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AEROSPACE TECHNOLOGY CONGRESS 2019
SUSTAINABLE AEROSPACE INNOVATION IN A GLOBALISED WORLD
FT2019

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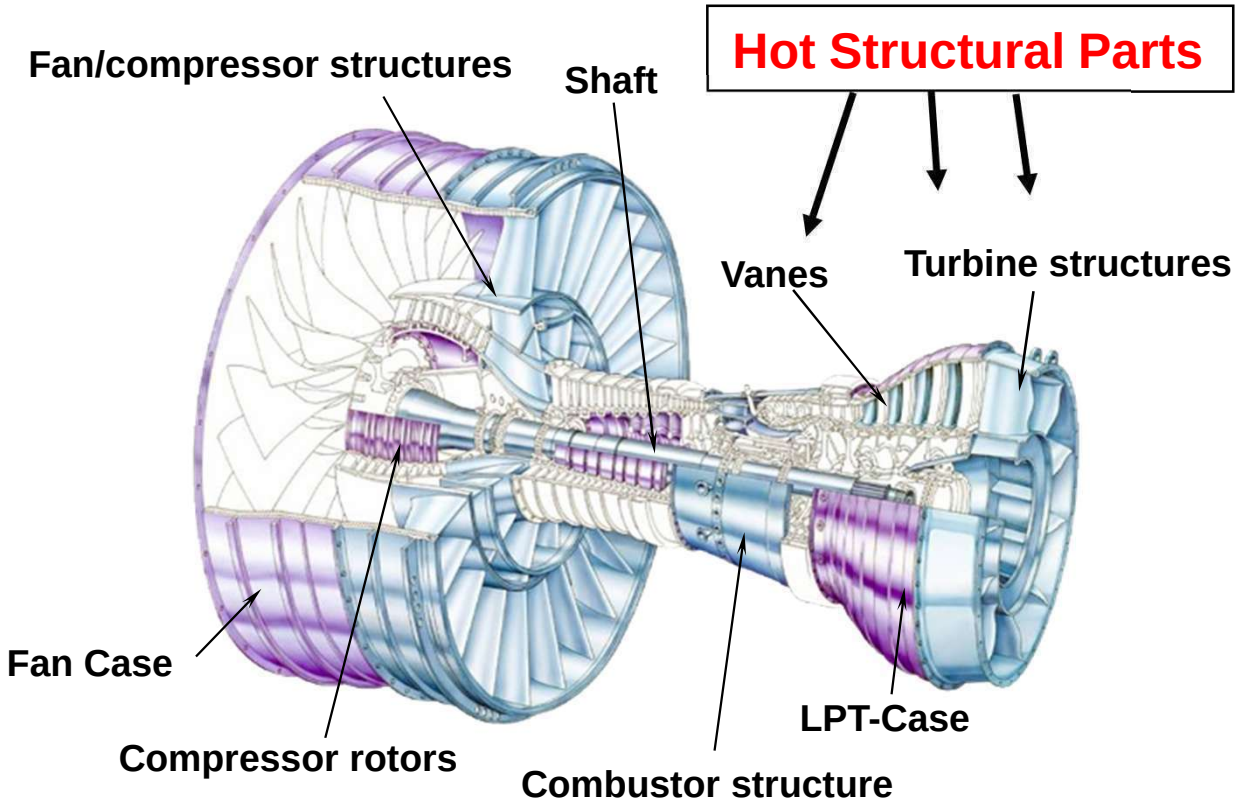
GKN AEROSPACE

Weld Cracking in a Cast Ni-based Superalloy

Sukhdeep Singh[1], **Joel Andersson**[2]

1. Department of Industrial and Materials Science, Chalmers University of Technology, Sweden
2. Department of Engineering Science, University West, Sweden

Introduction



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Cast Haynes® 282®

	Strengthening phase	Segregating phase
Haynes® 282®	***γ´ (gamma prime)***	***Mo-enriched***
Alloy 718	*γ´´ (double-prime)*	*Nb-enriched*

	Ni	Fe	Cr	Co	Nb	Mo	Ti	Al	…	Si	B
Cast 282	**Bal.**	**0.1**	**19.4**	**10.2**	**0.1**	**8.4**	**2.12**	**1.5**	**…**	**0.01**	**0.005**
Cast 718	52.98	Bal.	18.11	0.07	5.30	2.98	0.99	0.42	…	0.07	0.03

Composition in wt%

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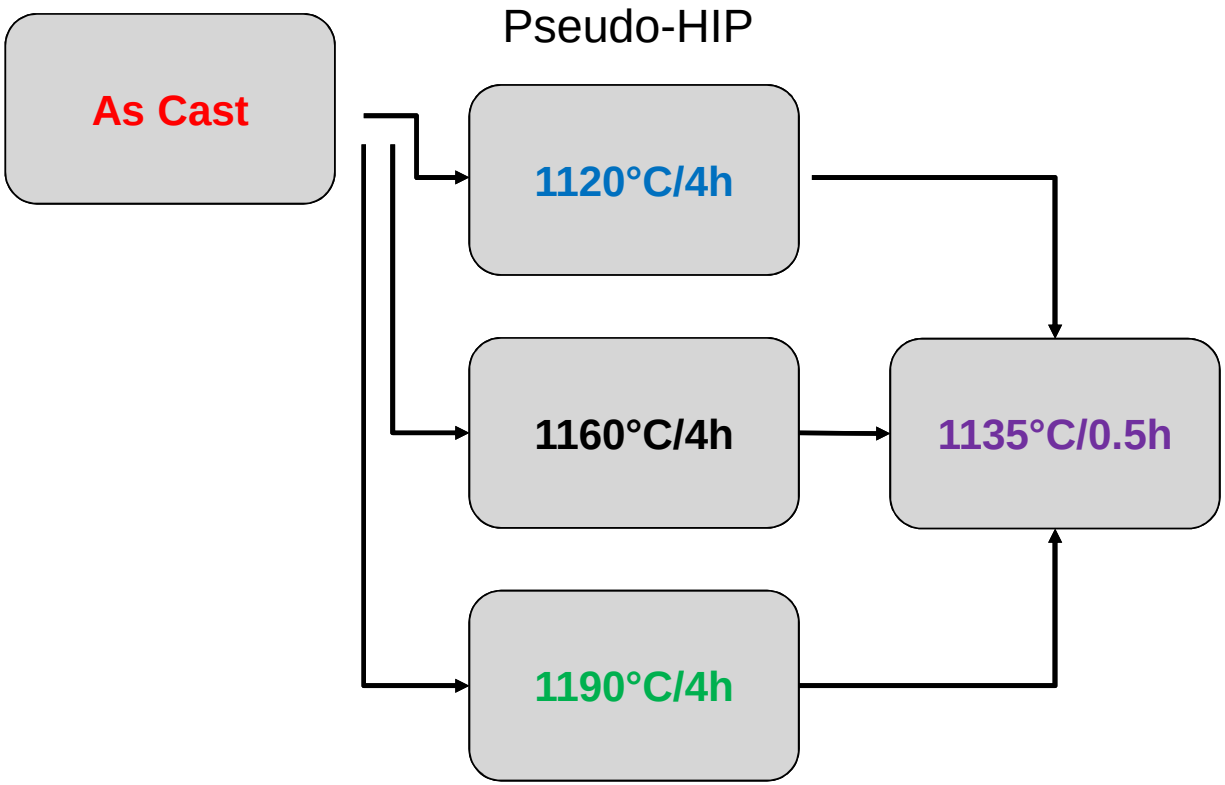
Heat Treatments



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Research Objective

How different heat treatments affect the HAZ liquation cracking susceptibility of cast Haynes® 282® ?

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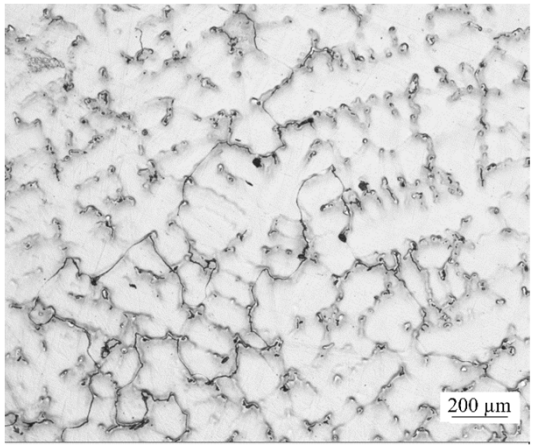
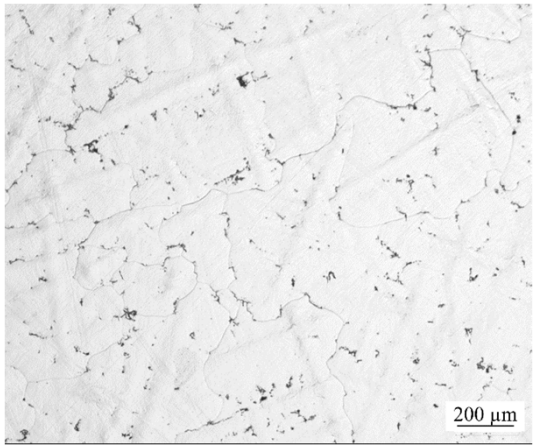
Heat Treatments

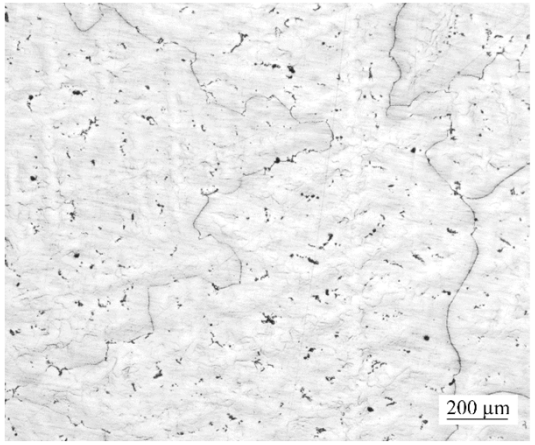
As Cast

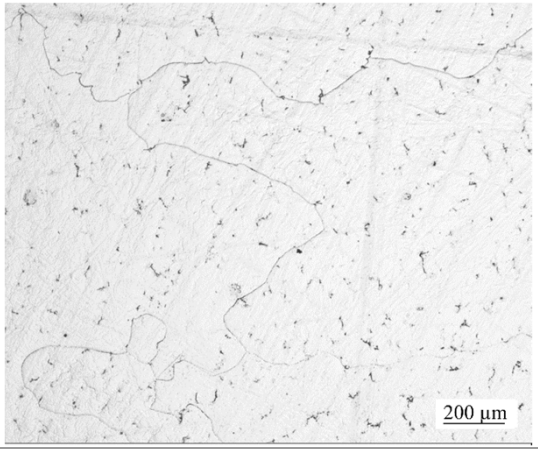




1120°C/4h

1160°C/4h





1190°C/4h

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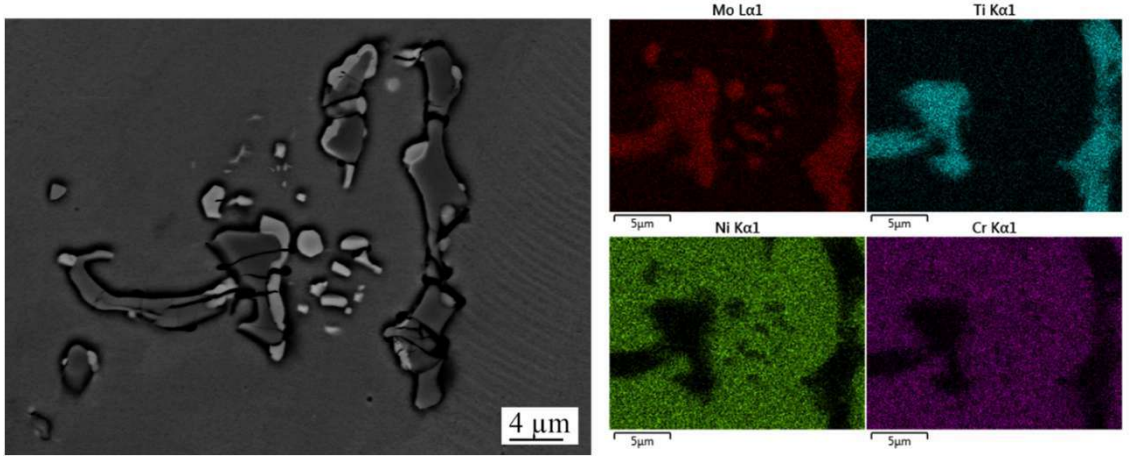
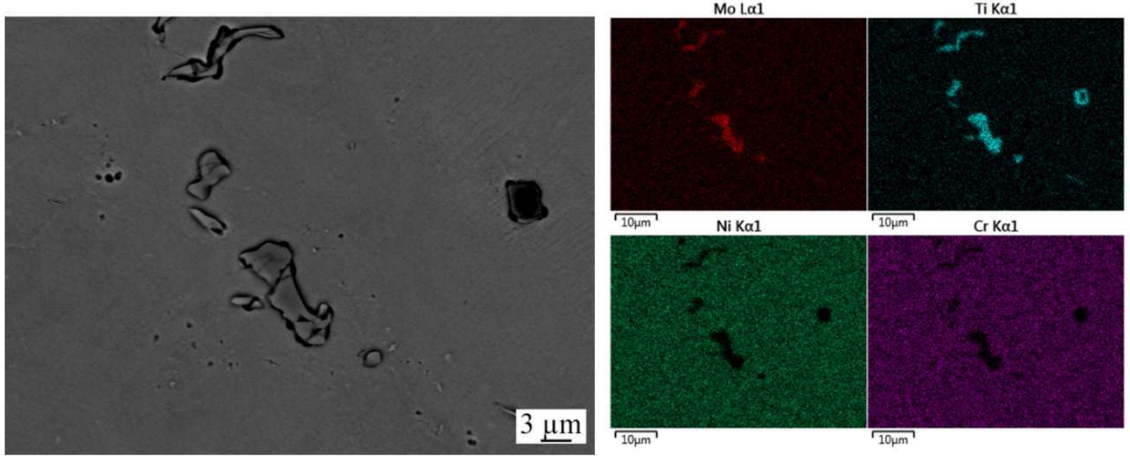
Heat Treatments

1120°C/4h



1190°C/4h



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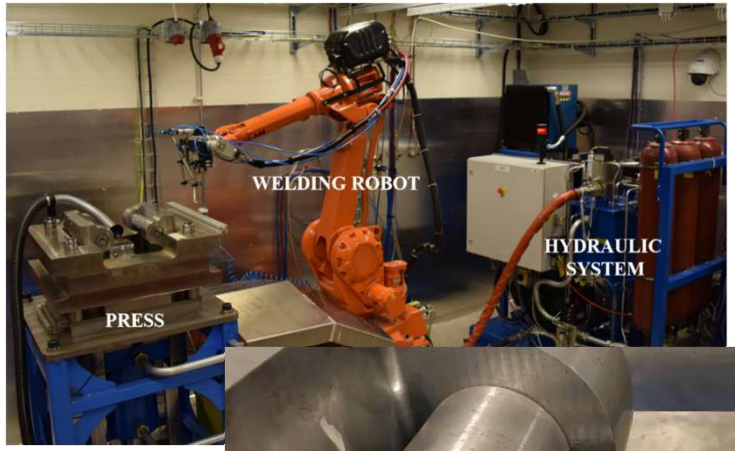
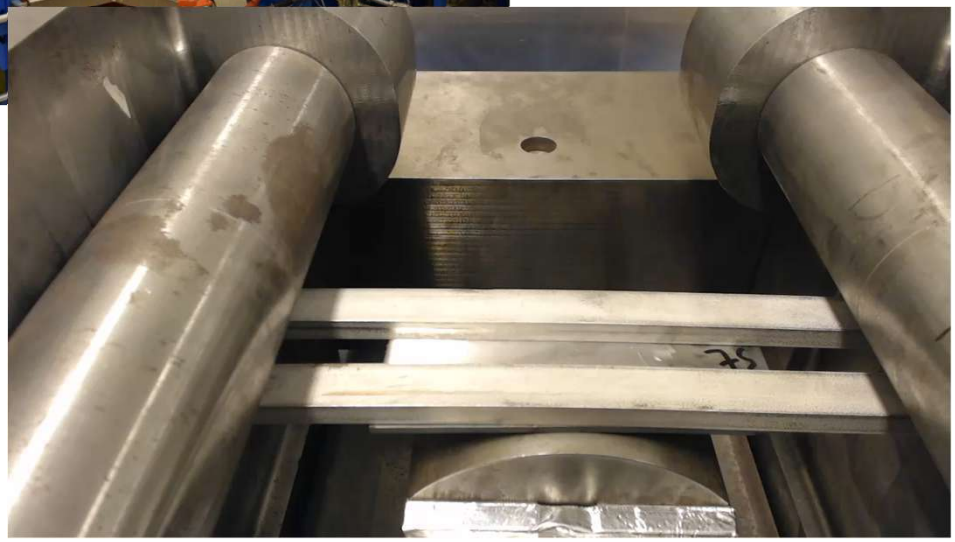
Varestraint Testing





Parameters:

- Welding Speed = 1 mm/s
- Stroke rate = 10 mm/s
- Current = 70 A
- Arc =2 mm
- Ar gas flow = 15 l/min

- Radii: 60,100,150 (mm)

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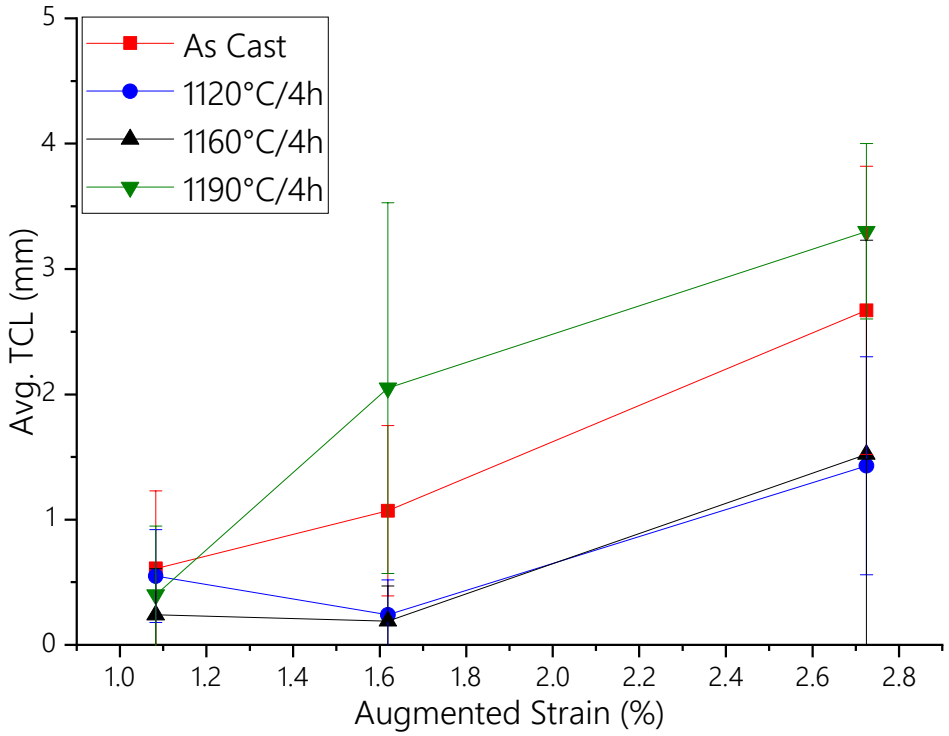
HAZ Cracking



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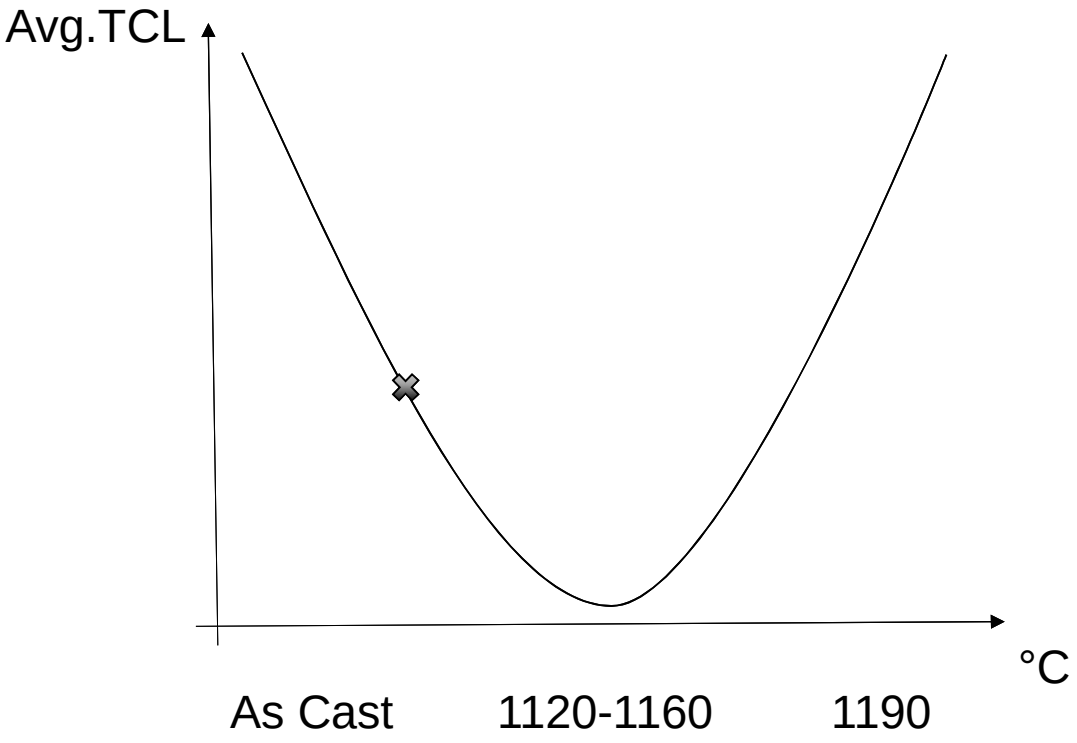
HAZ Cracking



	As Cast	1120°C/4h	1160°C/4h	1190°C/4h
GS	1.6±0.4	1.5±0.2	1.6±0.3	1.6±0.2
HV	245±40	215±10	230±20	220±10
Vv%	1.5±0.2	0.9±0.1	0.7±0.1	0.5±0.1

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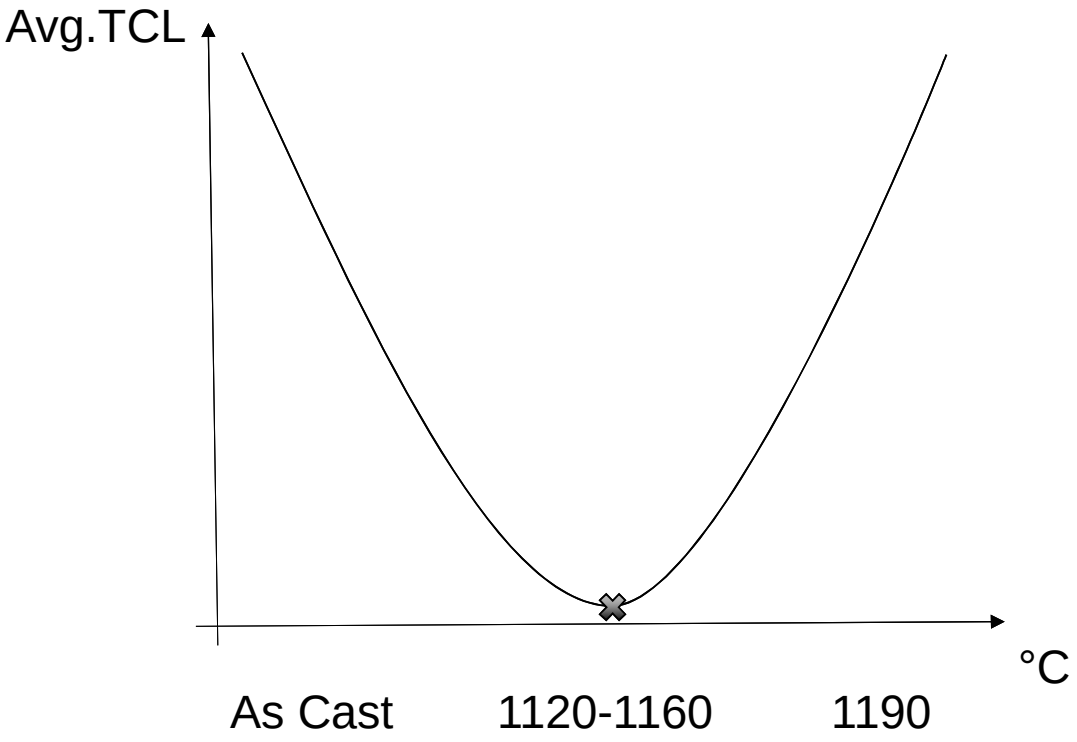
HAZ Cracking



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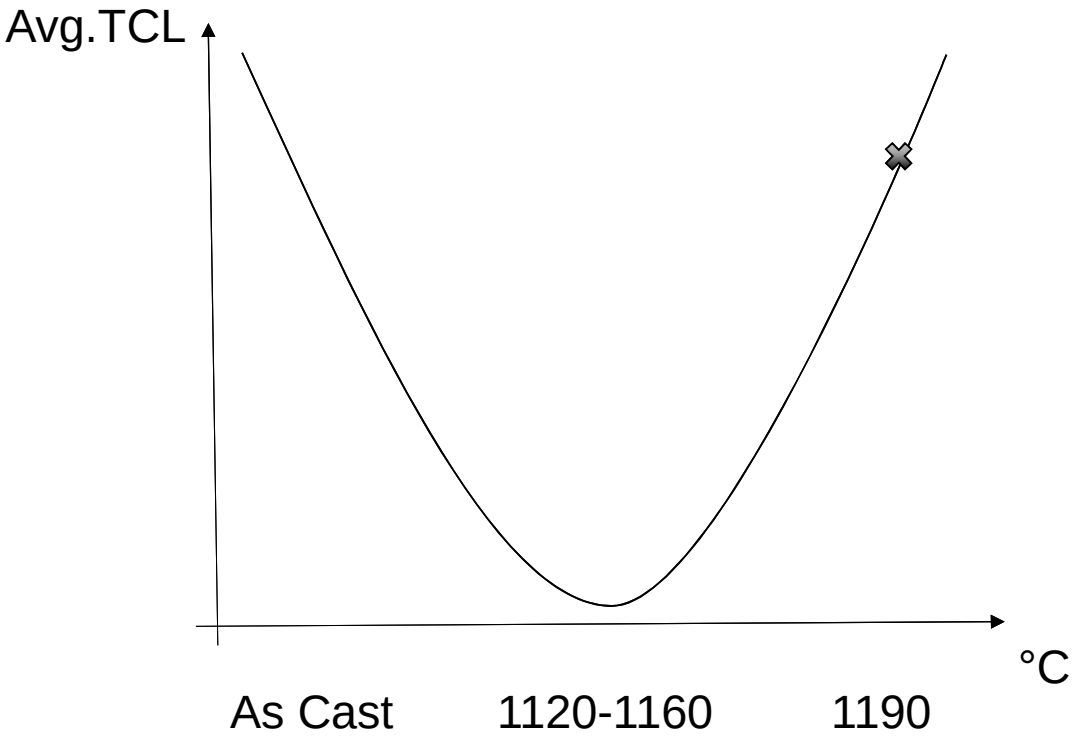
Vv%	1.5±0.2	0.9±0.1	0.7±0.1	0.5±0.1

HAZ Cracking



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GS	1.6±0.4	1.5±0.2	1.6±0.3	1.6±0.2
HV	245±40	215±10	230±20	220±10
Vv%	1.5±0.2	0.9±0.1	0.7±0.1	0.5±0.1

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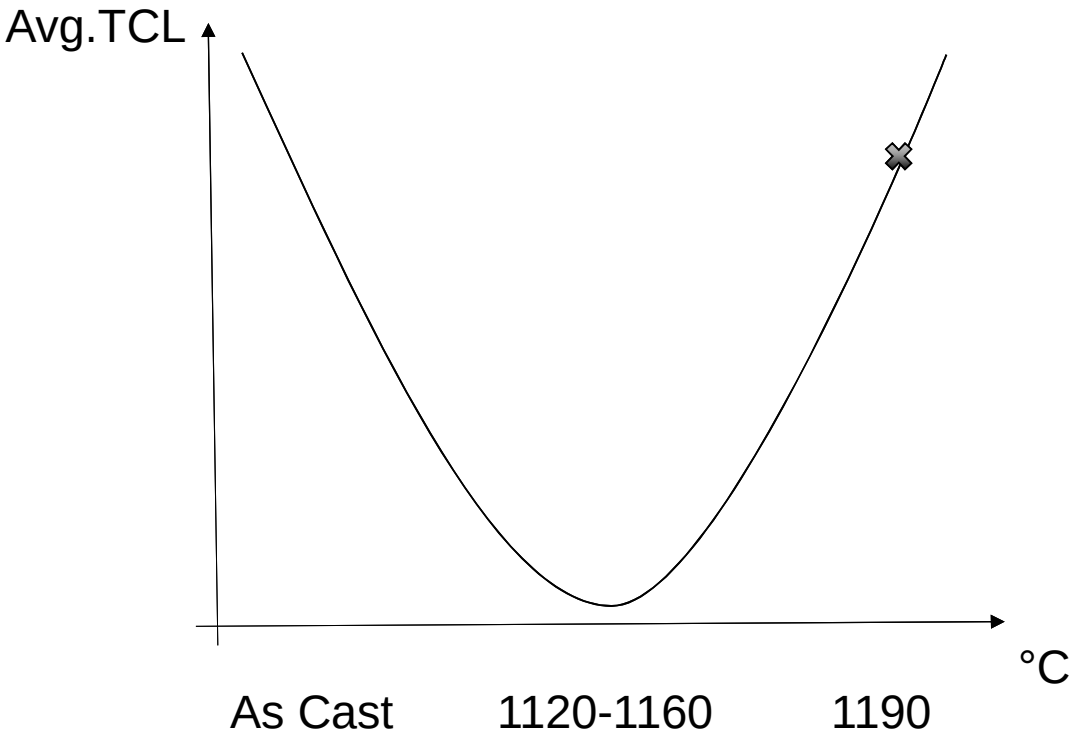
HAZ Cracking



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GS	1.6±0.4	1.5±0.2	1.6±0.3	1.6±0.2
HV	245±40	215±10	230±20	220±10
Vv%	**1.5±0.2**	**0.9±0.1**	**0.7±0.1**	**0.5±0.1**

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NanoSIMS Analysis

- Objective :
  - Primary : recorded B distribution in grain boundaries, variations among heat treatments
  - Secondary : Si and P imaging

- Conditions :
  - 1120,1160,1190°C/4h

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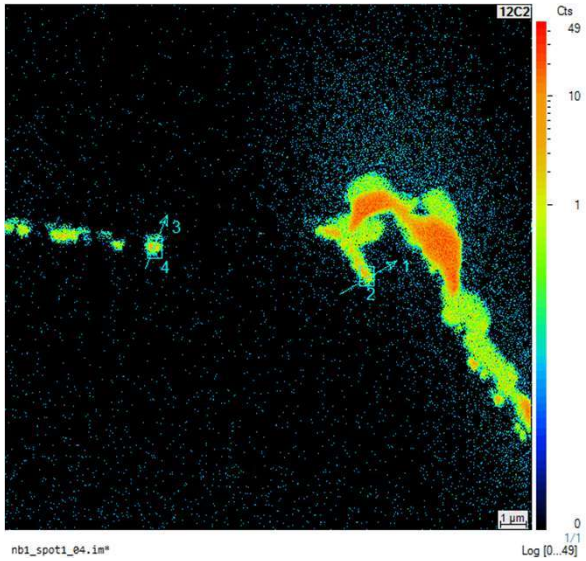
NanoSIMS analysis at 1120°C

Carbon



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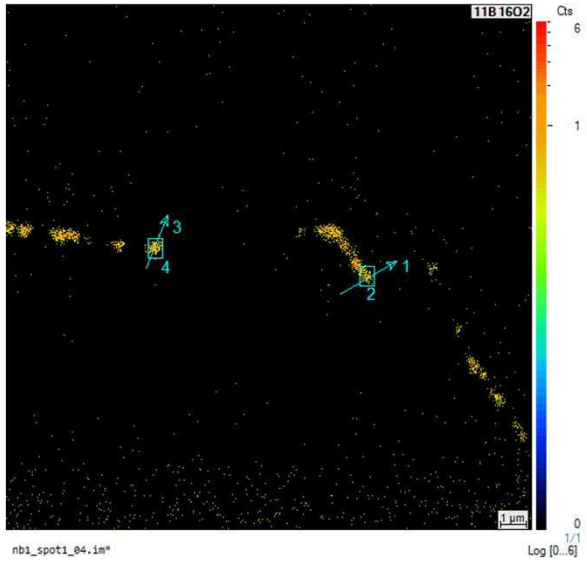
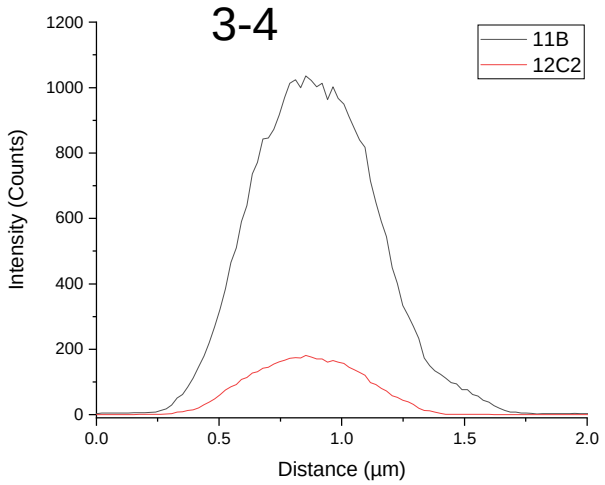
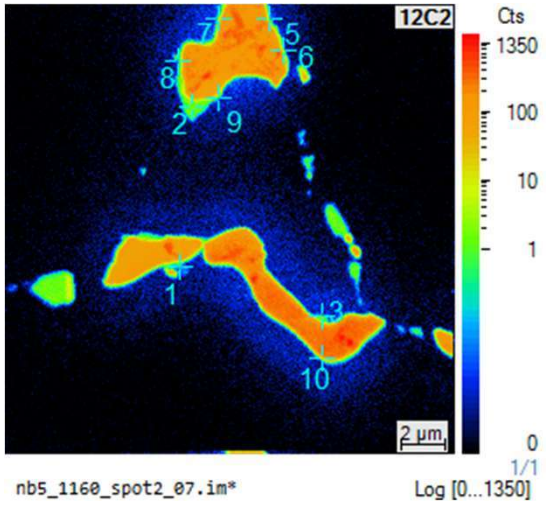




NanoSIMS analysis at 1160°C

Carbon



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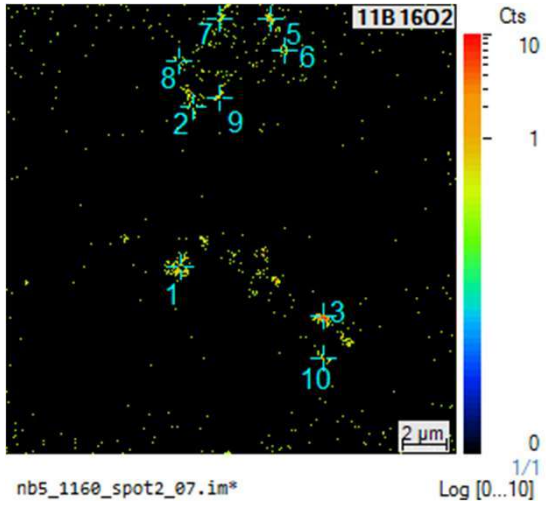

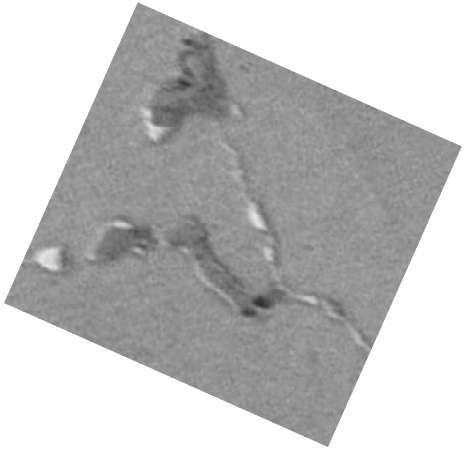

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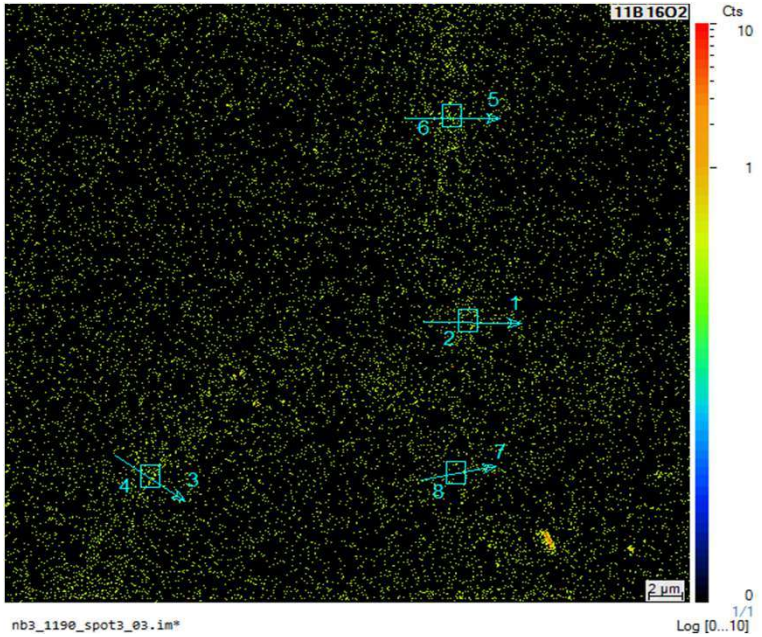
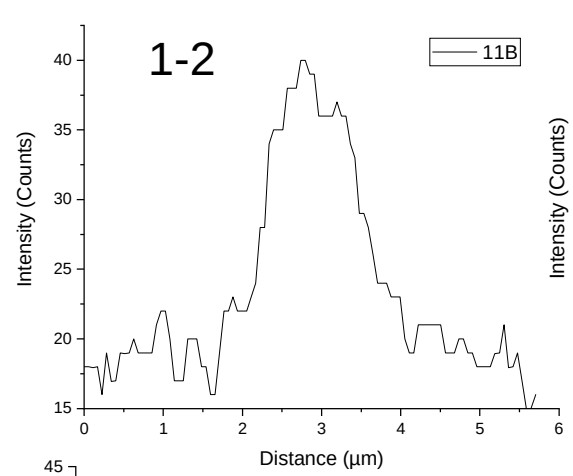
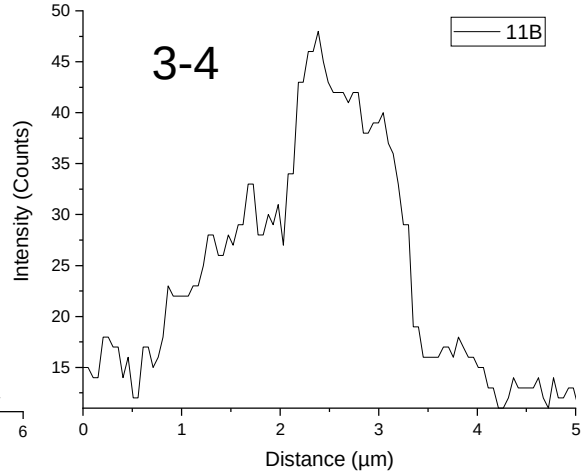
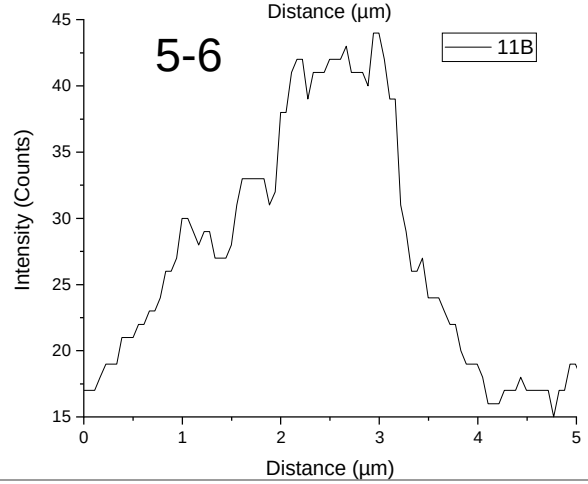
NanoSIMS analysis at 1190°C









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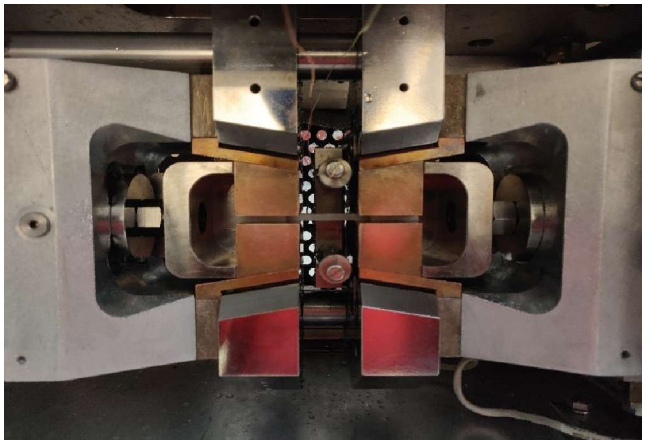
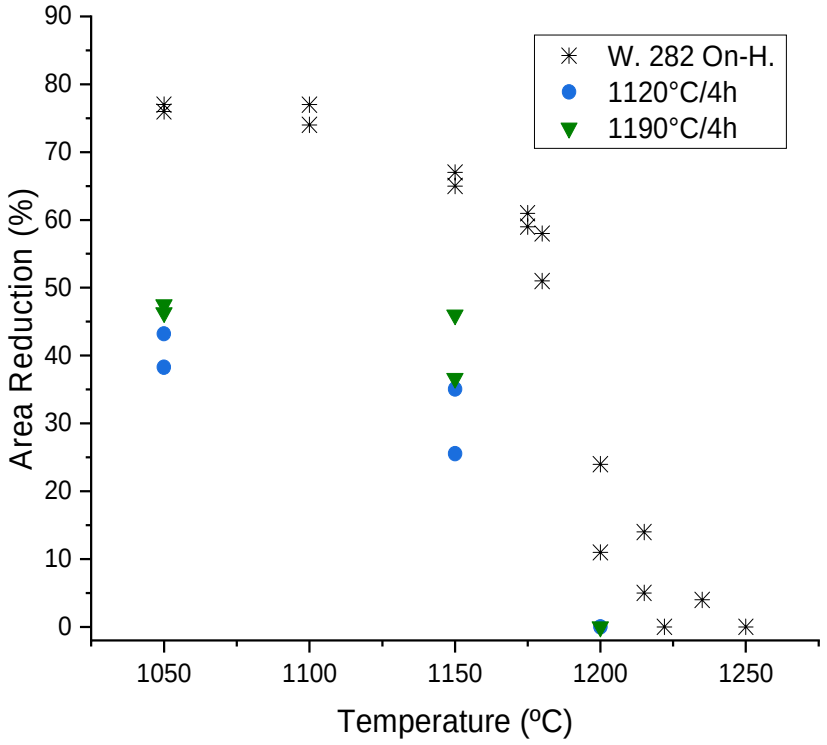
Hot Ductility - On Heating



Gleeble Parameters:

- Heating rate 111 °C/s
- Peak temperature 1200 °C
- Stroke rate 55 mm/s
- Holding time at peak temperature 0.03 s
- Holding time at test temperature 0.03 s



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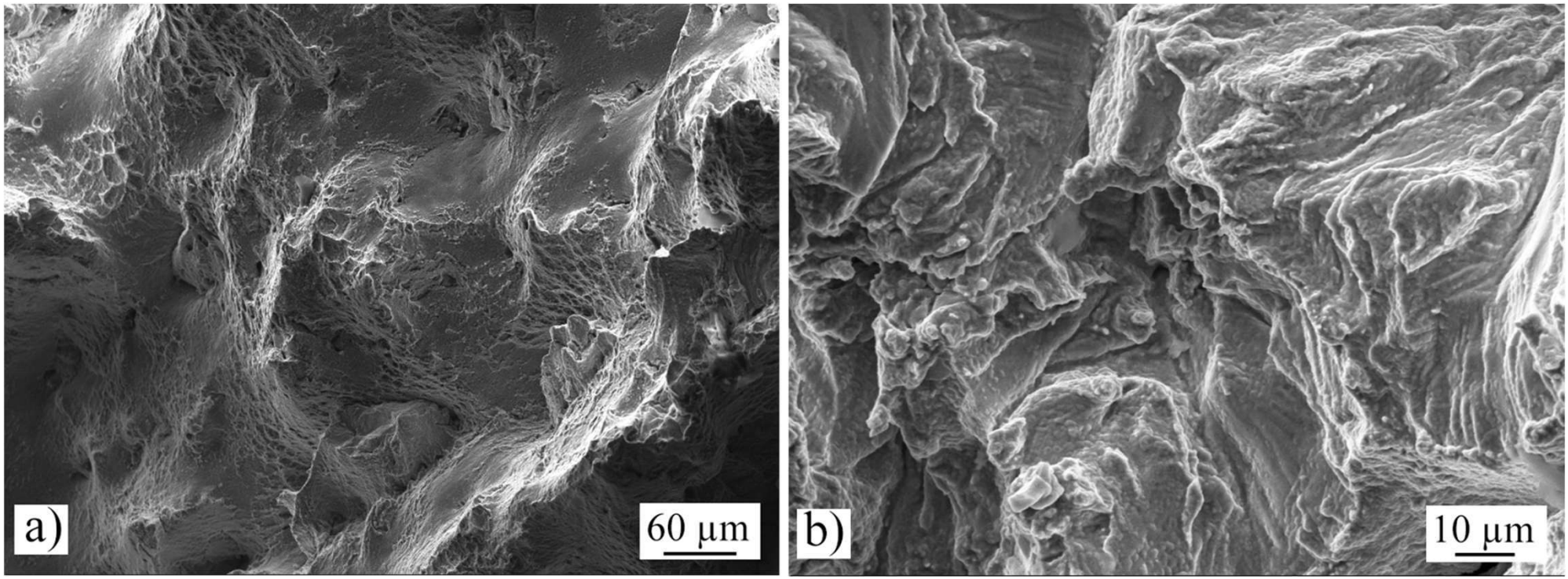
Hot Ductility - On heating at 1150°C



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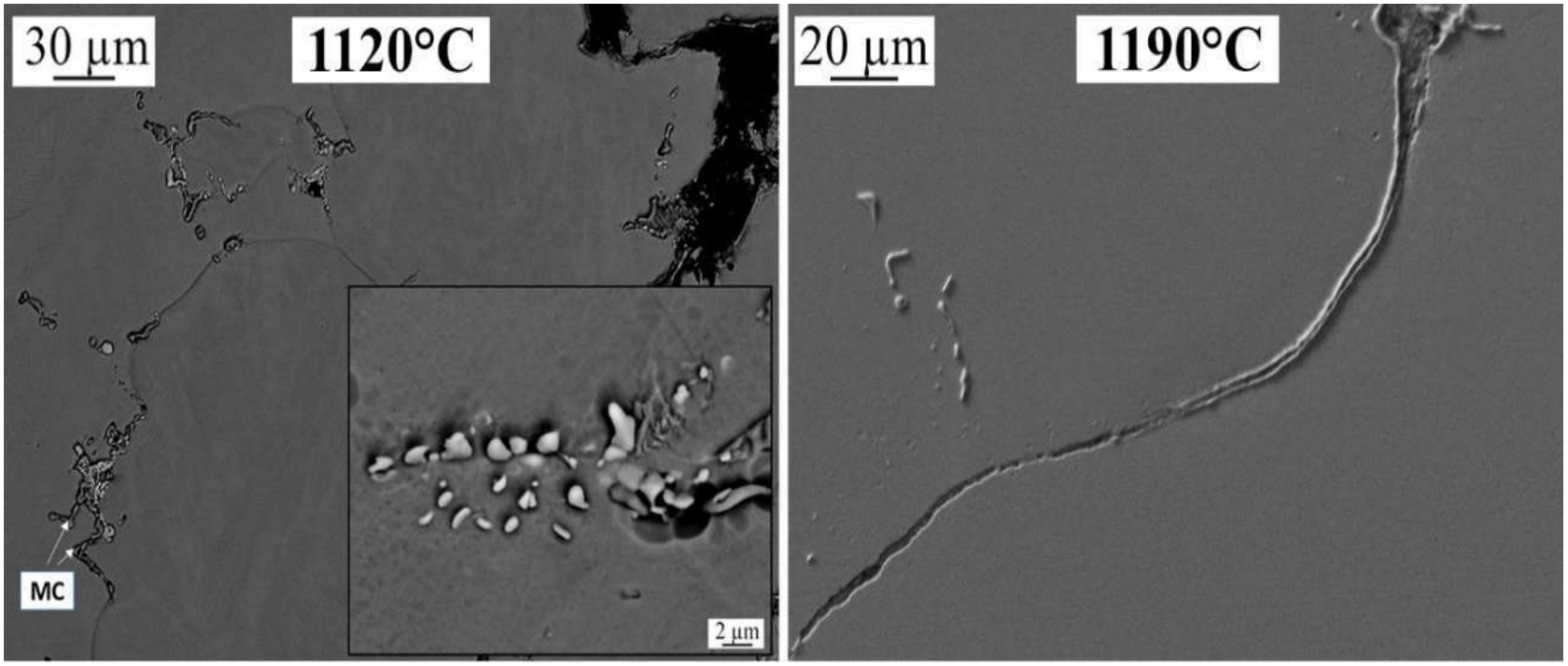
Hot Ductility - On heating at 1200°C



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Summary

- Ranking according to Varestraint weldability study:
  - 1190°C/4h higher cracking
  - 1120-1160°C/4h lower cracking sensivity

- NanoSIMS analysis:
  - B is found only in compound at 1120° and 1160° together with C
  - B segregates at the grain boundaries at 1190°
  - Complete dissolution of C-B particles and the segregation at the grain boundaries contributed to exacerbated HAZ cracking

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Thank You!

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Equilibrium vs Non-Eq. Segregation

- Occurs when a material is held at high temperature sufficiently long to permit appreciable diffusion of solute atoms from the matrix to the grain boundaries
- Decreases with increasing temperature

- Occurs during cooling from high temperature due to diffusion of vacancy-solutes to vacancy sinks
- Increases with increasing temperature

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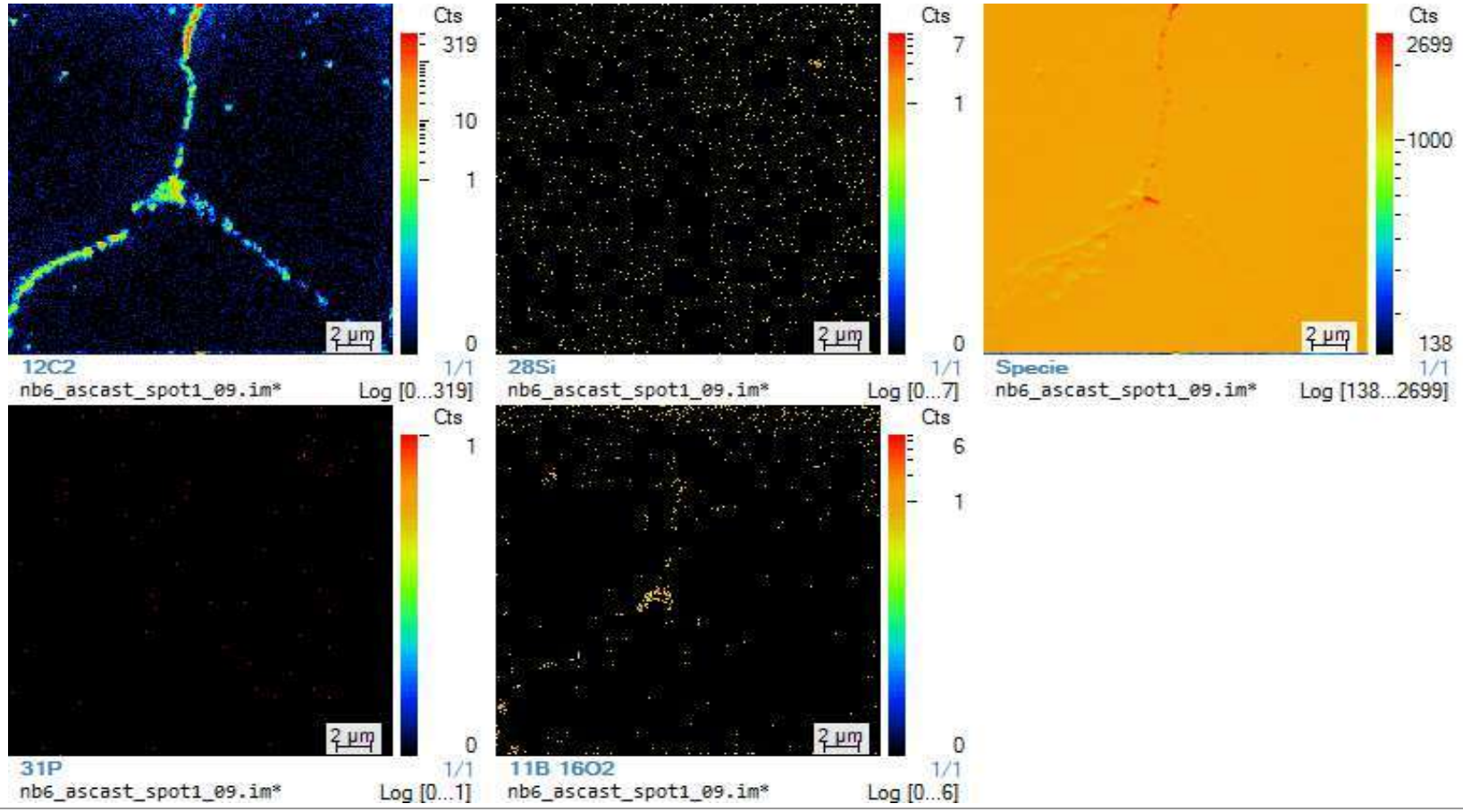
NanoSIMS analysis at As cast



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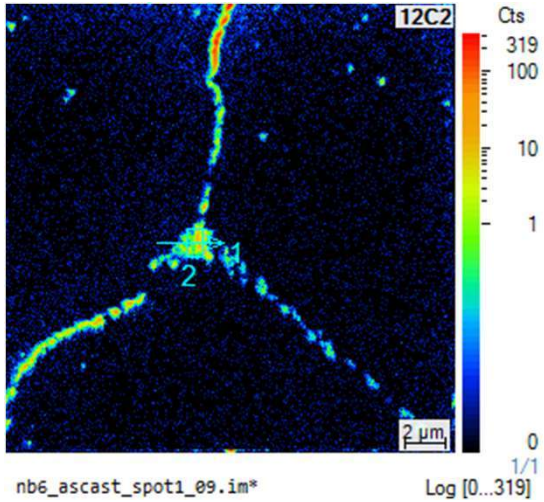
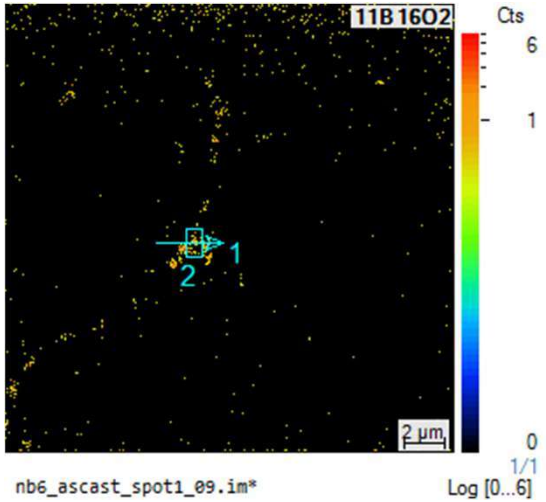
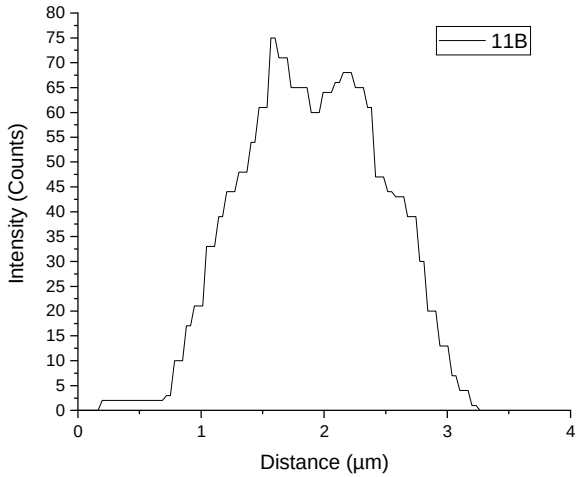
NanoSIMS analysis at As Cast







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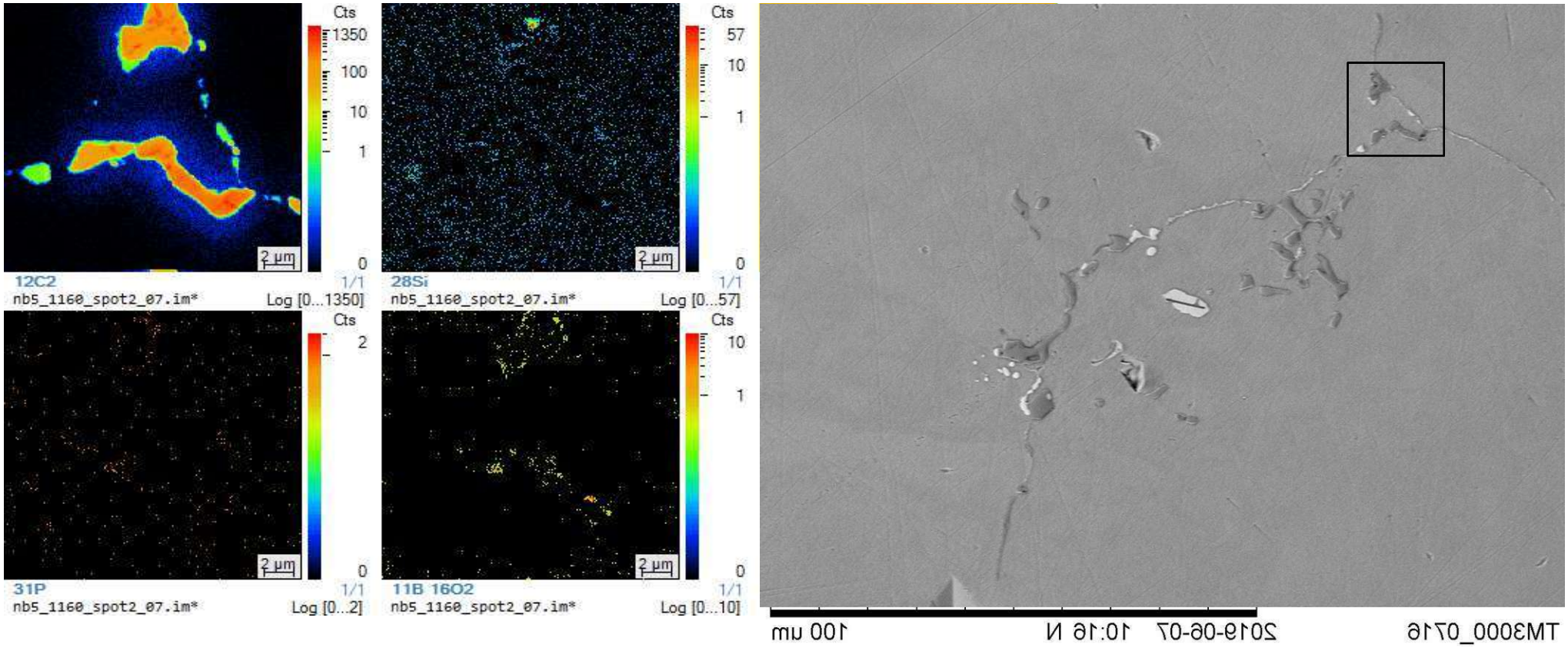
NanoSIMS analysis at 1160°C



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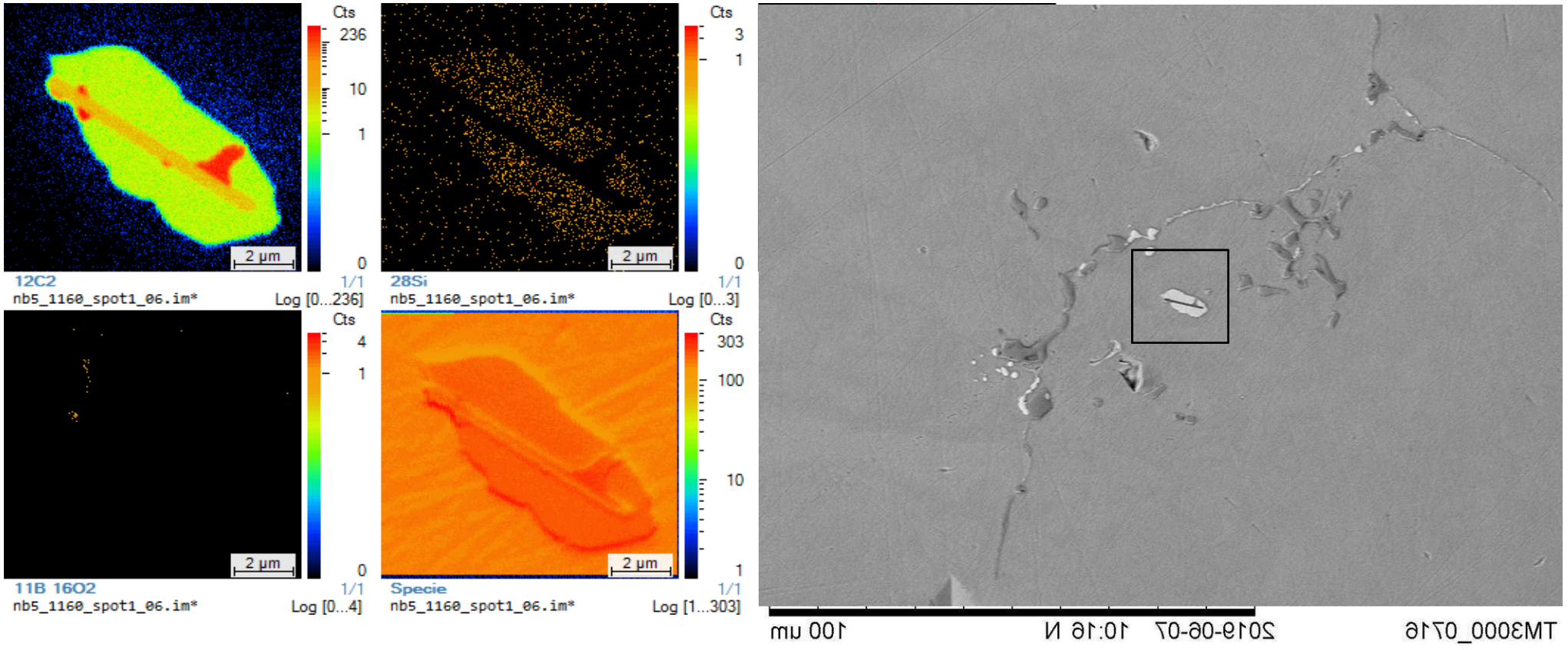
NanoSIMS analysis at 1160°C



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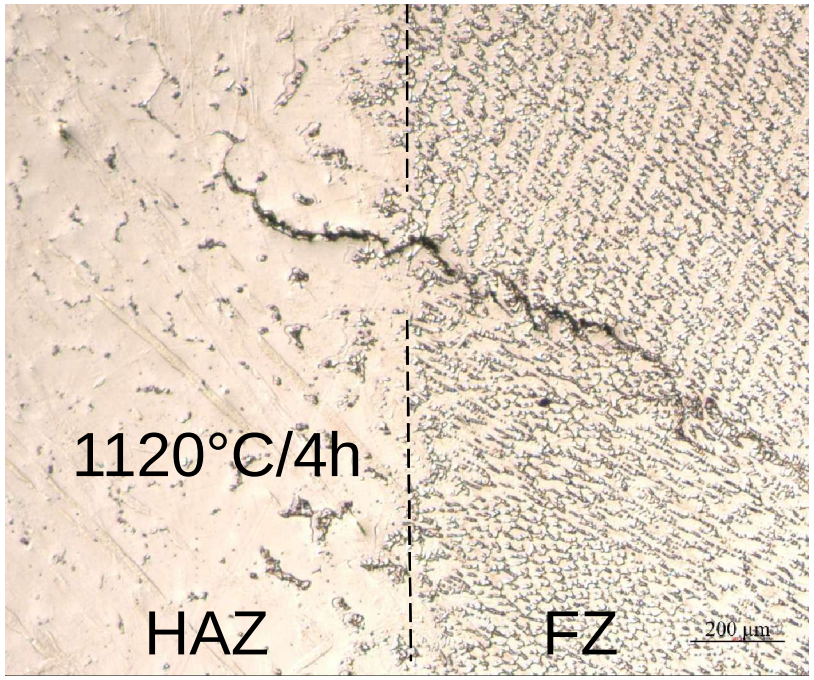
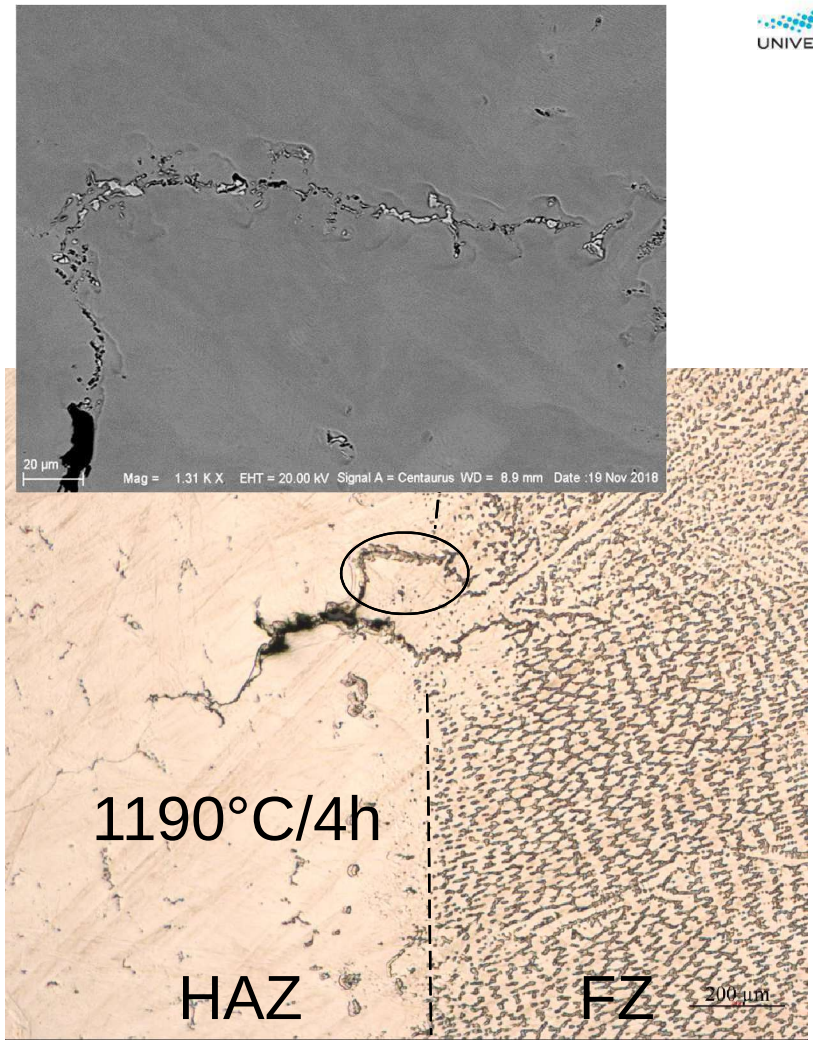
HAZ Cracking





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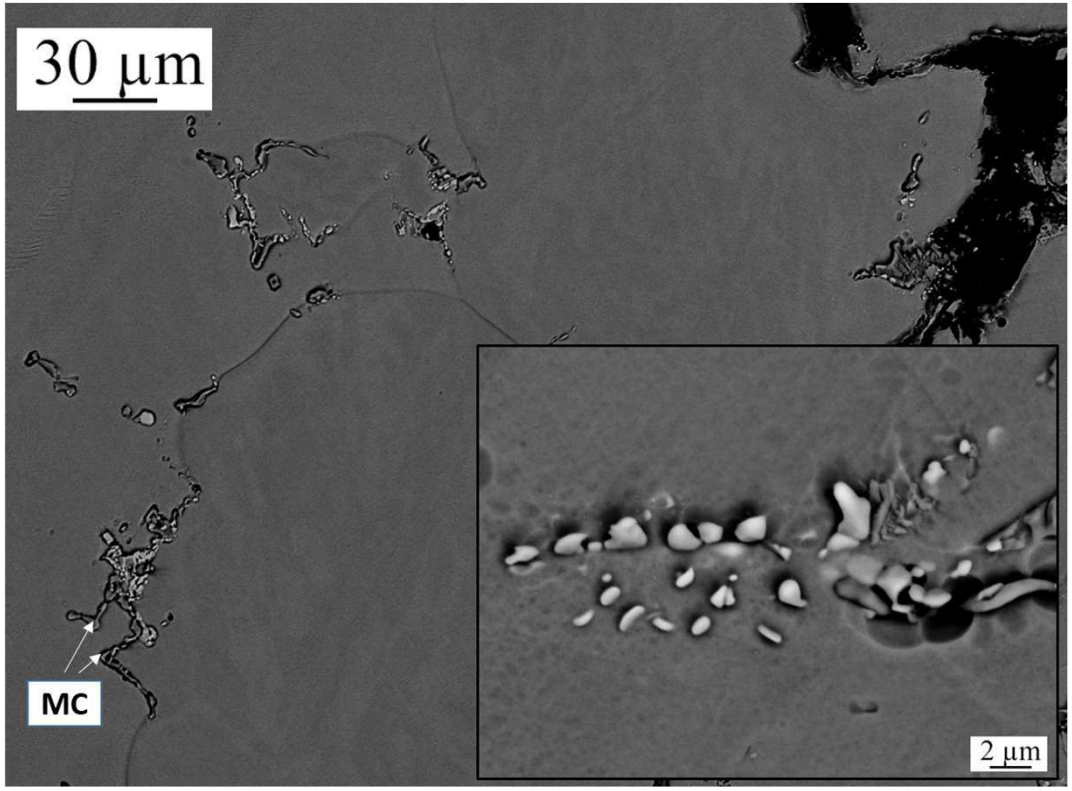
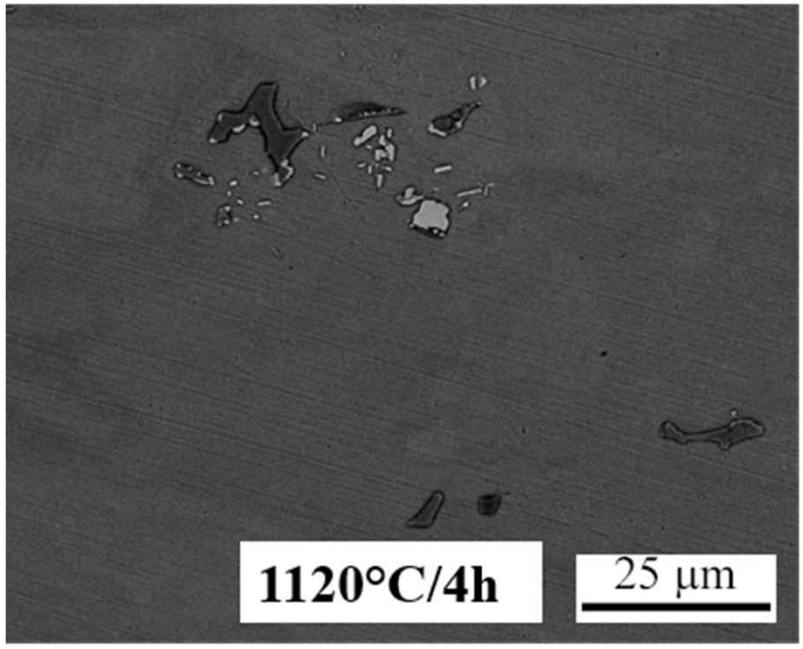
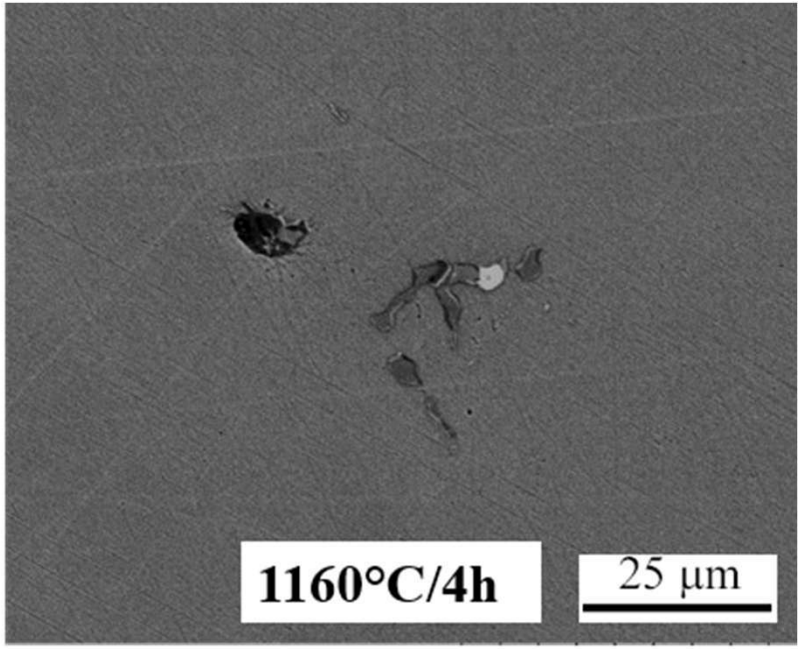
Hot Ductility - On heating at 1200°C



1120°C/4h

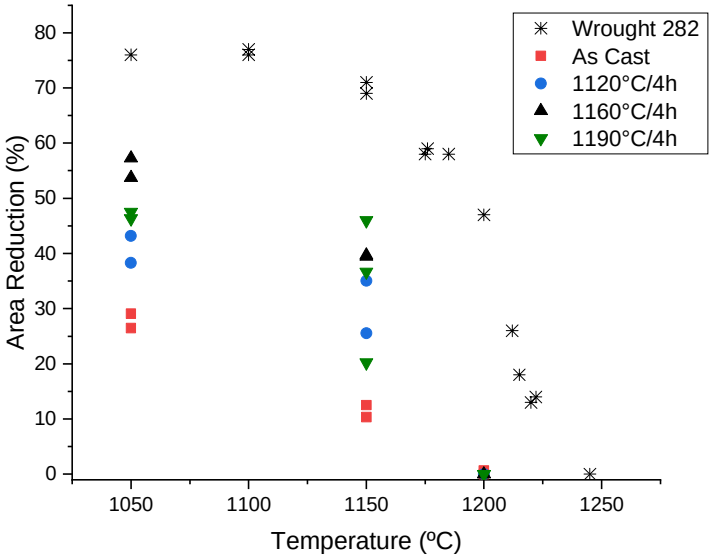
Mo-rich precipitates





	As Cast	1120°C/4h	1160°C/4h	1190°C/4h
Vv Mo(%)	0.14±0.2	0.31±0.2	0.13±0.2	00±00

On-Heating/On-Cooling f(B)



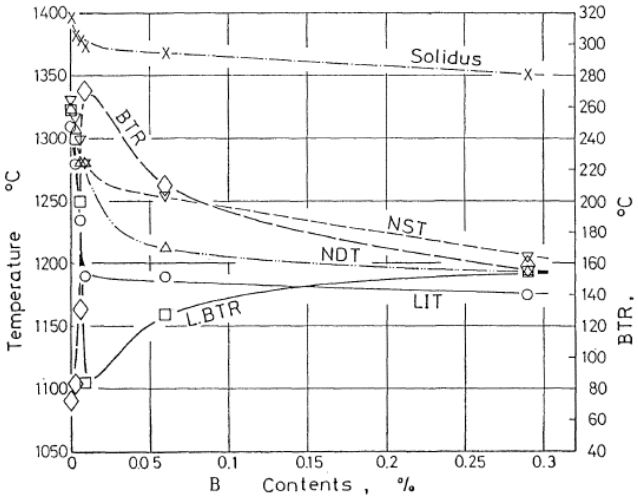
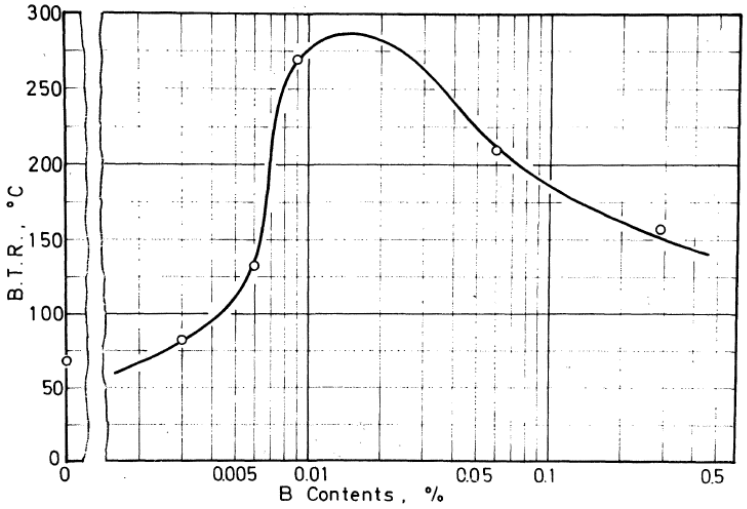
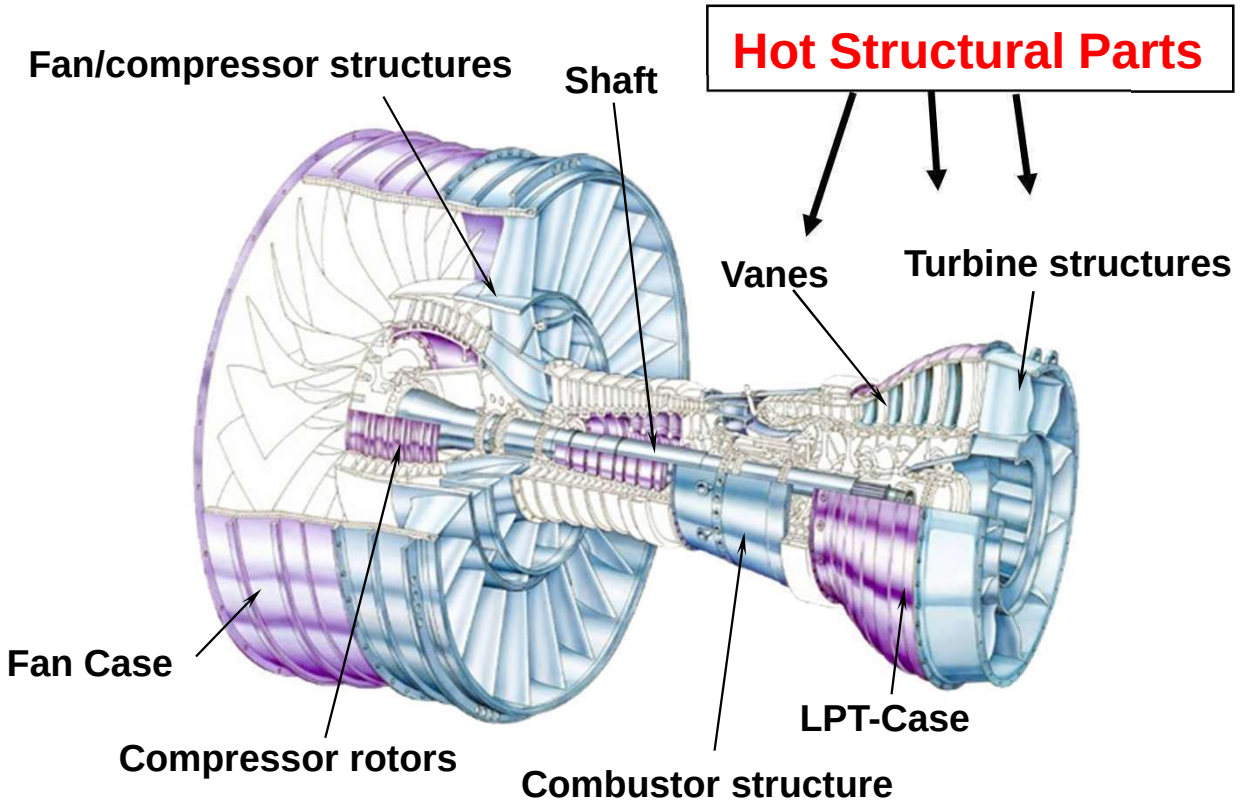


Fig. 8. The effect of B contents on the hot ductility characteristics of Incoloy 800.



Influence of B content on Hot Cracking sensivity of weld heat affected zone in Incoloy 800
Saito et al., Transactions ISIJ, Vol. 27, 1987

Introduction



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Heat Treatments

	Vv%	GS	HV
As Cast	1.5±0.2	1.6±0.4	245±40
1120°C/4h	0.9±0.1	1.5±0.2	215±10
1160°C/4h	0.7±0.1	1.6±0.3	230±20
1190°C/4h	0.5±0.1	1.6±0.2	220±10

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Heat Treatments

	Vv%	Vv Mo%	GS	HV
As Cast	1.5±0.2	0.14±0.2	1.6±0.4	245±40
1120°C/4h	0.9±0.1	0.31±0.2	1.5±0.2	215±10
1160°C/4h	0.7±0.1	0.13±0.2	1.6±0.3	230±20
1190°C/4h	0.5±0.1	00±00	1.6±0.2	220±10

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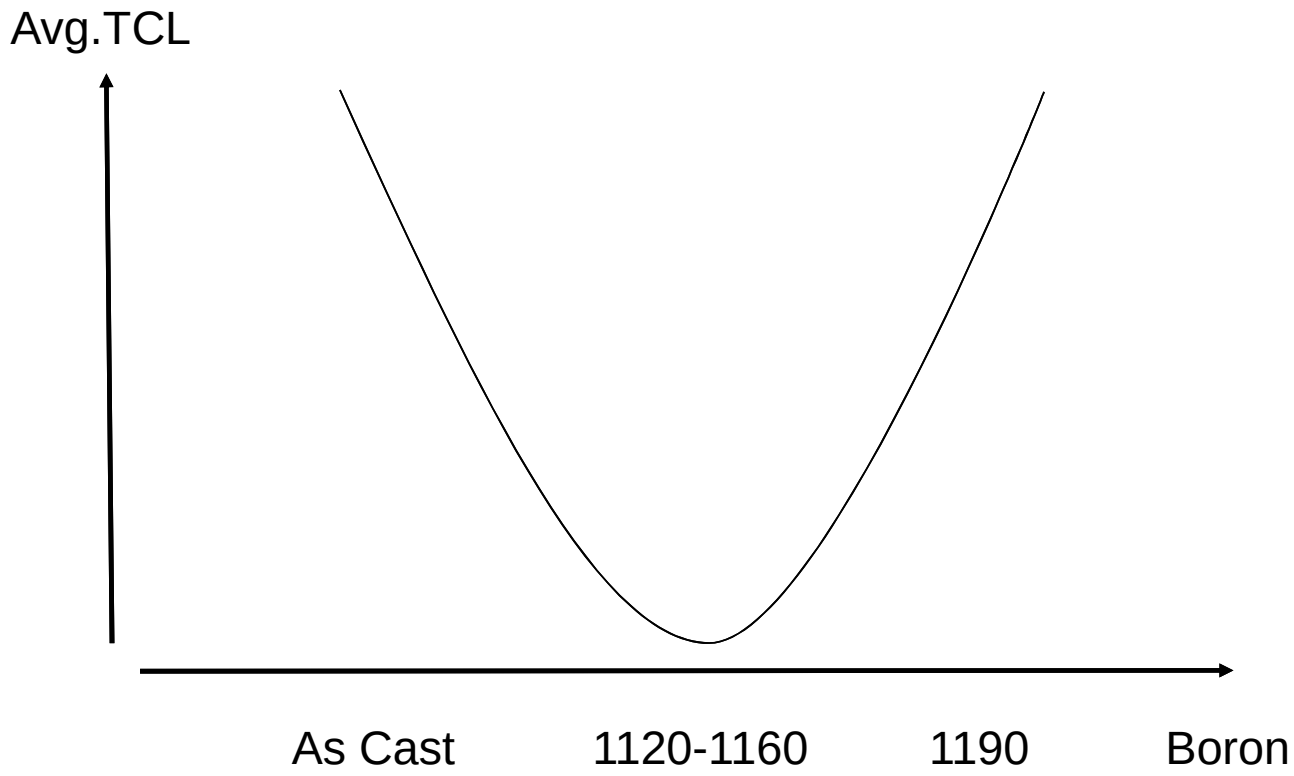
HAZ Cracking



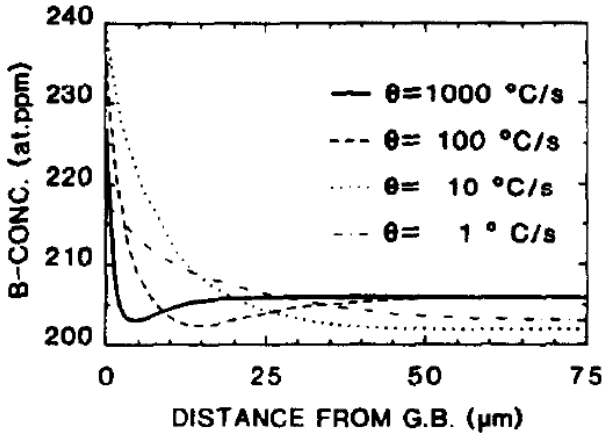


Fig. 3. Simulated segregation profiles in austenite with 206 at. ppm boron after cooling at 1000, 100, 10 and 1°C/s. The starting temperature was 1250°C, the grain size 150 μm and Set 2 (Table 1) parameter values were used.

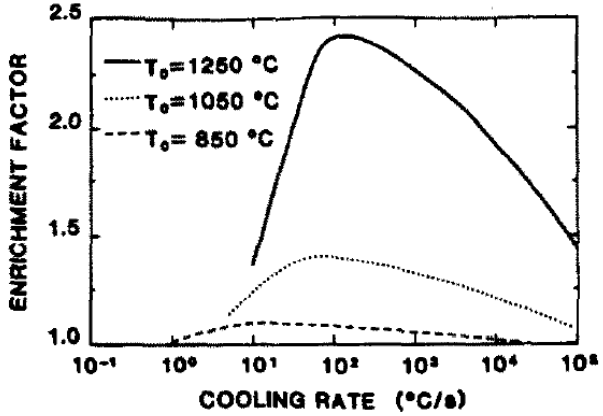


Fig. 8. Calculated enrichment factors i.e. the boron concentration within 375 nm of the boundary divided by the bulk concentration as a function of cooling rate for starting temperatures 1250, 1050, and 850°C. Austenite with 206 at. ppm boron, grain size 150 μm and using Set 1 (Table 1) parameter values.

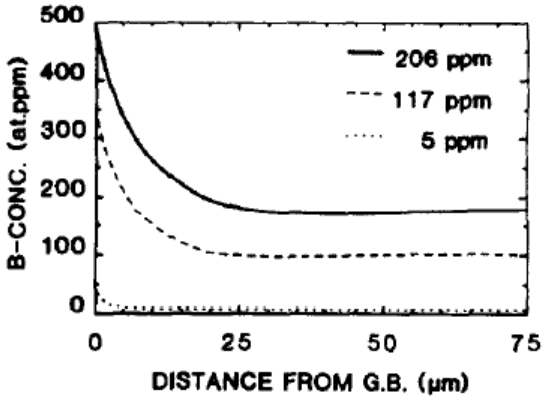
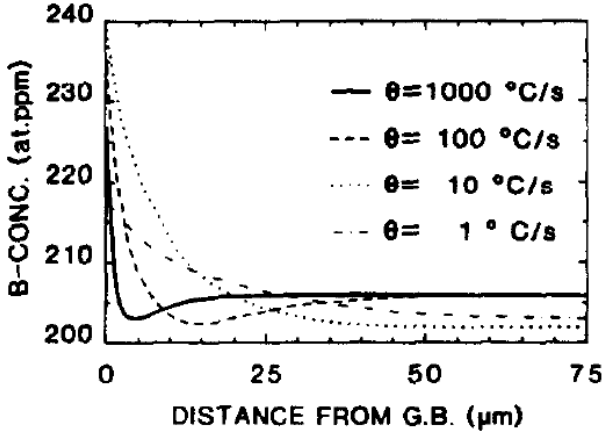


Fig. 6. Simulated segregation profiles in austenite with 206, 17 or 5 at. ppm boron. The starting temperature was 1250°C, the cooling rate 100°C/s and the calculations were performed using Set 1 (Table 1) parameter values for a grain size of 150 μm.

Enrichment factor: grain size, starting temperature, cooling rate…

Karlsson, Non-equilibrium grain boundary segregation of B in austenitic stainless steel_III. Computer simulations, Acta metall. Vol. 36, 1988



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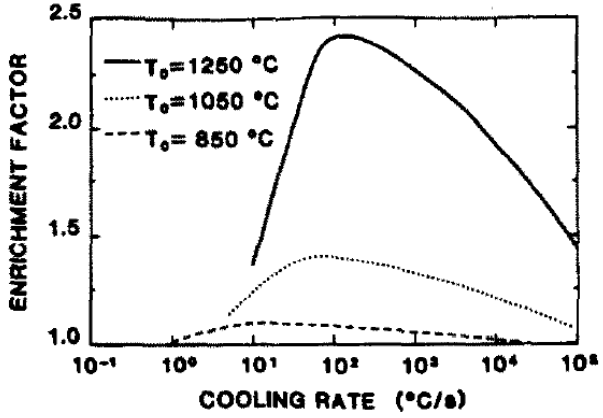

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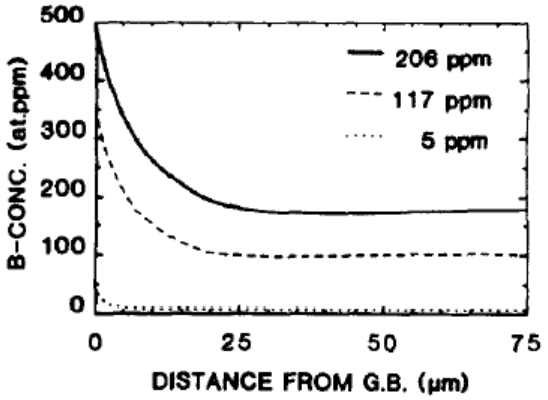

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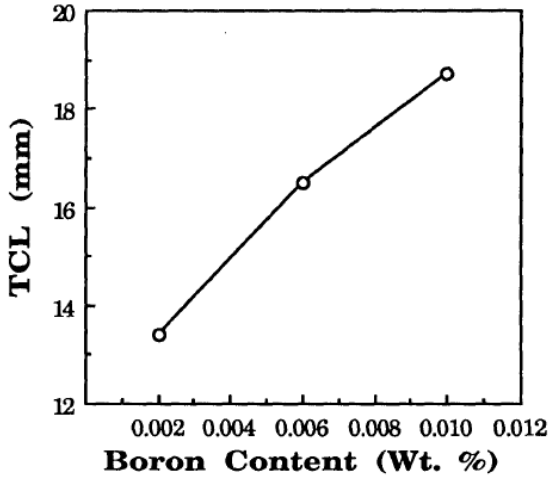

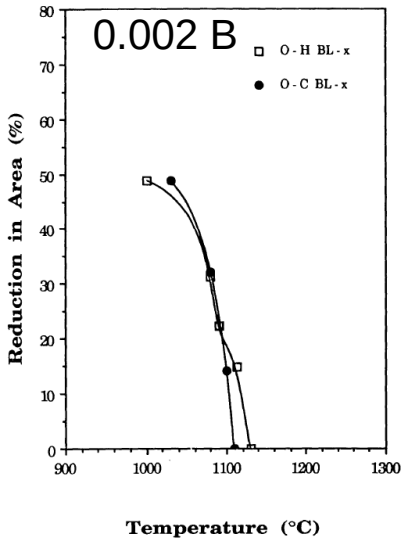

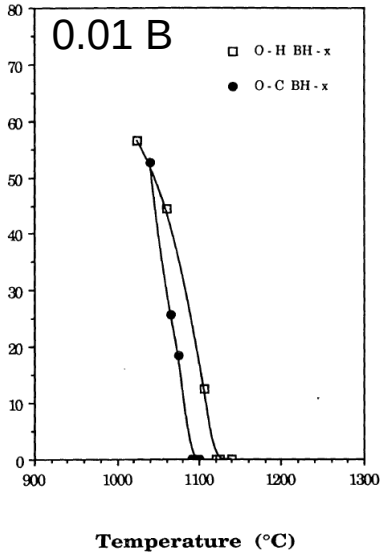

Peak Temp.: NDT+50

'e 56: Percent Reduction in Area Versus Test Temperature From On - Heating and On - Cooling Hot - Ductility Tests of Cast Controlled Boron Heat BL.

Percent Reduction in Area Versus Test Temperature From On - Heating and On - Cooling Hot - Ductility Tests of Cast Controlled Boron Heat BH.

Heat	NDT (°C)	NST (°C)	DRT (°C)(T_{peak} (°C))	T_{peak} - DRT (°C)
S1 - x	1150	1266	1055 (1220)	165
S4 - x	1155	1270	1080 (1225)	145
Ta - x	1182	1288	1130 (1240)	110
BL - x	1130	1216	1110 (1177)	67
BM - x	1125	1218	1085 (1176)	91
BH - x	1120	1202	1090 (1165)	75
W - x	1180	1255	1135 (1220)	85

West, S.L. Phd Thesis, A study of weld heat-affected zone liquation in cast nickel-base superalloys, The Ohio State University, 1991.

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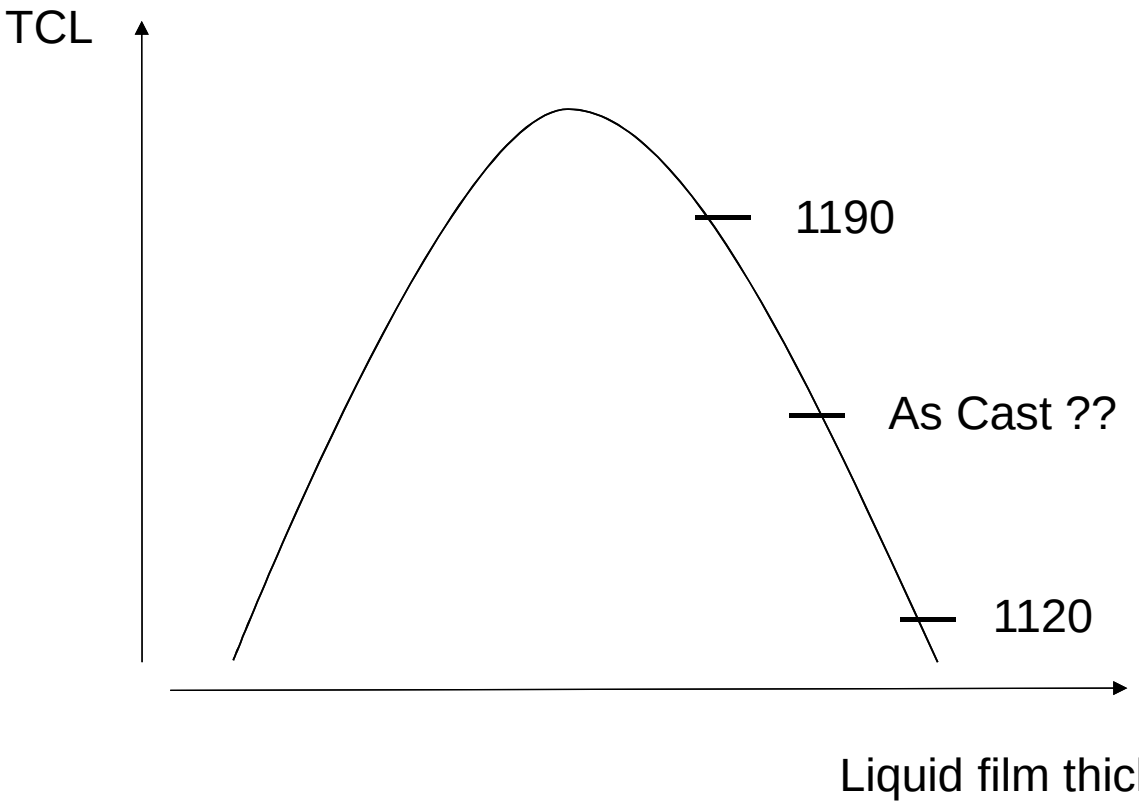
Stress relaxation through liquid



$$\sigma = 2\gamma_{SL}/h$$

$$\dot{E}_s = -\int_{\sum_{sf}} u\frac{\gamma_{ss} - 2\gamma_{sf}}{w} ds$$

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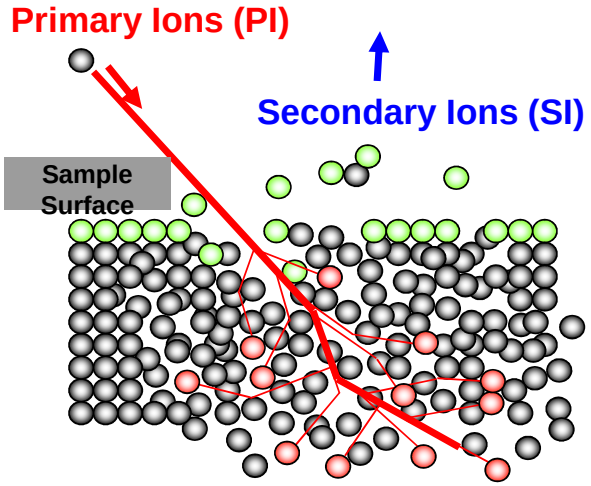
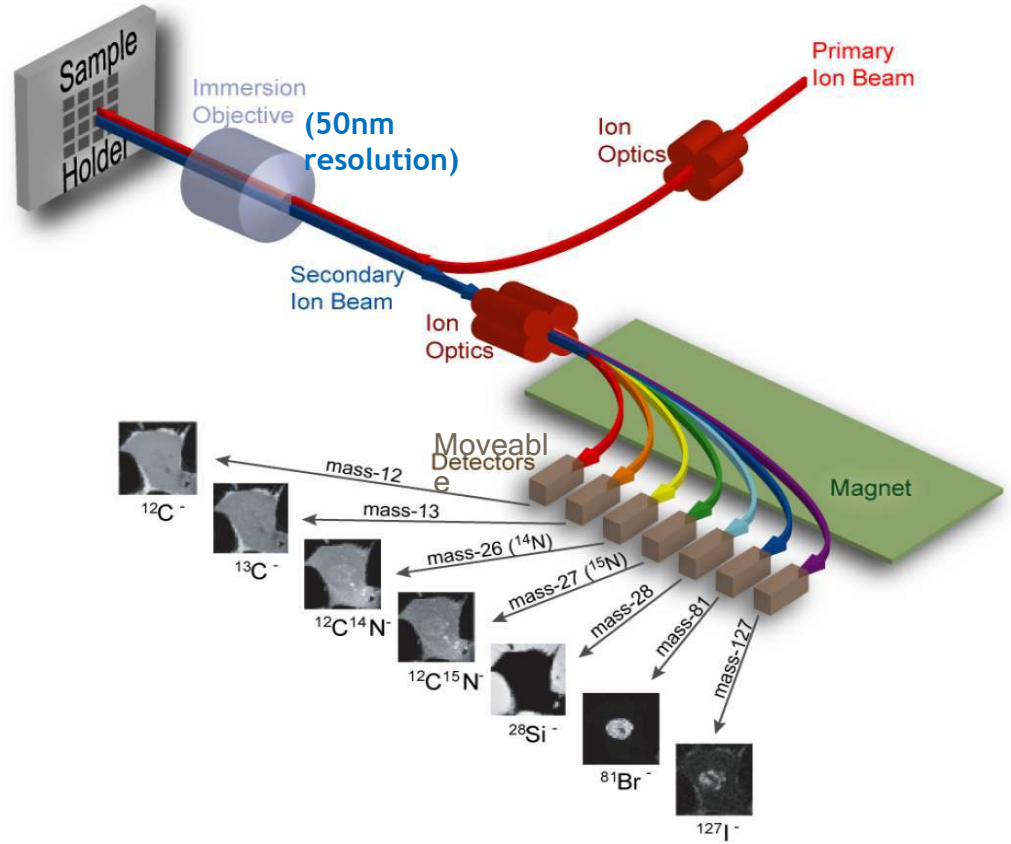
SIMS



NanoSIMS



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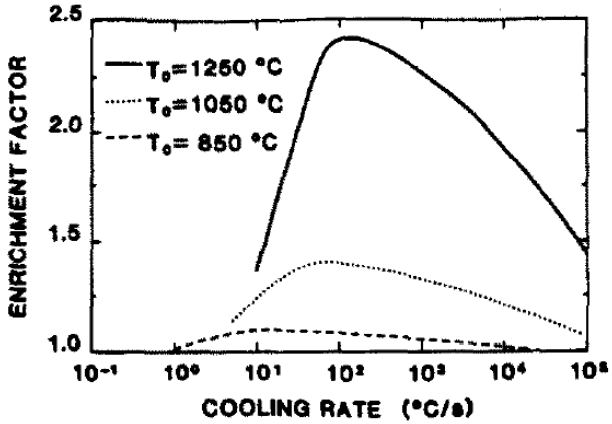
Outline

- Introduction
- Experimental
- Results & Discussion
- Summary
- Future Work

Non-equilibrium segregation

It is function of:

- Heat treatment temperature
- Cooling rate
- Concentration of solute atoms
- Binding energy between solute atoms and vacancies



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Effect of B on weldability

- High tendency of B to segregate at the grain boundary vacancies
- Surface active element affecting the grain boundary wettability

Varestraint Testing

- Cracking increases

Gleeble Testing

- Reduces the NDT and NST
- BTR increases

NanoSIMS for B analysis

- SETTINGS :
  - Implantation 1017Cs+.cm-2 with D11 and ~ 180pA
  - ES4 AS3 EnSopen, mass resolving power is put at ~10000
  - mass table for (11B-), 11B12C-, 12C-, (12C2-), 28Si-, 31P-, 11B16O2-
  - Current measurement ~ 1pA with D12,
- SAMPLES :
  - As Cast, 1120,1160,1190°C/4h
- Objective :
  - Primary : recorded B distribution in grain boundaries, variations among heat treatment
  - Secondary : Si and P imaging