SALZGITTER MANNESMANN FORSCHUNG

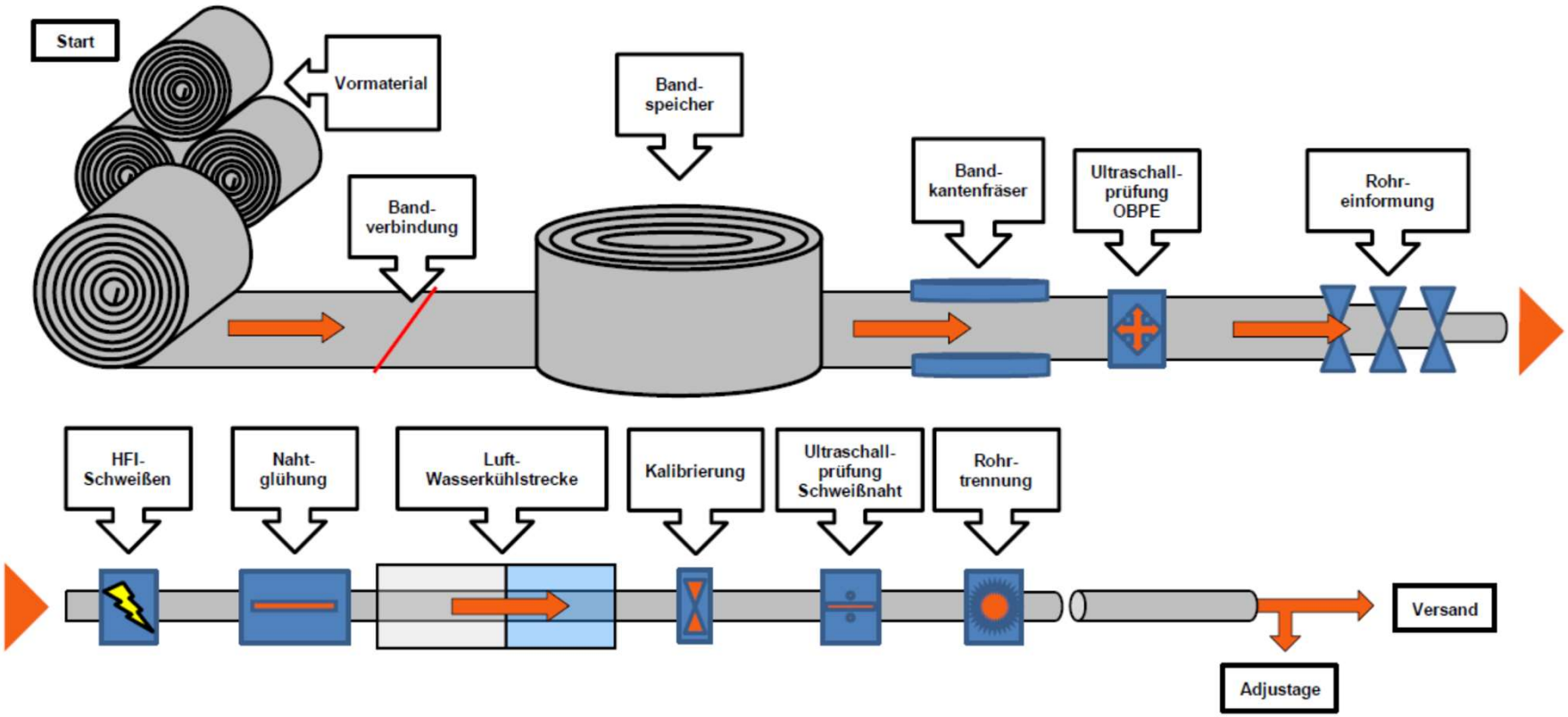
Ein Unternehmen der Salzgitter Gruppe

Slag formation and Internal oxidation during HFI welding of pipeline steels

Michael Spiegel and Philippe Schaffnit

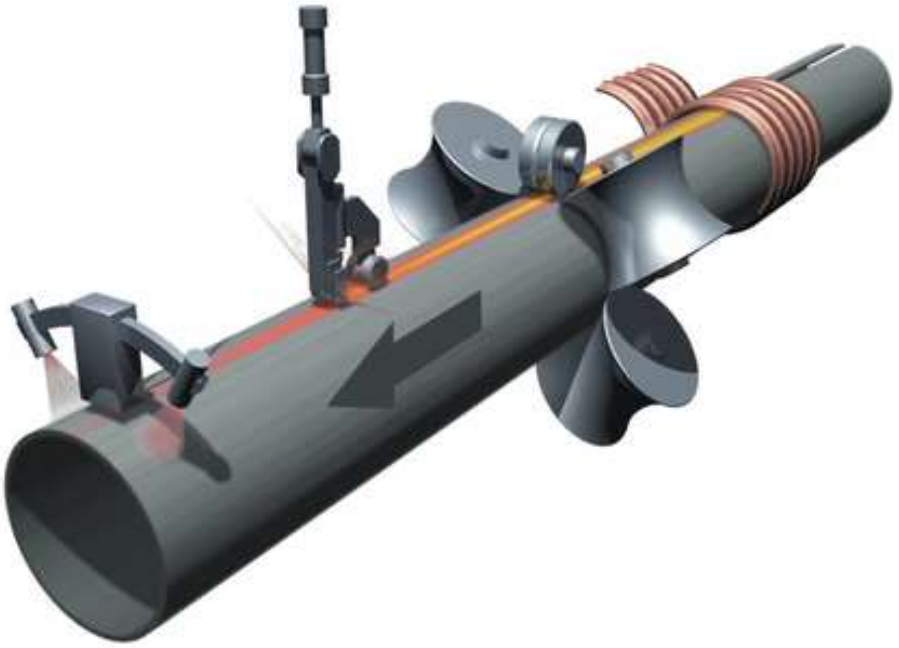
GTT user meeting, 27th June 2019

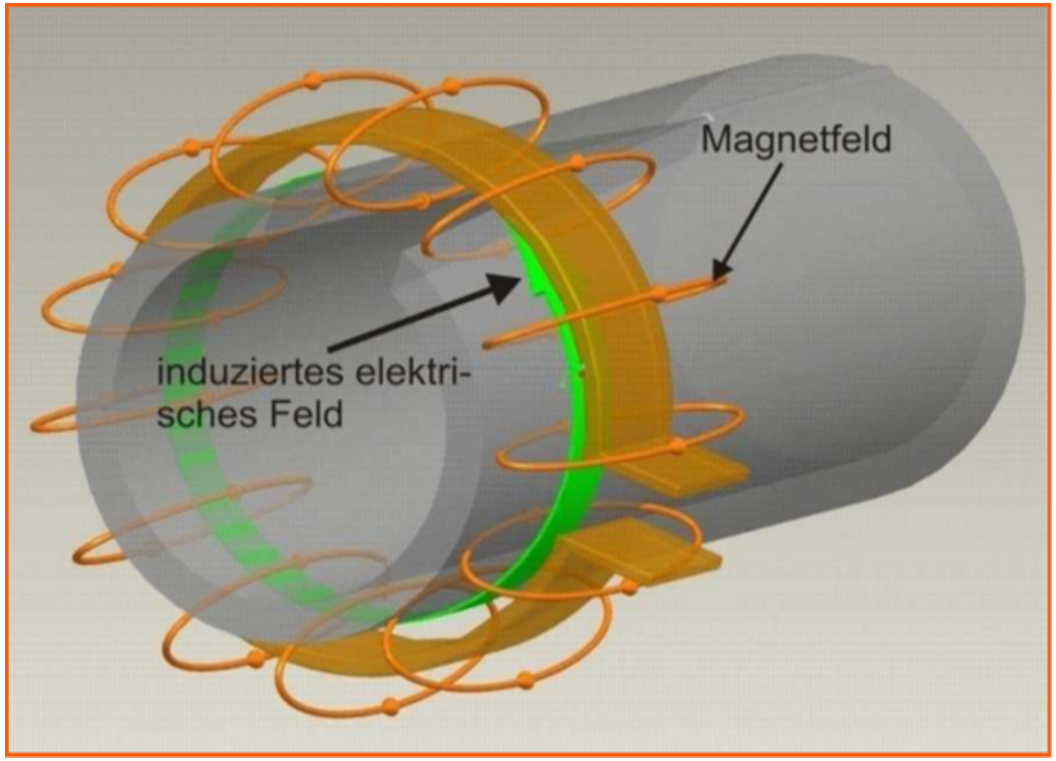
HFI-Process


Start
Vormaterial
Band-
speicher
Band-
verbindung
Band-
kantenfräser
Ultraschall-
prüfung
OBPE
Rohr-
einformung
HFI-
Schweißen
Naht-
glühung
Luft-
Wasserkühlstrecke
Kalibrierung
Ultraschall-
prüfung
Schweißnaht
Rohr-
trennung
Versand
Adjustage

HFI-Process

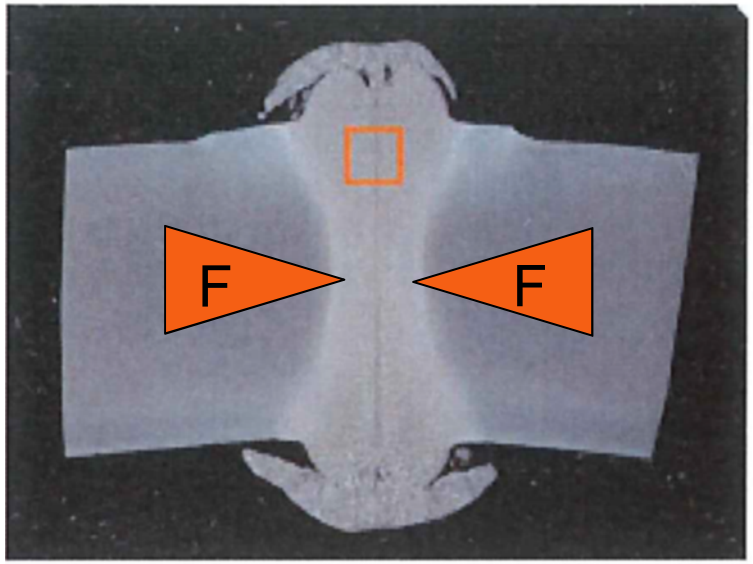
SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe



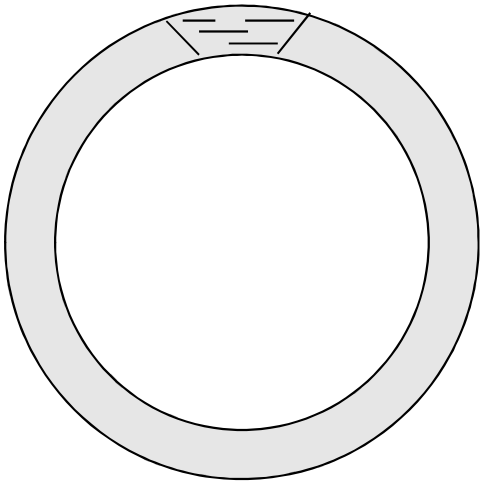


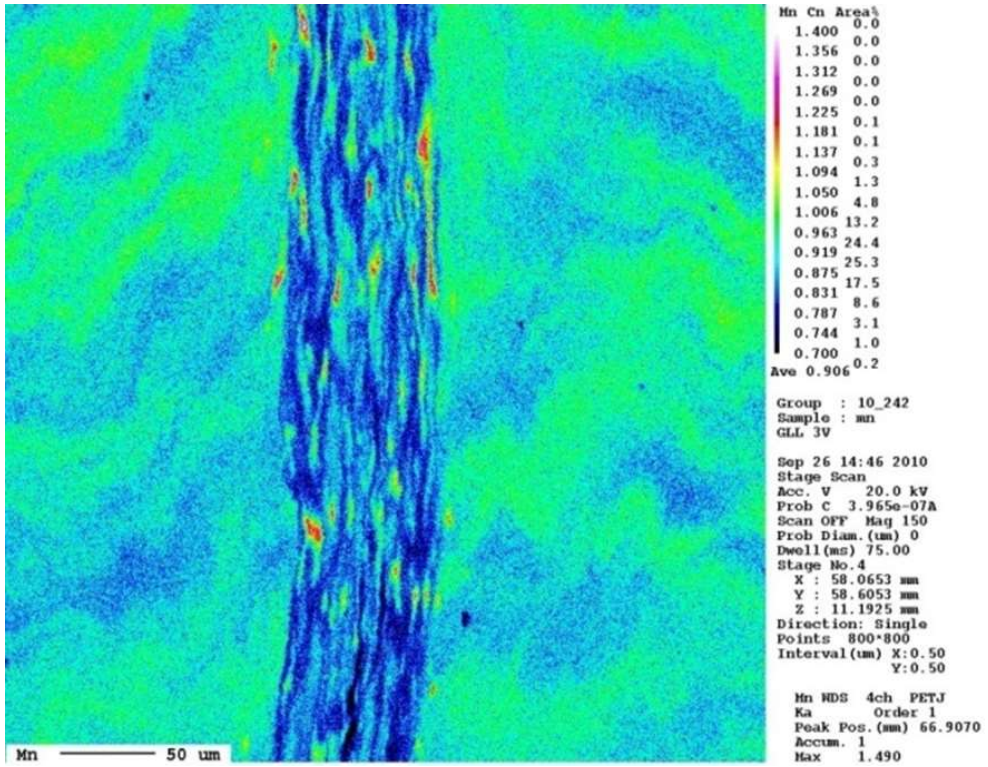
Ferrite line in the welded seam

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe



HFI weld





Ferrite line with Mn-rich oxides
Low charpy values !!

Introduction

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe

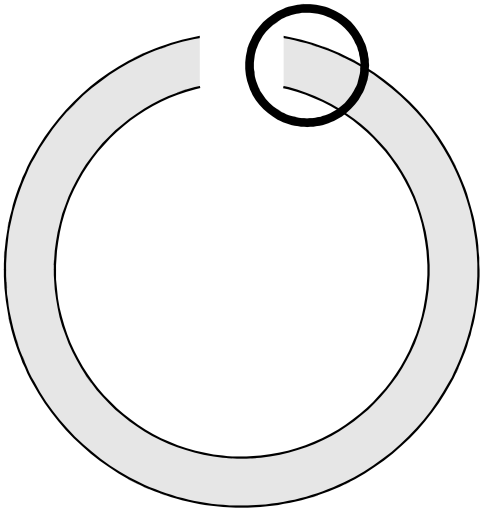
- During HFI welding, slag is formed and internal oxidation occurs
- Slag residuals and internal oxides lead to bad mechanical properties of the weld

  - 0,13%C - 1,39%Mn – 0.39Si – 0.033 Al
  - 0,04%C - 0,90%Mn – 0.39Si – 0.033 Al

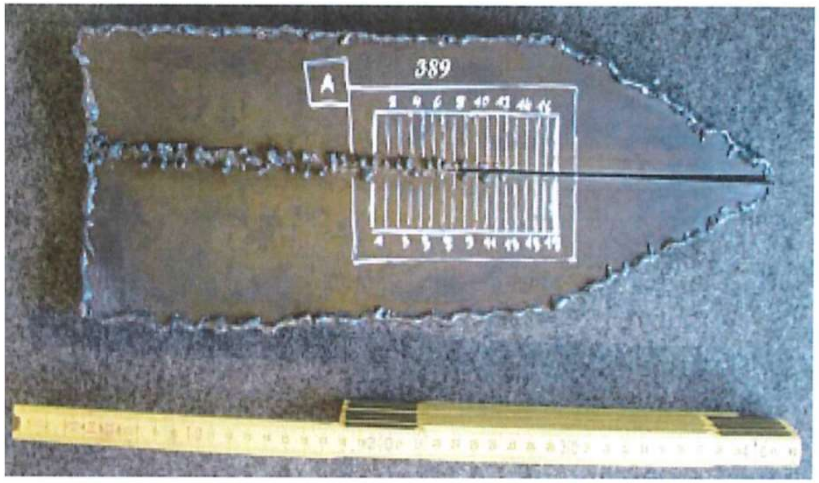
How does it look like ?

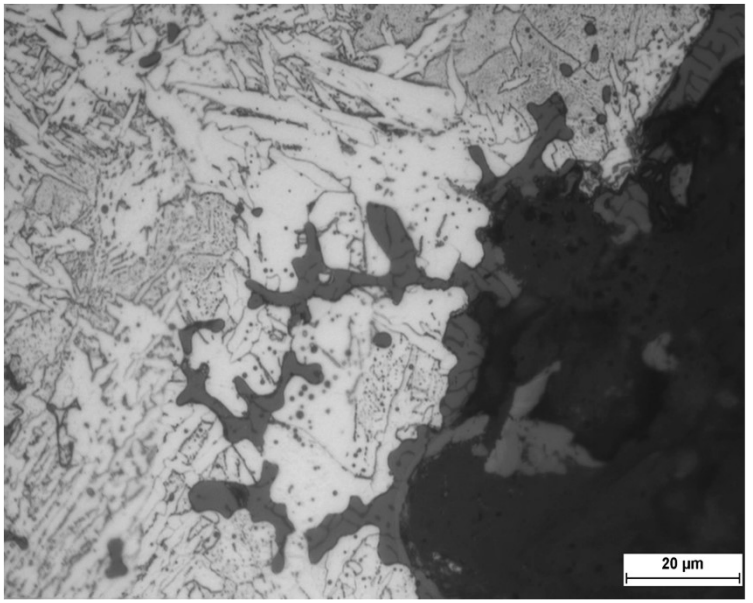
SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe

melting area



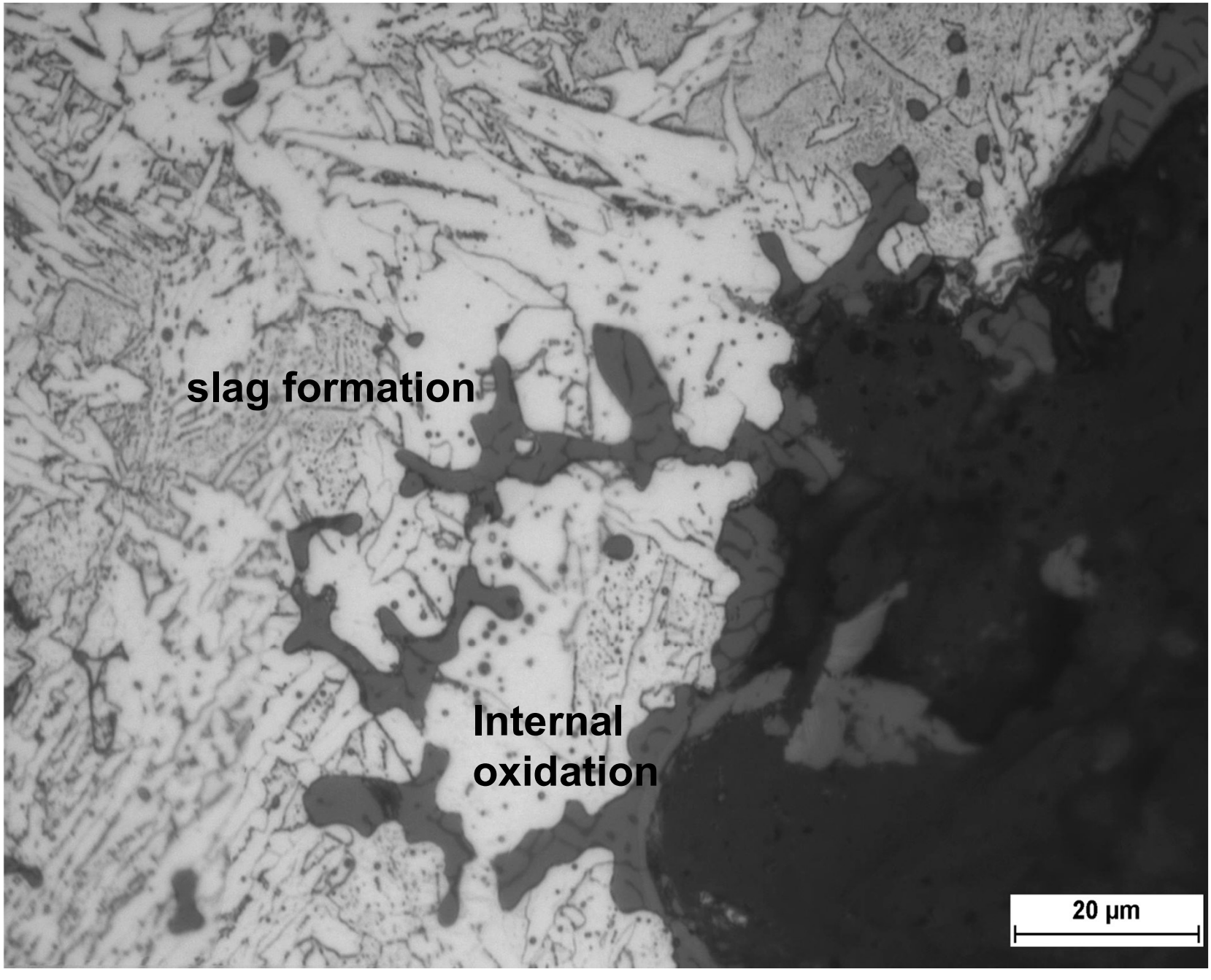
metal melting,
slag formation





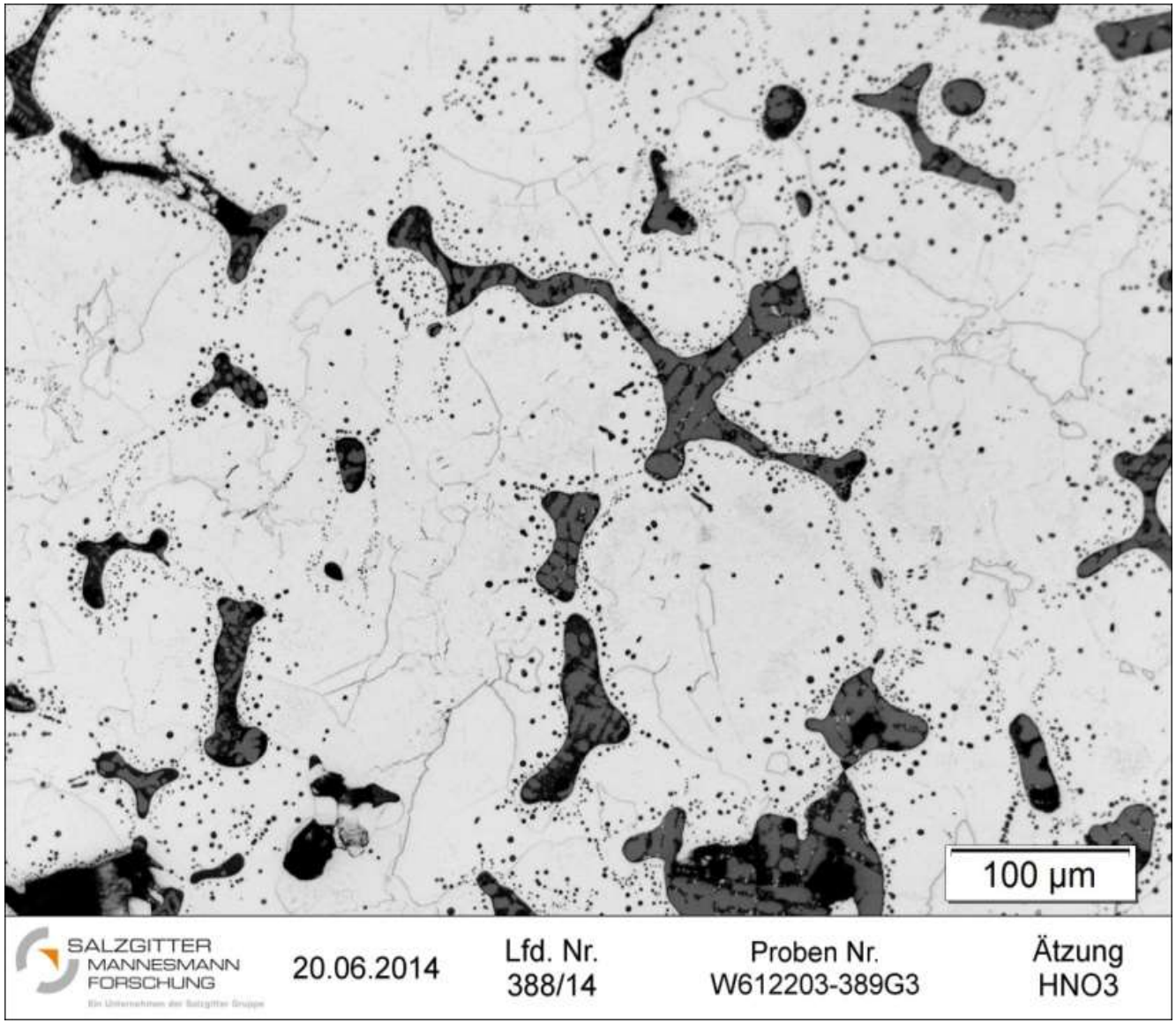
Slag formation and internal oxidation

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe



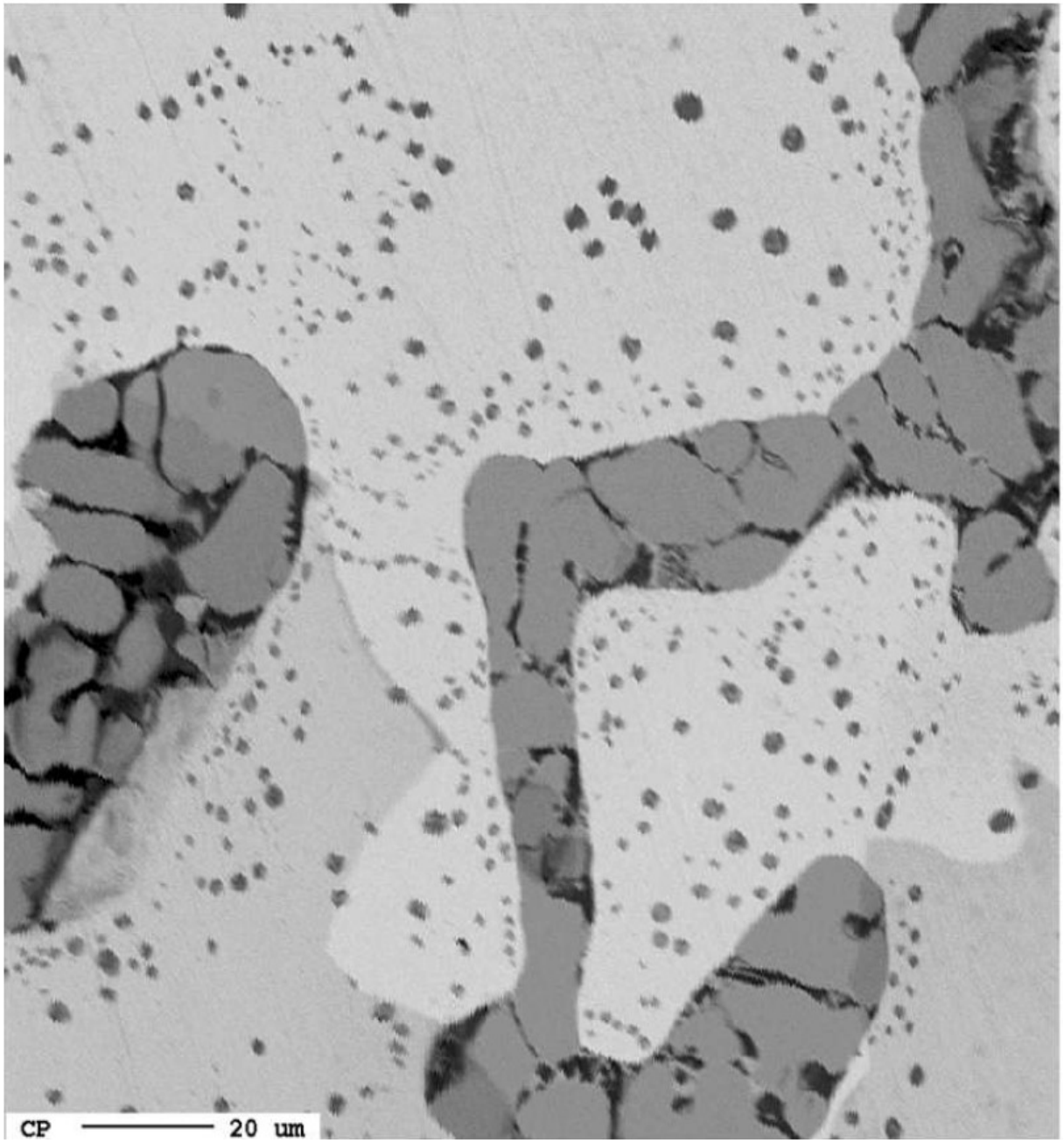
Slag formation and internal oxidation

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe



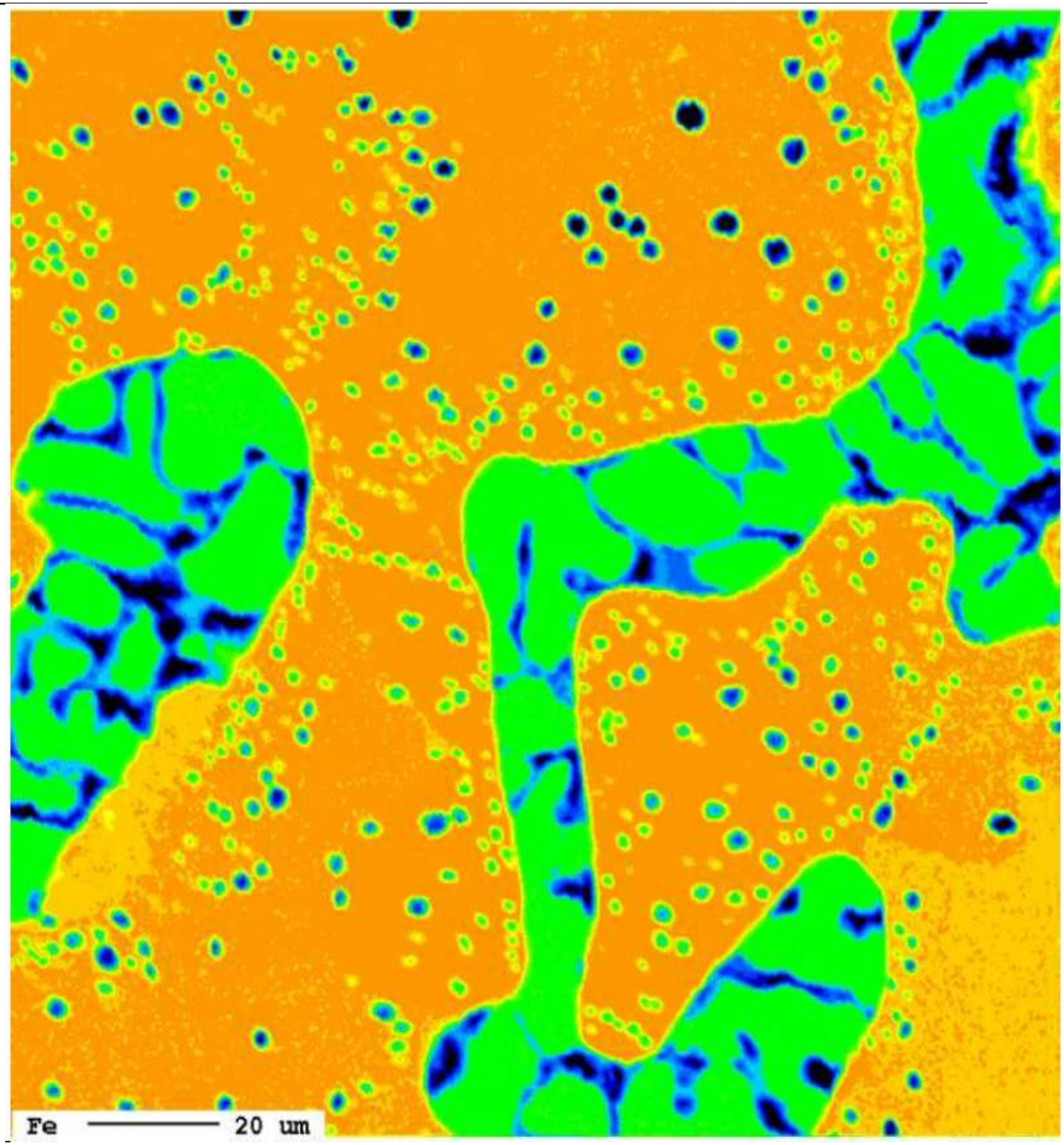
Slag formation and internal oxidation

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe



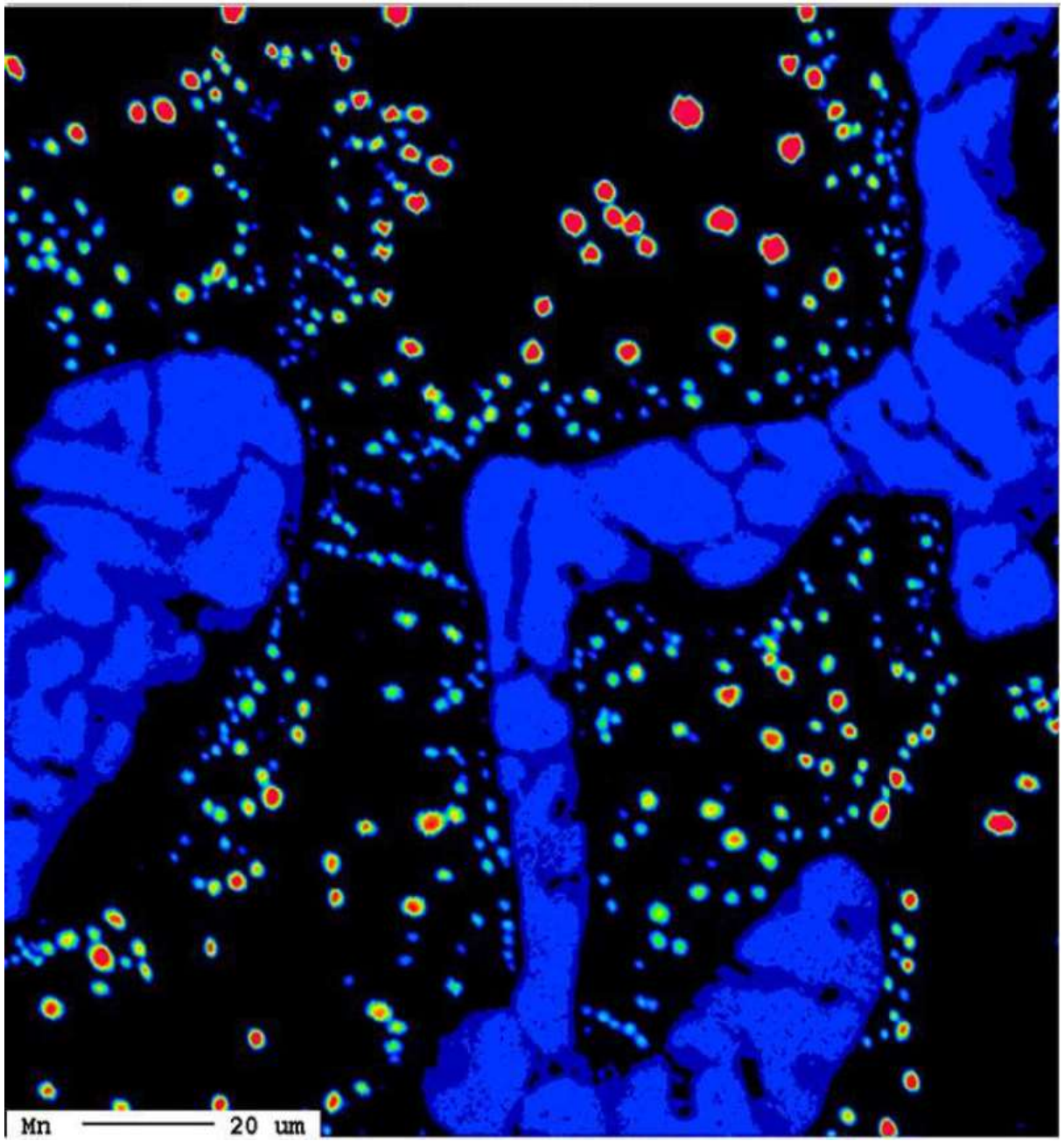
Slag formation and internal oxidation

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe



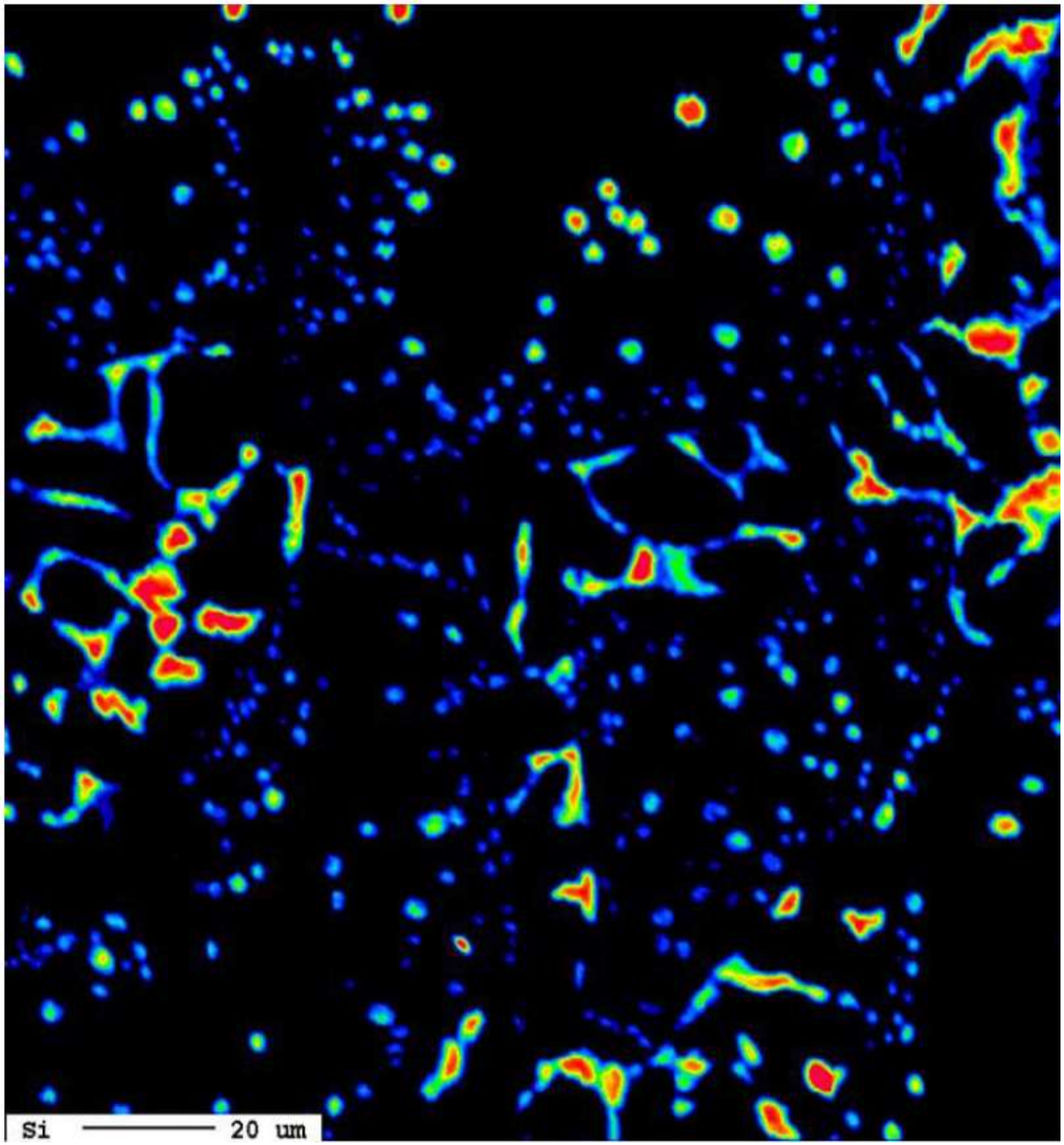
Slag formation and internal oxidation

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe



Slag formation and internal oxidation

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe



Introduction

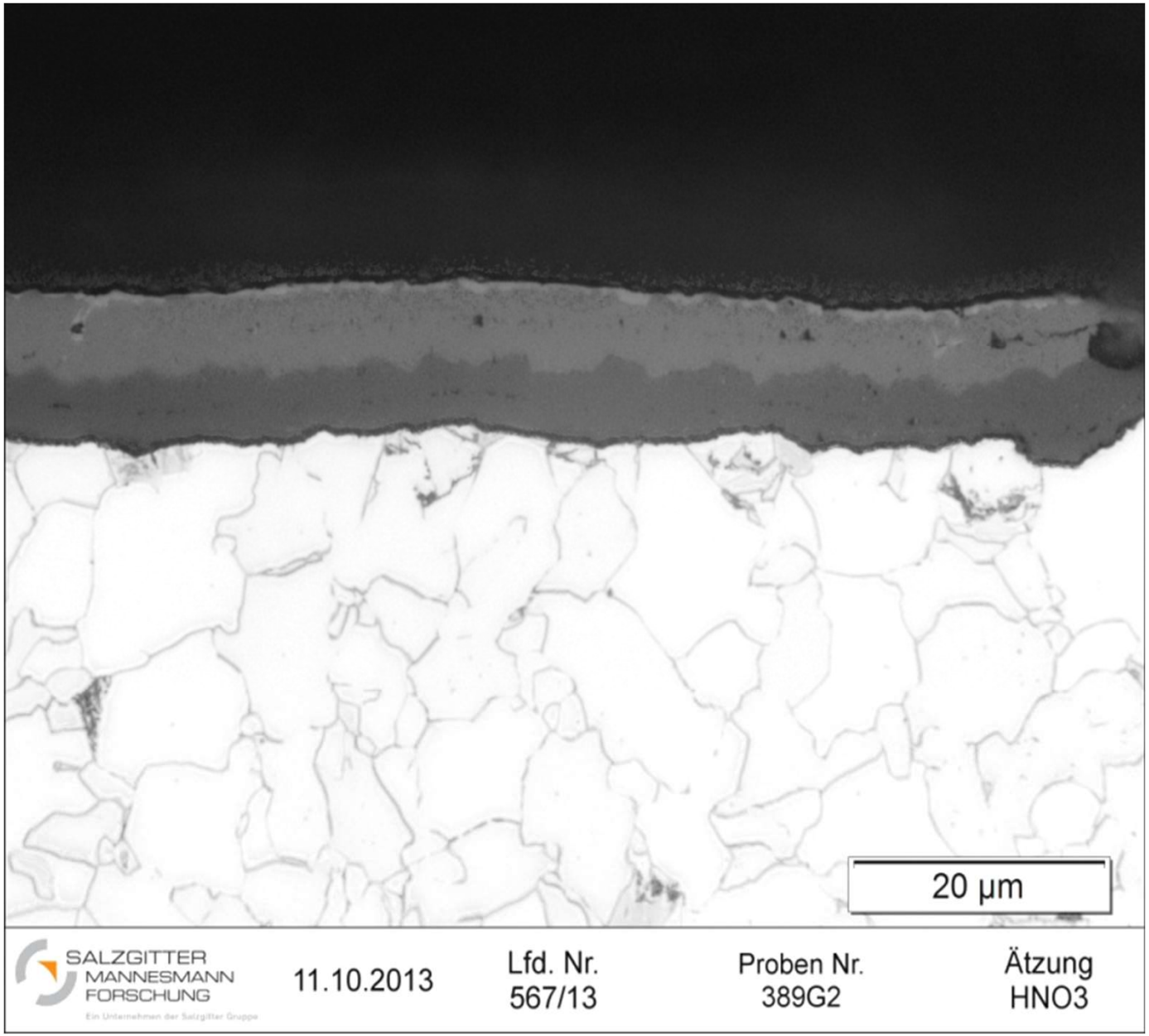
SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe

Short term oxidation experiments: Inductive heating: 90 sec.

Internal oxidation during HFI welding..

Oxidation: 750 °C

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe

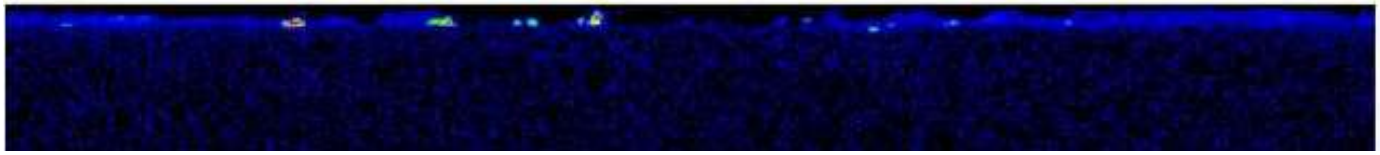


Oxidation: 750 °C

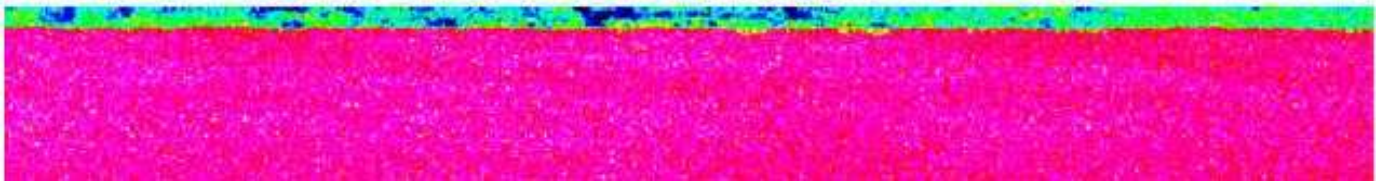
SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe

O

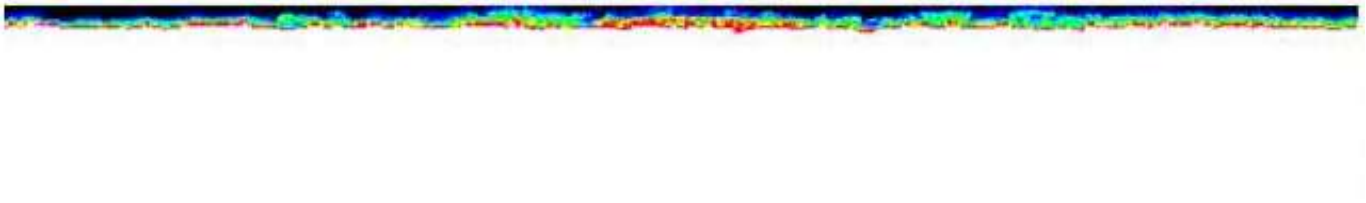
Si



Mn

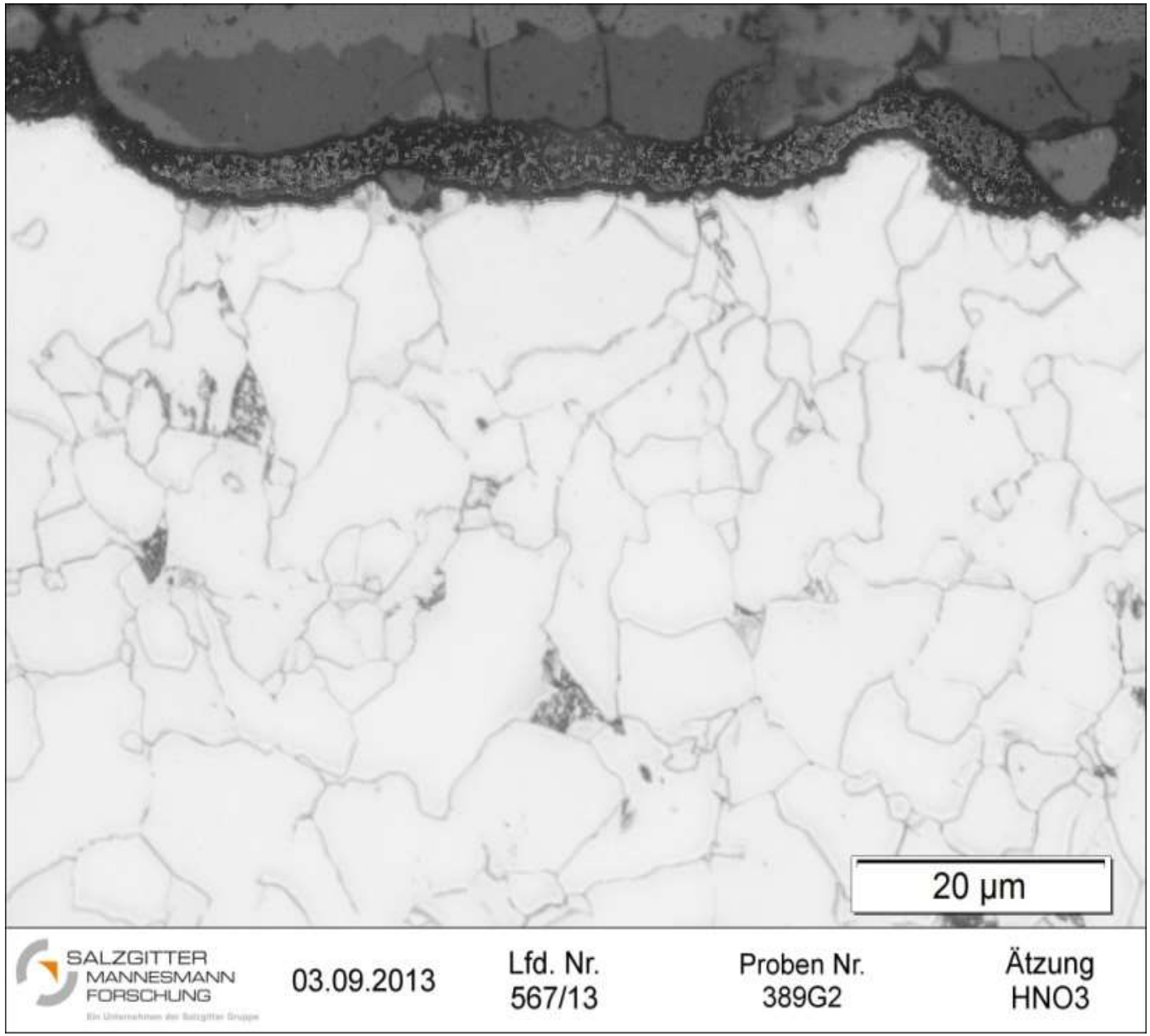


Fe



Oxidation: 1000 °C

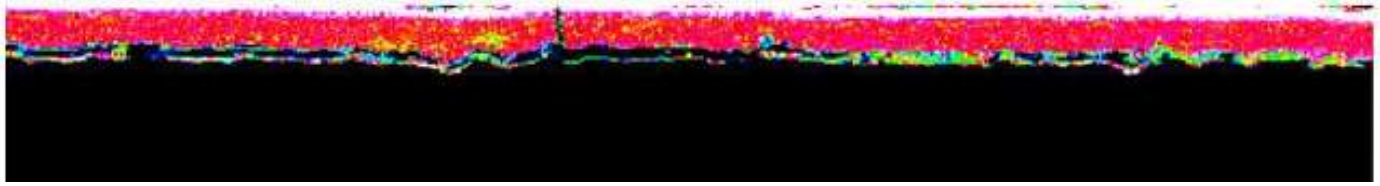
SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe



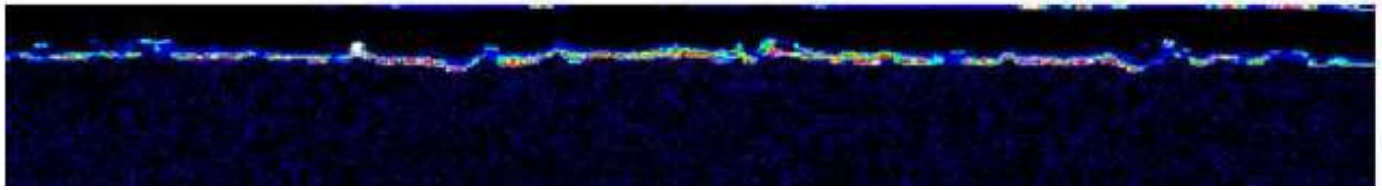
Oxidation: 1000 °C

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe

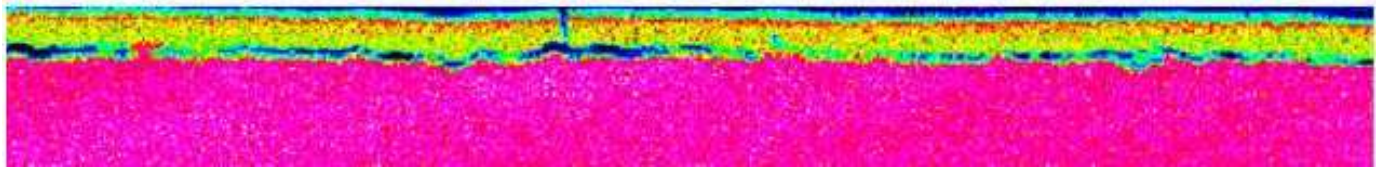
O



Si



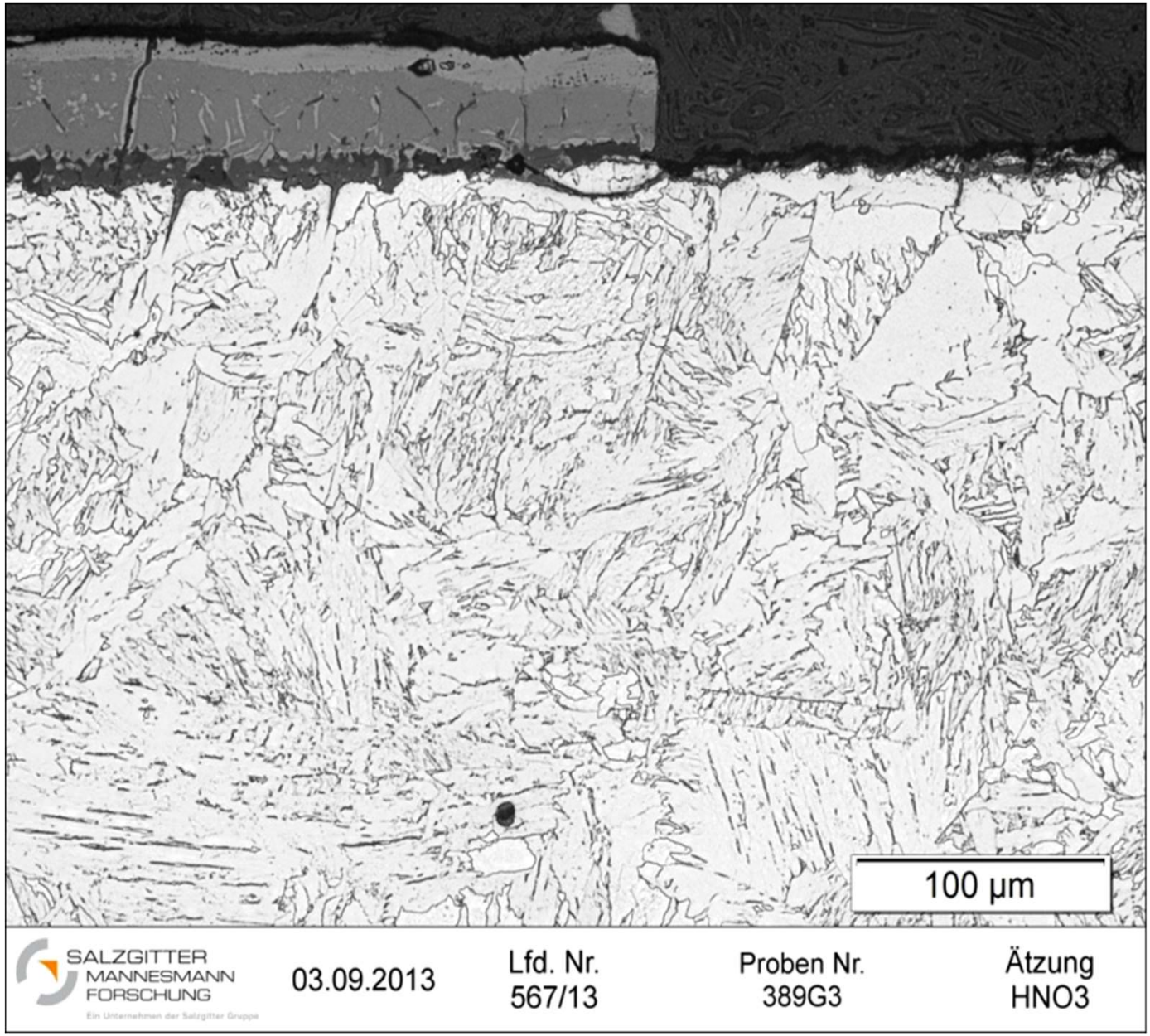
Mn



Fe

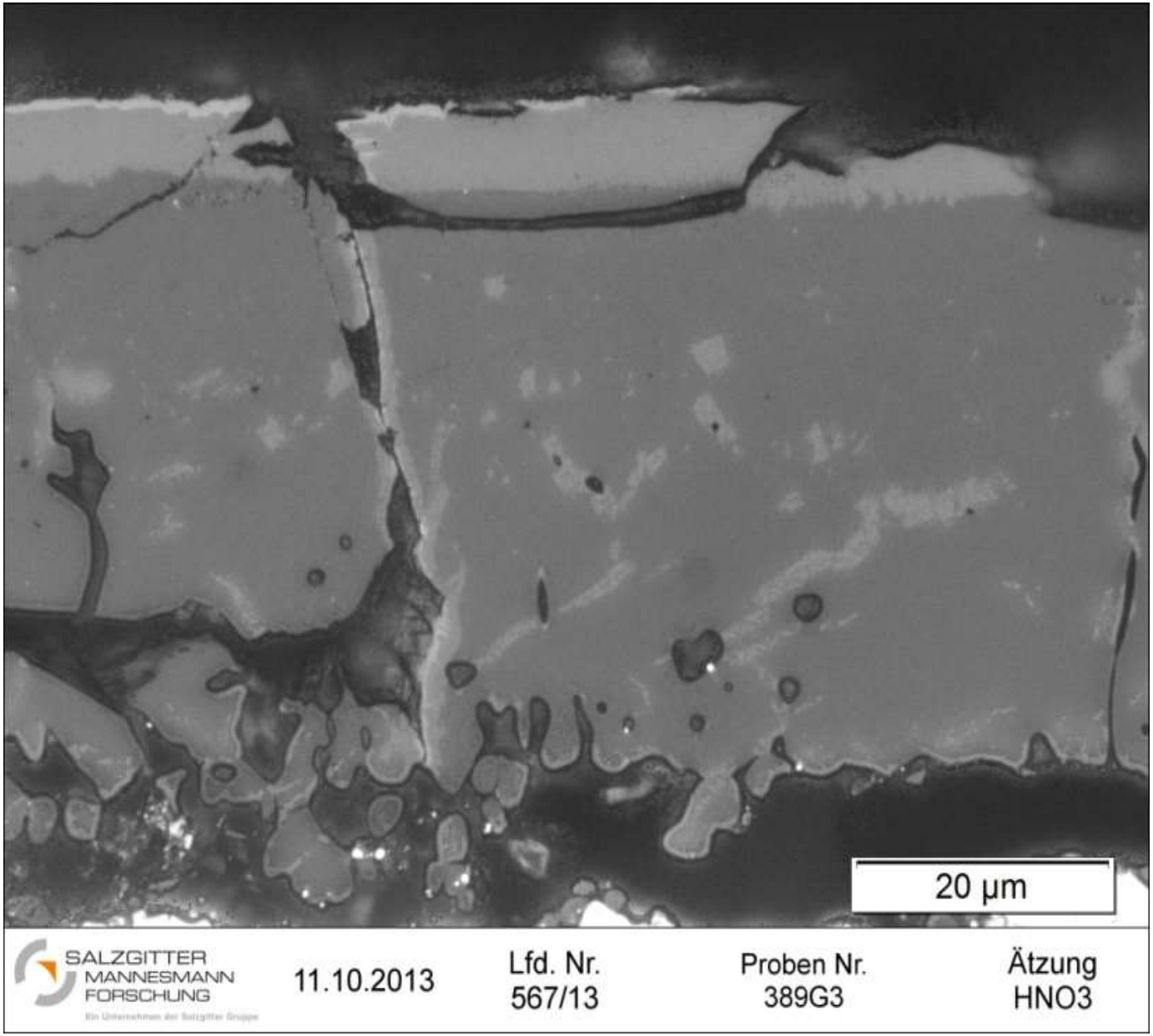
Internal oxidation during HFI welding..

Oxidation: 1300 °C



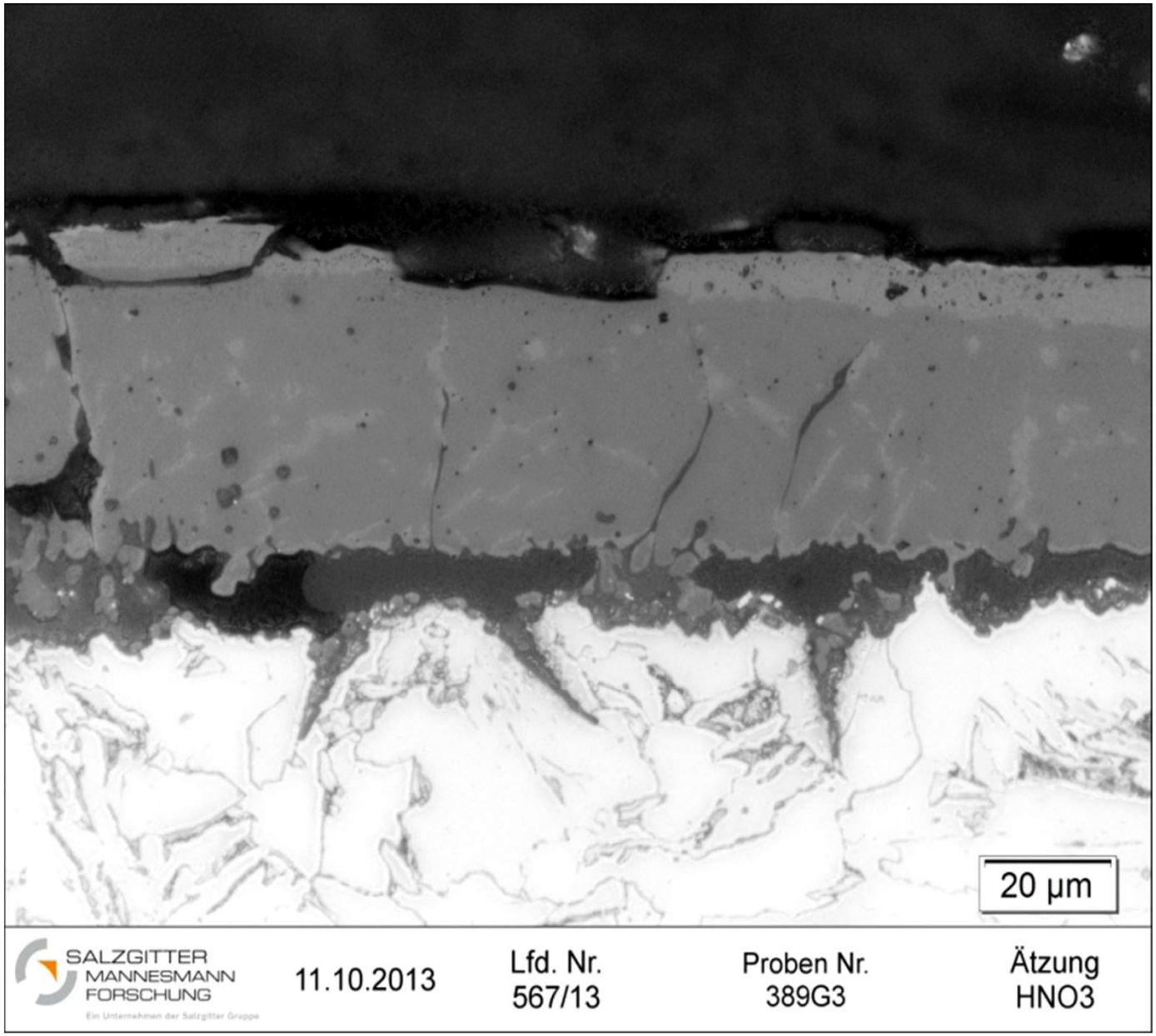
Innere Oxidation: 1300

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe



Oxidation: 1300 °C

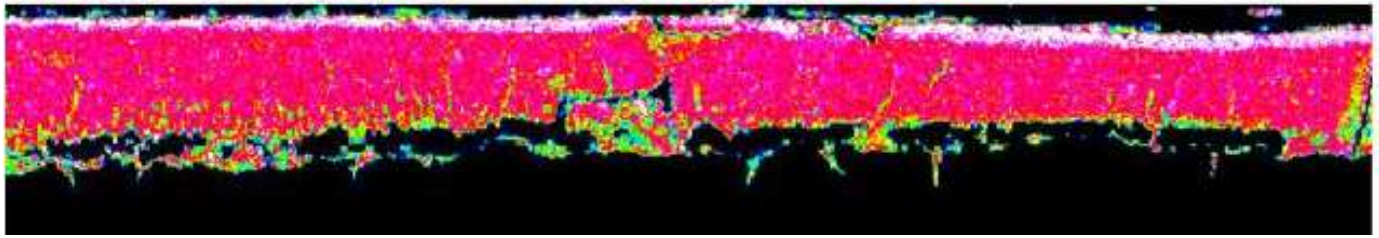
SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe



Oxidation: 1300 °C

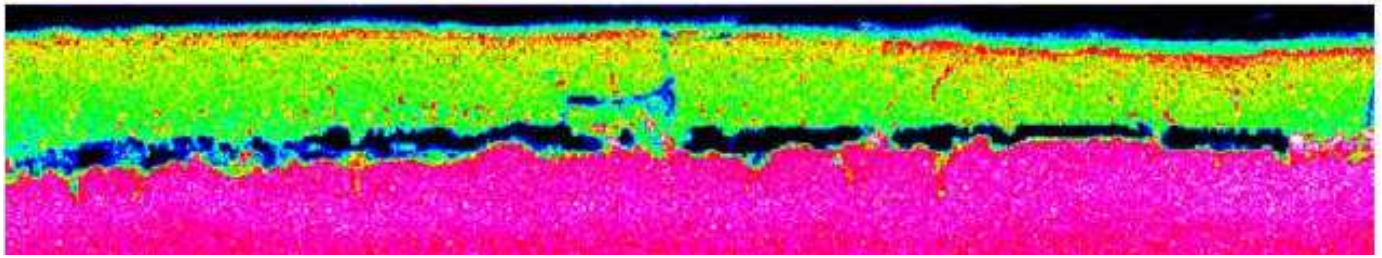
SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe

O

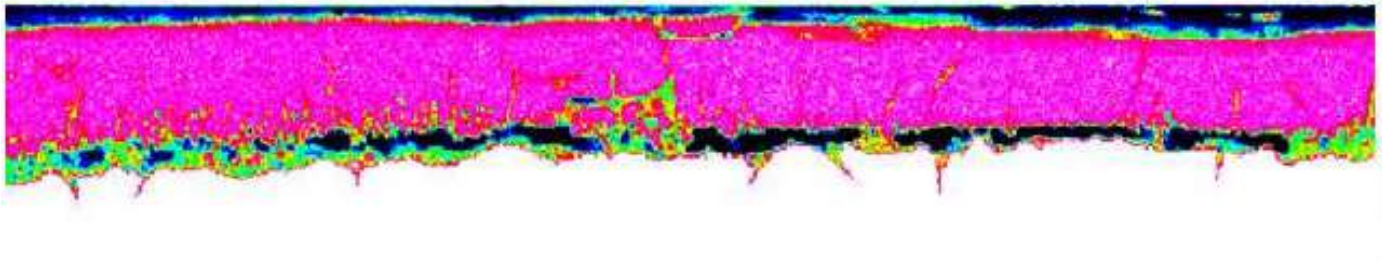


Si

Mn



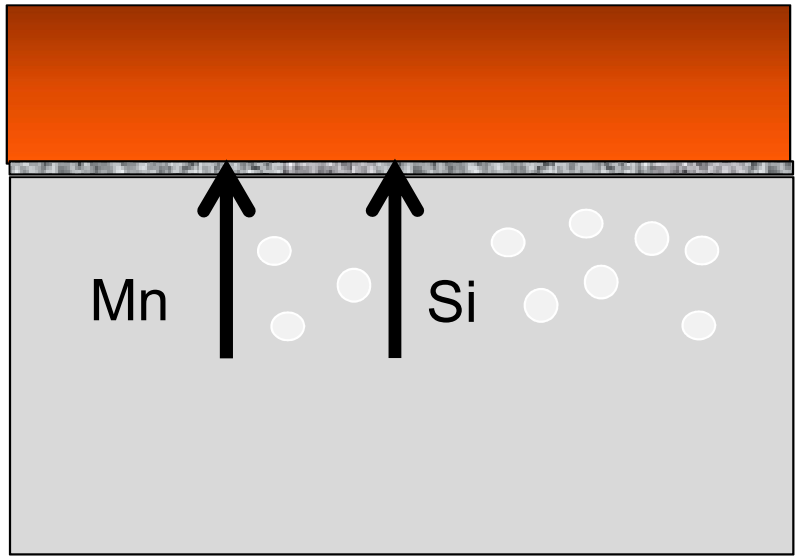
Fe



Innere Oxidation: Thermodynamik

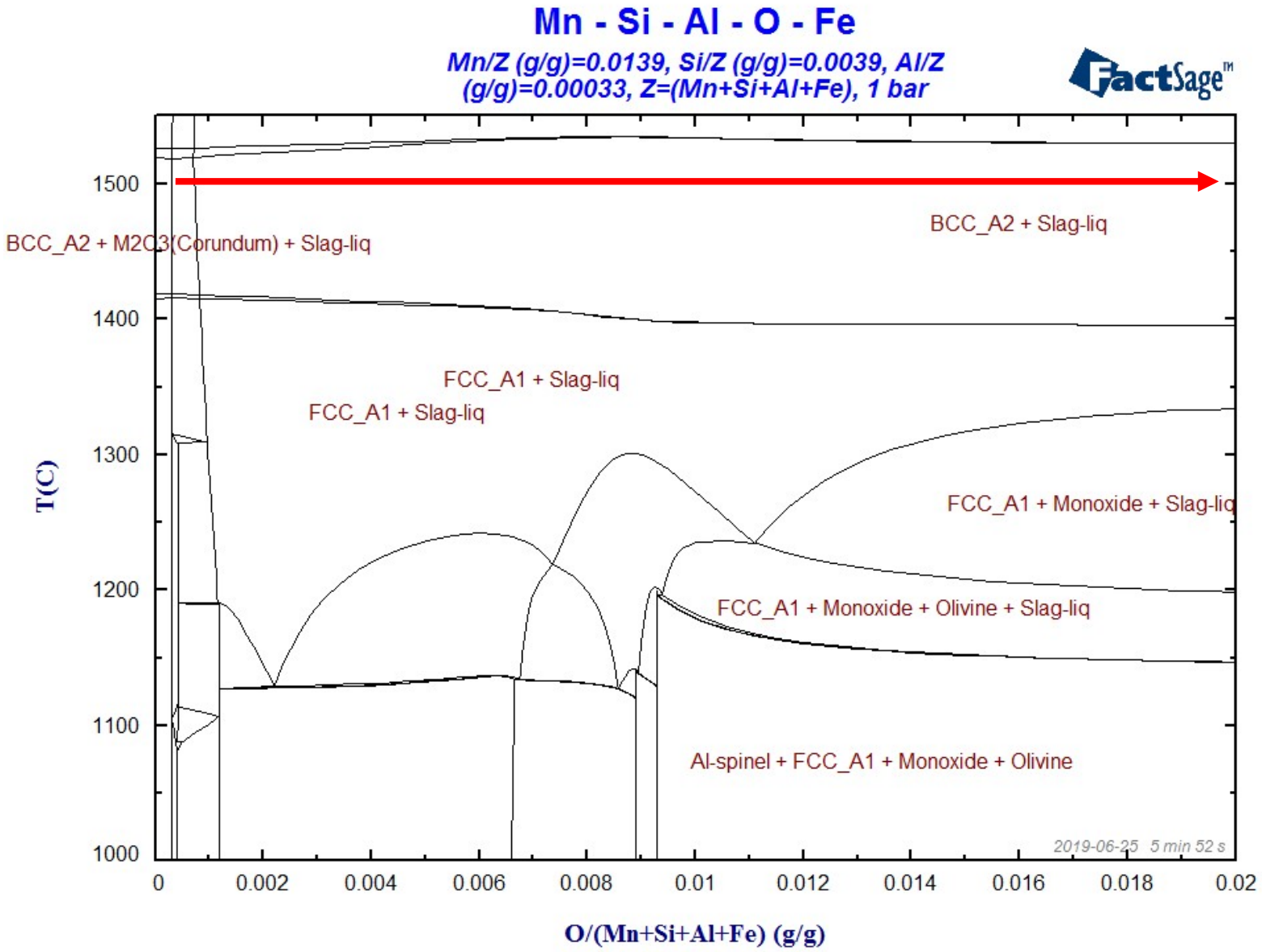
1300 °C

Fe-Mn-Oxide

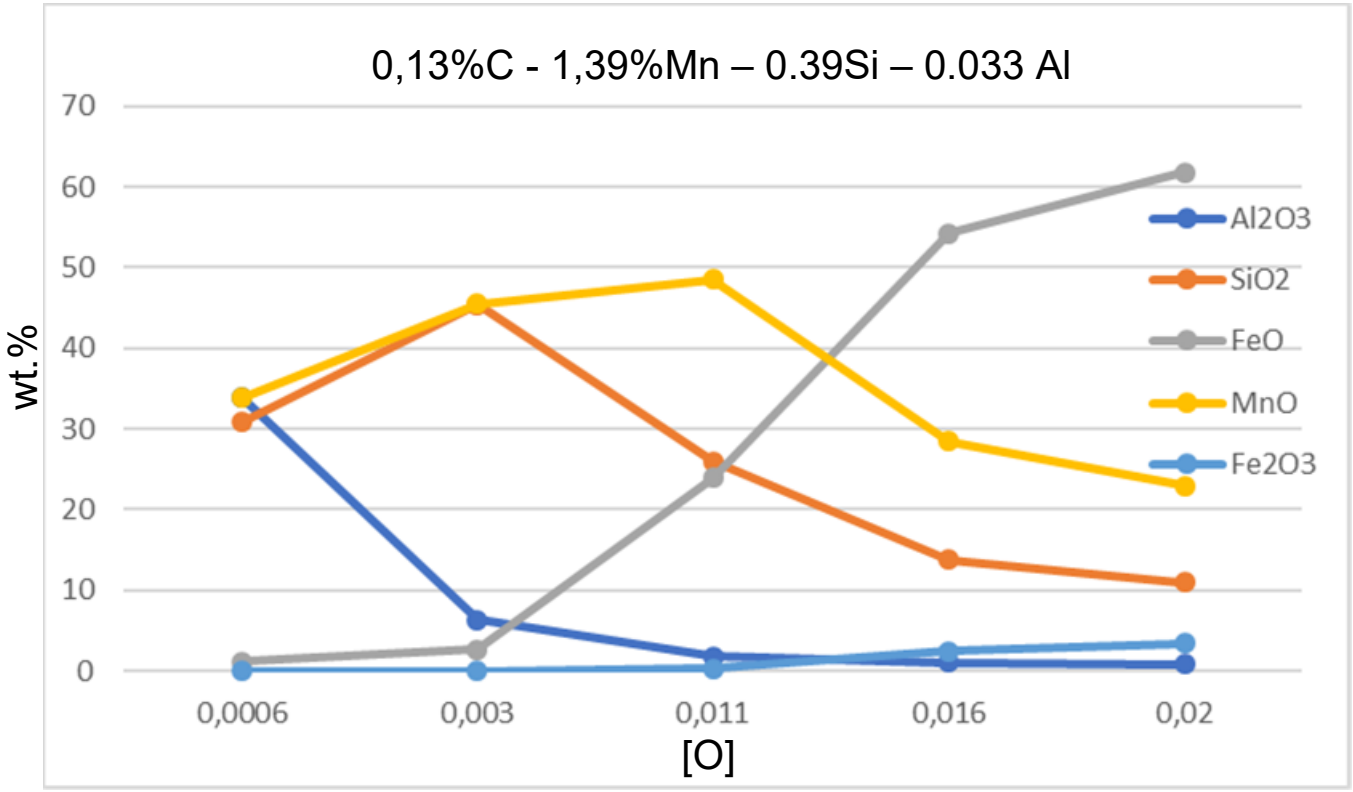


Slag formation and internal oxidation

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe

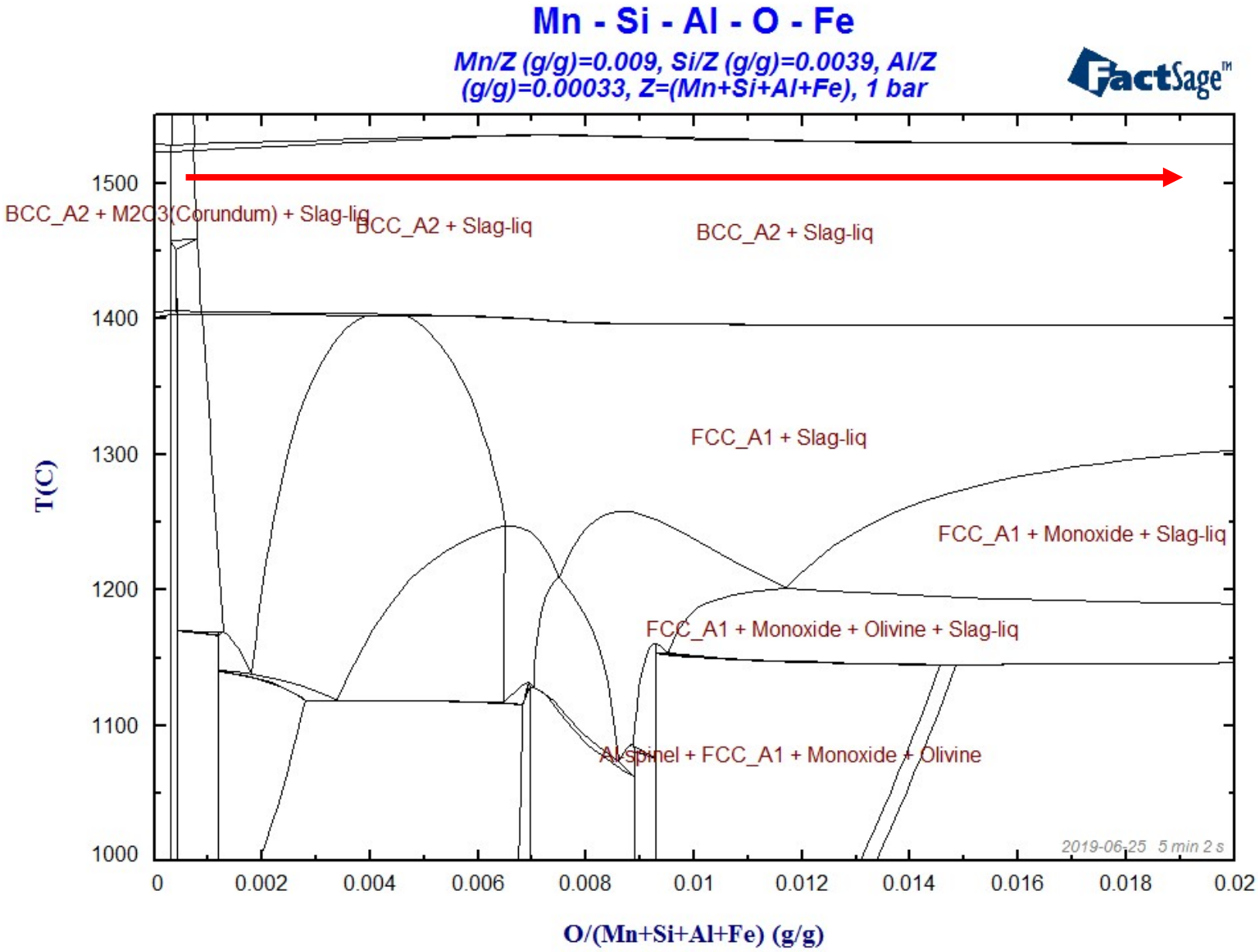


Slag formation and internal oxidation

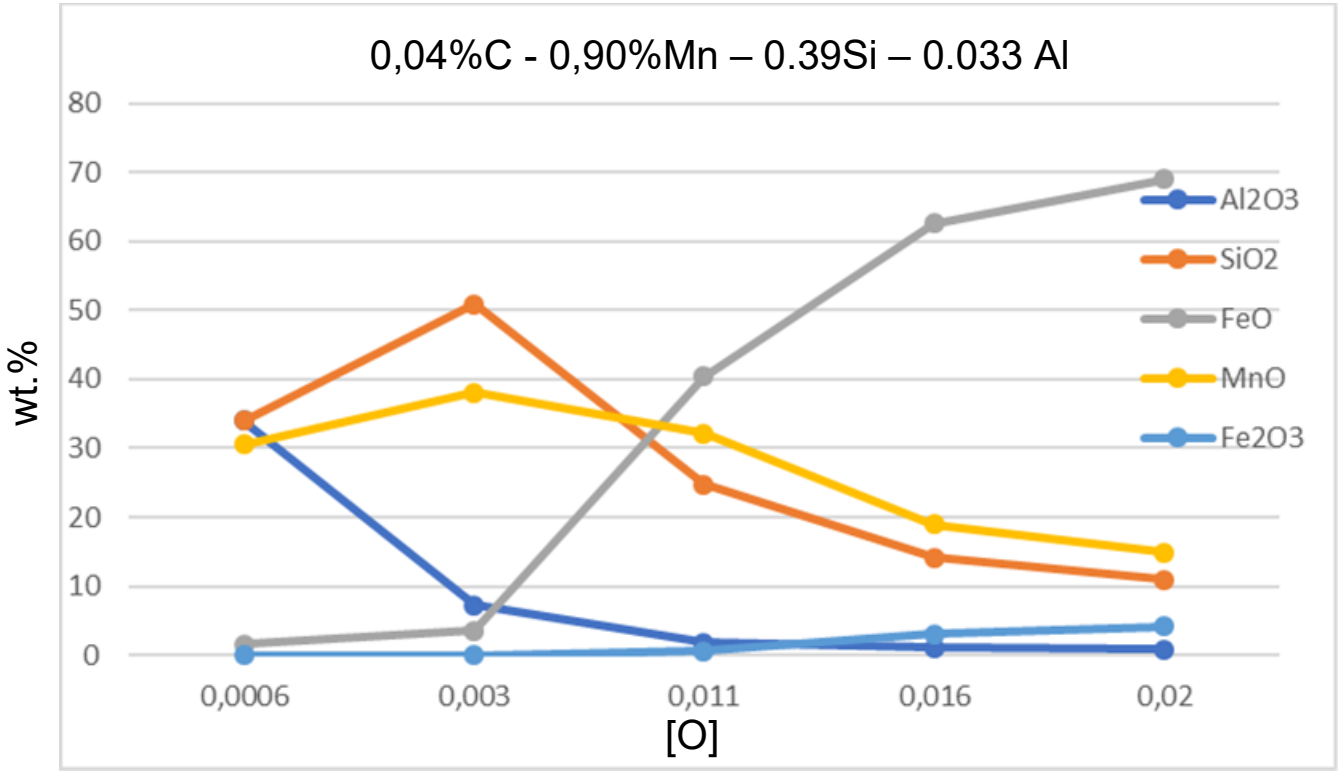


Internal oxidation during HFI welding..

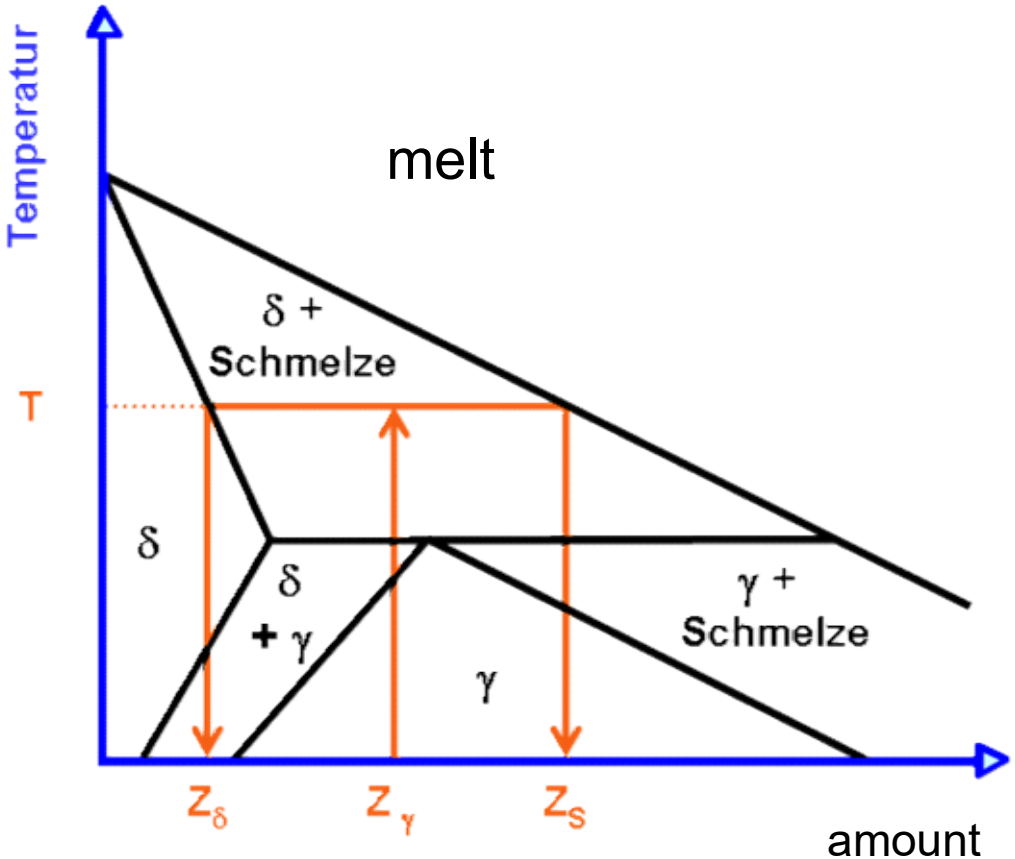
SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe

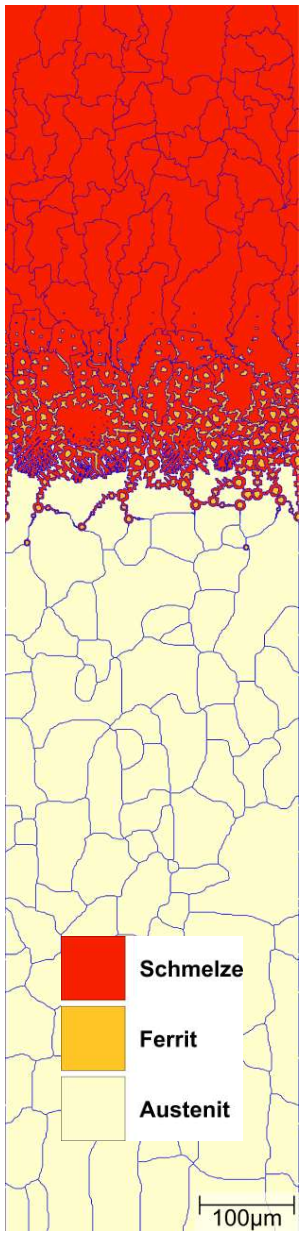


Slag formation and internal oxidation



Slag formation and internal oxidation

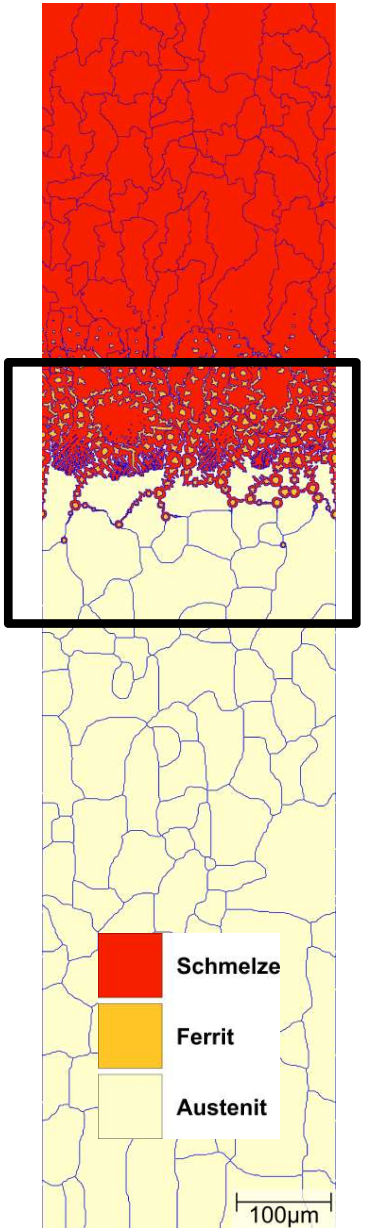




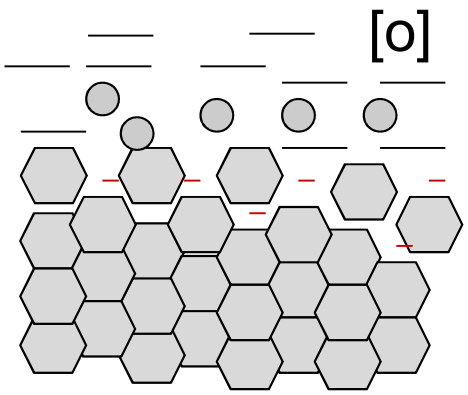
Homogenious melt

2-Phase seperation
Ferrite
Mn-Si enriched melt

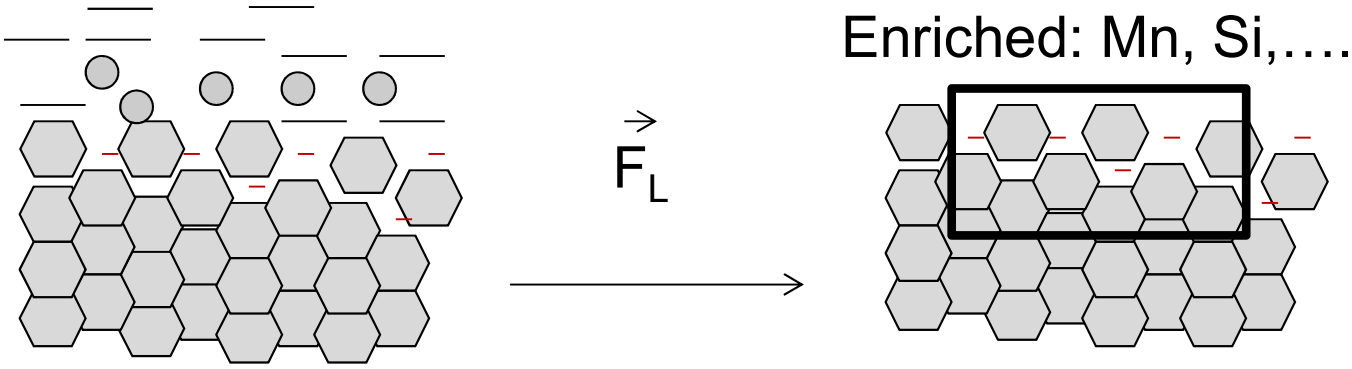
Slag formation and internal oxidation



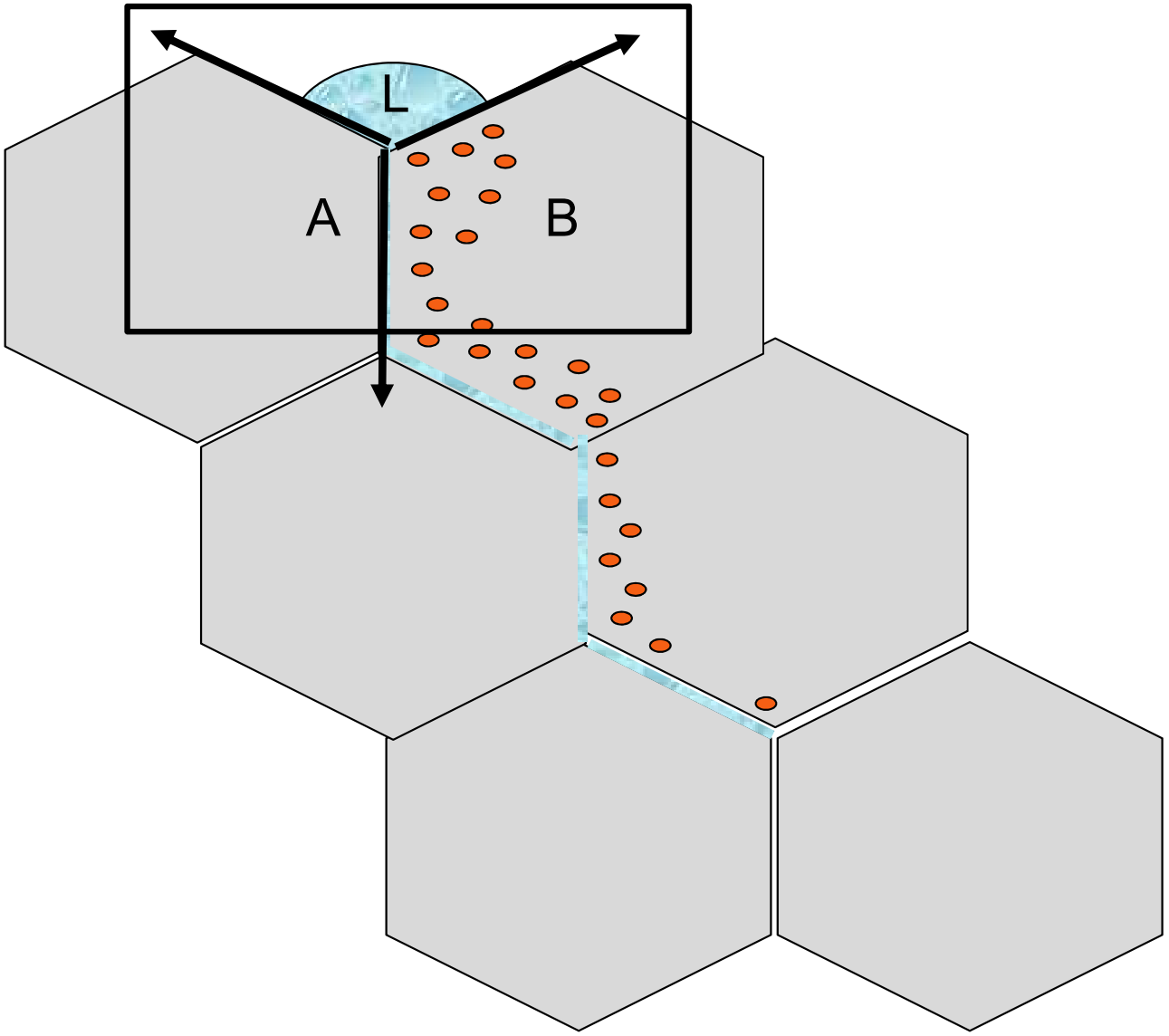
Homogenious melt



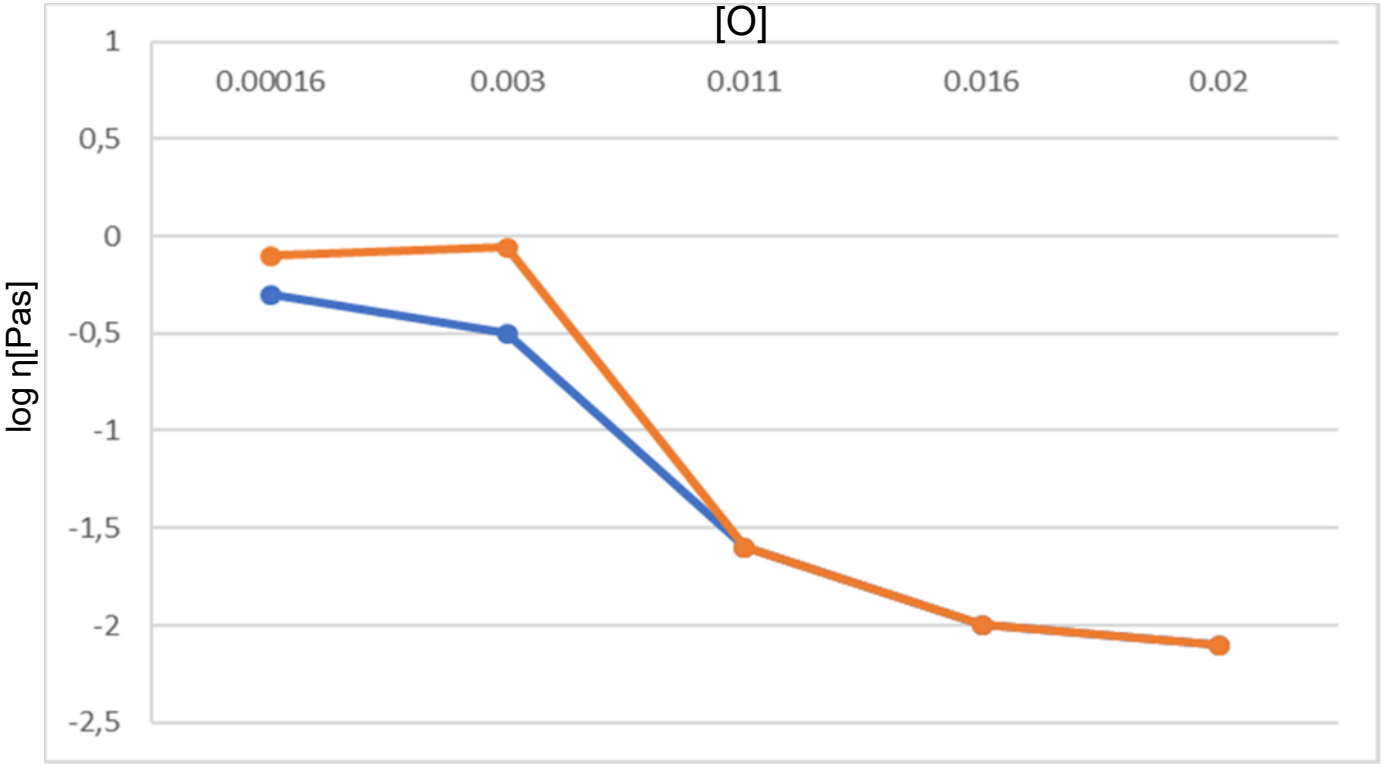
Enriched: Mn, Si,….

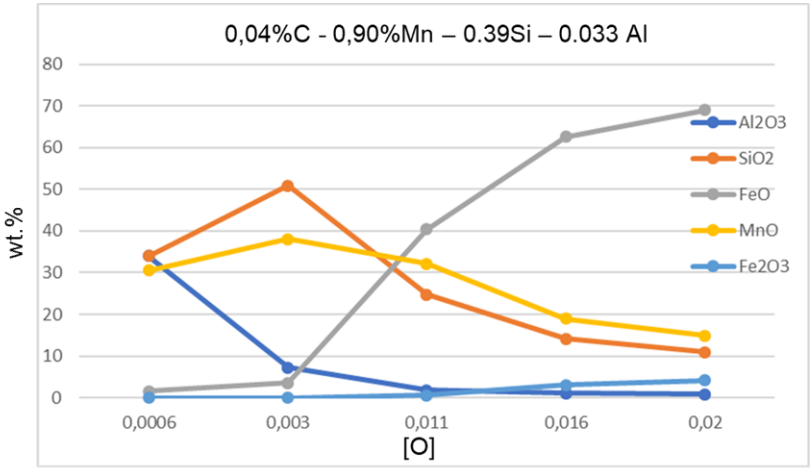


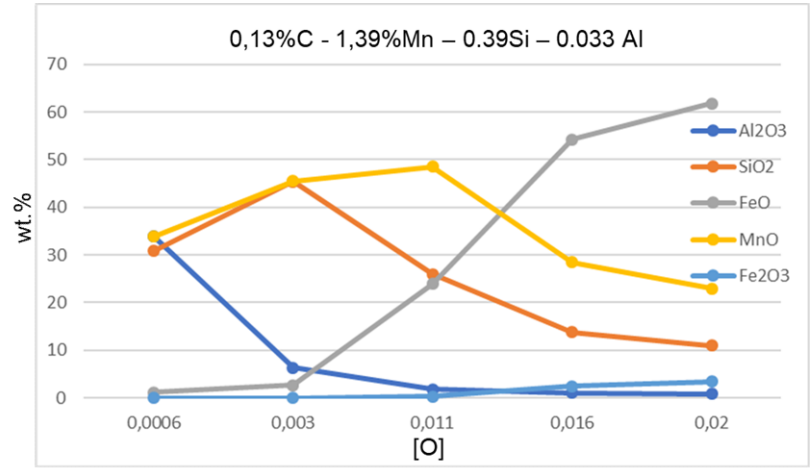
Slag formation and internal oxidation



Slag formation and internal oxidation



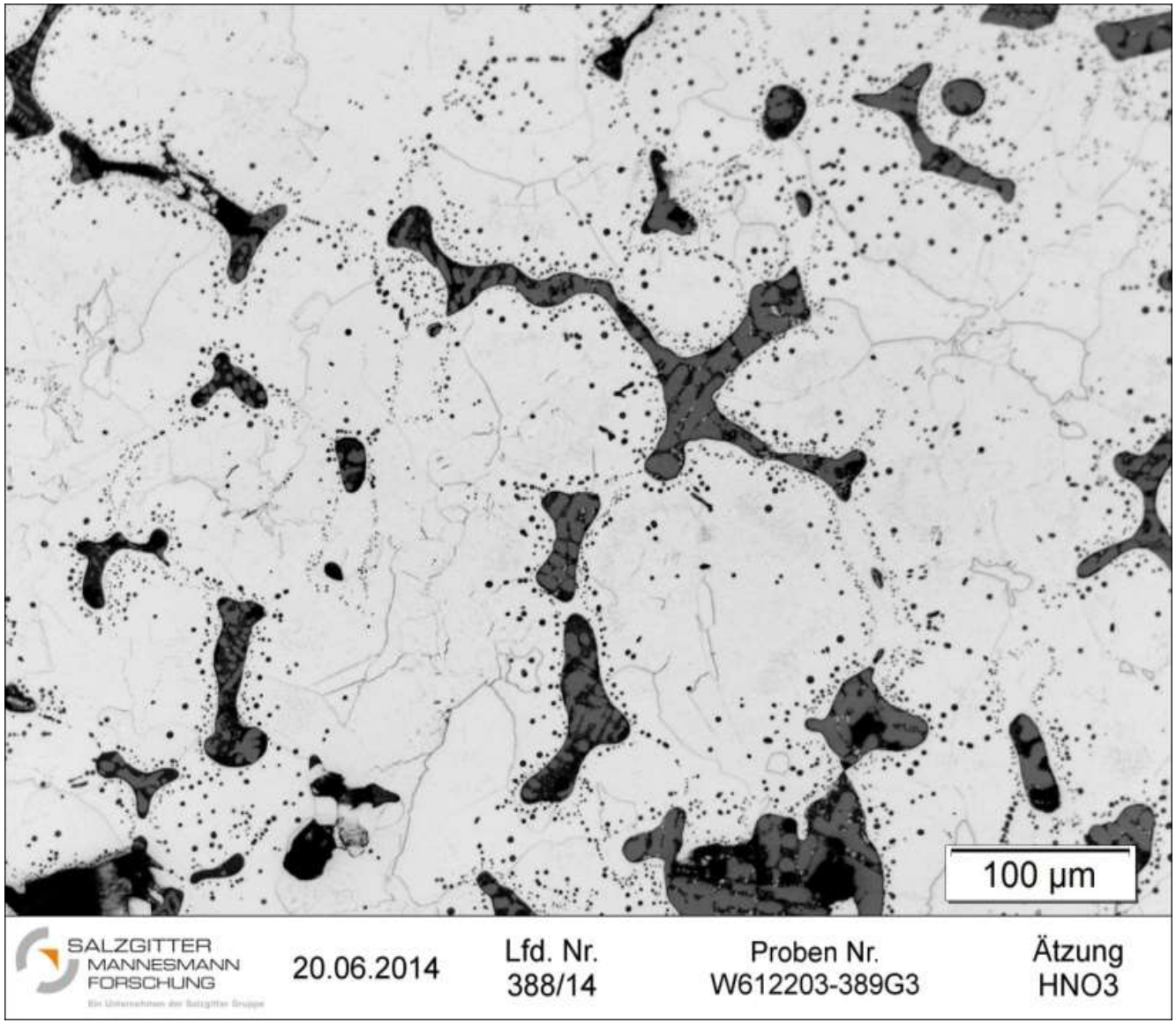




- Decreasing viscosity with increasing [O]

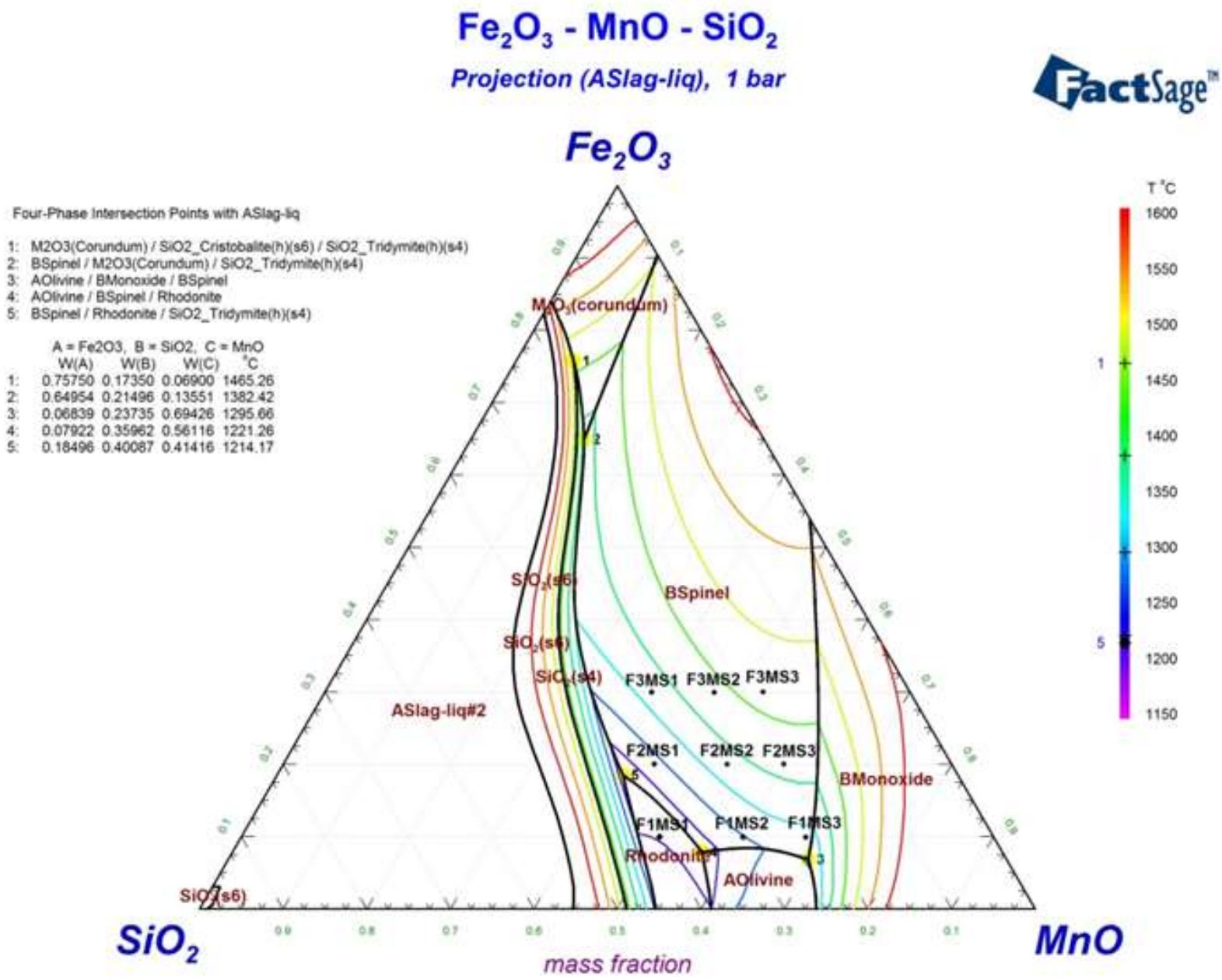
Slag formation and internal oxidation

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe



Slag formation and internal oxidation

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe



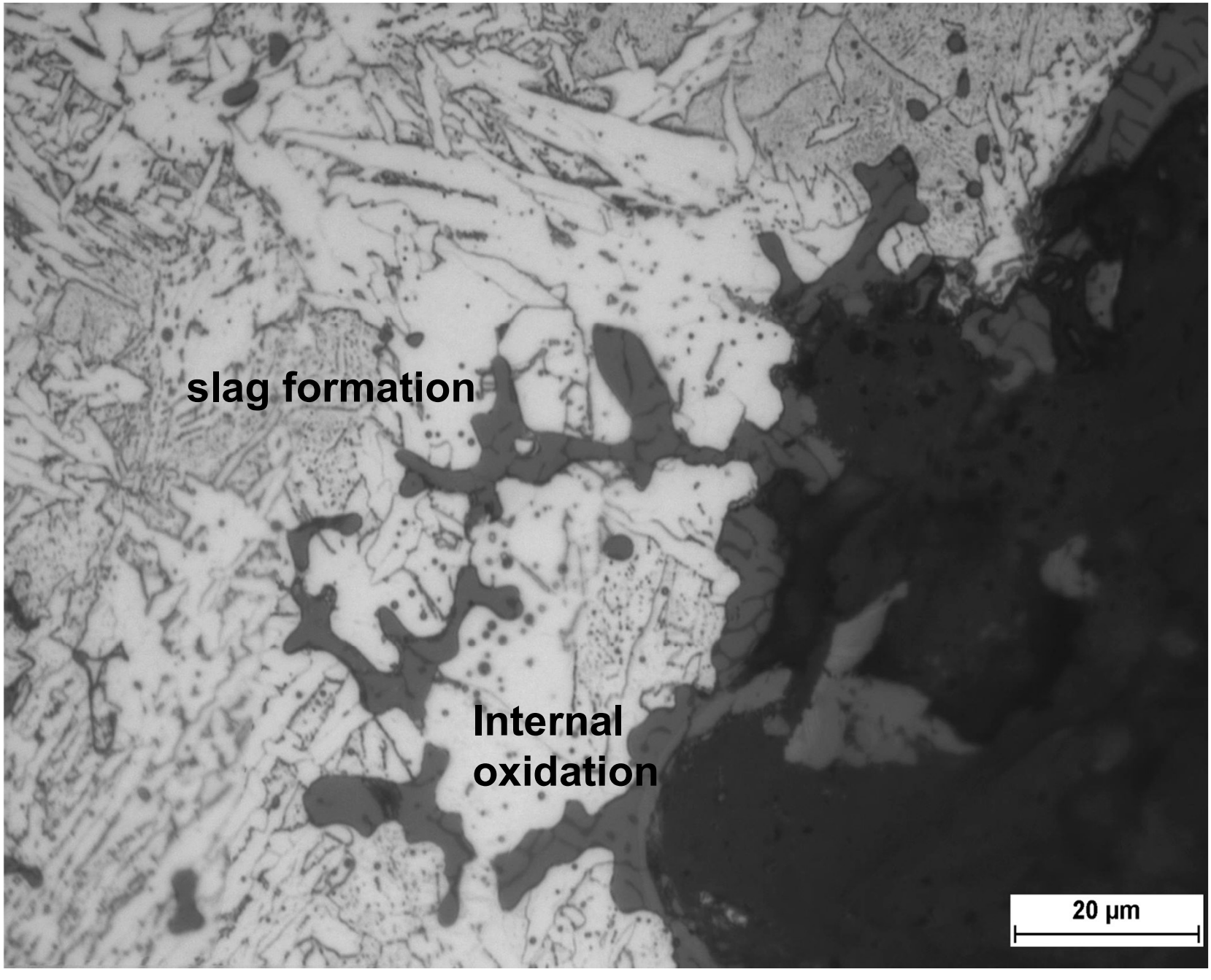
Slag formation and internal oxidation

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe

	Slag composition		
Slag	Fe_2O_3 [Gew. %]	MnO/SiO_2	melting point (FactSage) [°C]
F1MS1	10	1,25	1248
F1MS2	10	2,00	1296
F1MS3	10	3,00	1335
F2MS1	20	1,25	1299
F2MS2	20	2,00	1377
F2MS3	20	3,00	1413
F3MS1	30	1,25	1367
F3MS2	30	2,00	1436
F3MS3	30	3,00	1465

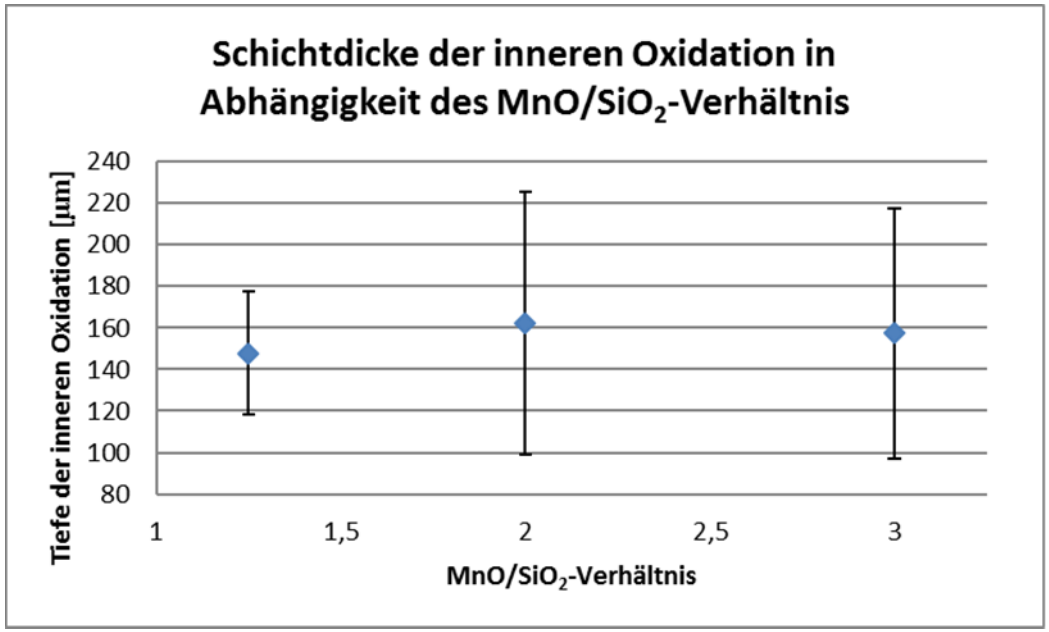
Slag formation and internal oxidation

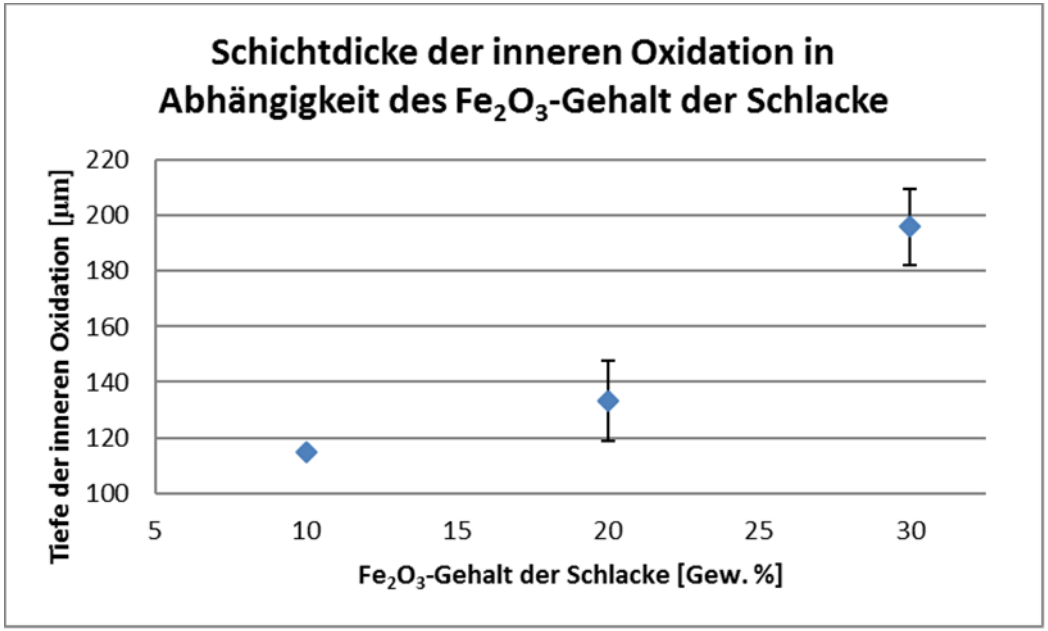
SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe



Slag formation and internal oxidation

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe





Summary

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe

- During melting of the metal a phase separation takes place
- Upon phase seperation ferrite and a Mn-Si enriched melt ist formed
- This melt oxidises to a liquid slag, which penetrates the grain boundaries
- The slag is rich in MnO and SiO2 at the beginning with high viscosity
- With ‚time' the slag becomes more rich in FeOx and the vicosity decreases
- The ‚FeOx' rich slag deliveres oxygen for internal oxidation

Open unsolved questions

SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe

- Is water vapour influencing the melt viscosity ?
- How can oxygen diffusion in the slag be simulated ?
- The role of Al2O3 is unclear. In may slags Al2O3 particles are found…