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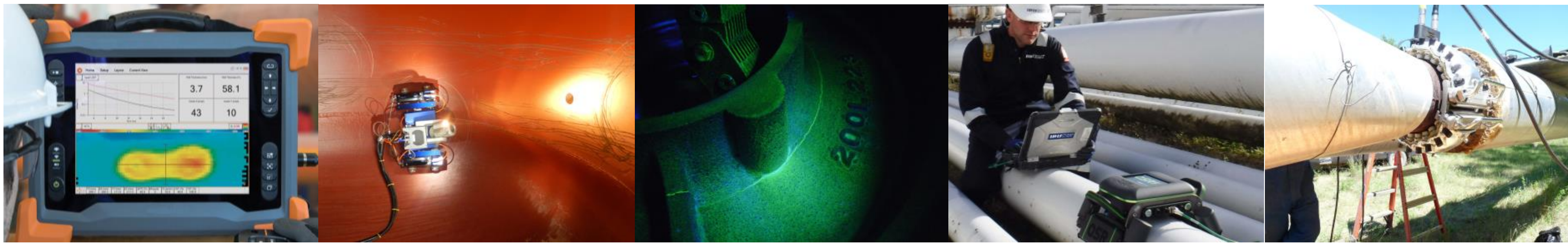

Metallographic Replication of In-Service Plant

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ICorr Aberdeen Branch

INSTITUTE OF CORROSION

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- Introduction
- What is a metallographic replica?
- Producing Metallographic Replicas
- Uses of replication
- Assessment of Metallographic Replicas
  - General microstructures
  - Specific damage mechanisms

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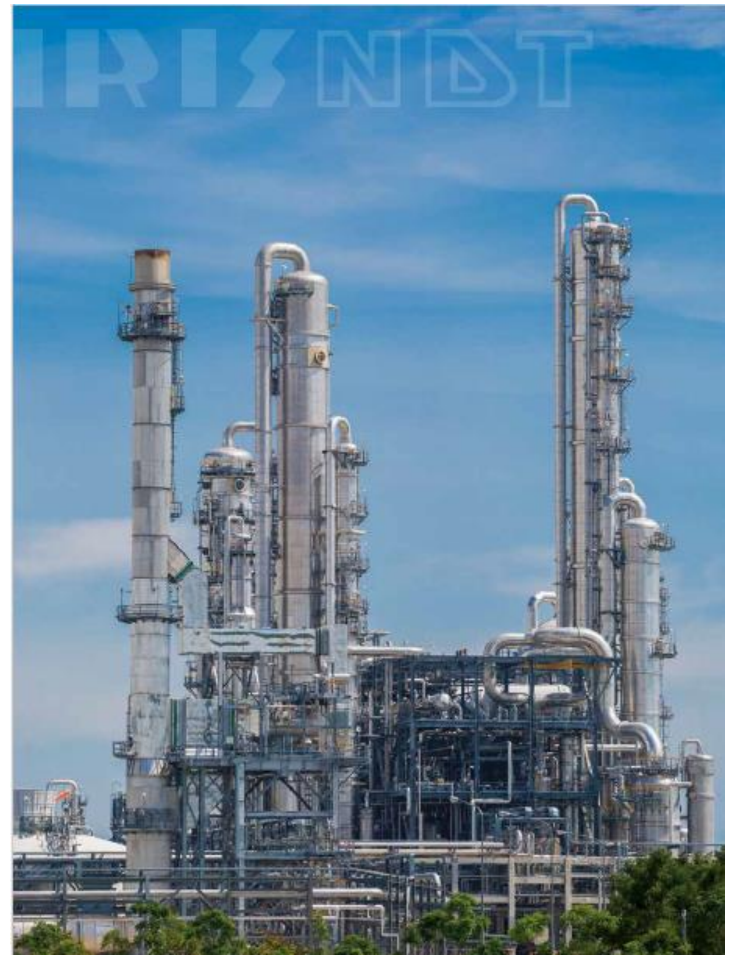
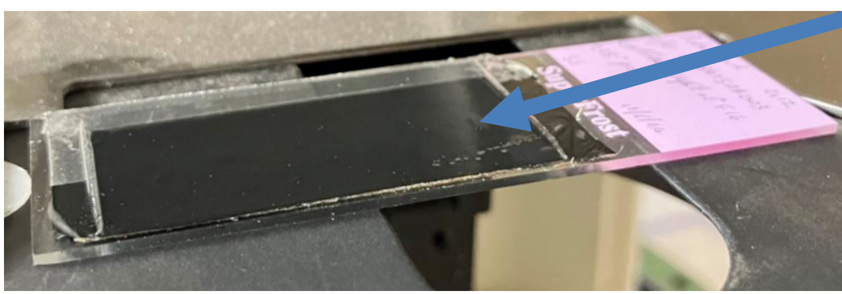
- Operations in the UK, USA, Canada and Australia.
- Offer both non-destructive and destructive testing
- Cover a range of industries including
  - Power Generation
  - Petrochemical
  - Manufacturing
  - Mining



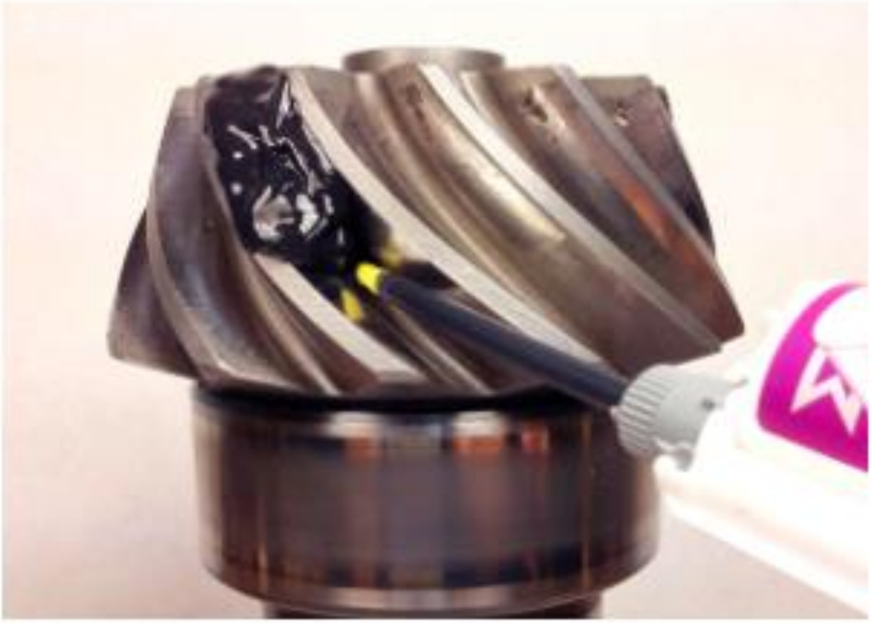
What is a Metallographic Replica?

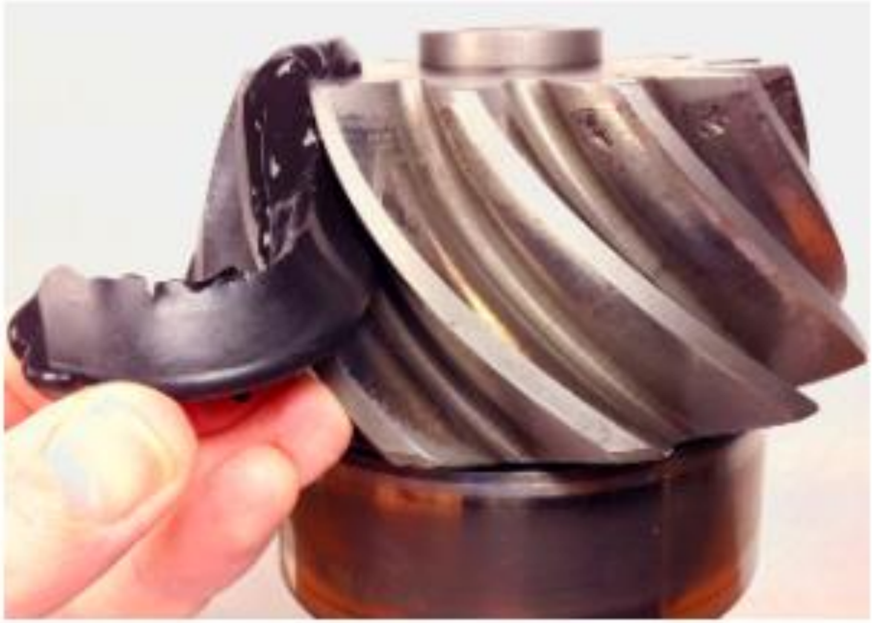
- A metallographic replica is a detailed ‘fingerprint’ of the metal surface of a component.
- It is utilised for assessment away from the component and to keep a physical record of the area.



Producing Metallographic Replicas

- Where surface morphology is required, a two-part putty can be used. This takes on the surface contours and sets hard for removal and assessment.
  - Assessment could include microscopy or macroscale measurements





Images from https://d3f2jcygtjrjjp.cloudfront.net/what-we-do/index.html

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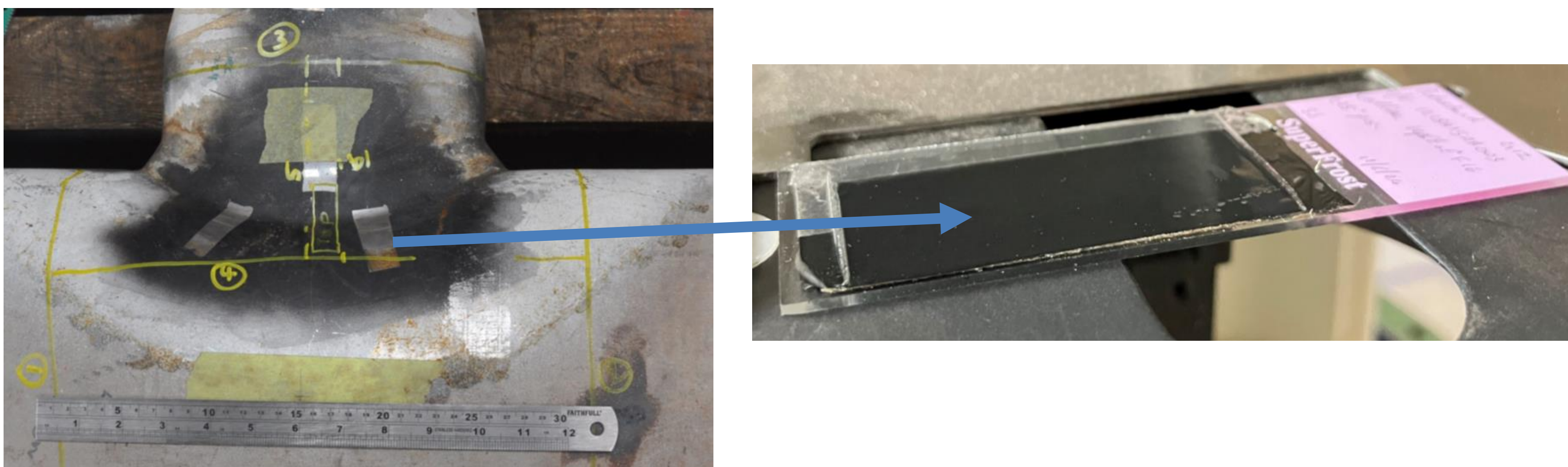
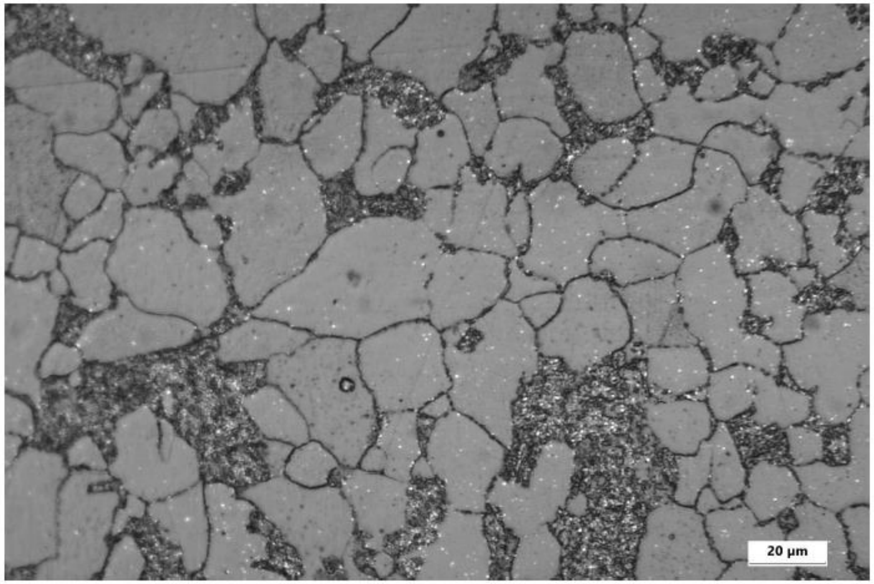
Producing Metallographic Replicas

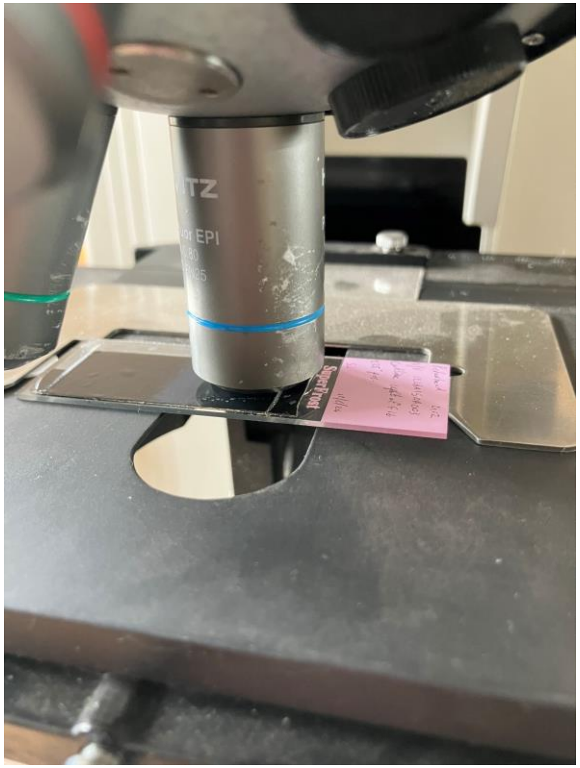
- The second method of replication is to polish the metal surface and etch it before partially melting an acetate sheet onto the surface.
- Once the acetate has hardened it is peeled off and adhered to a glass microscope slide.
- A curved surface is flattened for analysis under an optical microscope either on site or in the laboratory.



Producing Metallographic Replicas

- This technique provides the full metallurgical information from the area replicated.
- It can then be assessed remotely, providing a permanent physical record of the microstructure at that moment in its service life.





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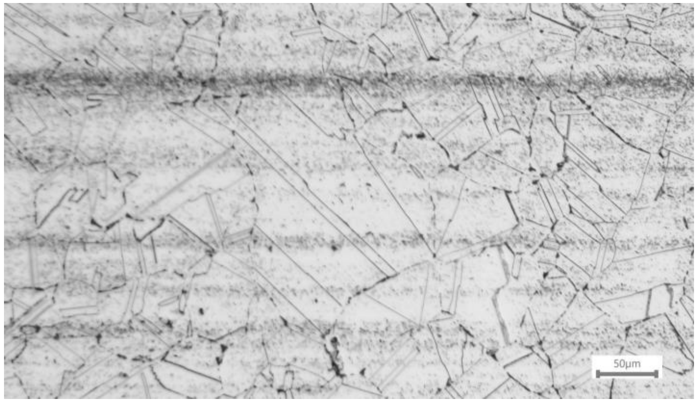
When to use Replication

- Replication is often used as part of routine inspection strategies to monitor the material condition over time.
- It is also employed to further evaluate unexpected damage revealed by NDT techniques or after unplanned events such as a fire
- It can also be used as part of the QA/QC process for weld repairs.



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Replication vs Direct Assessment

- It's not always possible to examine a component directly. Considerations include:
  - Component geometry. E.g. crotch position of a branch.
  - Access to a component.
  - Capability of portable equipment not equivalent to static equipment.
  - Assessment sometimes requires a flat surface.
- Need to retain a permanent record 'snapshot' for comparison with subsequent assessments. It can also be useful for failure examinations to take a record of a feature prior to destructive testing.

Replication vs Direct Assessment

- Some aspects of the metal component are not provided by the replica. These include:
  - Etch colour information.
  - Chemical composition information.
  - Mechanical properties.

- Complimentary techniques are required
  - Positive Material Identification (PMI).
  - In situ hardness testing.
- All in situ methods have limitations compared to destructive testing.

Image from:
https://www.nitonuk.co.uk/products-applications/positive-material-identification/
https://www.newsonic.de/en/products/hardness-testing/exchange-probes-sono-205

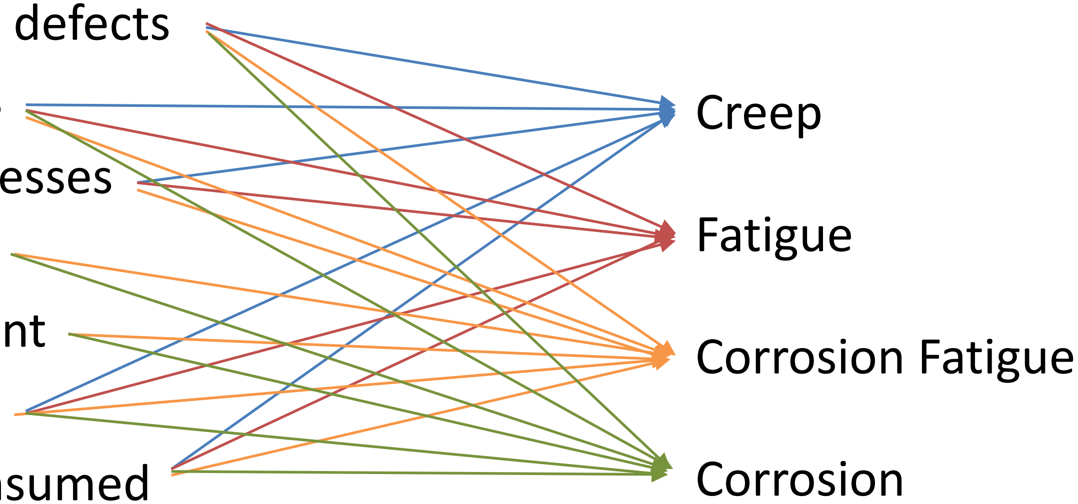
Uses for Metallographic Replicas

- Metallographic surface replicas can provide important information relating to the condition of a component that can have a direct bearing on its fitness for service.

- Fitness for service considerations can include a component's:
  - Susceptibility to corrosion
  - Metallurgical degradation
  - Corrosion degradation
  - Mechanical degradation

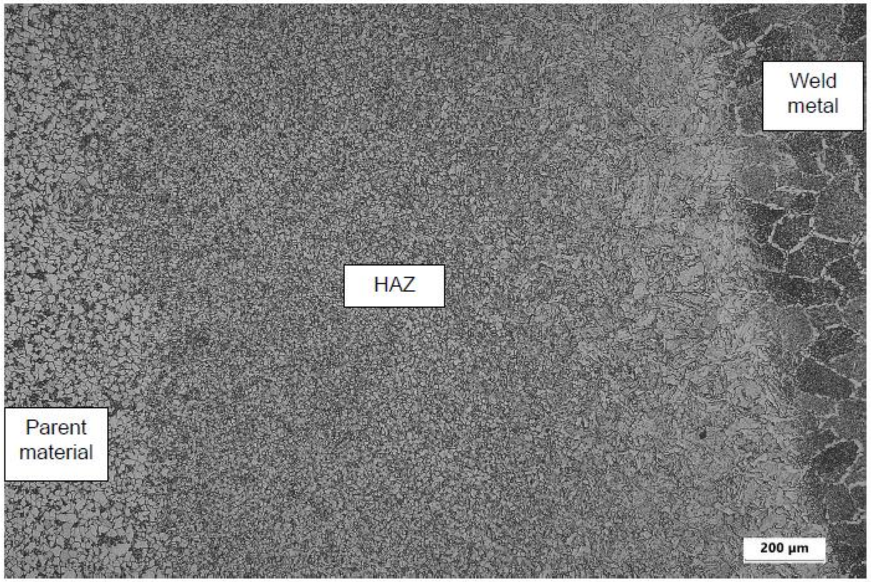
Utilising the Results of Replication

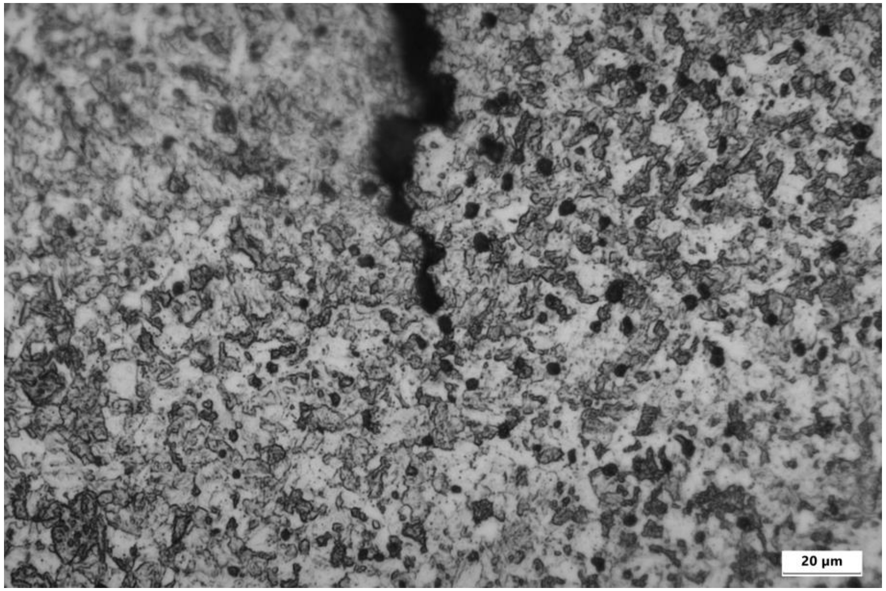
- The condition of metallic materials can be affected by several factors which include:
  - manufacturing defects
  - thermal inputs
  - mechanical stresses
  - process fluids
  - the environment
  - system design
  - service life consumed



Assessment

- Assessment of replicated microstructures is typically carried out by optical microscope using bright field illumination.
- Depending on the degradation mechanism of interest, magnifications of up to x1000 are used.



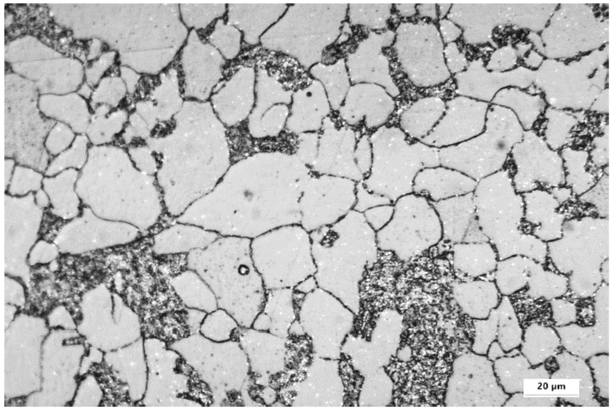


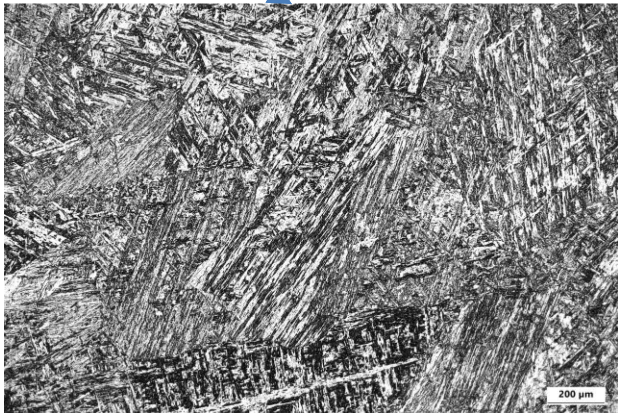
Assessment
Parent Microstructures (1)

- Effect of heat treatment on microstructure.

Austenite

Slow cooling | Rapid cooling

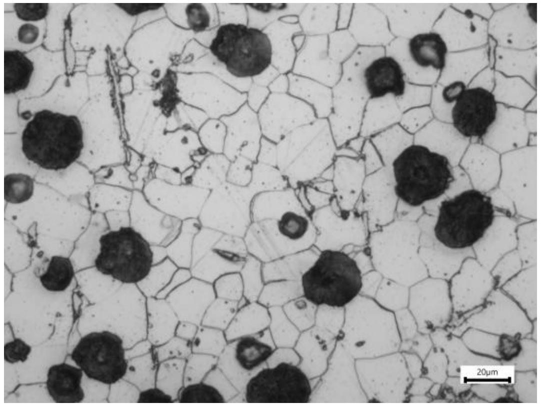


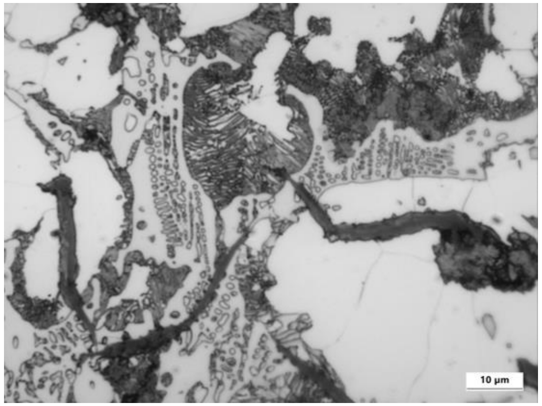


Assessment
Parent Microstructures (2)

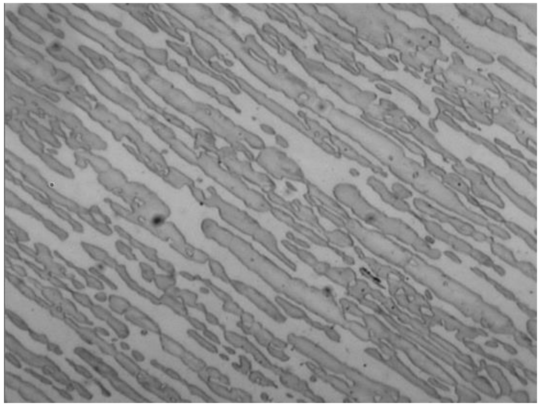
- Effect of alloy composition on microstructure.

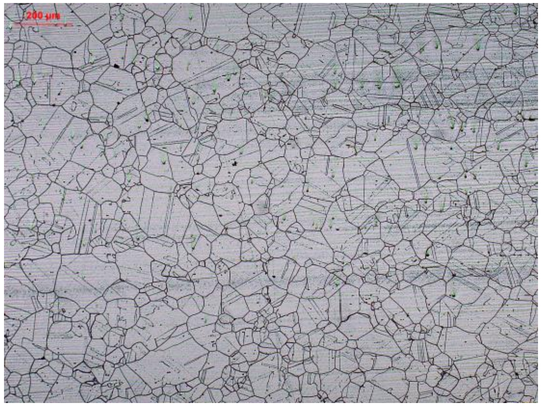
- Cast Iron





- Stainless Steel

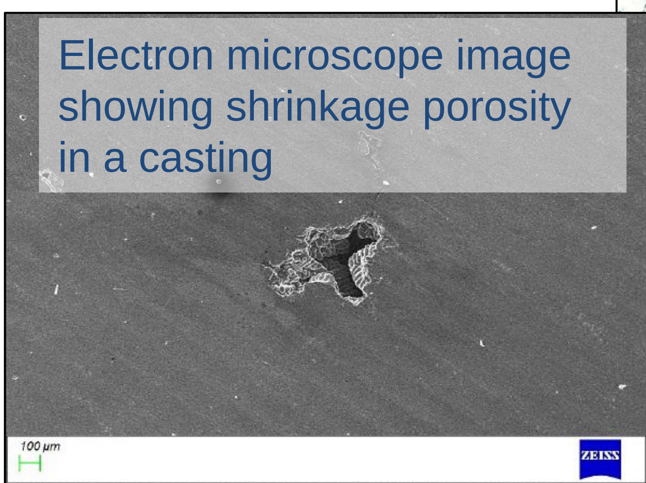




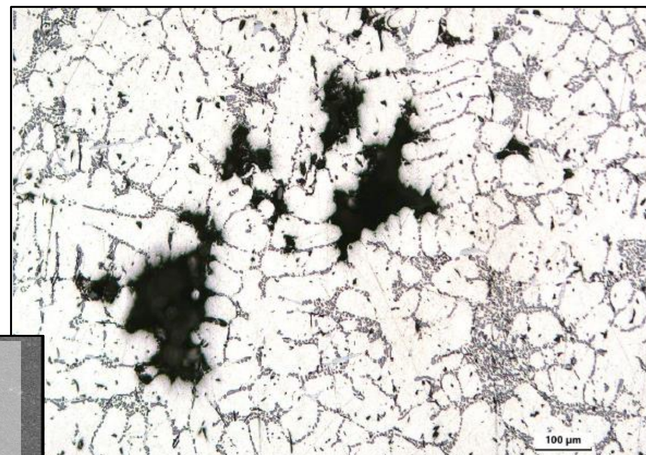
Assessment – Casting Defects

- One example of a manufacturing defect is shrinkage porosity in an aluminium casting:

Indication initially detected by Dye-penetrant inspection.



Electron microscope image showing shrinkage porosity in a casting



Assessment of a replica can confirm the presence of a defect and defect type

Assessment of the microstructure can provide root cause of the defect

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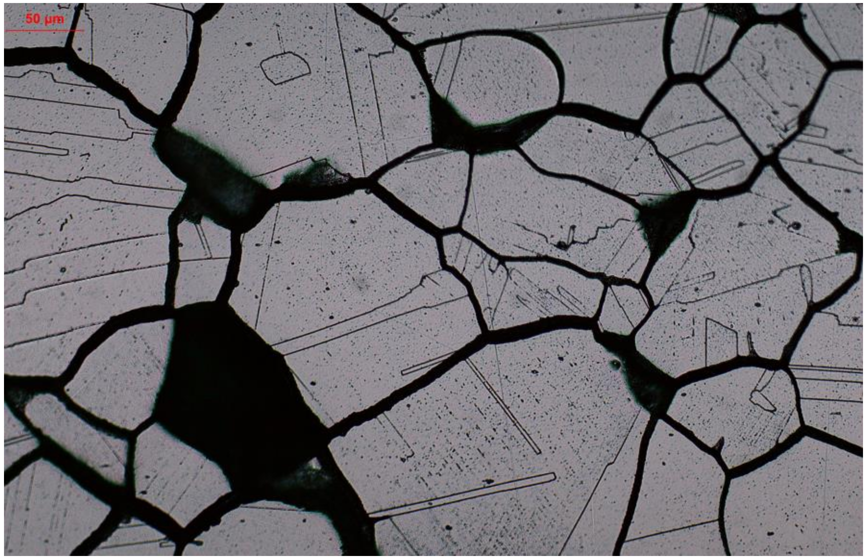
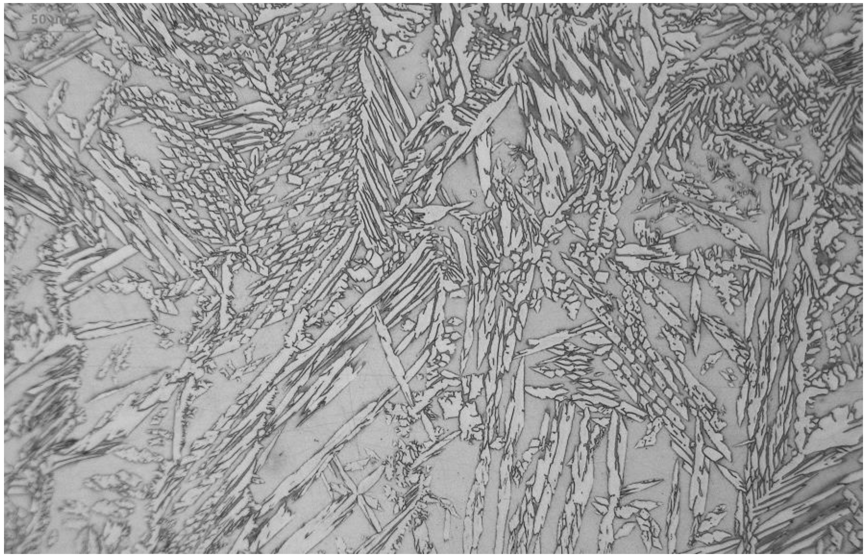
Assessment – Deleterious Microstructures

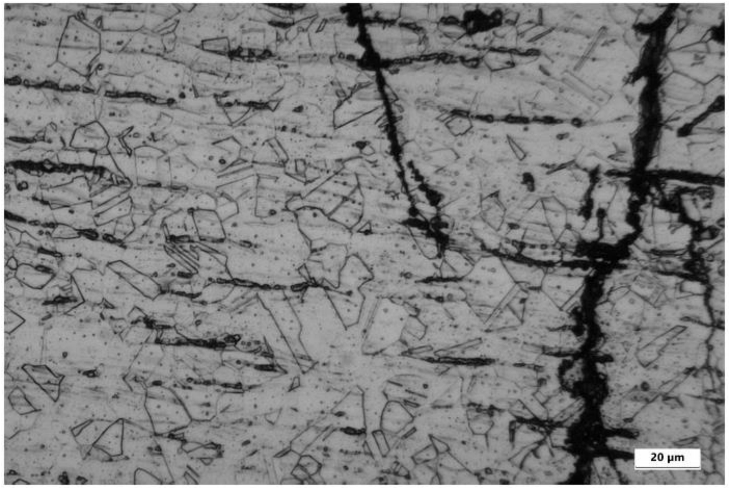
- Some microstructural evolutions that can affect a material's corrosion resistance include:
  - Sigma phase in stainless steels
  - Sensitisation in stainless steels
  - Phase balance in Duplex Stainless steels

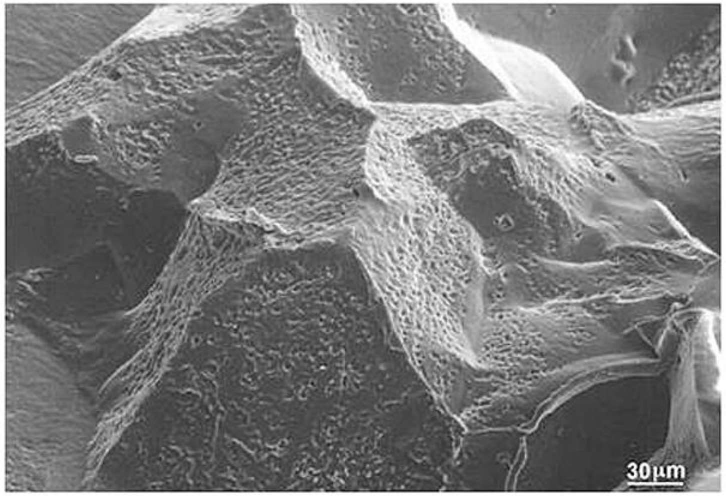




Assessment - Corrosion

- Assessment can provide information about the type and extent of corrosion on a component. Typical corrosion mechanisms include:
  - Pitting corrosion
  - Stress corrosion Cracking (SCC)
  - Corrosion fatigue
  - Hydrogen cracking





Right–hand Image from https://d3f2jcygtjrjjp.cloudfront.net/what-we-do/index.html

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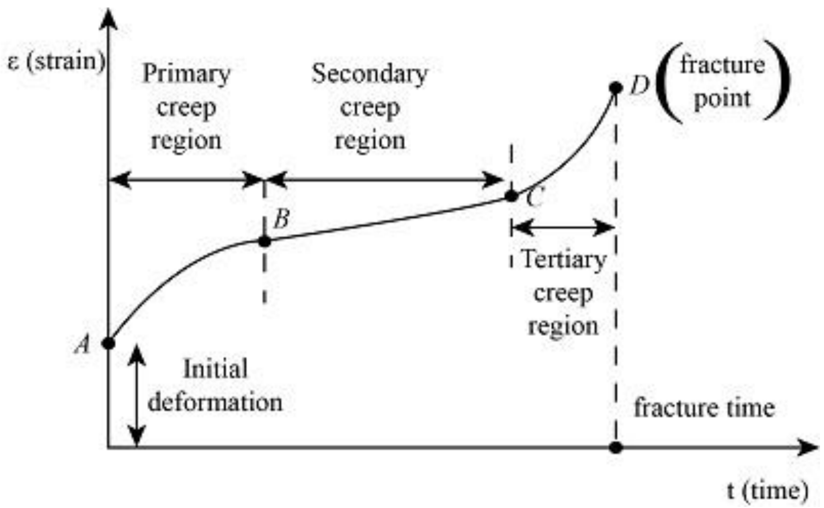
Assessment – Creep (1)



- Creep is the process of slow elongation / deformation under the action of a mechanical stress that is below the yield stress of the material i.e. time-dependent deformation.
- Creep occurs when metals are required to operate at temperatures above 30 to 40% of their melting point (in Kelvin).
- Damage forms at grain boundaries – voids / cavities are typical but can be wedge-like grain boundary separation.
- Damage links to form micro-cracking and then macro-cracking.
- Creep follows an Arrhenius relationship (an 8 to 10°C increase in temperature can double the creep rate / half the creep life).
- Other factors include applied stress, alloying content, heat treatment condition and grain size.

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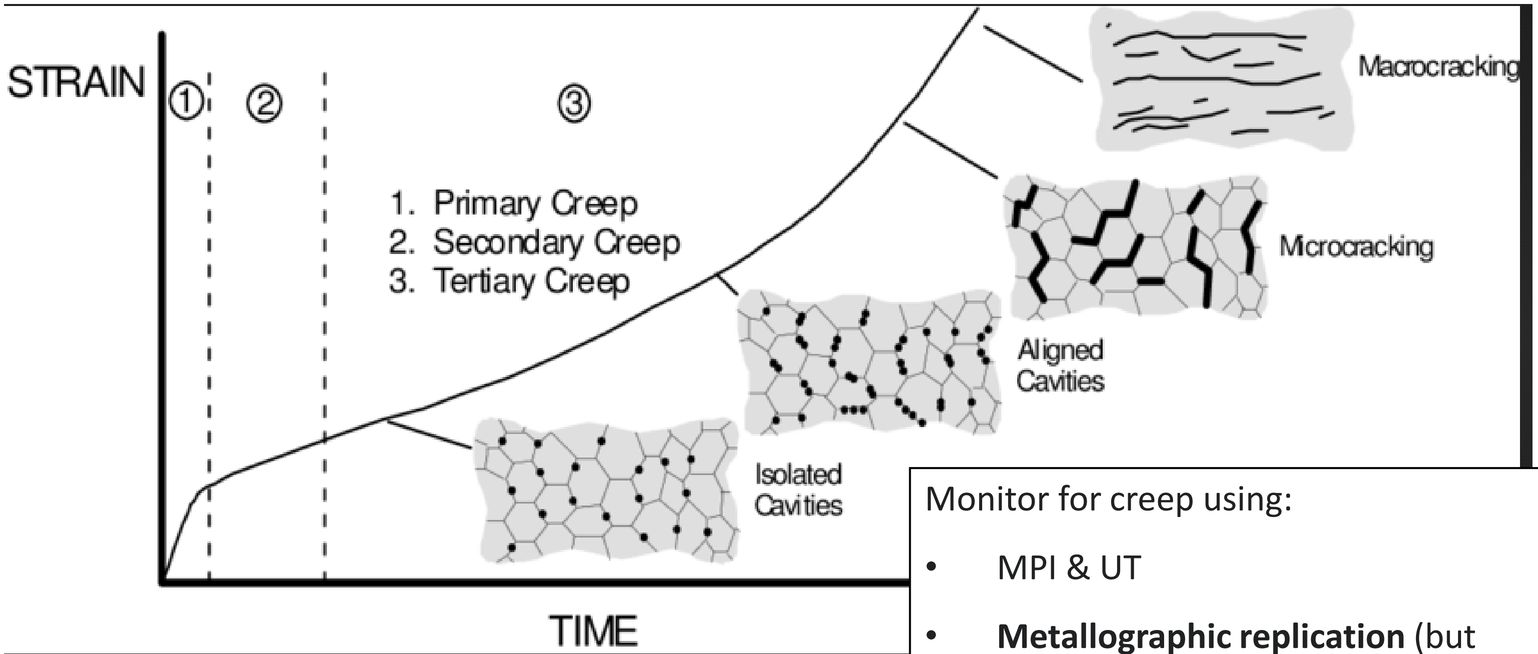
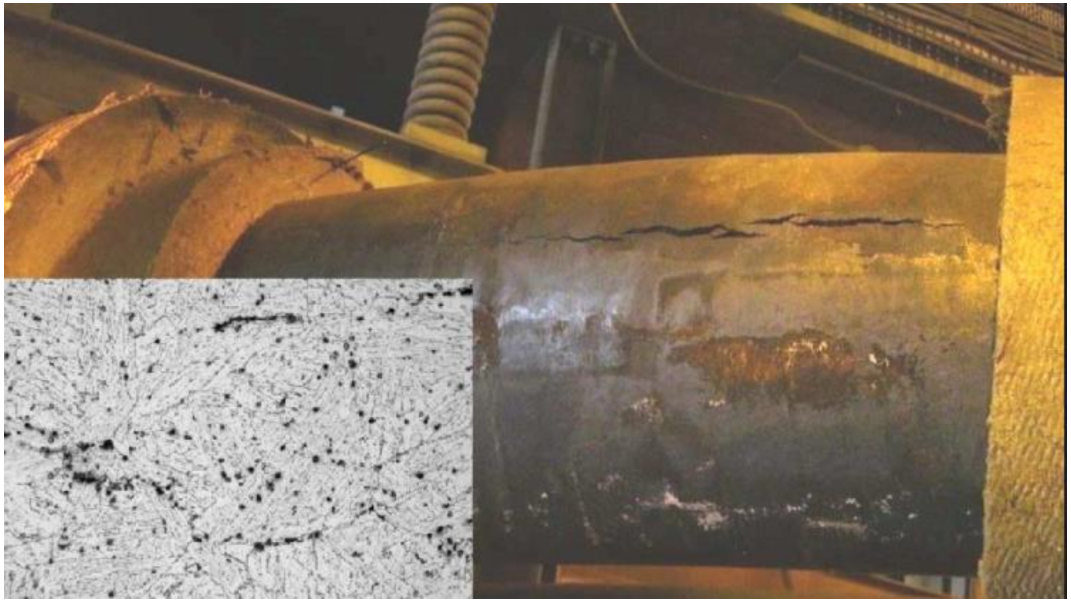
Assessment – Creep (2)



Monitor for creep using:

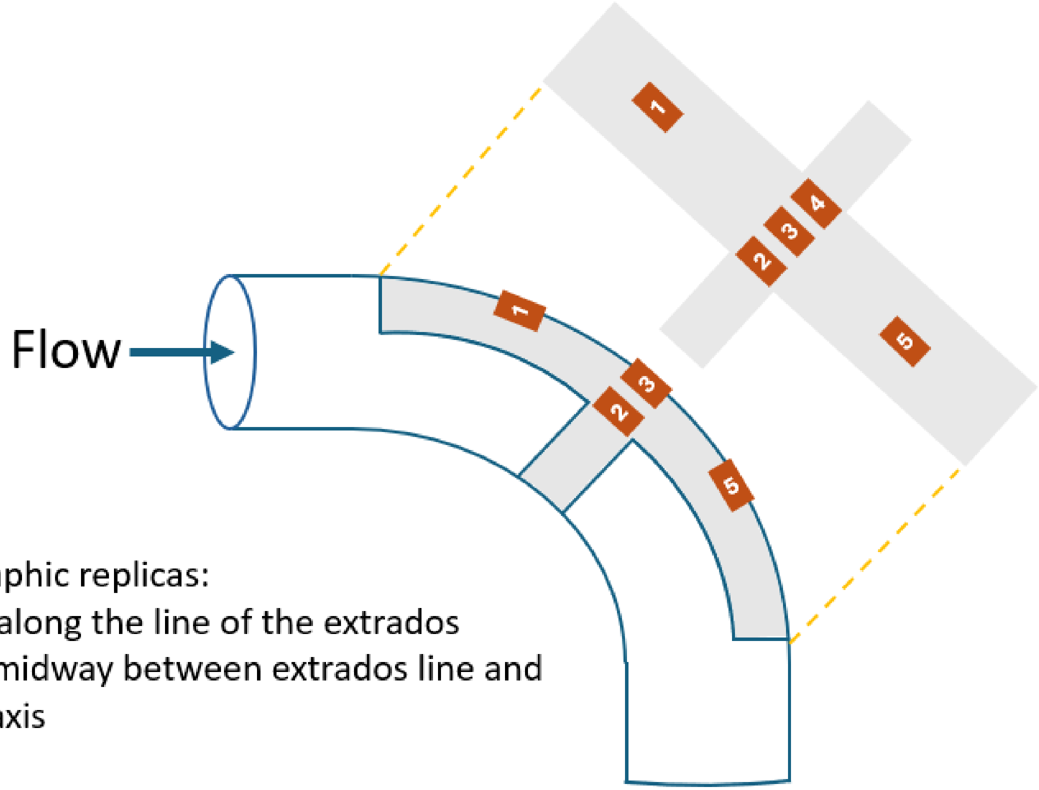
- MPI & UT
- **Metallographic replication** (but note, damage can be sub-surface e.g. Type IV creep damage in butt welds)

Assessment – Creep (3)
Steam Pipework Bends



Main steam bend (½Cr½Mo¼V steel) – steam leak due to extended through-wall creep crack after ~200,000 hours operation at 565°C (initial stages were global creep, final stage was creep crack growth).

Assessment – Creep (4)
Steam Pipework Bends



Metallographic replicas:
- 1, 3 & 5 along the line of the extrados
- 2 and 4 midway between extrados line and neutral axis

Seamless HTP Bend – Metallographic Replica Positions

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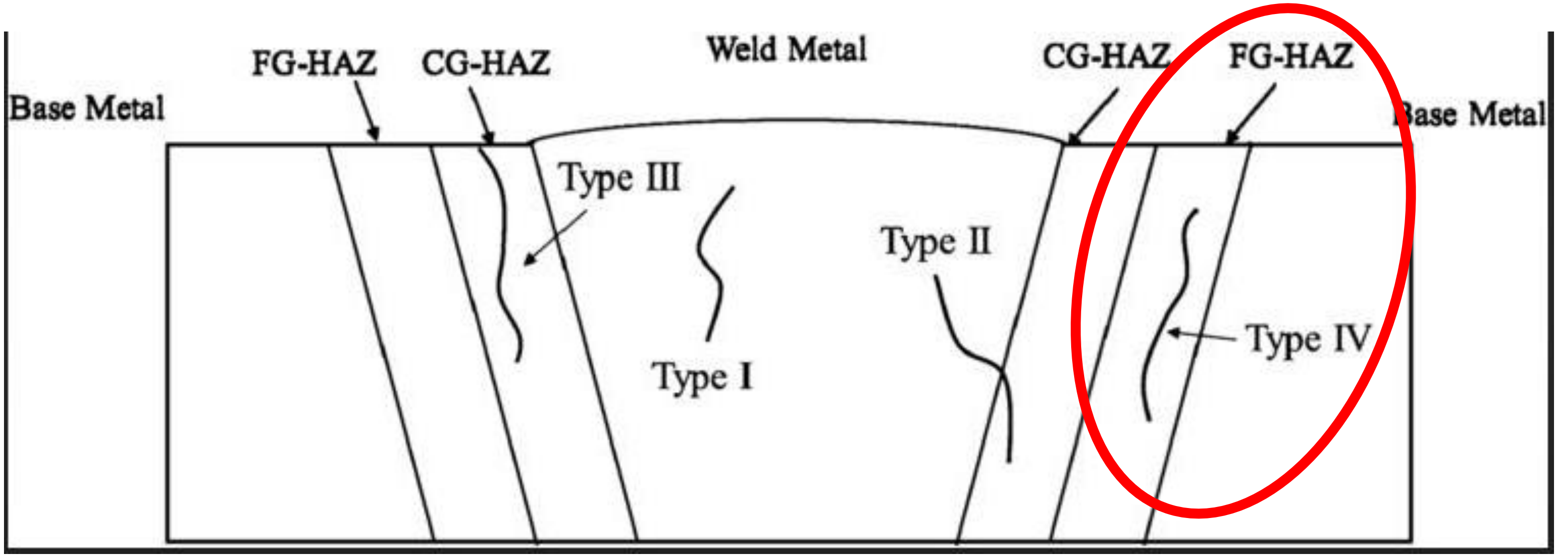
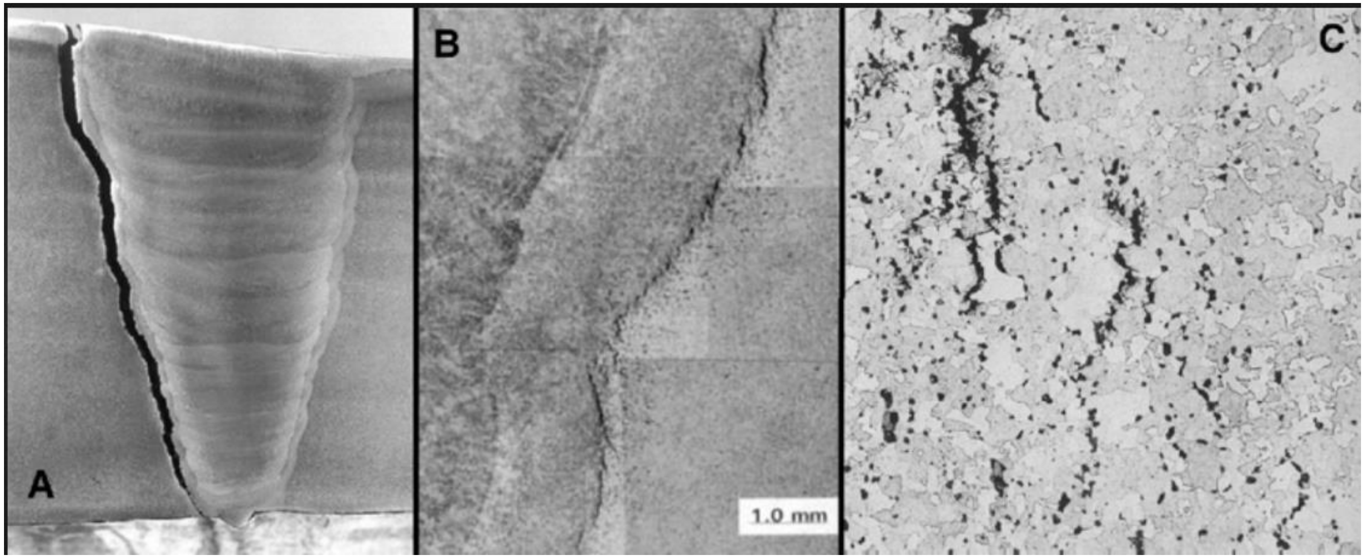
Assessment – Creep (5)
Type IV Damage



Assessment – Creep (6)
Type IV Damage



- Creep weak zone (over-tempered / inter-critical / fine-grain region of the HAZ).
- Responsible for pipe girth weld failures on UK coal-fired sites after ~40,000 hours operation (this orientation is acted on by the axial stress not the hoop stress, therefore an influence from system loads).

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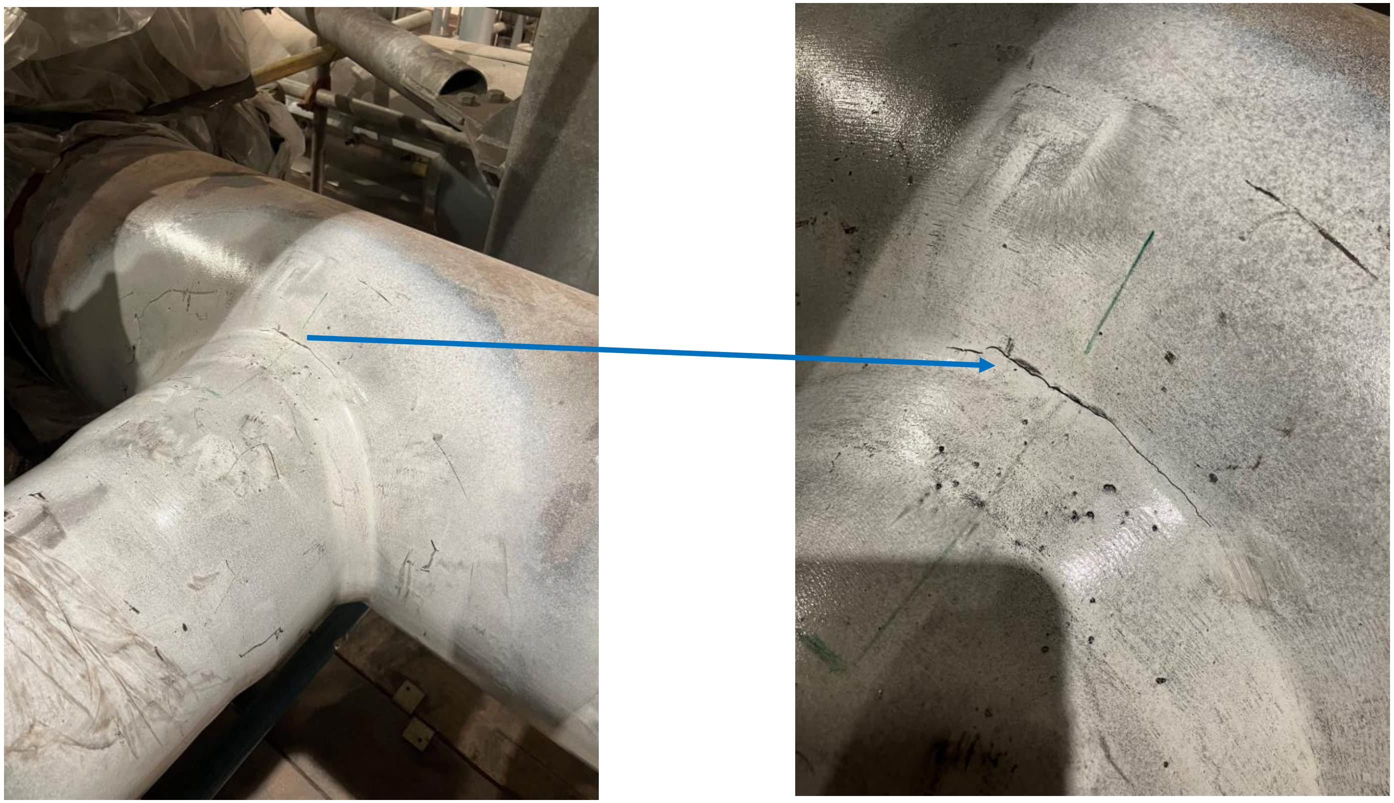
Assessment – Creep (7)
Type IV Damage



Branch in Hot Reheat System (Grade 91) – Cracking discovered by MPI after ~40,000 hours operation at 540°C

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Assessment – Creep (8)
Type IV Damage

Branch in Hot Reheat System (Grade 91) – Cracking discovered by MPI after ~40,000 hours operation at 540°C

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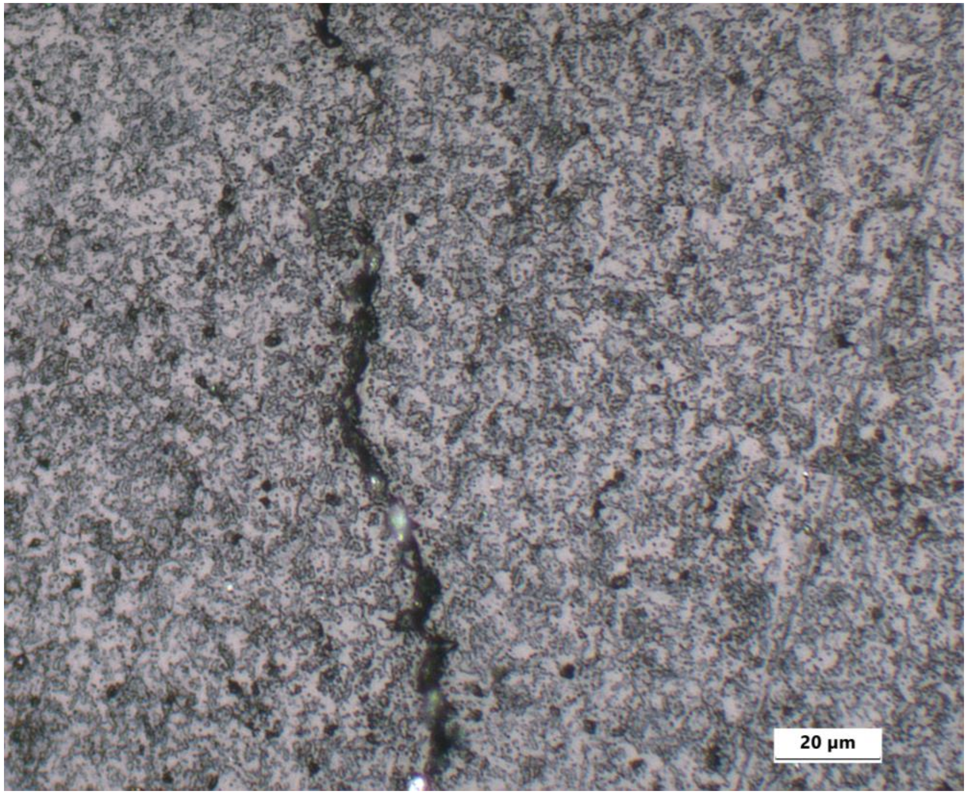
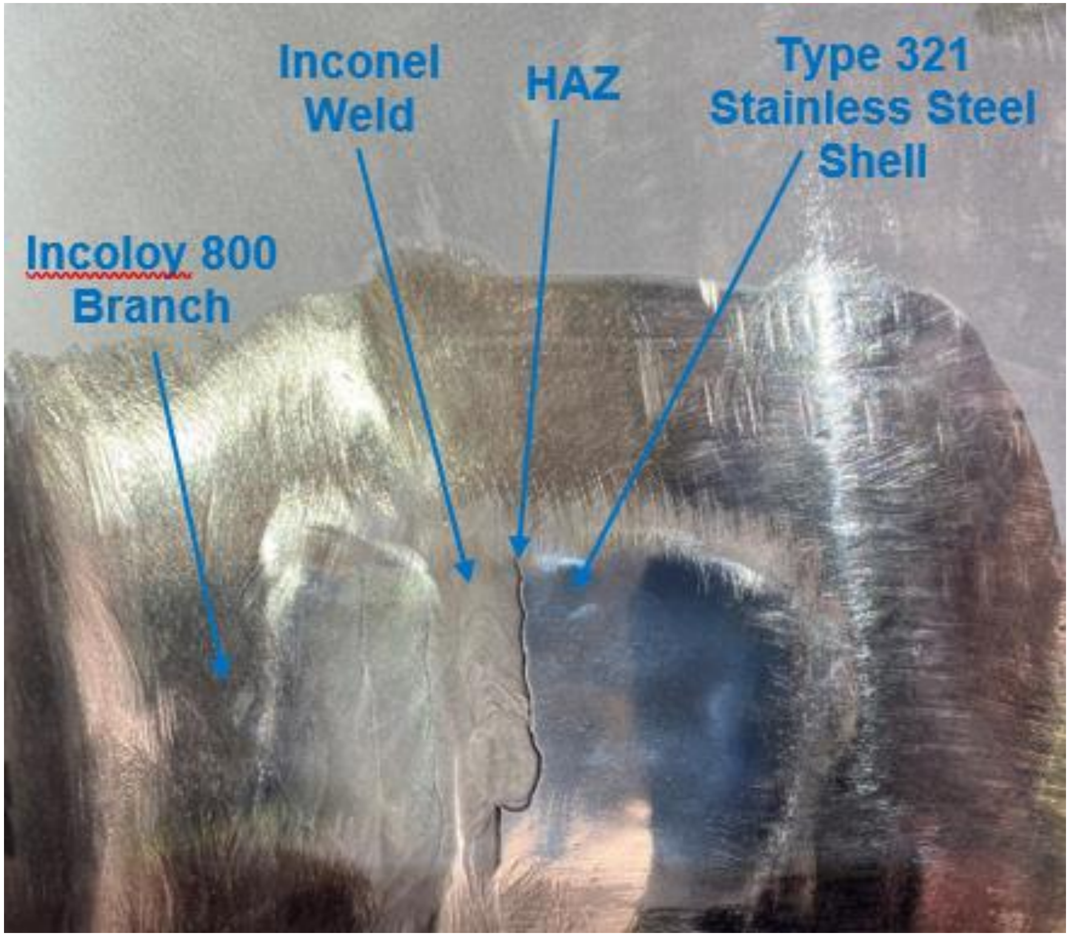
Assessment – Creep (9)
Type IV Damage



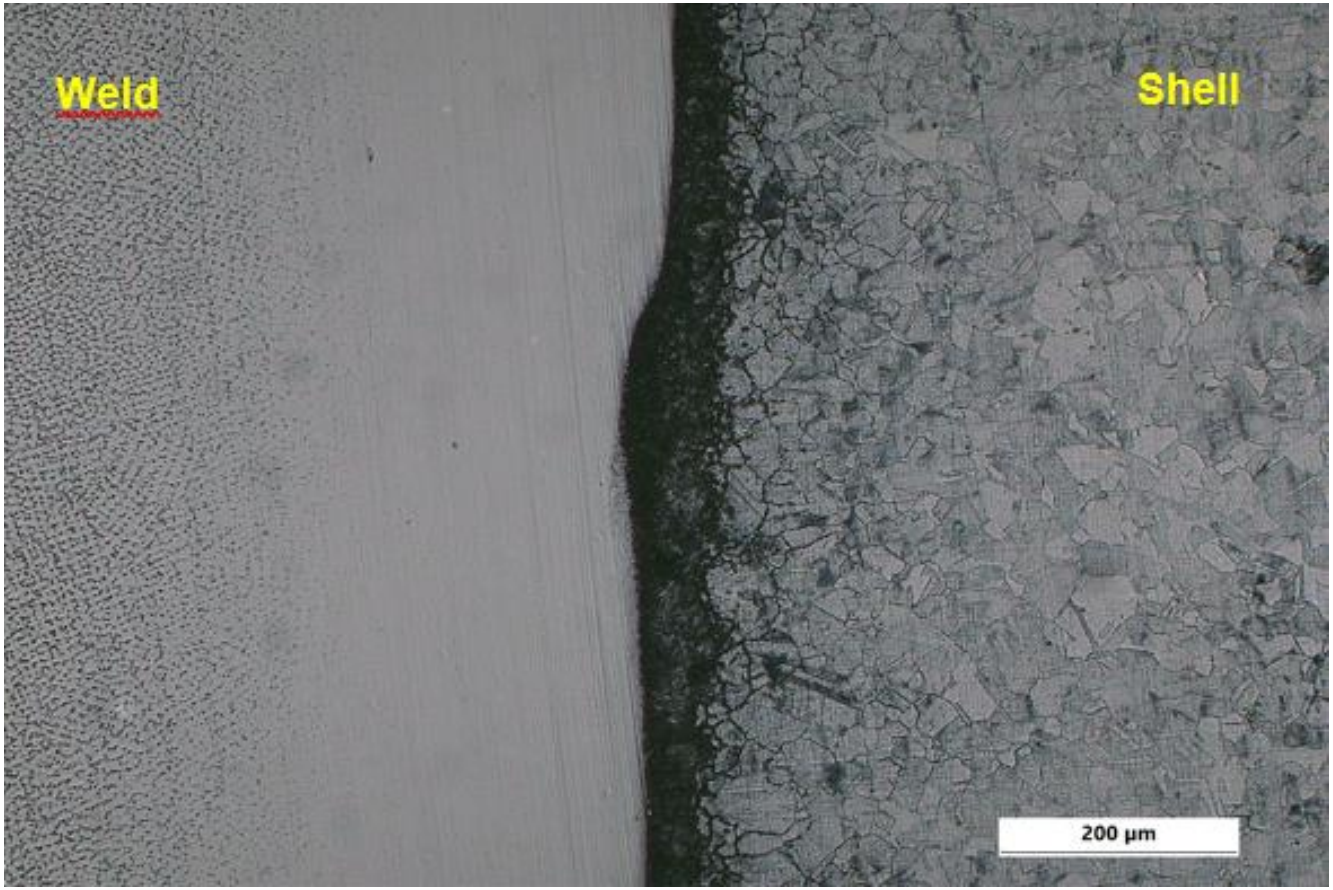
Branch in Hot Reheat System (Grade 91)

Acetate Replica of Type IV Cracking (x500)

Assessment – Dissimilar Welds

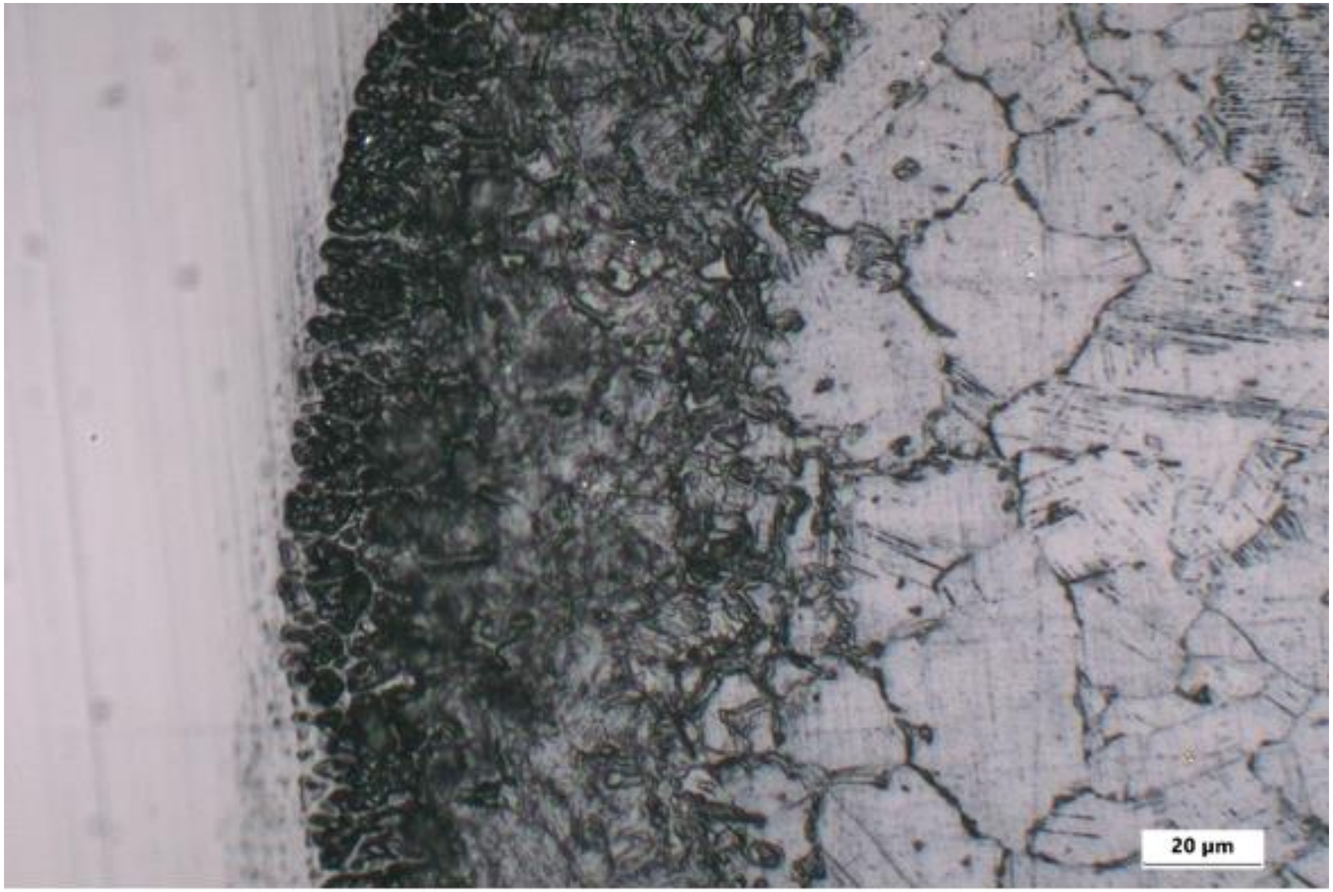


Assessment – Dissimilar Welds



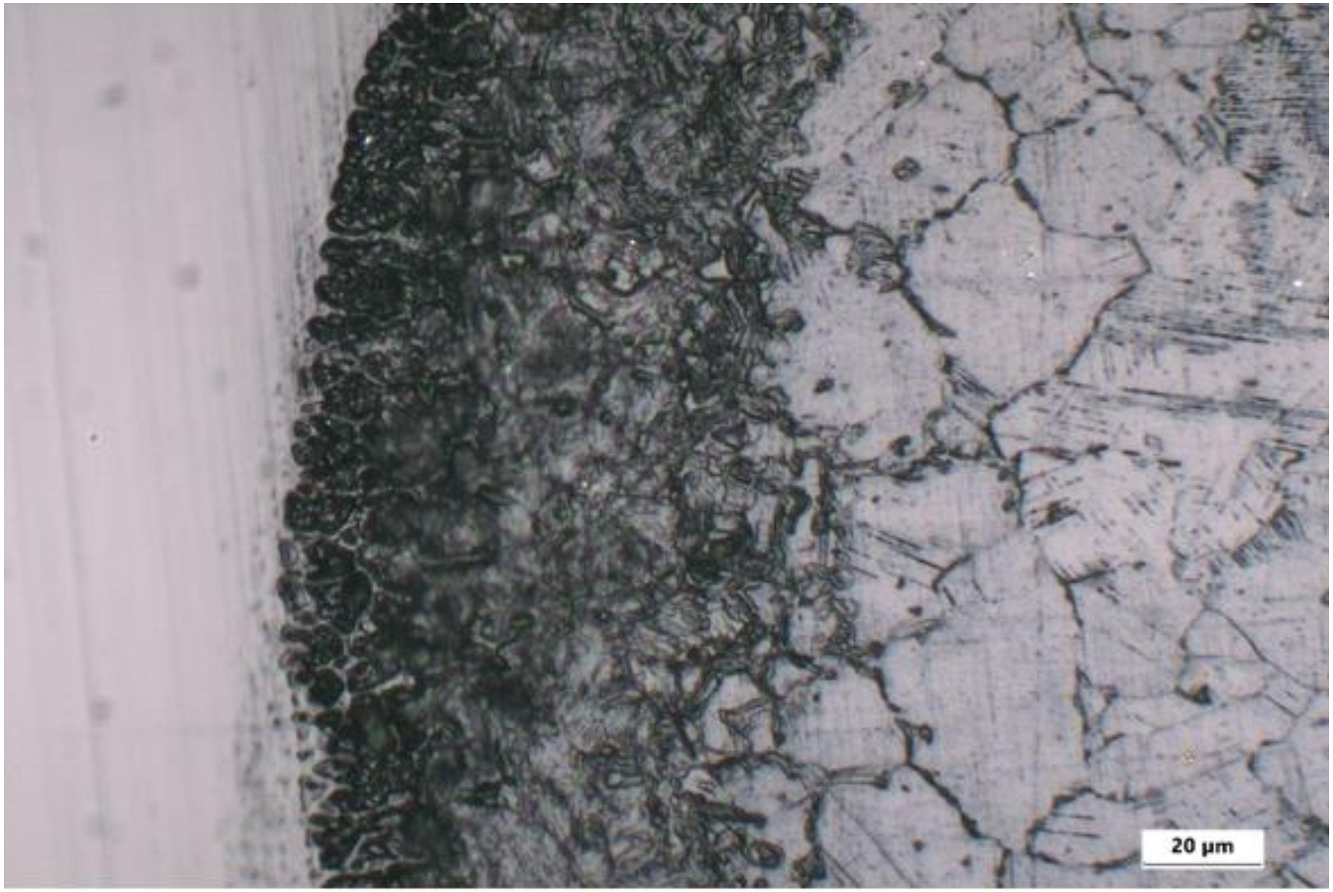
Acetate Replica (x200)

Assessment – Dissimilar Welds



Acetate Replica (x500)

Assessment – Dissimilar Welds



Etch effect or carbon migration?

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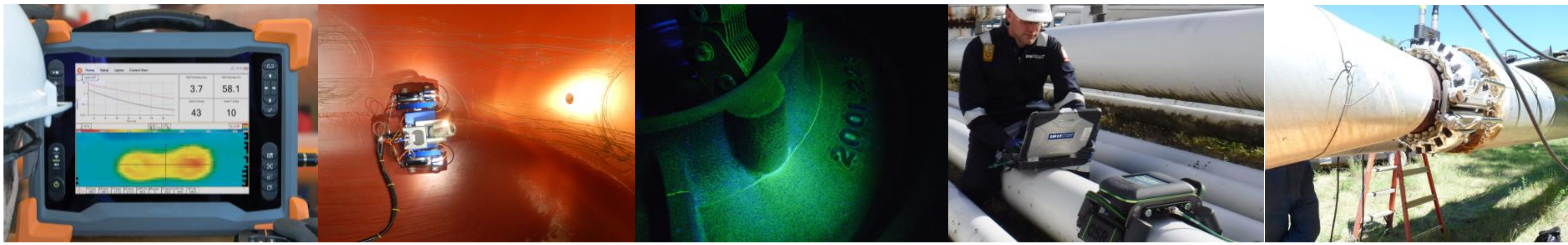

Thank You & Any Questions

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