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Rapid Alloy Prototyping
A PROSPERITY PARTNERSHIP

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Oxidation of a Dual Phase Steel during Rapid Alloy Prototyping (RAP)

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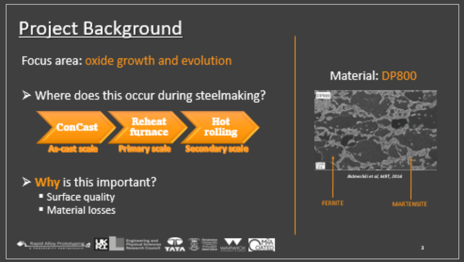
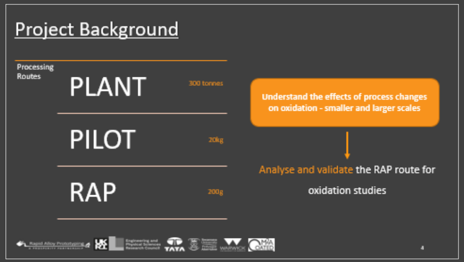
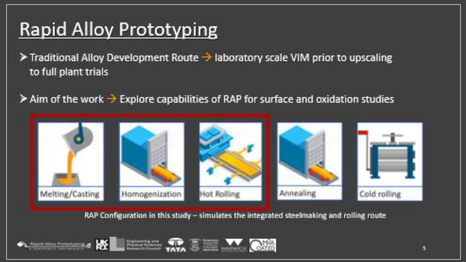
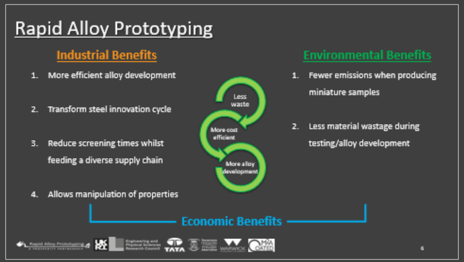
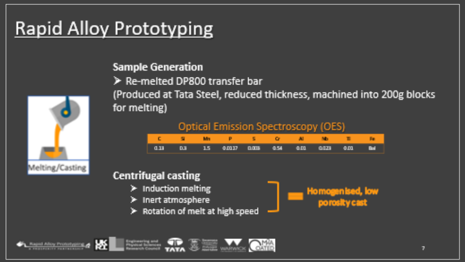
Contents

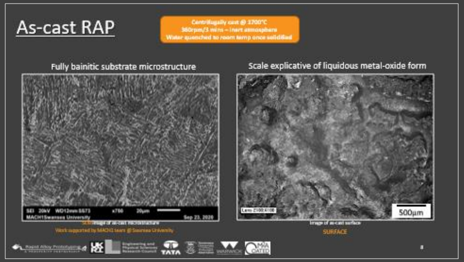

Project Background
Focus area: oxide growth and evolution
Where does this occur during steelmaking?
ConCast
Reheat furnace
Hot rolling
Why is this important?
Surface quality
Material losses
Material: DP800

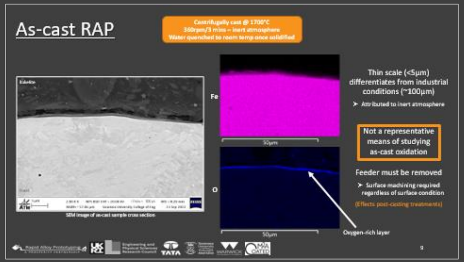

Project Background
PLANT
PILOT
RAP
Understand the effects of process changes on oxidation - smaller and larger scales
Analyse and validate the RAP route for oxidation studies

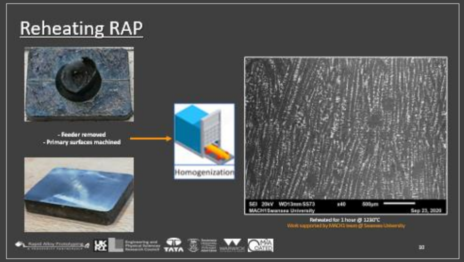

Rapid Alloy Prototyping
Traditional Alloy Development Route → laboratory scale VIM prior to upscaling to full plant trials
Aim of the work → Explore capabilities of RAP for surface and oxidation studies

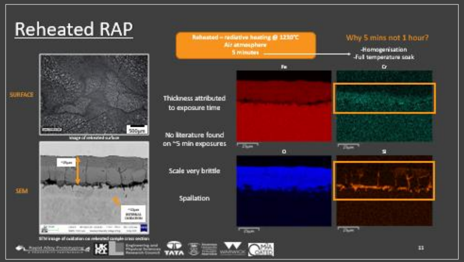

Rapid Alloy Prototyping
Industrial Benefits
Environmental Benefits
Economic Benefits

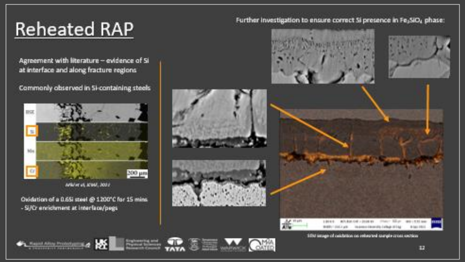

Rapid Alloy Prototyping
Sample Generation
Optical Emission Spectroscopy (OES)
Centrifugal casting

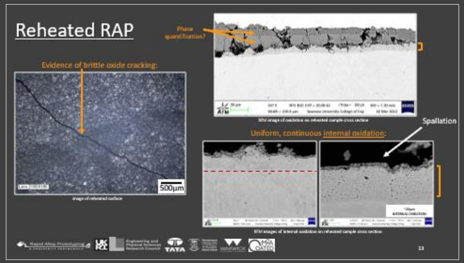

As-cast RAP
Fully bainitic substrate microstructure
Scale explicative of liquidous metal-oxide form


As-cast RAP
Not a representative means of studying as-cast oxidation

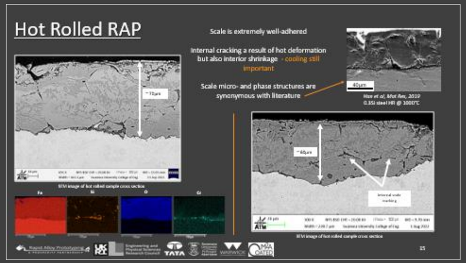

Reheating RAP
Homogenization

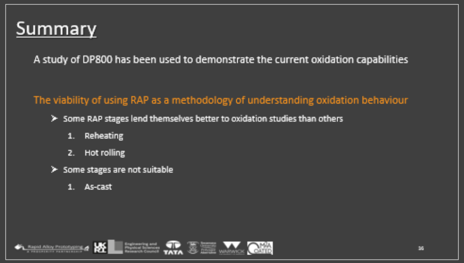

Reheated RAP


Reheated RAP


Reheated RAP
Evidence of brittle oxide cracking
Spallation
Uniform, continuous internal oxidation


Hot Rolled RAP
Roll direction


Hot Rolled RAP
Scale is extremely well-adhered


Summary
A study of DP800 has been used to demonstrate the current oxidation capabilities
The viability of using RAP as a methodology of understanding oxidation behaviour
Some RAP stages lend themselves better to oxidation studies than others
1. Reheating
2. Hot rolling
Some stages are not suitable
1. As-cast

Project Background

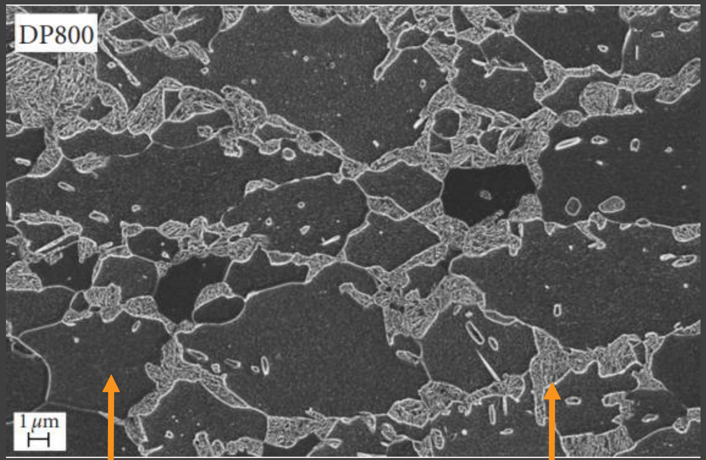
Focus area: oxide growth and evolution

- Where does this occur during steelmaking?

ConCast	Reheat furnace	Hot rolling
As-cast scale	Primary scale	Secondary scale

- **Why** is this important?
  - Surface quality
  - Material losses

Material: DP800



Bidmeshki et al, MRT, 2016

FERRITE

MARTENSITE

Project Background

Processing Routes

PLANT	300 tonnes
PILOT	20kg
RAP	200g

Understand the effects of process changes on oxidation - smaller and larger scales

Analyse and validate the RAP route for oxidation studies

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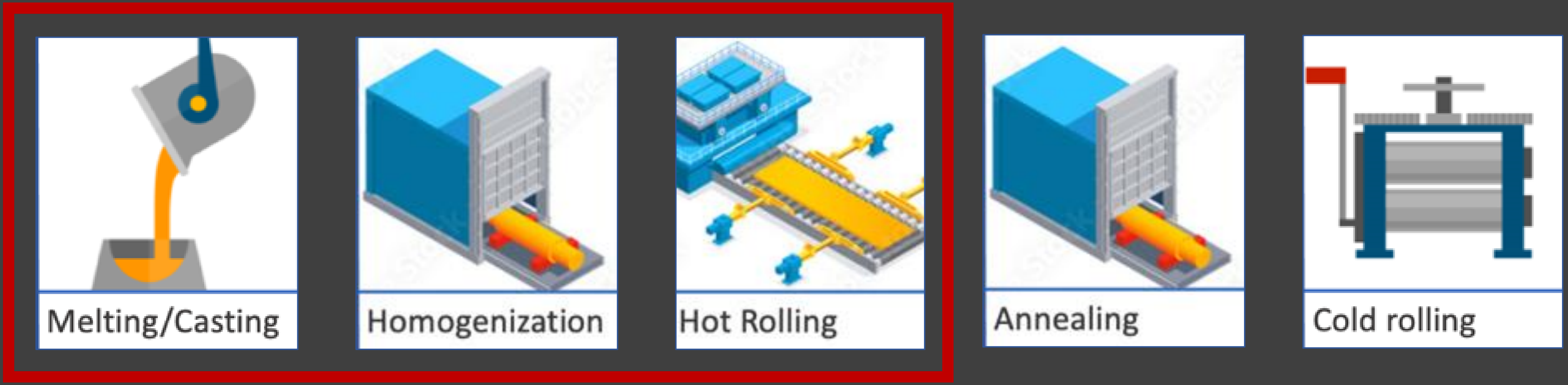
Rapid Alloy Prototyping

- Traditional Alloy Development Route → laboratory scale VIM prior to upscaling to full plant trials

- Aim of the work → Explore capabilities of RAP for surface and oxidation studies

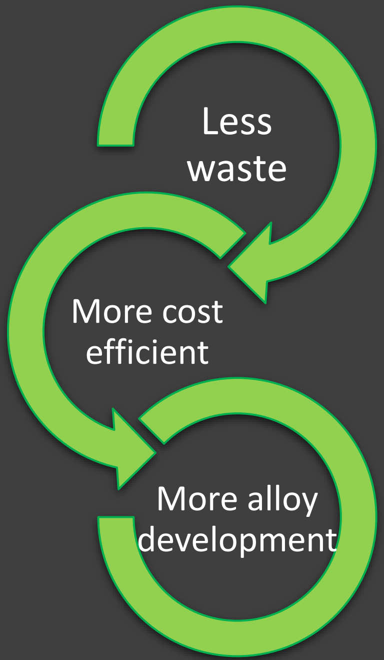


RAP Configuration in this study – simulates the integrated steelmaking and rolling route

Rapid Alloy Prototyping

Industrial Benefits

1. More efficient alloy development
2. Transform steel innovation cycle
3. Reduce screening times whilst feeding a diverse supply chain
4. Allows manipulation of properties



Environmental Benefits

1. Fewer emissions when producing miniature samples
2. Less material wastage during testing/alloy development

Economic Benefits

Rapid Alloy Prototyping

Sample Generation

- Re-melted DP800 transfer bar

(Produced at Tata Steel, reduced thickness, machined into 200g blocks for melting)

Optical Emission Spectroscopy (OES)

C	Si	Mn	P	S	Cr	Al	Nb	Ti	Fe
0.13	0.3	1.5	0.0117	0.003	0.54	0.01	0.023	0.01	Bal

Centrifugal casting

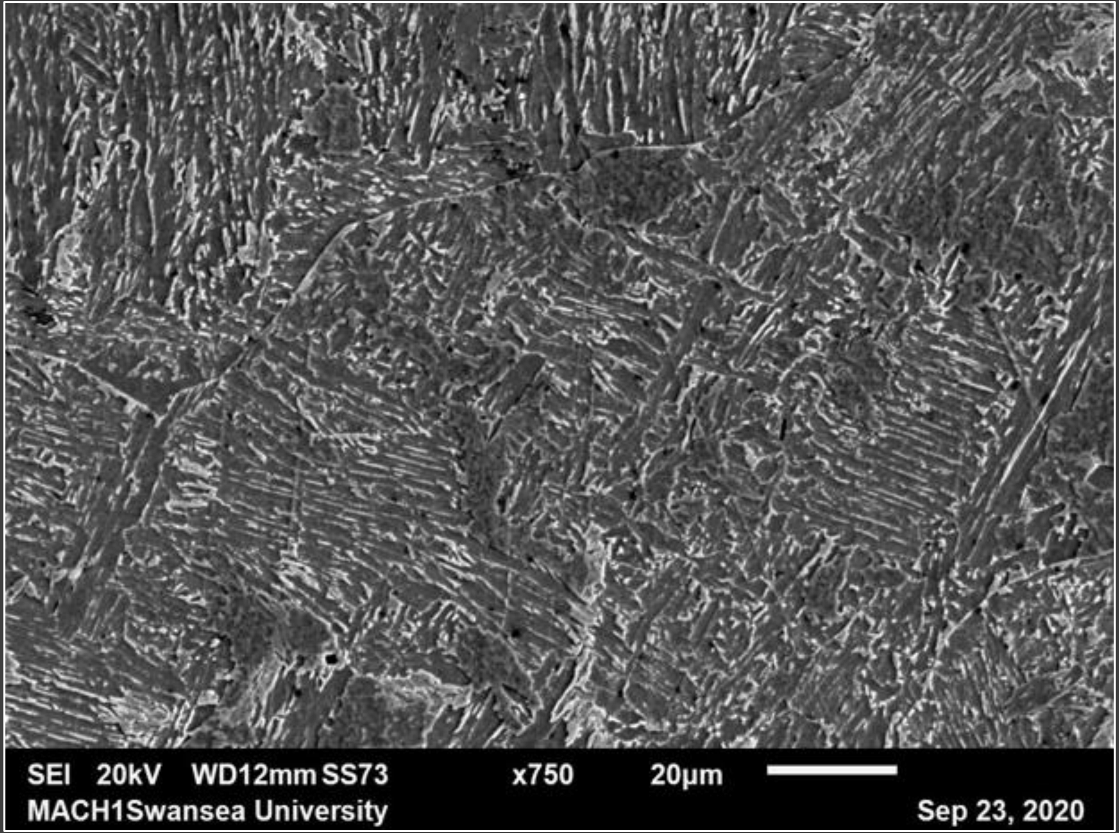
- Induction melting
- Inert atmosphere
- Rotation of melt at high speed

= Homogenised, low porosity cast

As-cast RAP

Centrifugally cast @ 1700°C
360rpm/3 mins – inert atmosphere
Water quenched to room temp once solidified

Fully bainitic substrate microstructure



SEM image of as-cast microstructure

Work supported by MACH1 team @ Swansea University

Scale explicative of liquidous metal-oxide form

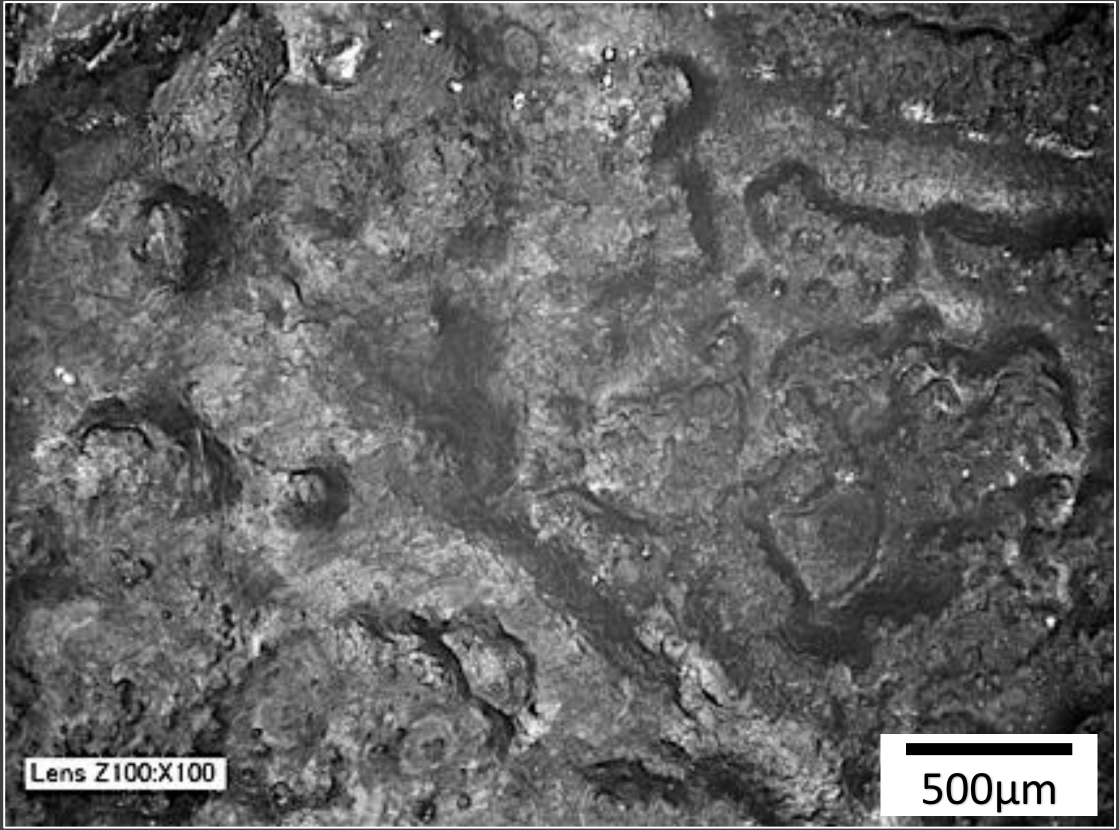
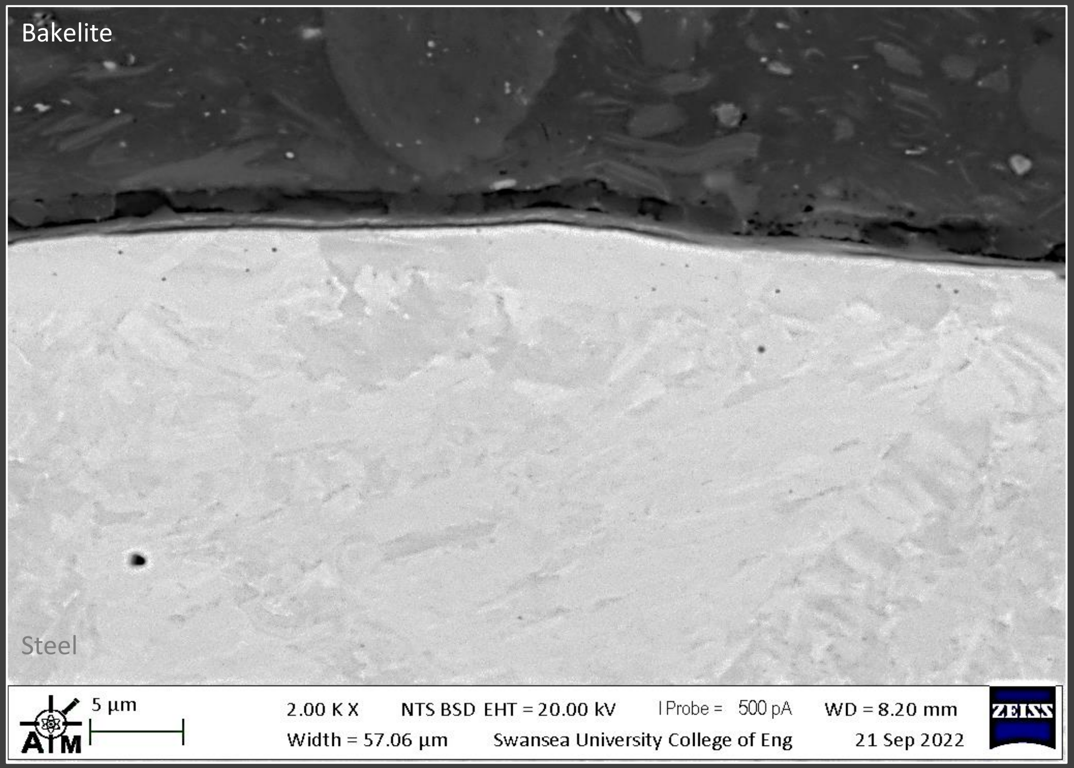


Image of as-cast surface

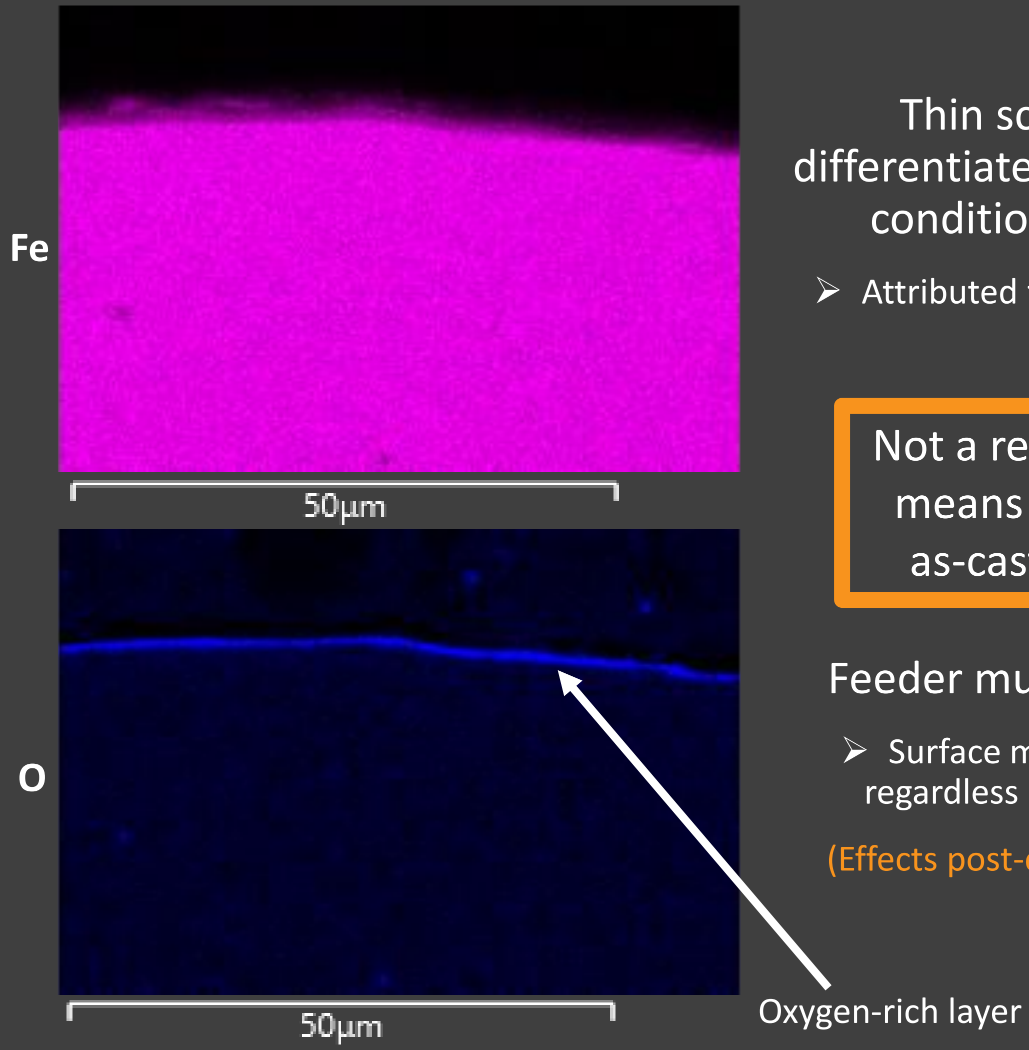
SURFACE

As-cast RAP

Centrifugally cast @ 1700°C
360rpm/3 mins – inert atmosphere
Water quenched to room temp once solidified



SEM image of as-cast sample cross section



Thin scale (<5µm) differentiates from industrial conditions (~100µm)

- Attributed to inert atmosphere

Not a representative means of studying as-cast oxidation

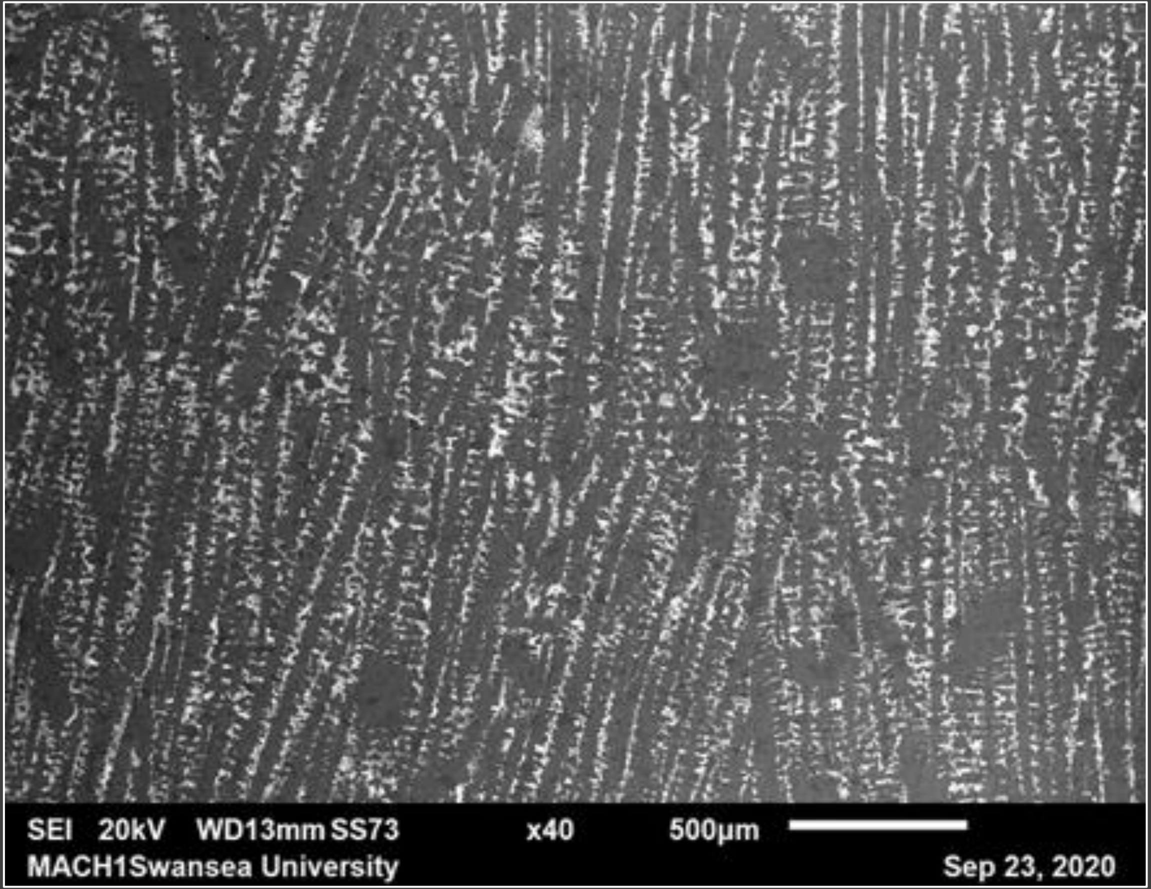
Feeder must be removed

- Surface machining required regardless of surface condition

(Effects post-casting treatments)

Reheating RAP

- Feeder removed
- Primary surfaces machined



Reheated for 1 hour @ 1230°C

Work supported by MACH1 team @ Swansea University

Reheated RAP

Reheated – radiative heating @ 1230°C
Air atmosphere
5 minutes

Why 5 mins not 1 hour?

-Homogenisation
-Full temperature soak

SURFACE

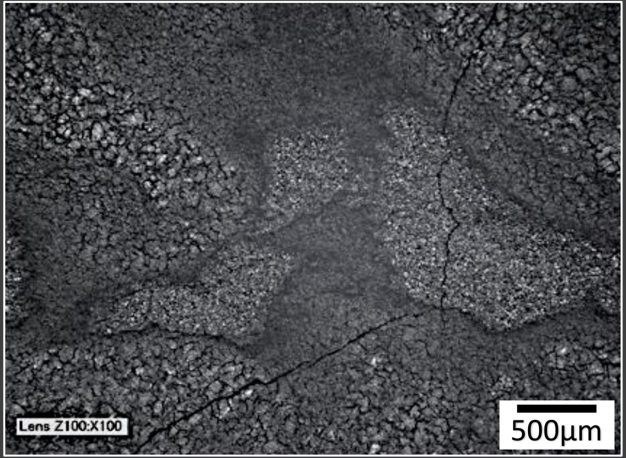
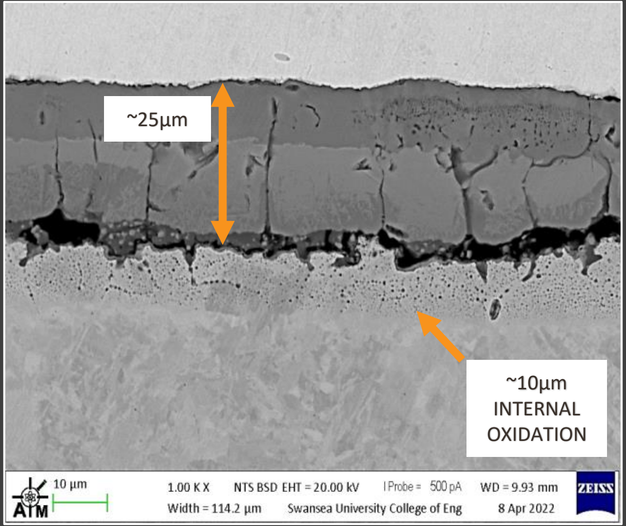


Image of reheated surface

SEM



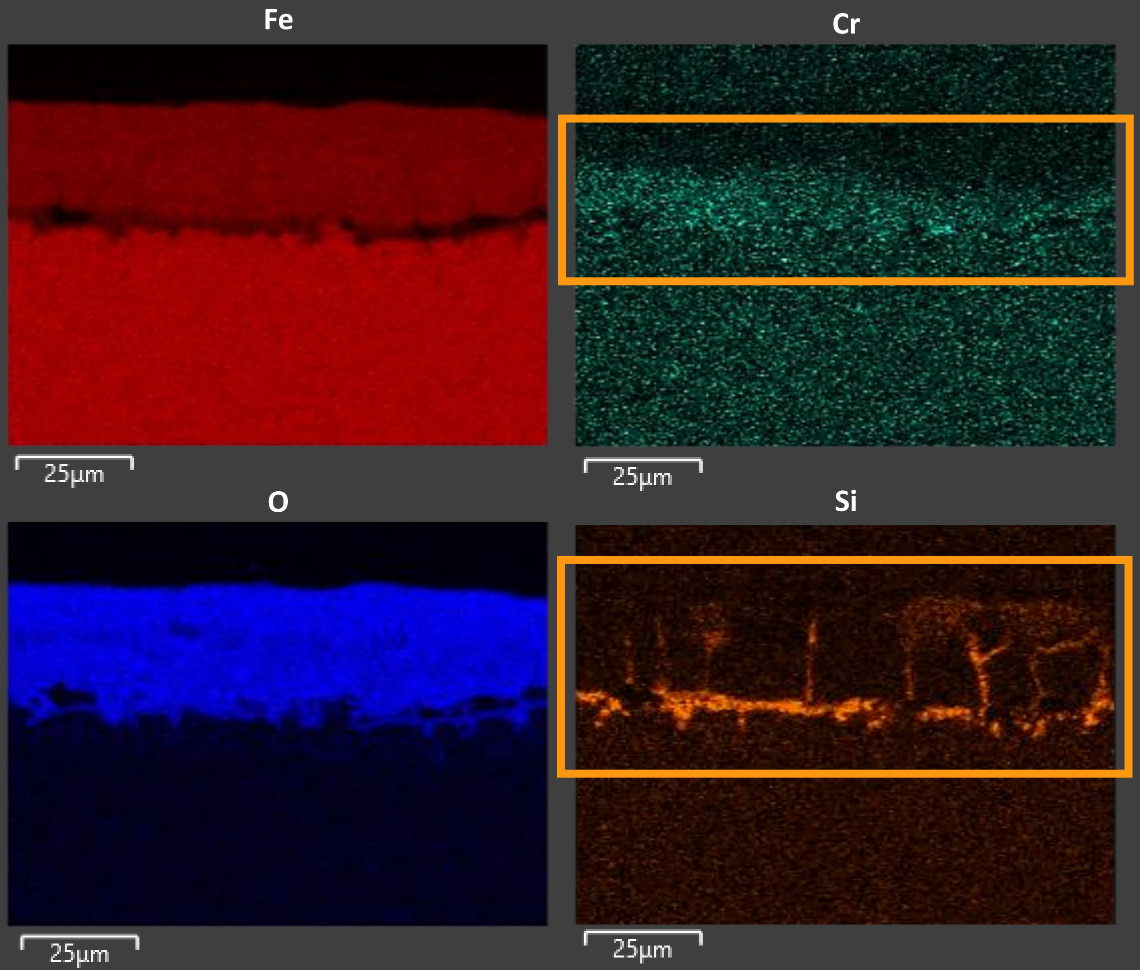
SEM image of oxidation on reheated sample cross section

Thickness attributed to exposure time

No literature found on ~5 min exposures

Scale very brittle

Spallation

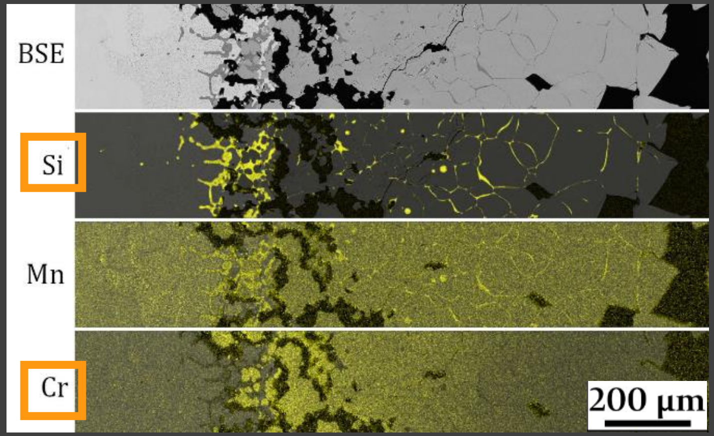


Reheated RAP

Further investigation to ensure correct Si presence in Fe_2SiO_4 phase:

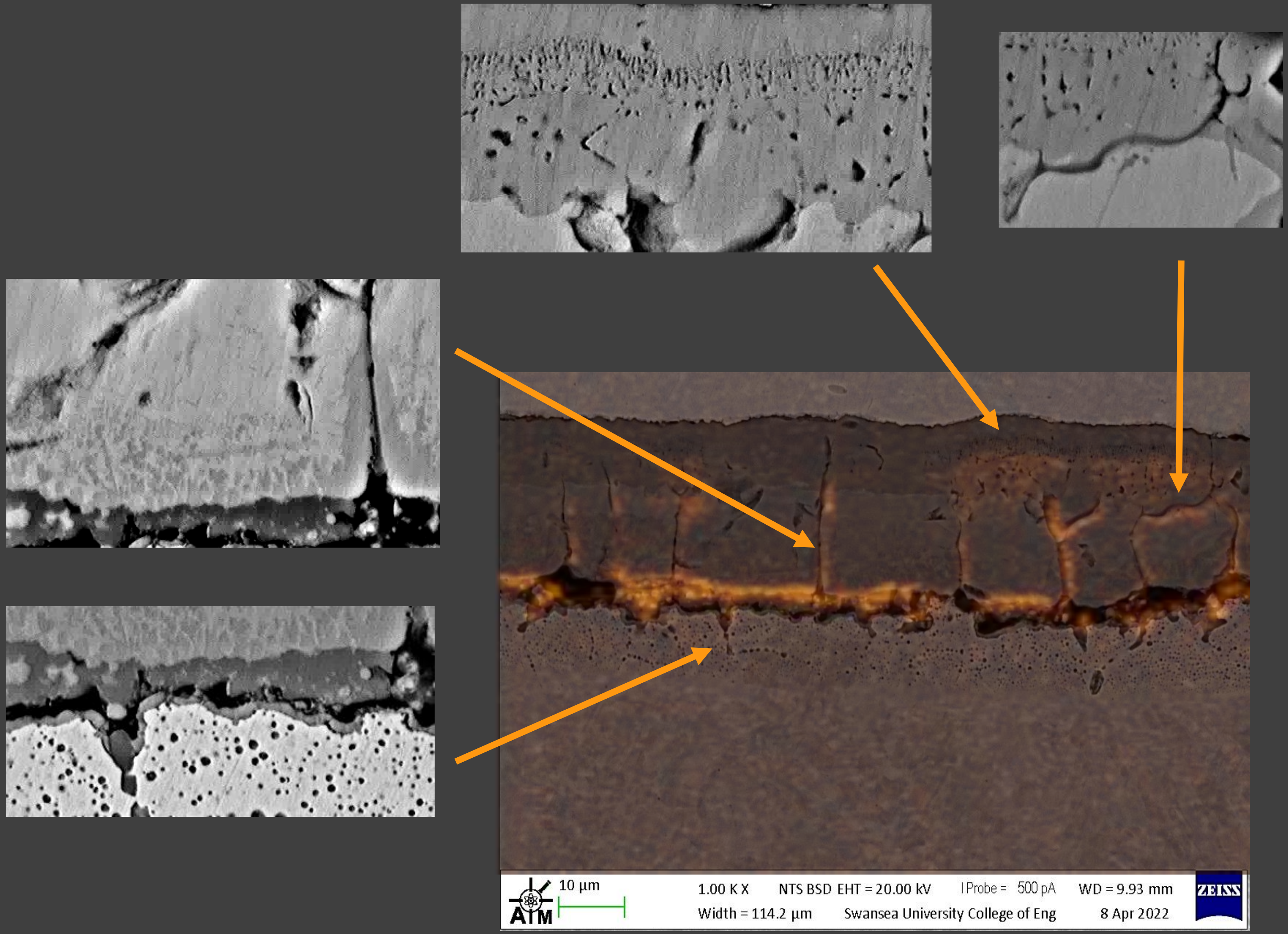
Agreement with literature – evidence of Si at interface and along fracture regions

Commonly observed in Si-containing steels



Mikl et al, JCME, 2021

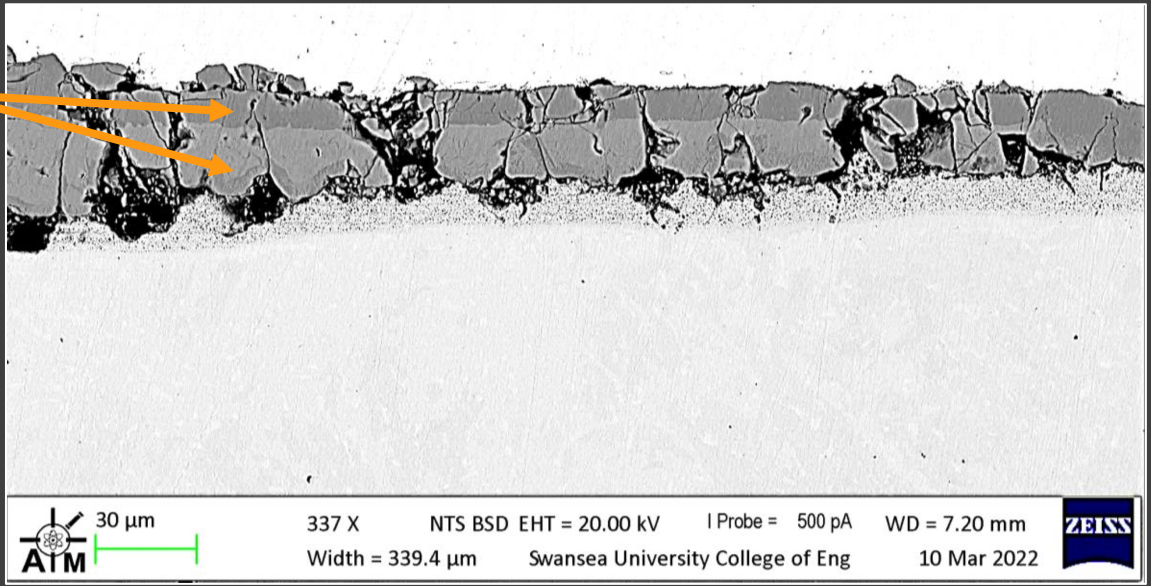
Oxidation of a 0.6Si steel @ 1200°C for 15 mins
- Si/Cr enrichment at interface/pegs



SEM image of oxidation on reheated sample cross section

Reheated RAP

Phase quantification?



SEM image of oxidation on reheated sample cross section

Evidence of brittle oxide cracking:

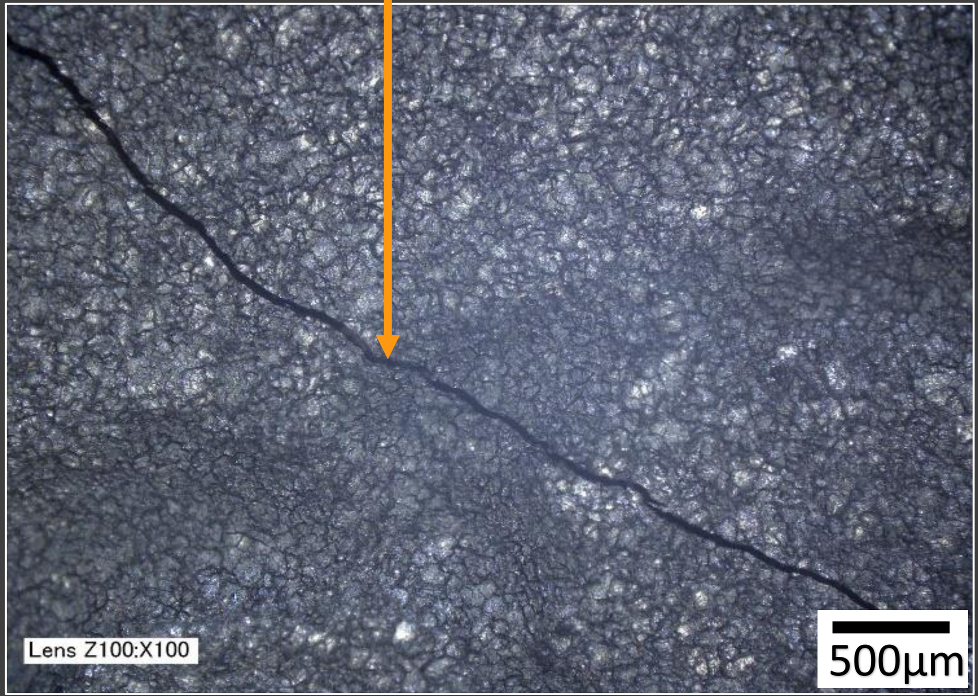
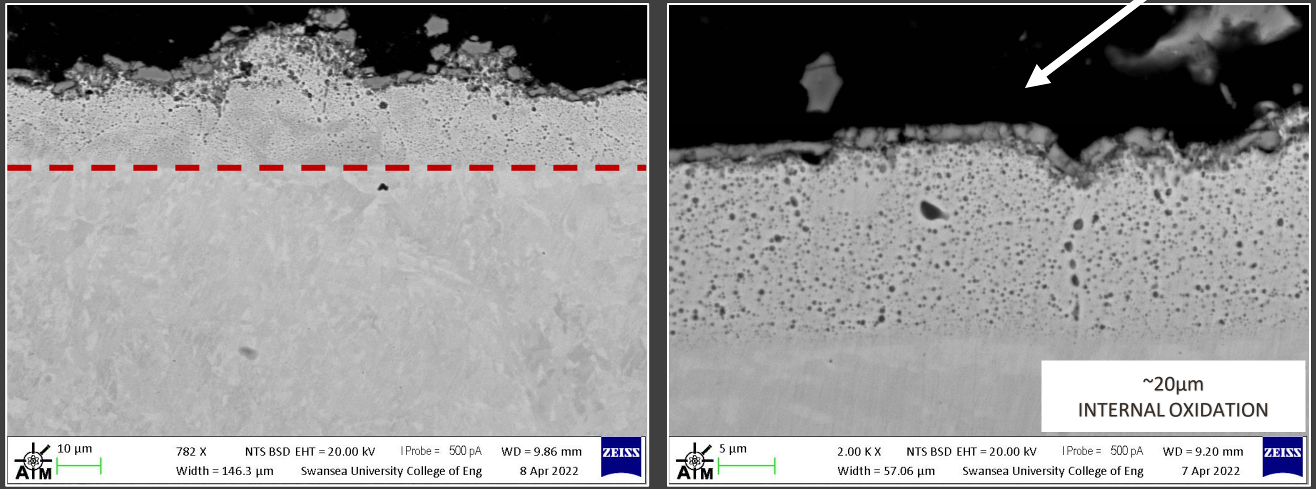


Image of reheated surface

Spallation

Uniform, continuous internal oxidation:

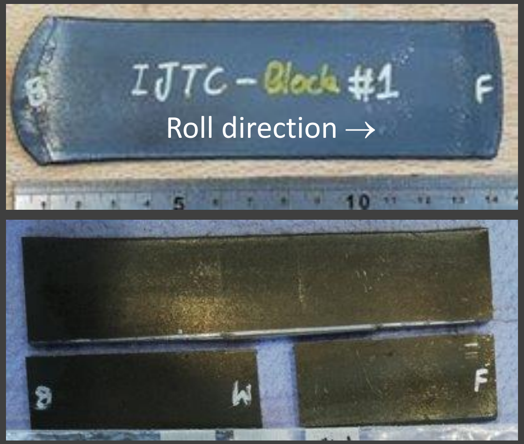


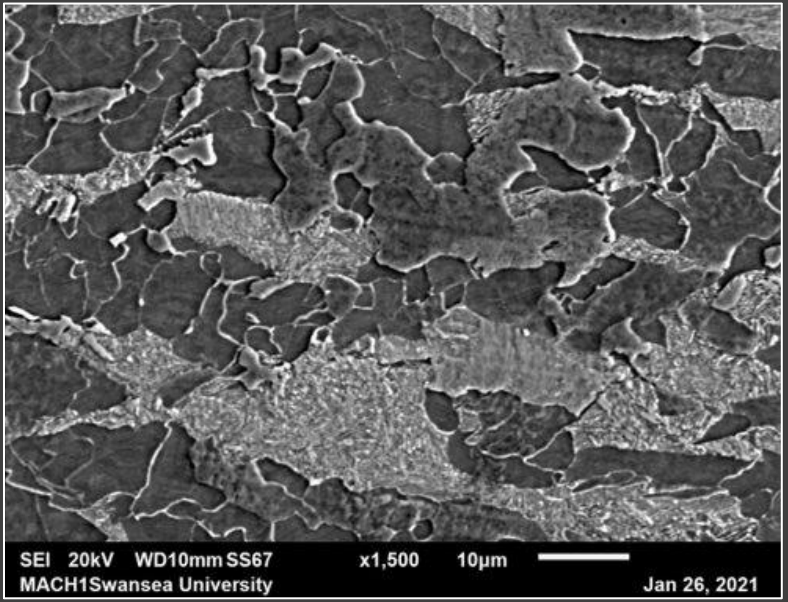
SEM images of internal oxidation on reheated sample cross section

Hot Rolled RAP

Reheated @ 1230°C for 5 mins in air
Hot rolling temperatures:
- 1190°C entry
- 850°C exit

7.7mm → 3.5mm (58% reduction – single pass)
Ferrite-martensite, 33% pearlite





Work supported by MACH1 team @ Swansea University

Roll direction →

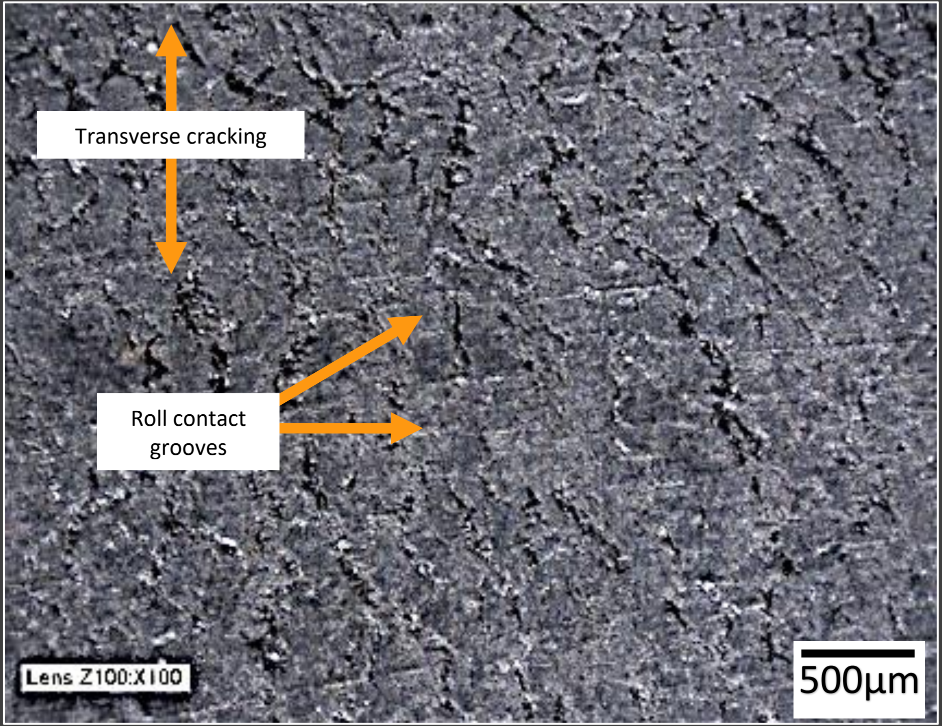


Image of hot rolled surface

General topography in agreement with literature
(i.e., presence of transverse cracking/roughness)

Evidence of roll contact grooves at the surface – literature suggests mechanical feature could present sites of entrapment

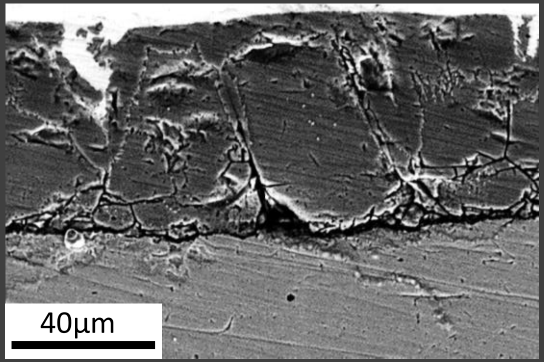
Nioi et al, JMPT (2017)

Hot Rolled RAP

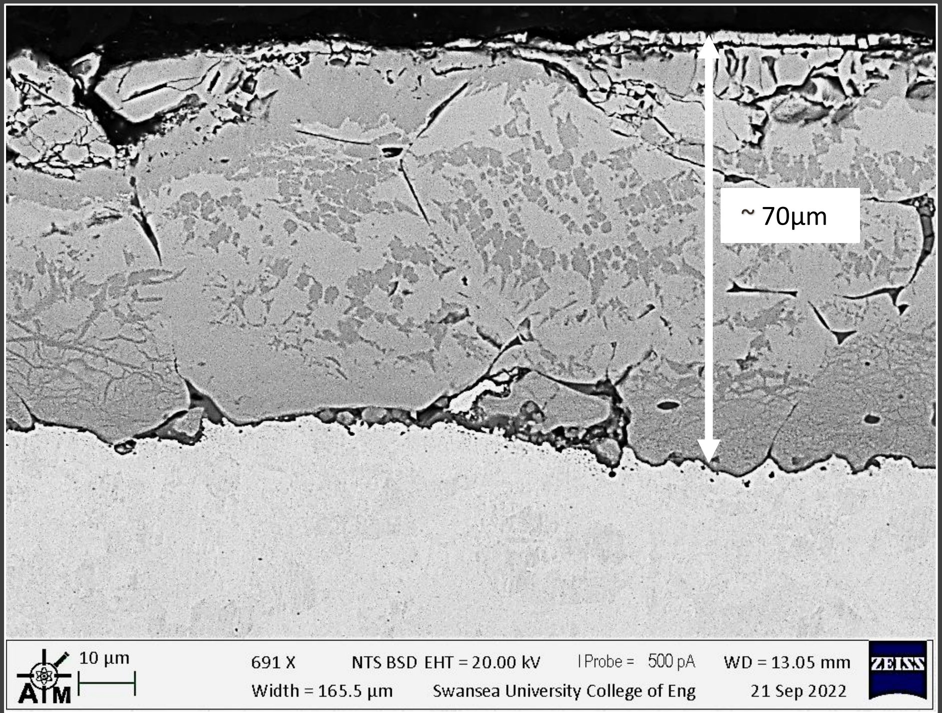
Scale is extremely well-adhered

Internal cracking a result of hot deformation but also interior shrinkage - cooling still important

Scale micro- and phase structures are synonymous with literature

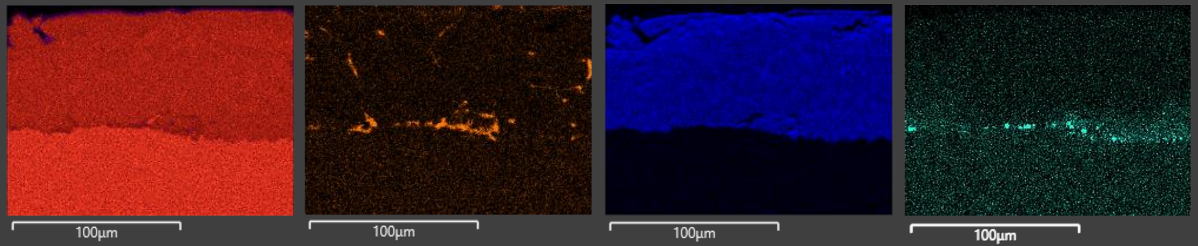


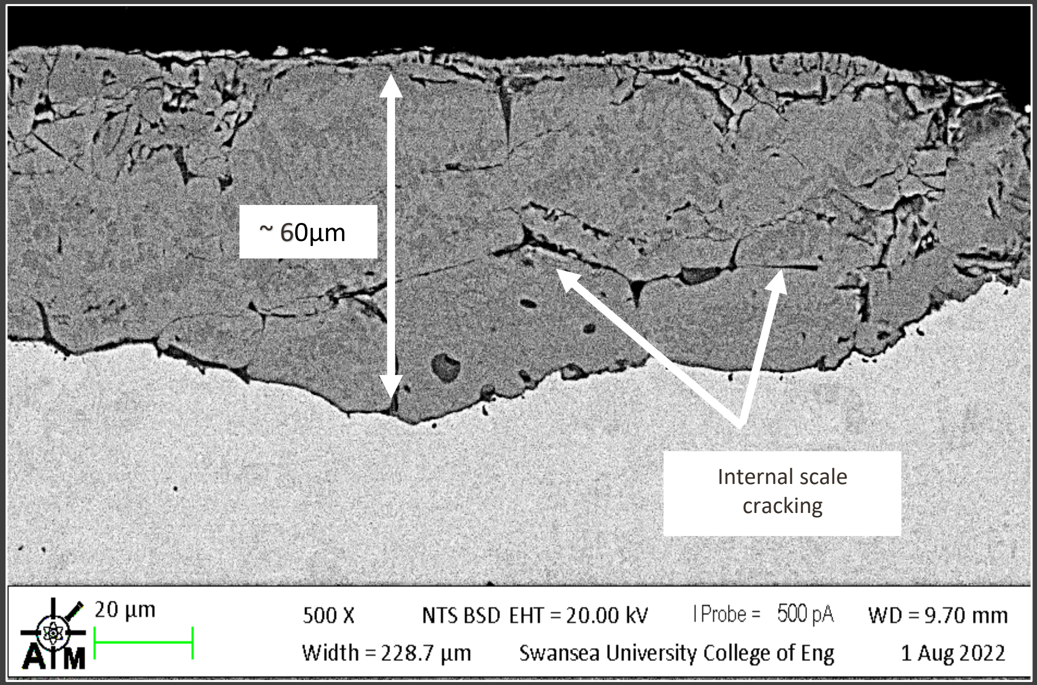
Han et al, Mat Res, 2019
0.3Si steel HR @ 1000°C



SEM image of hot rolled sample cross section

Fe Si O Cr





SEM image of hot rolled sample cross section

Summary

A study of DP800 has been used to demonstrate the current oxidation capabilities

The viability of using RAP as a methodology of understanding oxidation behaviour

- Some RAP stages lend themselves better to oxidation studies than others
    1. Reheating
    2. Hot rolling
- Some stages are not suitable
    1. As-cast

Thank you for listening.

Any Questions?

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