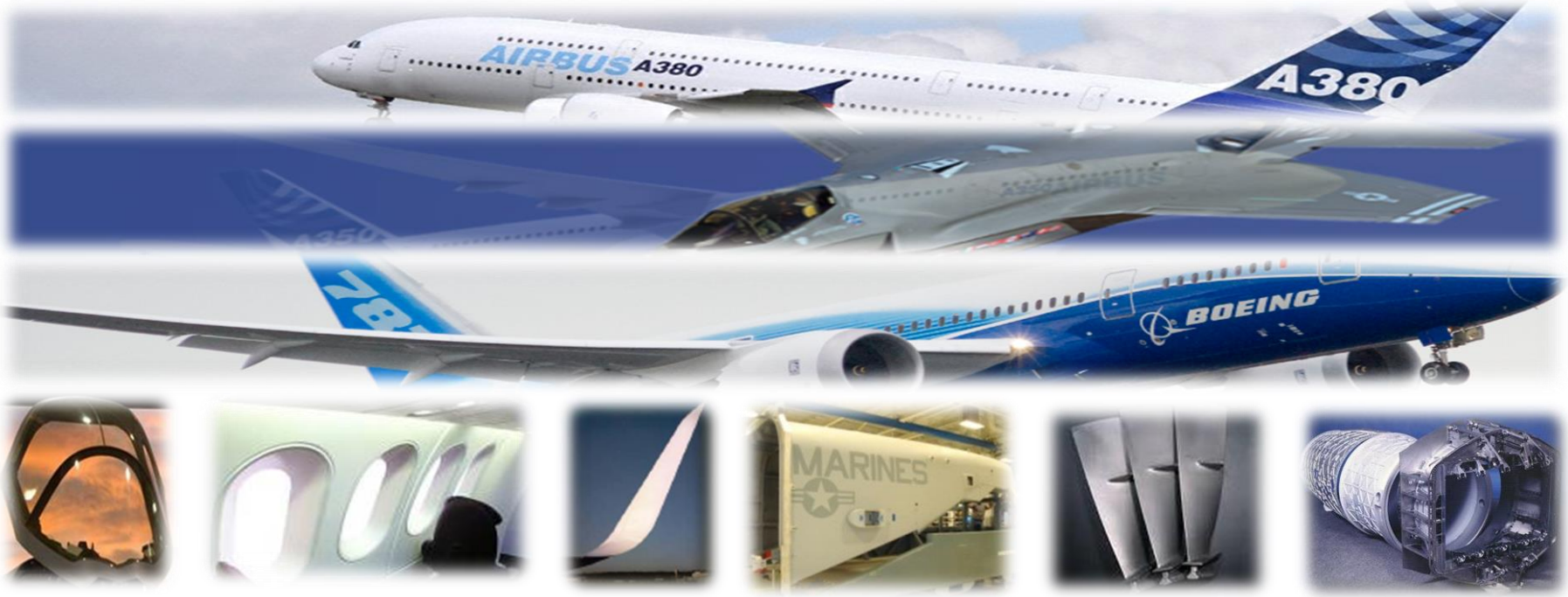
GKN AEROSPACE



Strain age cracking in nickel base superalloys (KME-706)
Development of weldability assessment and understanding of hot cracking in boiler and gas turbine materials (KME-719)

HTC/KME research symposium
March 20-21, 2018

Fabian Hanning, Sukhdeep Singh, Joel Andersson & Lars Nyborg

Weldability of nickel-base superalloys for energy applications

KME 706

Fabian Hanning, Joel Andersson & Lars Nyborg

Aim of KME 706

- **Provide a better understanding of hot cracking and Strain age cracking (SAC) in Ni-based superalloys**
  - Clarify fundamental causes for weld cracking, with focus on SAC
  - Develop a testing rationale to assess susceptibility towards SAC

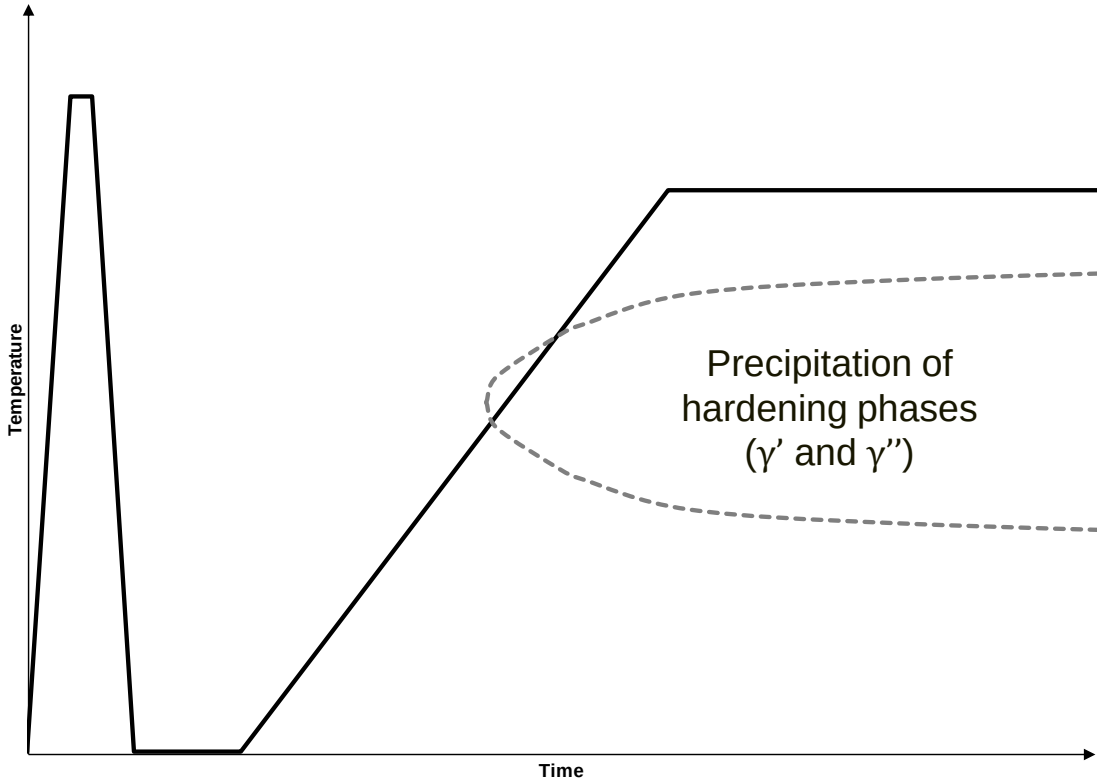
Aim of KME 706 – cont.

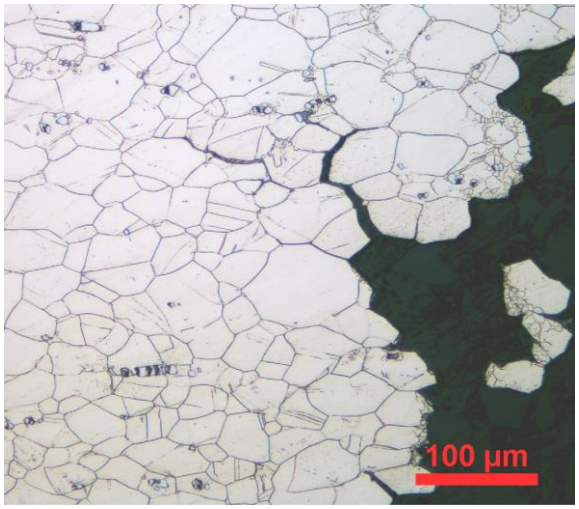
- **Weldability studies on newly developed alloys**
  - Cast ATI 718Plus
  - Haynes 282
- **Development of testing procedures**
  - Screening test for SAC susceptibility
  - Test to investigate underlying mechanism

Strain age cracking

- **Occurs specifically in precipitation hardening nickel based superalloys**
- **Cracks form during heating to post weld heat treatment**
  - Warm cracking phenomenon, as no liquid phase is involved
- **Influenced by**
  - High temperature
  - Precipitation of hardening phases
  - Residual stresses

Strain age cracking (SAC)





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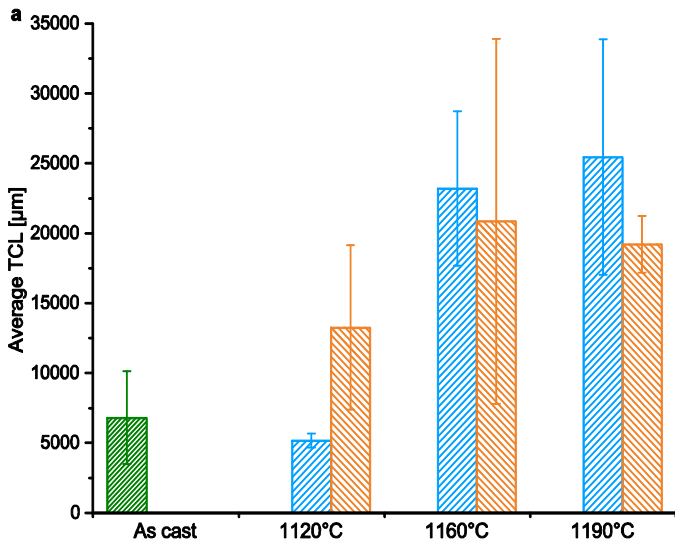
Weldability of cast ATI 718Plus and Haynes 282

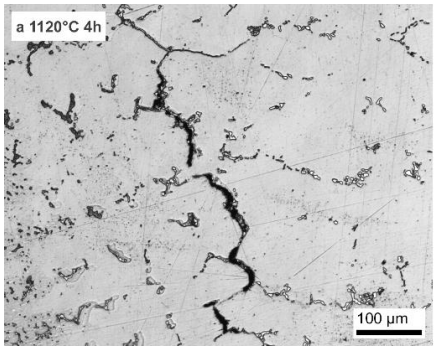
- **Newly developed alloys**
  - Not much data on welding behaviour available

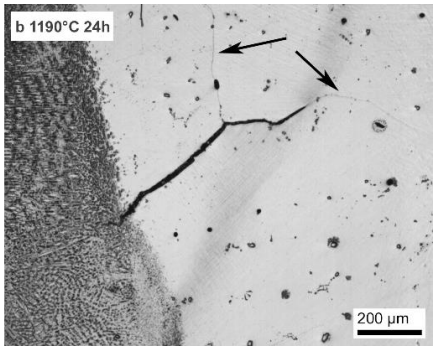
- **Investigation of the effect of base metal thermal history on weld cracking response**

Weldability of cast ATI 718Plus

- Investigation of different base material conditions
  - As Cast
  - 1120, 1160, 1190°C, 4+24h
- As cast microstructure shows best weld cracking resistance
- Solutionising heat treatments removed Nb-rich precipitates in interdendritic areas
- Crack localisation on solidification grain boundaries in heat treated material







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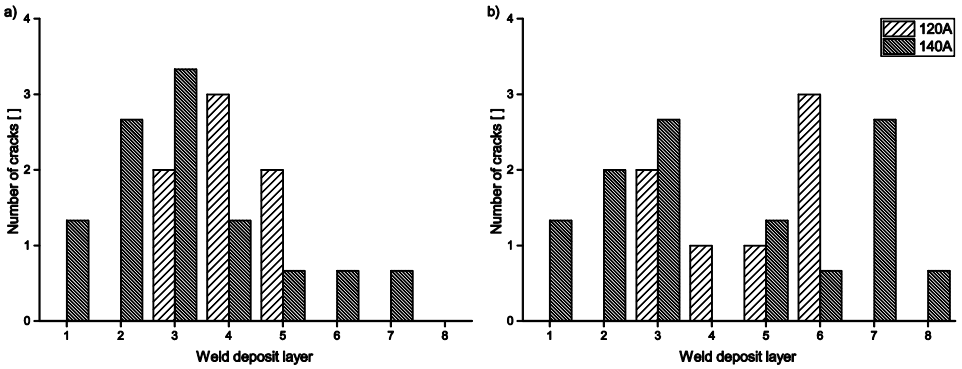
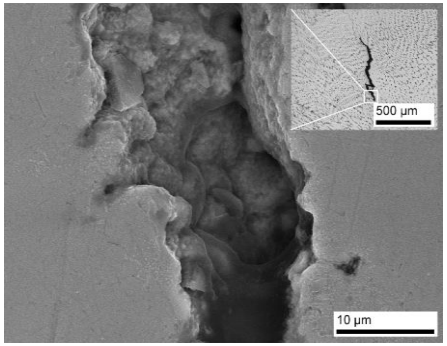
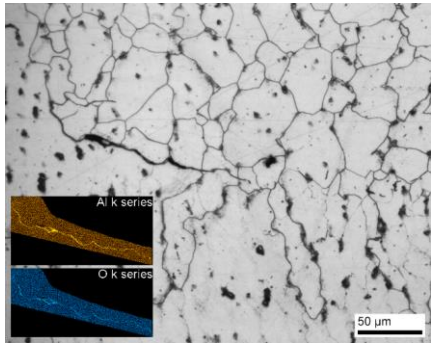
Weldability of cast Haynes 282

- Investigation of different base material conditions
  - Mill-annealed
  - Solution heat treated
  - Fully age hardened
- No cracks in base metal HAZ
- High weld heat input increased cracking by factor 1.5
- Solidification cracks along solidification grain boundaries
- Suspected strain age cracks in the fusion zone identified as Al-rich oxide layers







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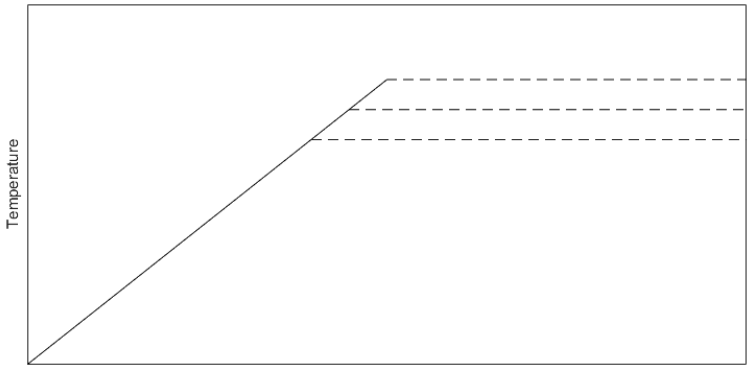
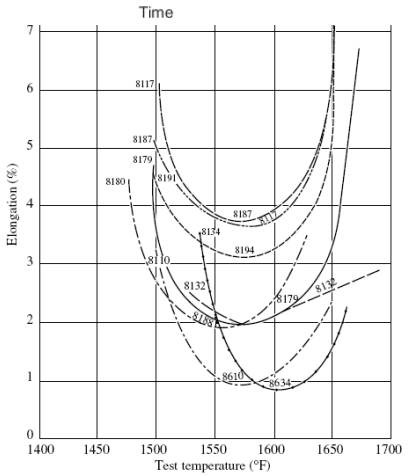
Development of testing procedure for SAC

- **Constant heating rate test (CHRT)**
  - Simulates post weld heat treatment (PWHT)
  - Ductility is measured to create material ranking
  - Material rankings can be created
  - Does not include HAZ microstructure





J. B. Carlton and M. Prager. *Variables Influencing the Strain-Age Cracking and Mechanical Properties of René 41 and Related Alloys*. WRC Bulletin 1970;150:13–23.

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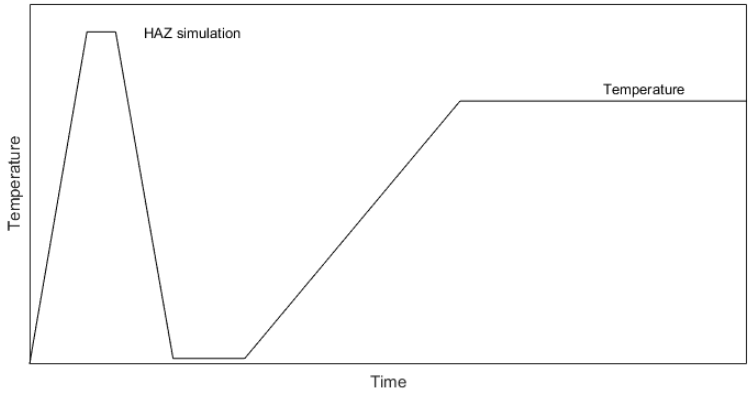
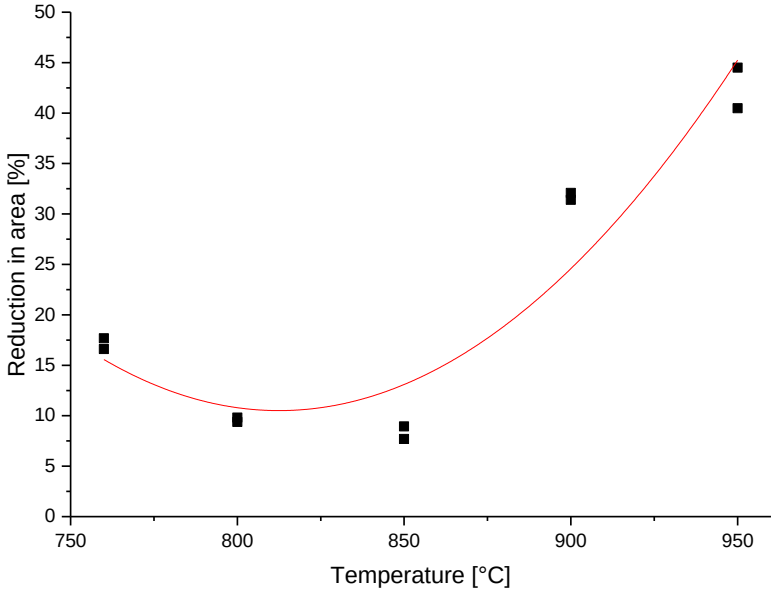
Modified controlled heating rate test

- Includes HAZ simulation
- Can be used for material rankings





J. Andersson. *Weldability of Ni-Based Superalloys*. Proceedings of the 8th International Symposium on Superalloy 718 and Derivatives, The Minerals, Metals & Materials Society; 2014, p. 249–62.
F. Hanning. *Strain Age Cracking of Nickel Based Superalloys*. Master Thesis. Chalmers University of Technology, 2015.

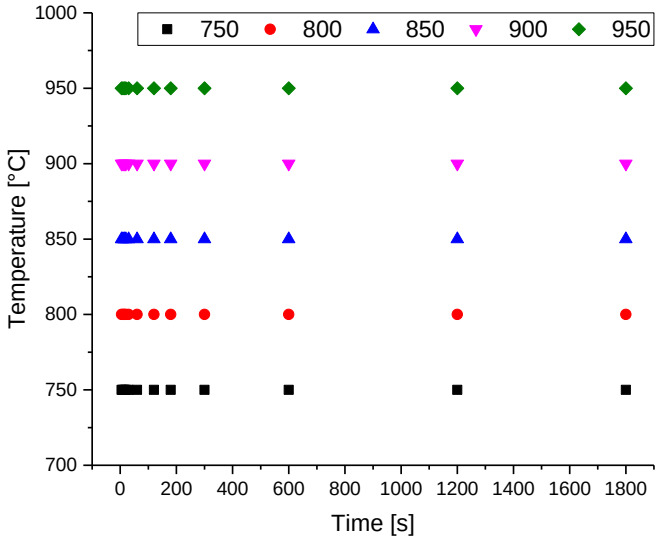
Why another test?

- **Advantages of constant heating rate test**
  - Ease of use
  - Measure for relative performance
  - Material rankings can be created

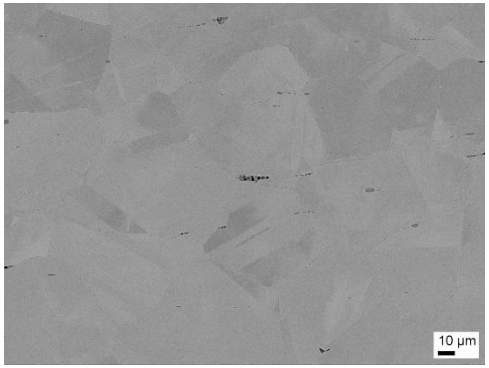
- **Disadvantages**
  - Does not provide insight into mechanism (influence of precipitates)
  - Does not account for different heating rates/ exposure times

Testing procedure

- Heating rate 1000°C/s
- Holding time from 5s to 1800s
- Stroke rate 50mm/s
- Cooling rate >50°C/s



- Material: wrought Haynes 282



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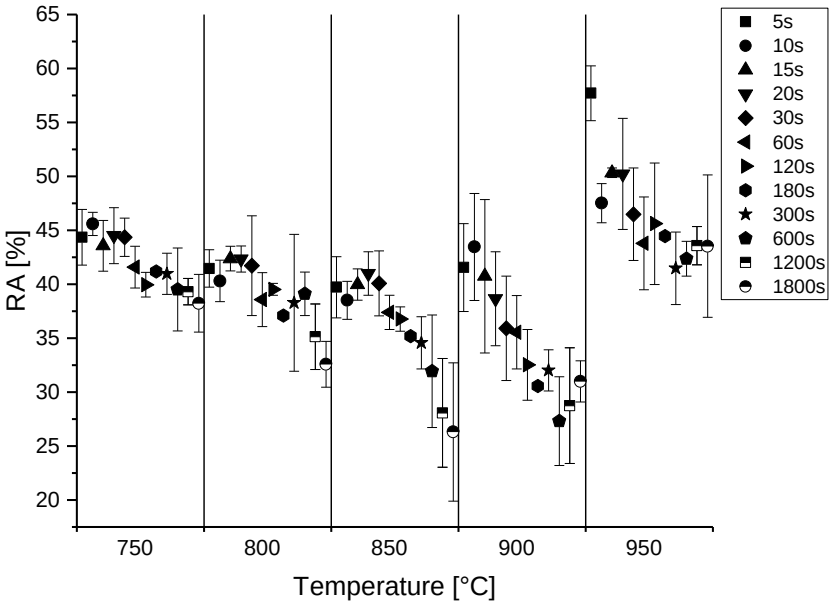
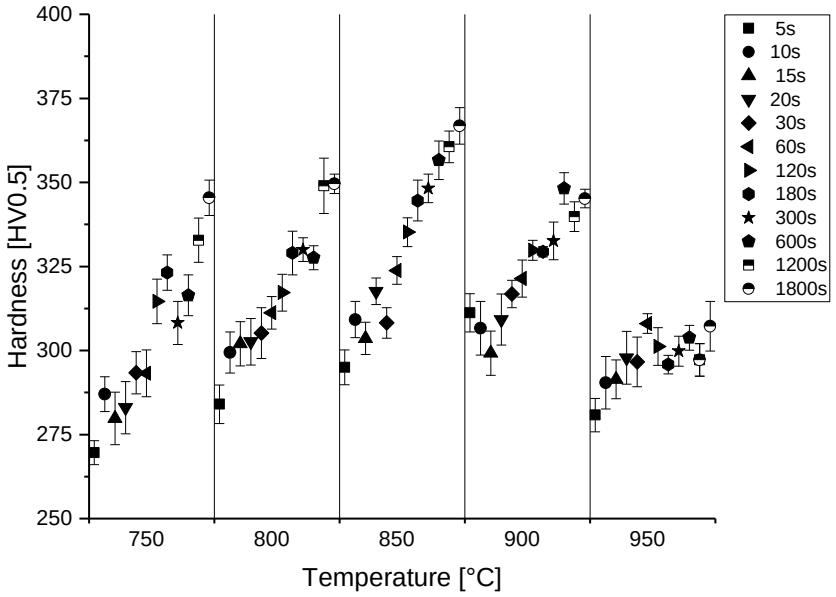
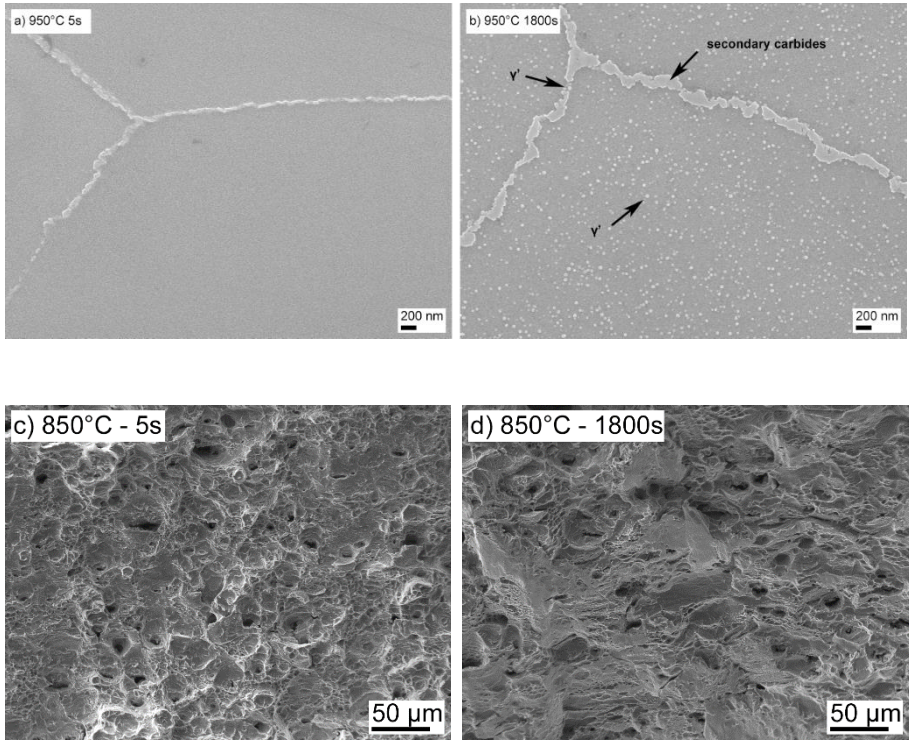
Effect of exposure time on ductility





Effect of exposure time on ductility

- Rapid hardening response of Haynes 282
- Ductility minimum at 850°C (identical to results from CHRT)
- Ductility strongly dependent on precipitation reactions in the material
- Transition in cracking mode from ductile transgranular to brittle intergranular at 850°C



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Summary

- **Weldability of two newly developed alloys has been investigated**
  - Low melting Nb-rich phases have positive effect on HAZ liquation cracking in cast ATI 718Plus
  - Absence of HAZ cracks in Haynes 282 suggests good weldability
- **Development of test procedures for SAC**
  - Modified CHRT investigates HAZ microstructures and enables relative comparison of different materials
  - Varying the exposure time in the SAC temperature range provides information about the influence of early stages of hardening reactions on SAC

Future work

- **Continue to investigate weldability of new alloys**
  - E.g. Haynes® 282® and ATI 718Plus™
  - Properties of cast versions is important for industrial applications
- **Physical simulation of HAZ microstructures**
  - Thermal cycling of multi-pass welding operations
  - In-depth microstructural characterization

Development of Weldability Assessment and Understanding of Hot Cracking in Boiler and Gas Turbine Materials

KME 719

Sukhdeep Singh, Joel Andersson & Lars Nyborg

Aim of KME 719

- **Increase the knowledge concerning hot cracking of austenitic stainless steels and Ni-based superalloys:**
  - Generate weldability test data on materials relevant to the boiler industry
  - Recommend materials and parametres for improved weldability
  - Establish a testing methodology that can be used for assessing weldability with respect to hot cracking susceptibility

Materials

Cast Alloy 718

Cast ATI® 718Plus™

How the heat treatments influence the hot cracking?

Austentic Stainless Steel 314

How the welding parametres influence the hot cracking?

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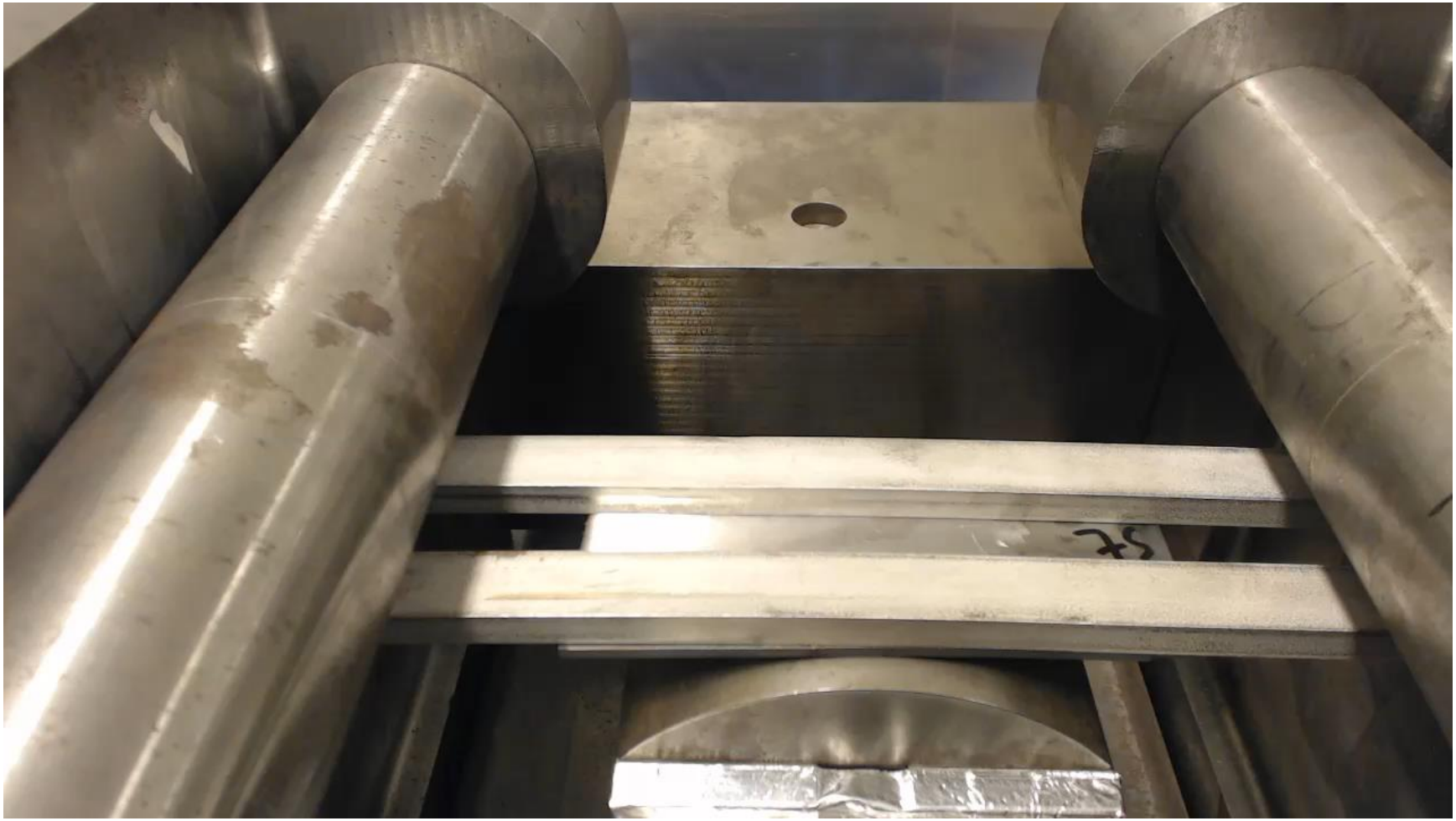
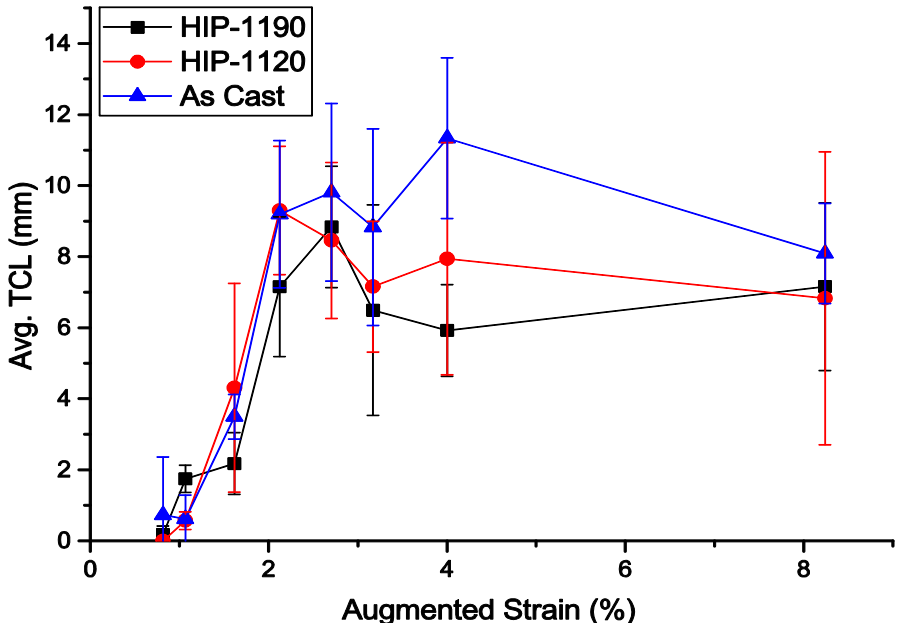
Varestraint Test

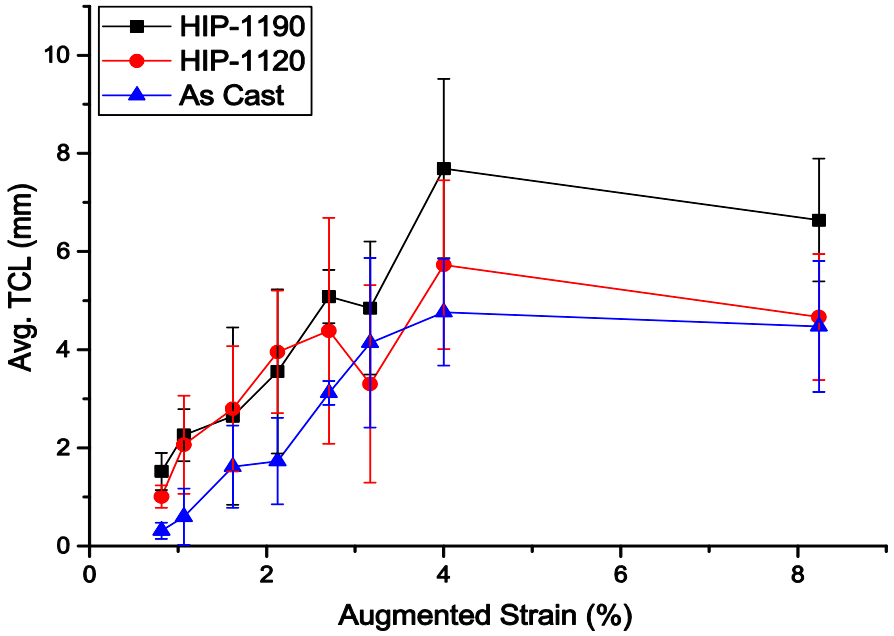


Cast Alloy 718

Solidification Cracking



Heat Affected Zone Cracking



No difference

Ranking: As Cast
HIP-1120
HIP-1190

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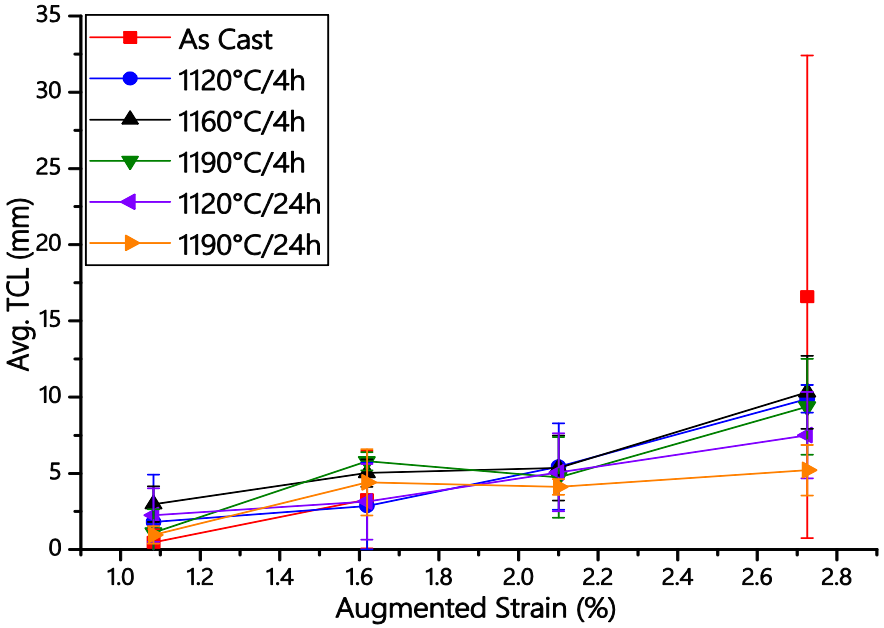
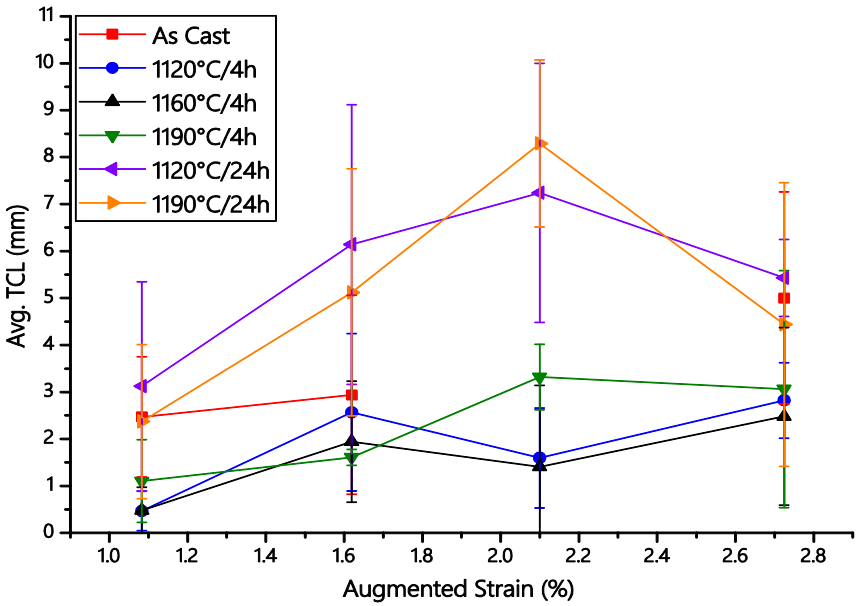
Cast ATI® 718Plus™

Solidification Cracking



No difference

Heat Affected Zone Cracking



Ranking: 20, 60, 90 - 4h
As Cast
20, 90 - 24h

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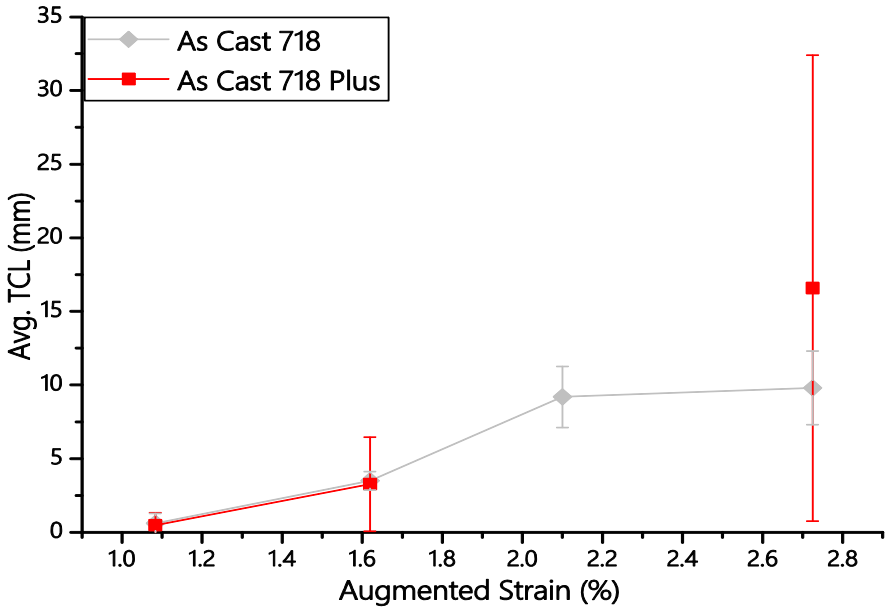
Cast ATI® 718Plus™ vs Cast Alloy 718

Solidification Cracking



No difference

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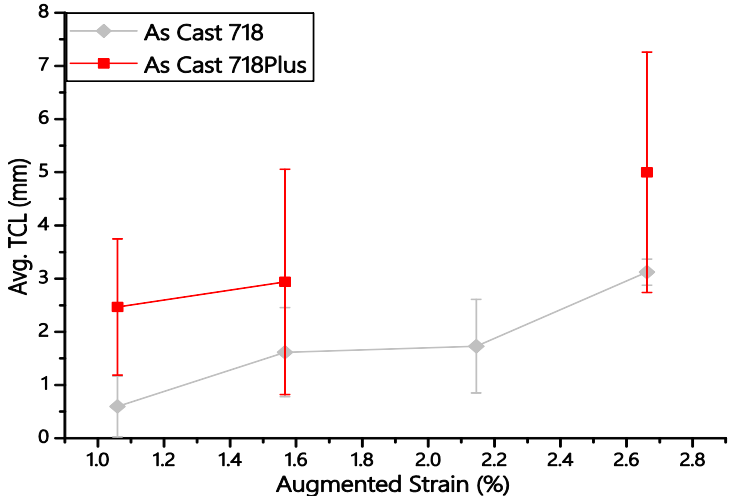
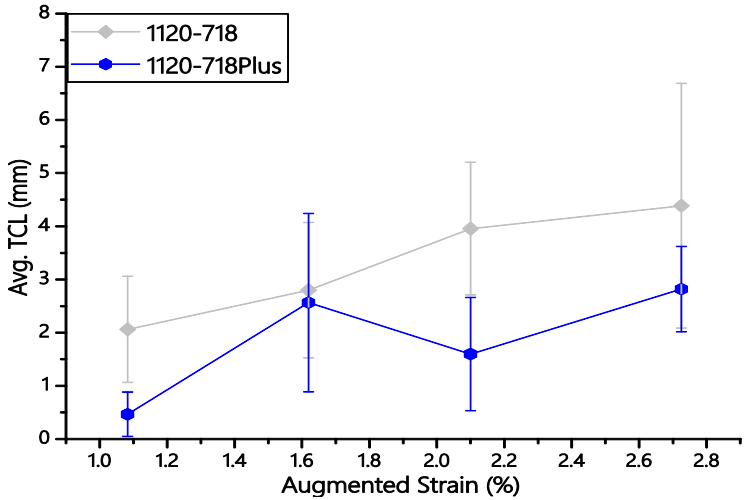
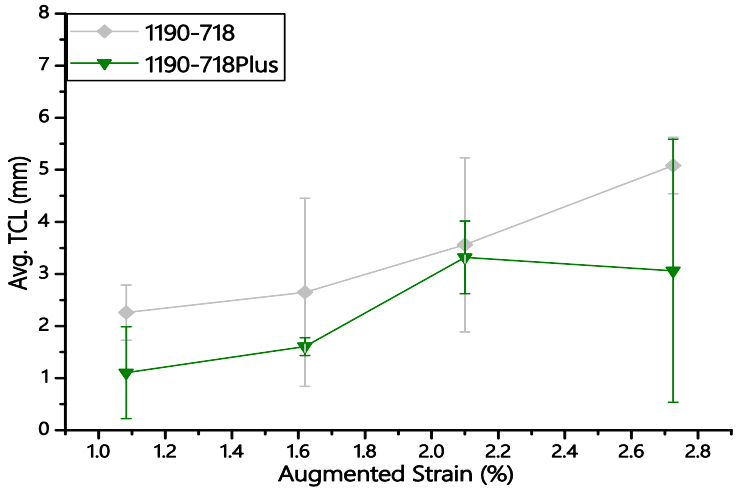
Cast ATI® 718Plus™ vs Cast Alloy 718

Heat Affected Zone Cracking

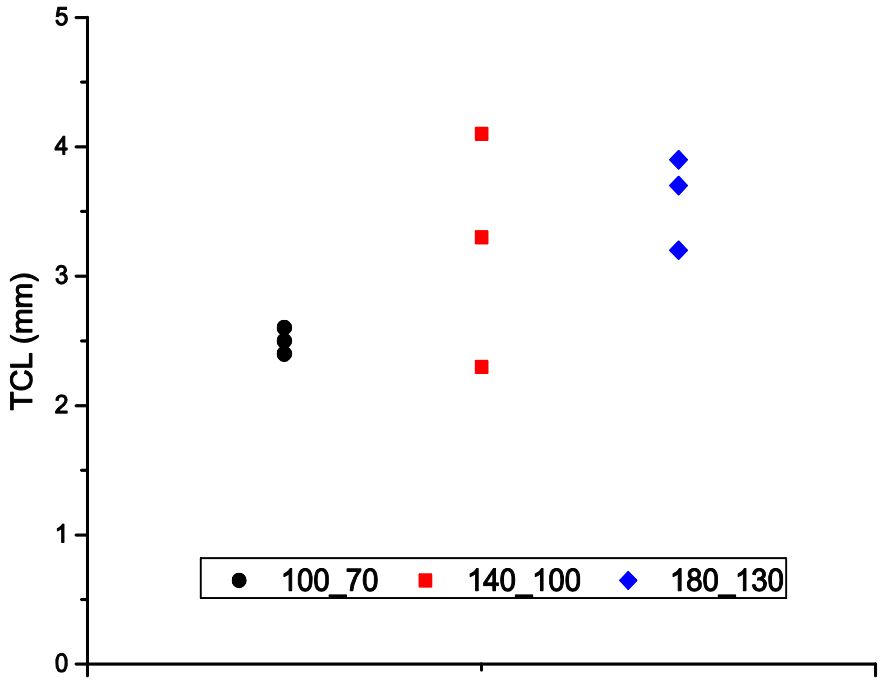






Austenitic Stainless Steel 314

Solidification Cracking



Low welding Speed and current

Future Work

- More testing
- What are the microstructural reactions?
- Advanced characterization. TEM, EBSD

Thank You!