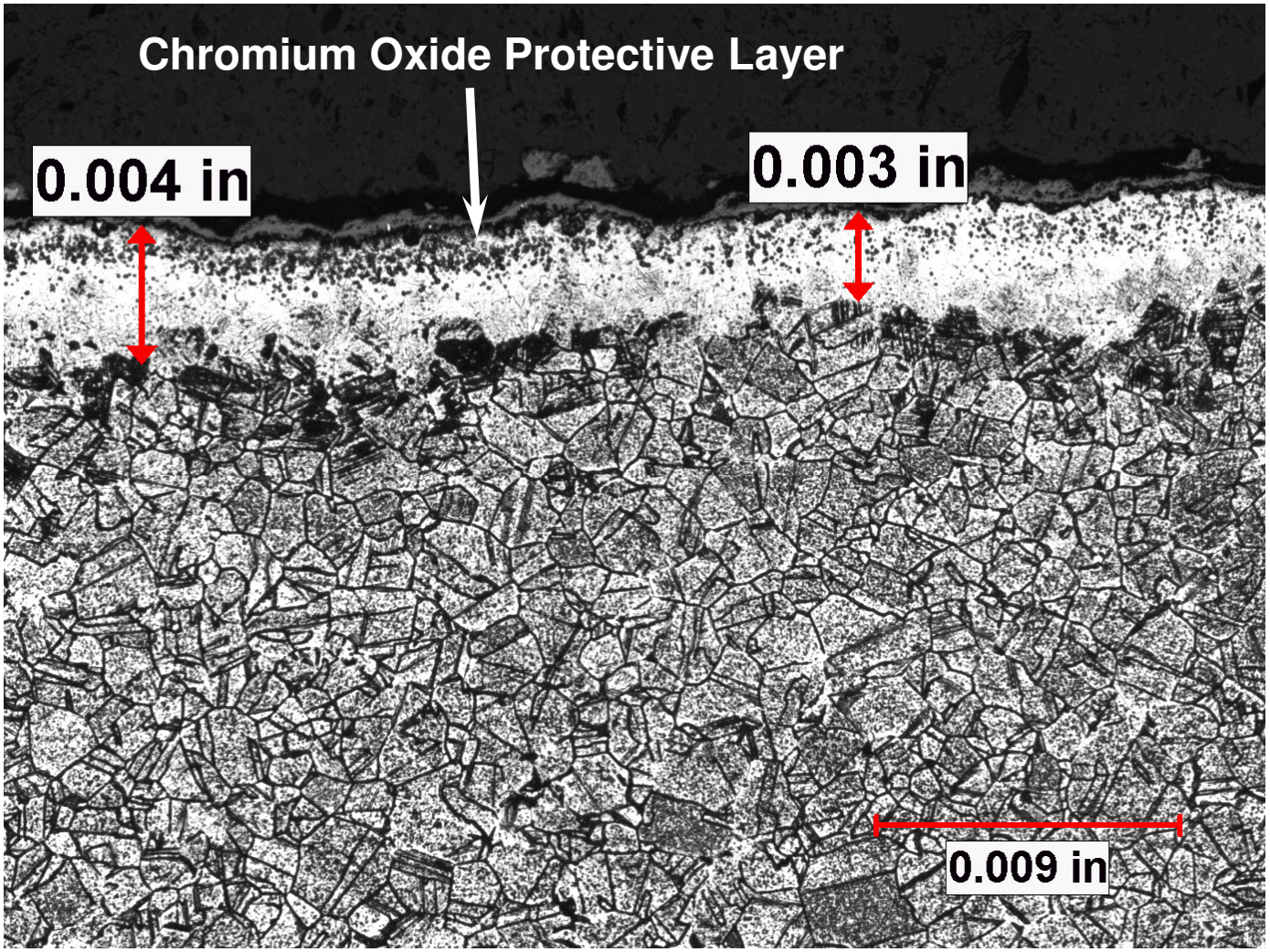


Electron Microscope View of the Damage



Chromium Oxide Prevents Stainless Corrosion

Etched with Oxalic Acid Original - 100X



Conclusions

- Hexmesh failures in FCC Reactors at the vessel wall can be significantly reduced or eliminated with cold wall reactor design.
- Cold wall design prevents diffusion of carbon into the weld metal and avoids brittle fracture of welds.
- Polythionic stress corrosion cracking occurs in the hexmesh steel due to sensitization at the welds holding the hexmesh to the wall.
- Hexmesh failures in FCC regenerators are caused by carburization of the 304H hexmesh and carburization of E308 or E309 weld metal.
- Corrosion in FCC regenerators occurs due to both oxidation and sulfidation. Carburization of the stainless promotes the corrosion.
- Going to full burn operation in the Regenerator should reduce the sulfidation corrosion and that could also reduce oxidation.
- Sigma formation in FCC Regenerator welds causes the weld metal to become brittle, and easily fracture in service or during turnarounds.
- The chromium oxide protective layer on the stainless is very thin and damage of that thin layer by refractory movement could occur

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