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Development of Functionally Graded Transition Joints to Enable Dissimilar Metal Welds

FY22 FECM Spring R&D Project Review Meeting Crosscutting (High-Performance Materials) Virtual Session

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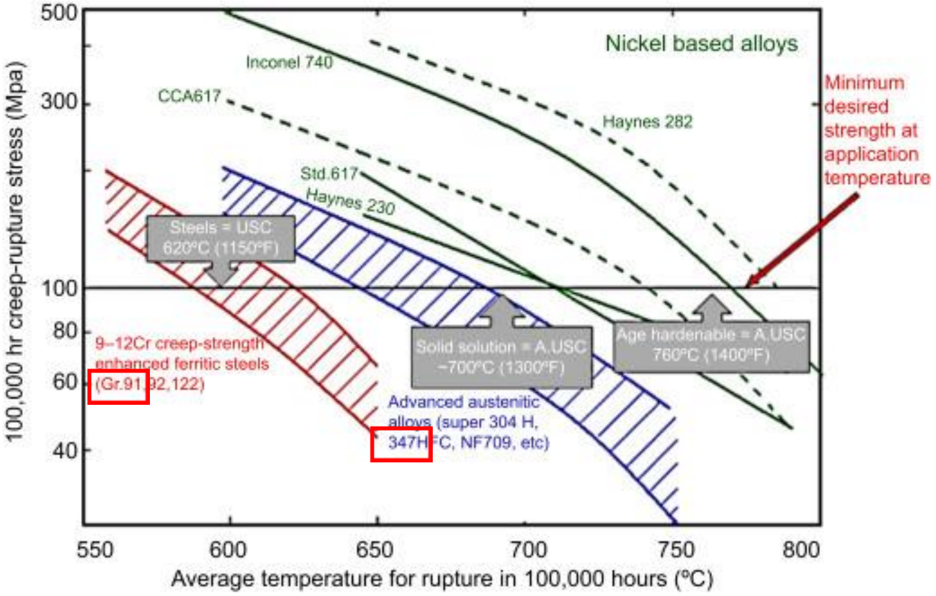
Outline

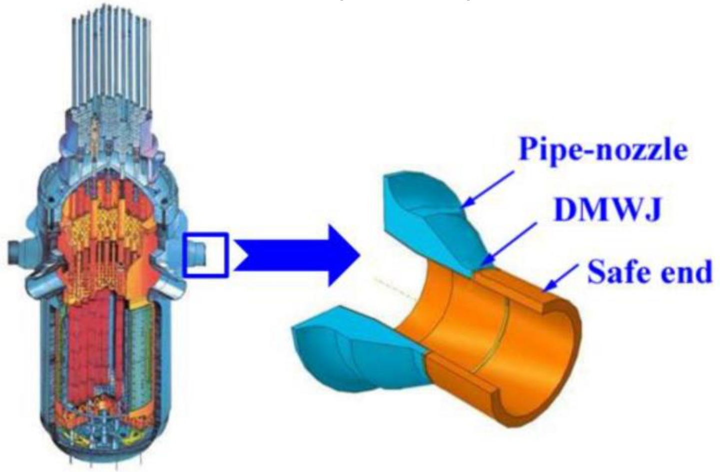
- Background
- Summary of the previous review meeting.
- Room temperature tensile testing on transition joints.
- Burst testing on transition joints.
- Cracking issues in 347H stainless steel.
- Design of non-linear transition joints.

Background

Creep properties of high temperature metals



Multi-material structures in fossil fueled power plants



- **Multi-material system** is used in fossil-fueled power plants increases the need for **dissimilar metal joining**.
- Challenges with dissimilar metal welding:
  - **Abrupt transition in thermo-physical properties** can lead to **pre-mature failure** if a proper filler metal/buttering layer is not used.
  - Costs associated with pre-mature failure $250,000-$850,000 per day.
  - Long term exposure results in **C migration** and weakening of the joint resulting in pre-mature failure.
  - **C migration needs** to be **< 10%** during service conditions.
- Adopting a **gradual transition** between dissimilar metals can **overcome** the problem.
- **Additive manufacturing (AM)** using blown powder-directed **energy deposition (DED)** opens up the development of **graded transition joints (GTJ)** for dissimilar metal welds.
- **Grade 91** steel and **347H** steel investigated in the current work

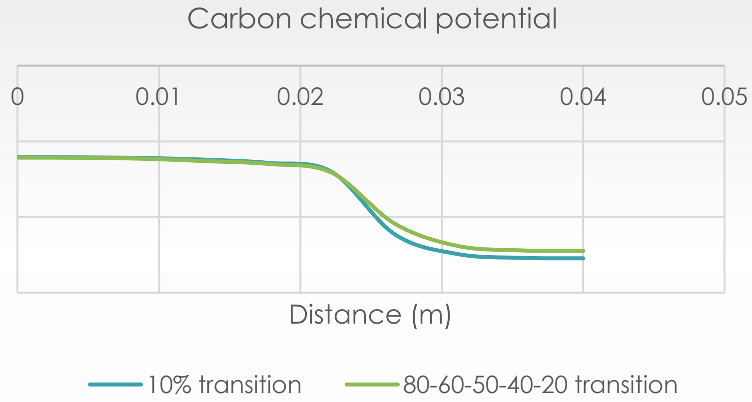
Summary of previous review meeting

Design of graded transition joints

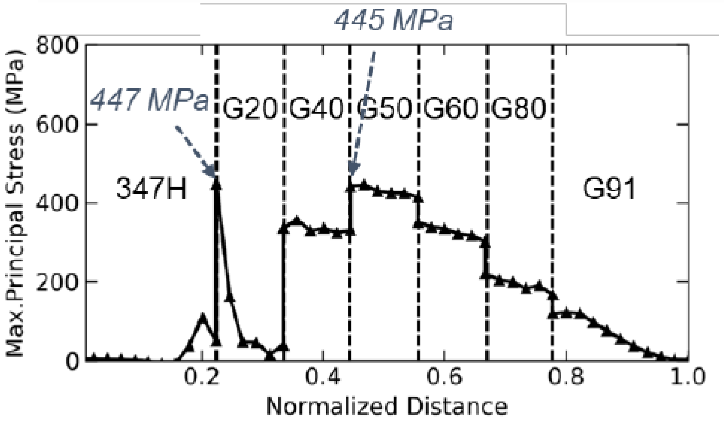
Used a CALPHAD approach coupled with stress analysis to identify the transition zone.

Proposed 80-60-50-40-20 transition with a shallower C potential

CALPHAD



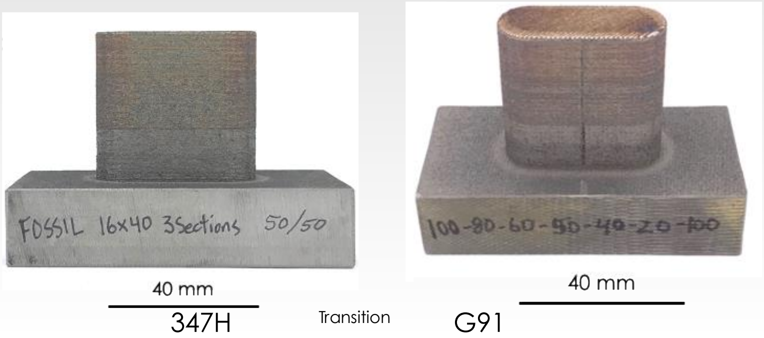
Stress analysis

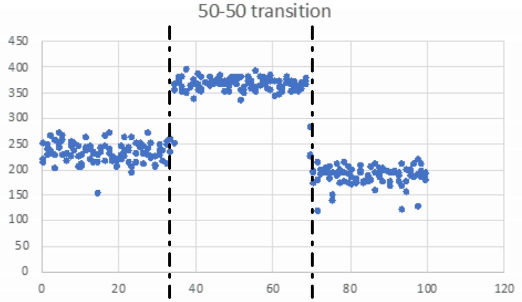


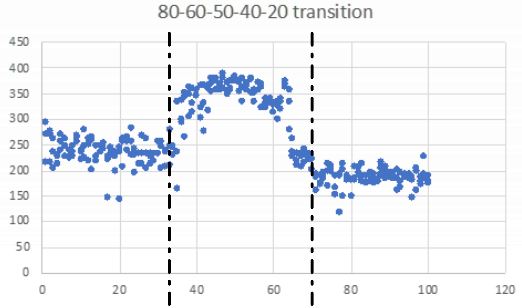
Fabrication of graded transition joints

Blown powder directed energy deposition of 50-50 transition joint and 80-60-50-40-20 transition joints.

Transition zone has higher hardness





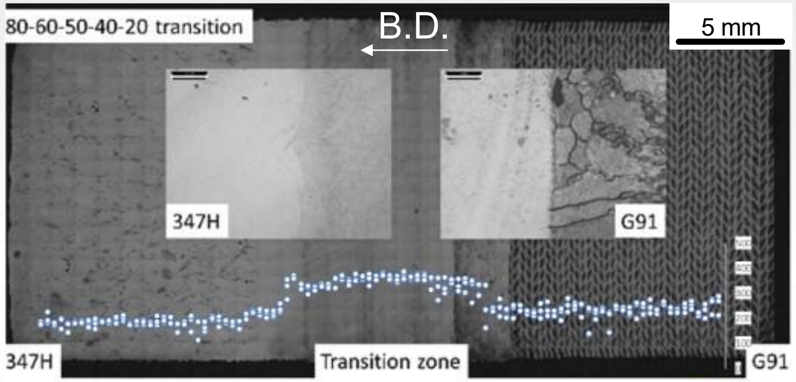


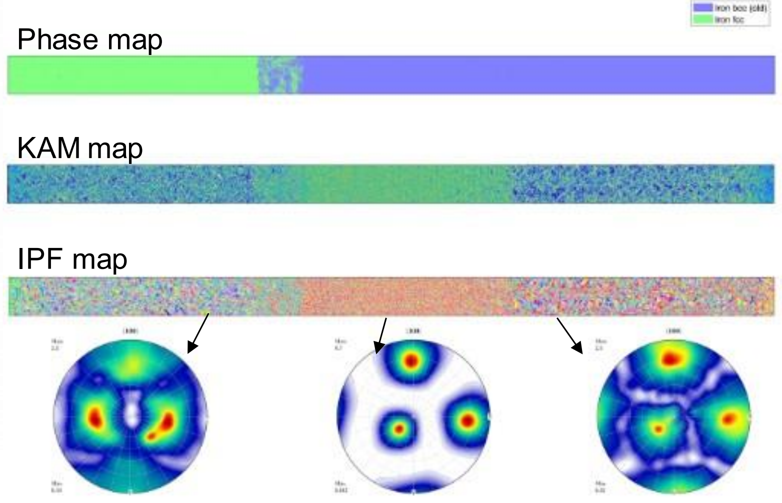
Characterization of graded transition joints

Cracking observed on 347H side.

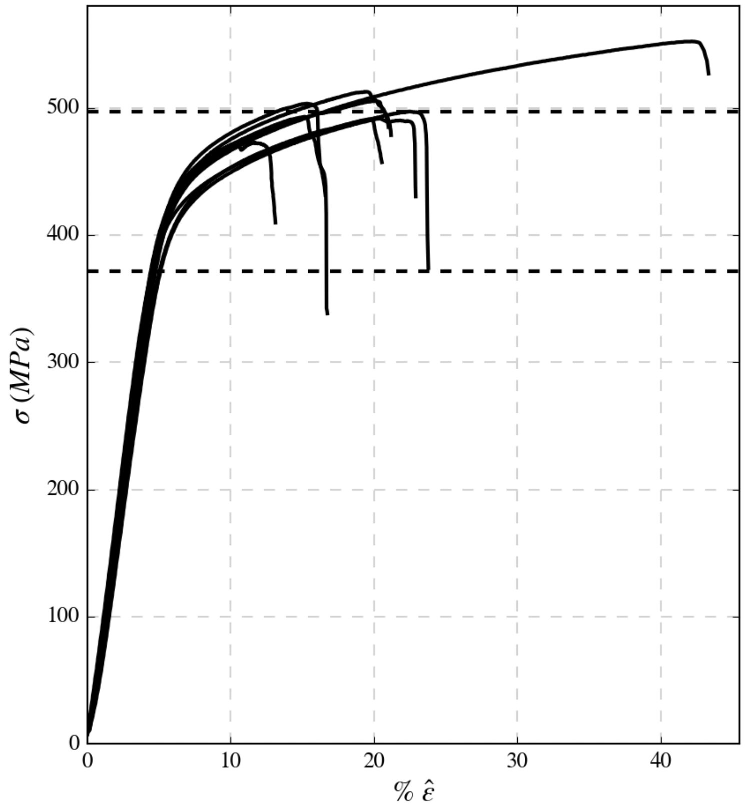
The transition zone has a finer structure than either of the base materials, explaining the higher hardness

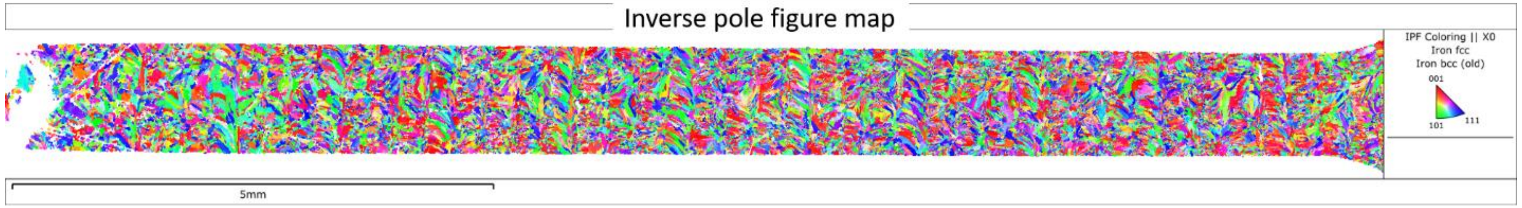
Texture changes from <001> in G91 and transition zone to <011> in 347H

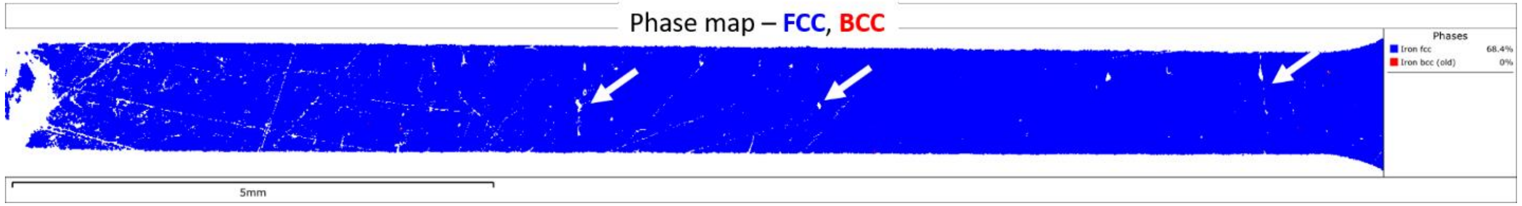




Room temperature tensile testing on transition joints



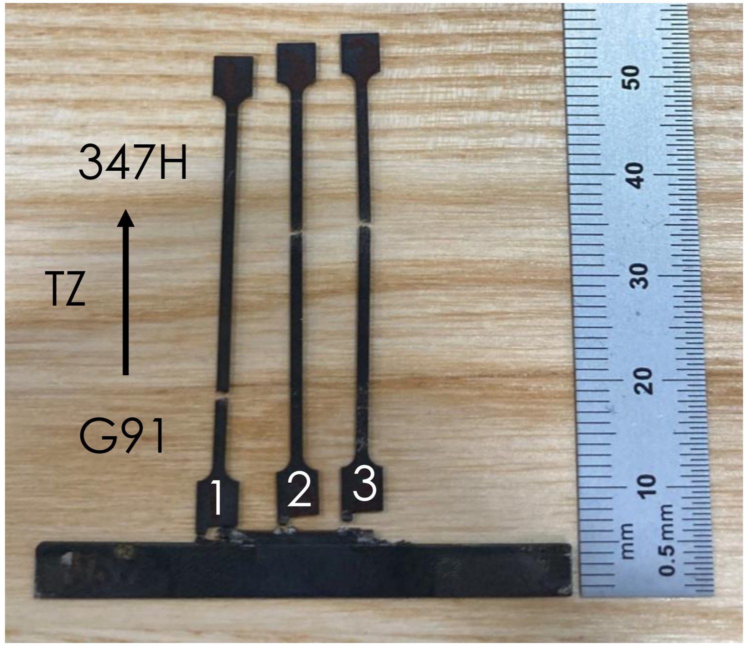


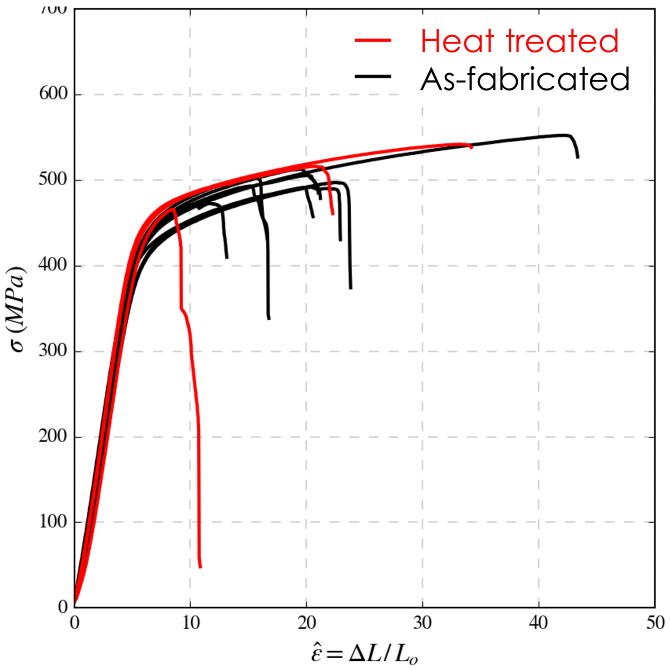


- The properties of the transition joints lie in between the specified yield strength, ultimate tensile strength, and elongation to failure as per ASTM A182 for grade 91 and UNS S34700 for 347H.
- Failure occurred in the 100% 347H side of the transition joint.

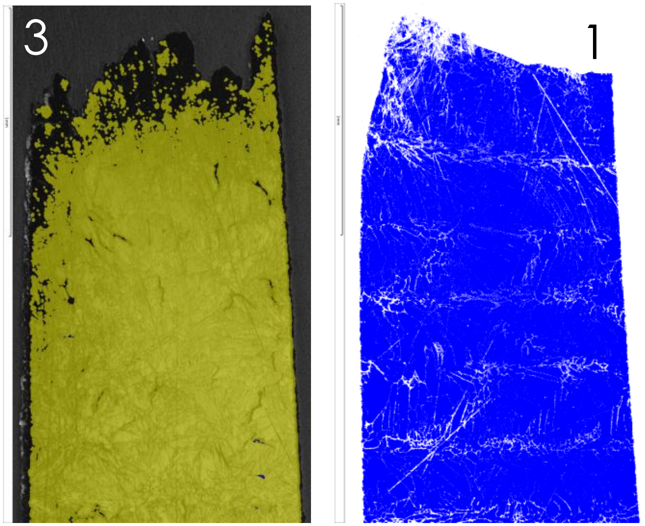
Effect of heat treatment on the tensile properties

- Tensile tests were conducted after heat treatment (760 °C for 2h).
- Reduction in strength and elongation after heat treatment.
- Failure location predominantly in FCC (347H). One sample failed in the grade 91 side (needs further investigation).
- Transition zone (TZ) is not the location of failure.





BCC ,FCC

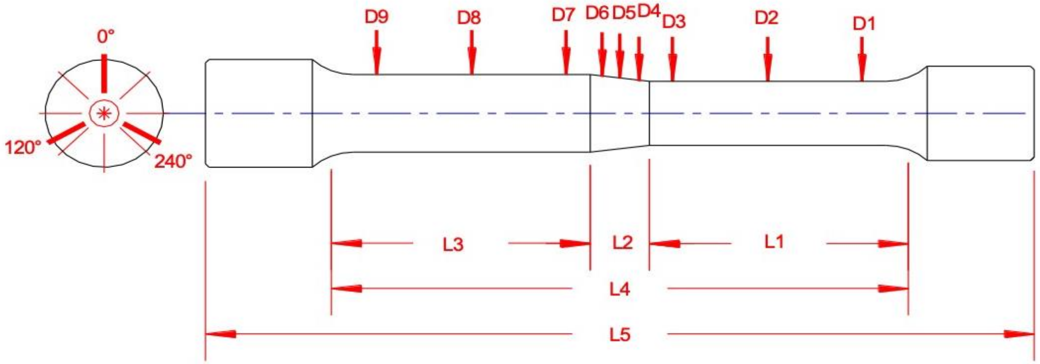


Burst testing on transition joints

- 50/50 and 100G91-80-60-50-40-20-100347H transition joints were burst tested in accordance with the ASME Boiler and Pressure Vessel Code, Section IX: Welding and Brazing
- A rupture time of 500 h at 650 °C was targeted.
- Internally pressurized with a pressure of 46.25 MPa.
- Change in diameter of the tube at various locations measured over time (D1-D9).
- Axial change in length and axial strain estimated over time (L1 – L5)

GTAW GTAW

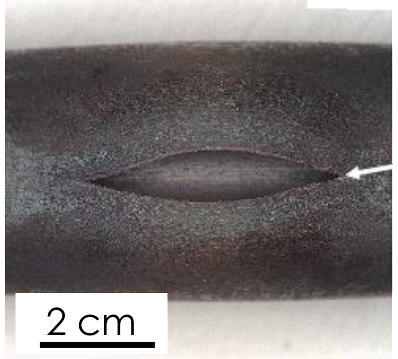
G91 TJ 347H



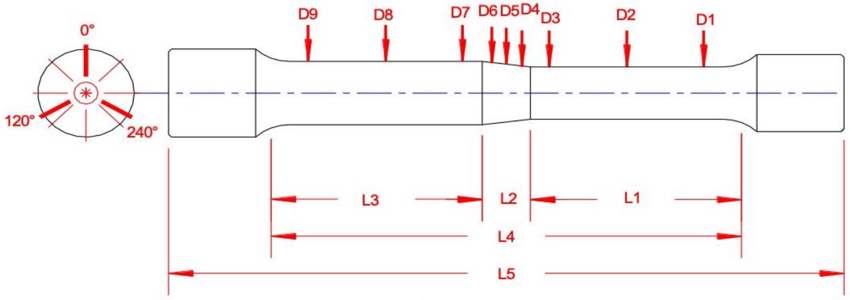
Burst testing on 100G91-50G91-100347H transition joint

- Burst sample failed at 22 hours.
- Failure in the base metal grade 91 region.
- Base metal grade 91 has the highest tangential strain.
- Axial strain variations at the beginning of the test – stabilizes as the test progresses.

a

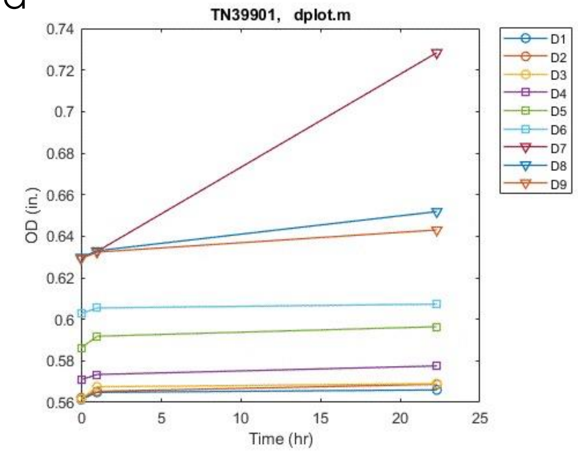


b



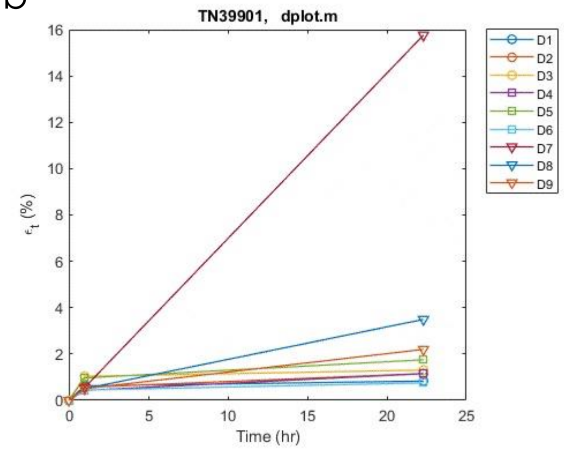
Tangential displacement

a



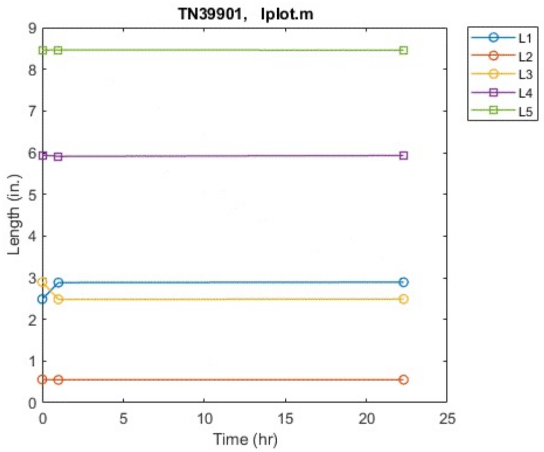
Tangential strain

b



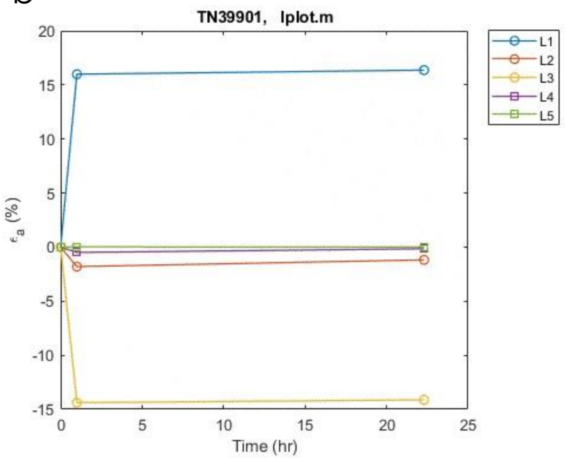
Axial displacement

a



Axial strain

b

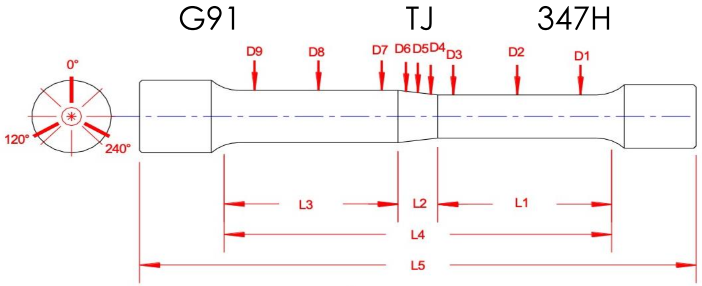


Burst testing on 100G91-80G91-60G91-50G91-40G91-20G91-100347H transition joint

- Burst testing at three different temperature-time conditions, namely 650 °C, 46.25 MPa (6,710 psi) for 1 h, 600 °C, 44.06 MPa (6,680 psi) for 23 h, and 400 °C, 44.06 MPa for 376 h corresponding to a total creep time of 400h.
- Lower tangential and axial strain compared to the 50/50 transition joint.
- Creep rate in the first hour of exposure is lower compared to the 50/50 transition joint.

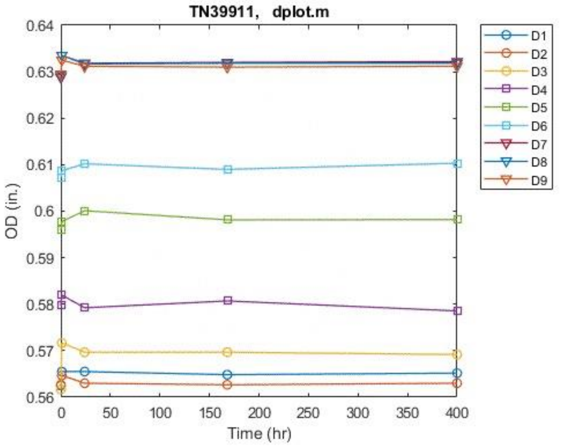
650 °C – 1 hour | 600 °C – 24 hours | 400 °C – 400 hours

G91 GTJ 347H | G91 GTJ 347H | G91 GTJ 347H



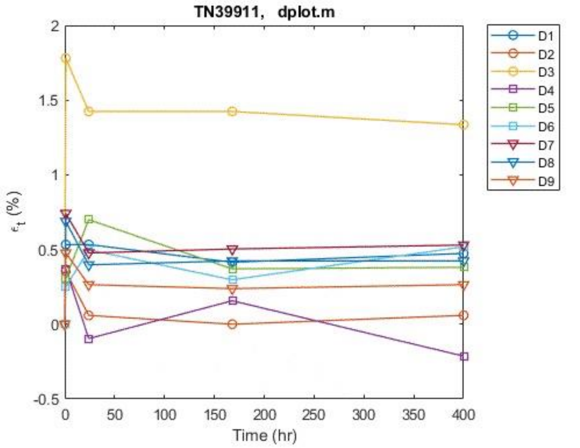
Tangential displacement

a



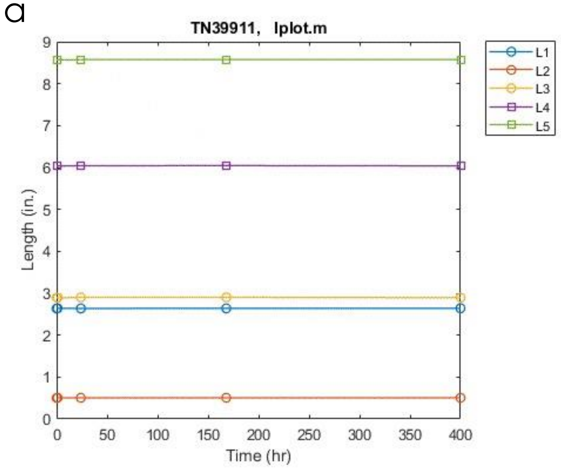
Tangential strain

b



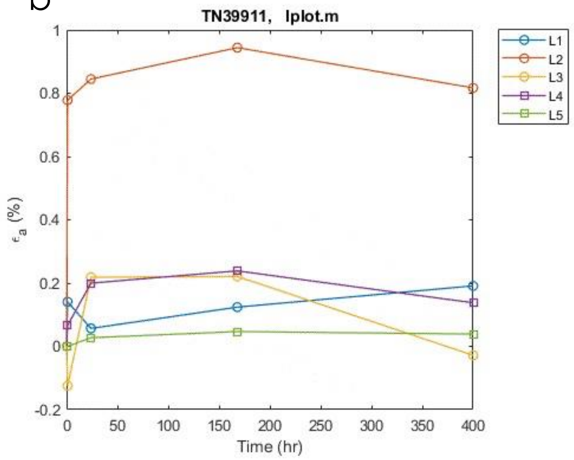
Axial displacement

a



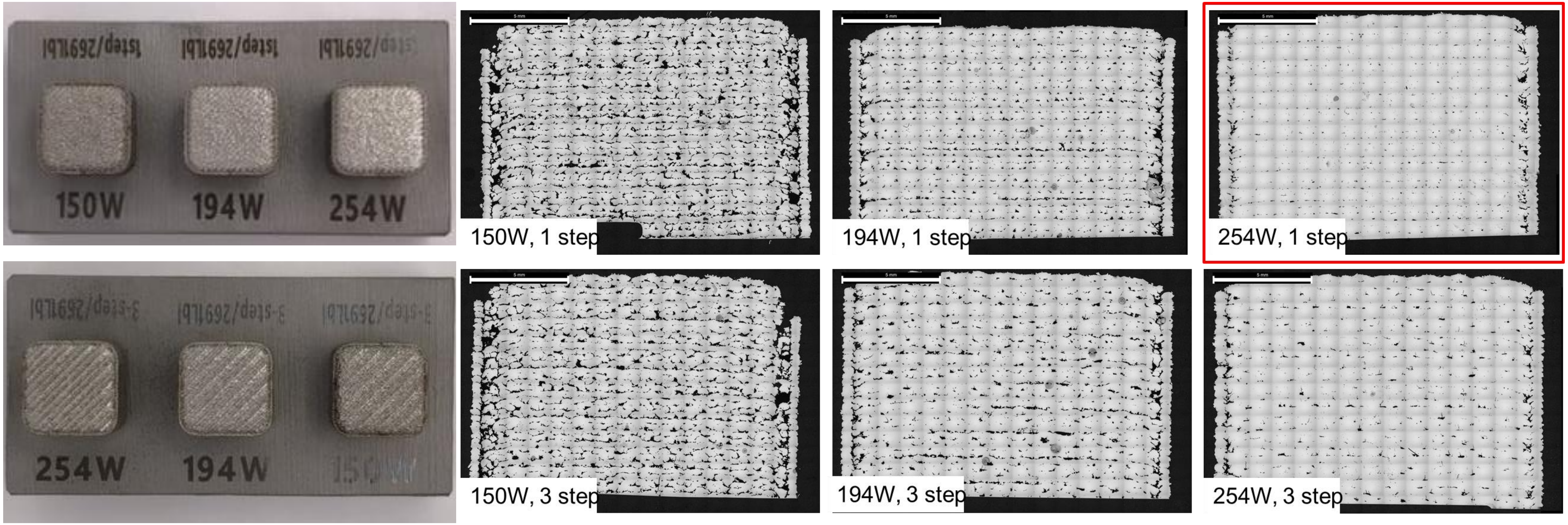
Axial strain

b



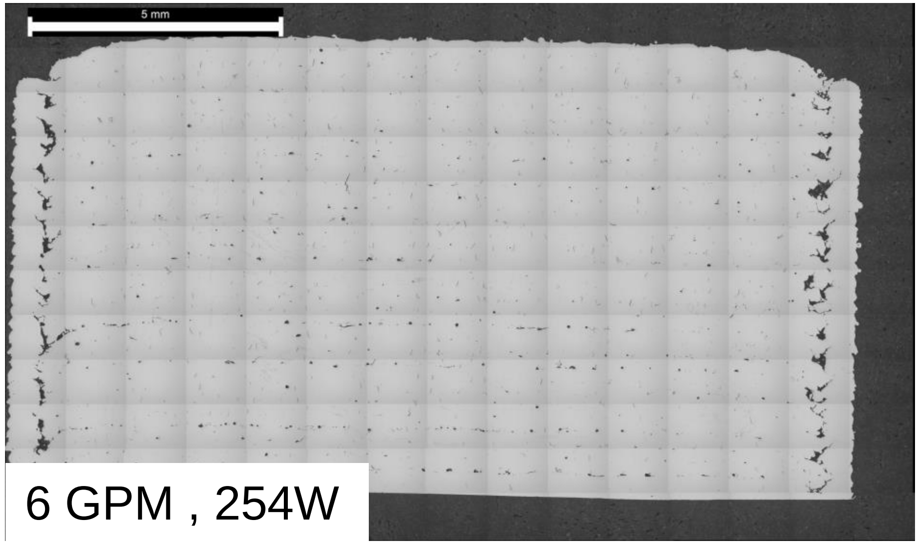
Process parameter studies on 347H to eliminate cracking

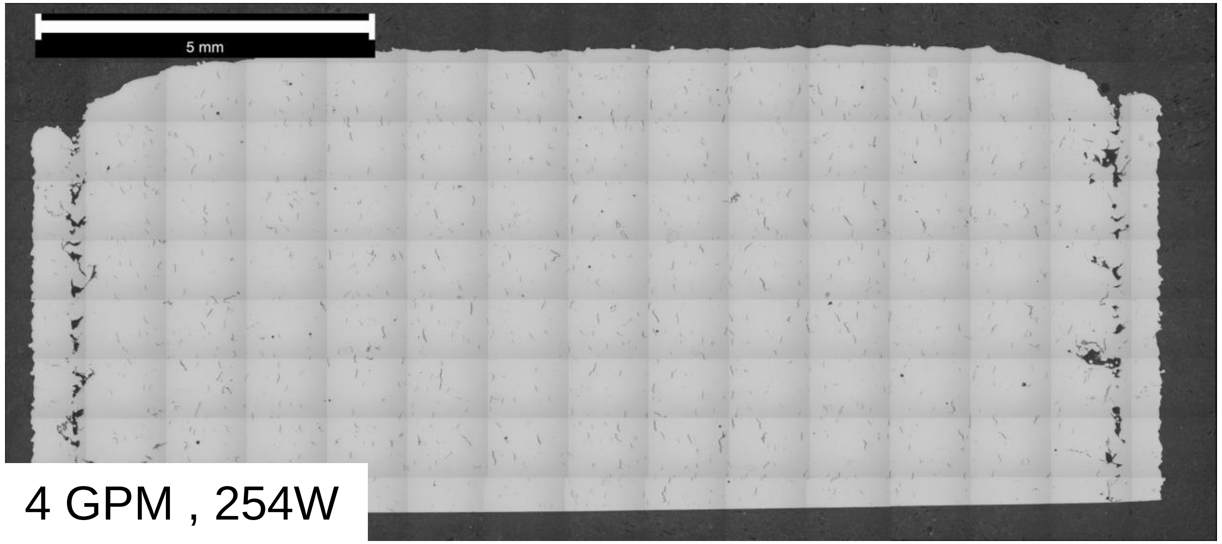
- Effect of scan strategy (1-step vs 3-step) and power



- 254 W, 1 step has the lowest porosity and cracking.
- Effect of powder flow rate on 254 W, 1 step was further analyzed.

Process parameter studies on 347H to eliminate cracking



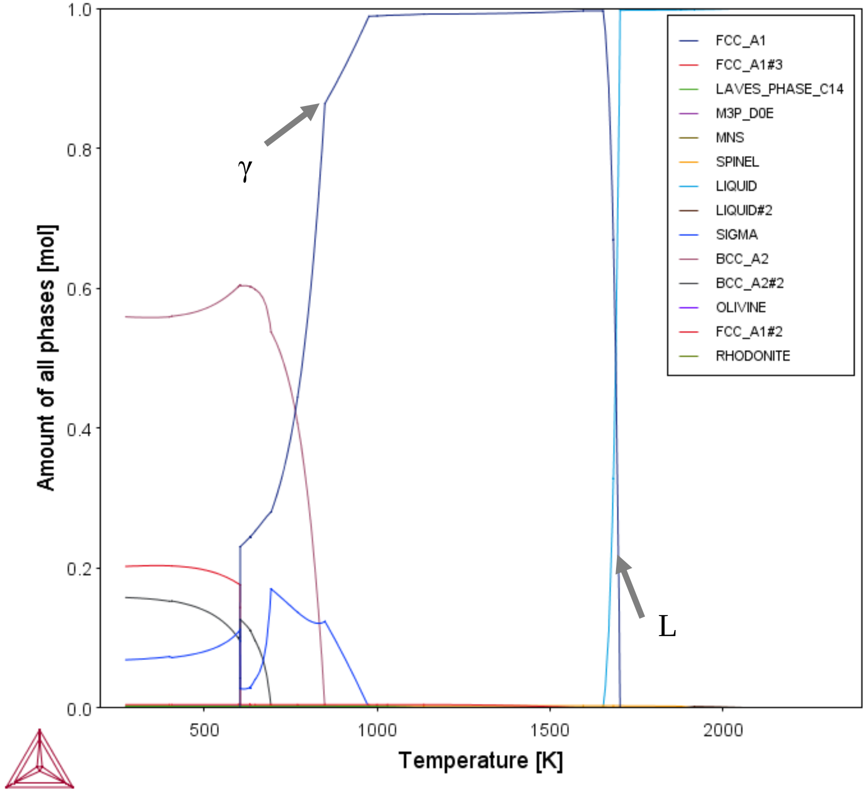


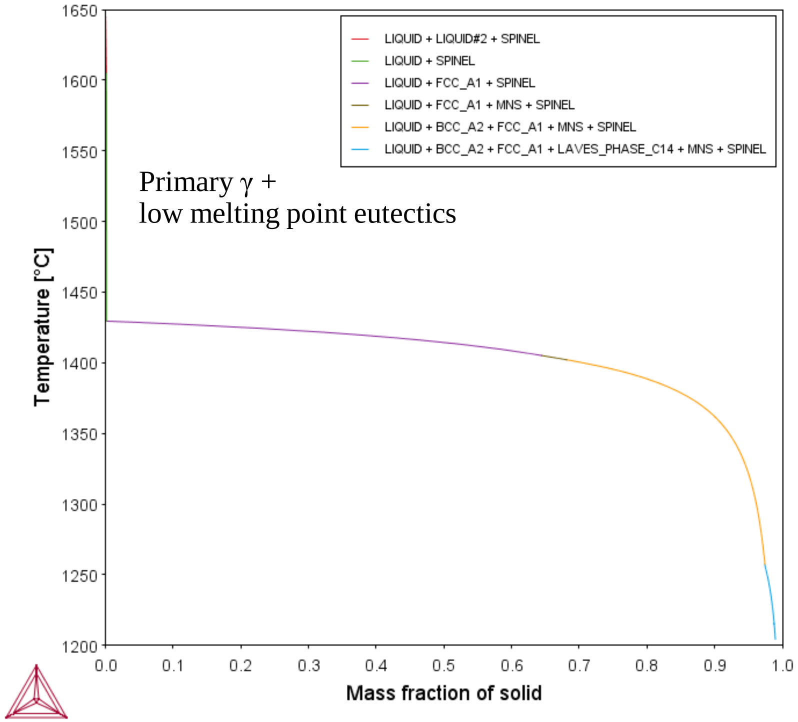
- Higher power with 1 step scan strategy and lower powder flow rate seems to provide microstructure with a relatively lower number of cracks.

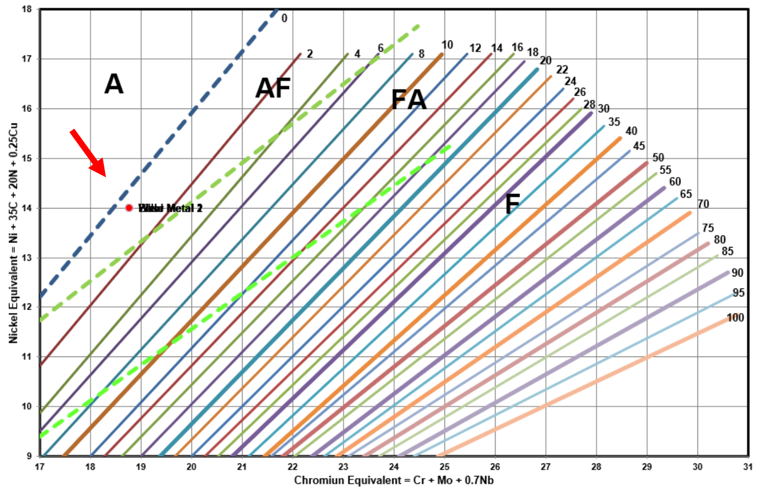
- Why does 347H crack?

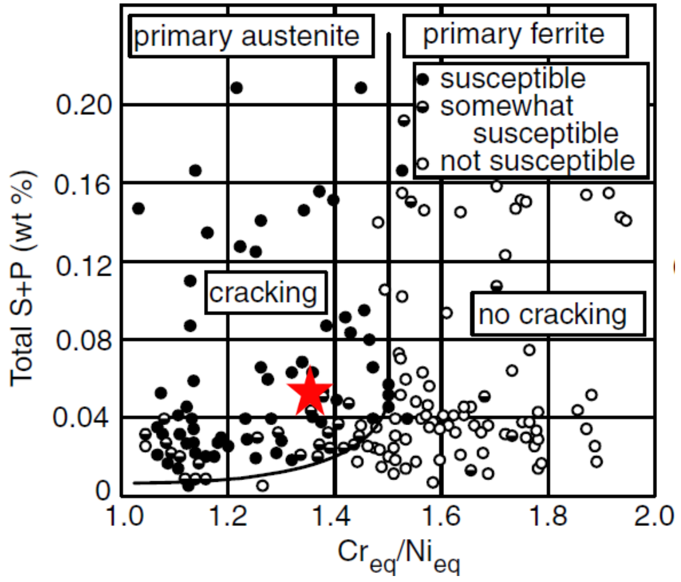
Powder composition renders 347H susceptible to cracking

347H



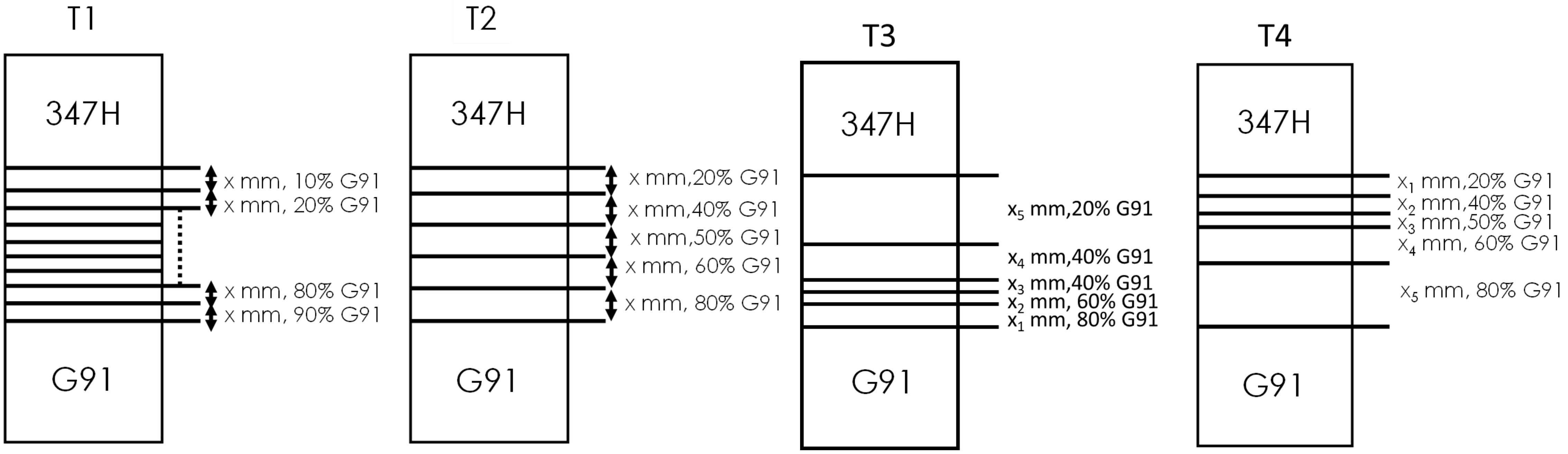






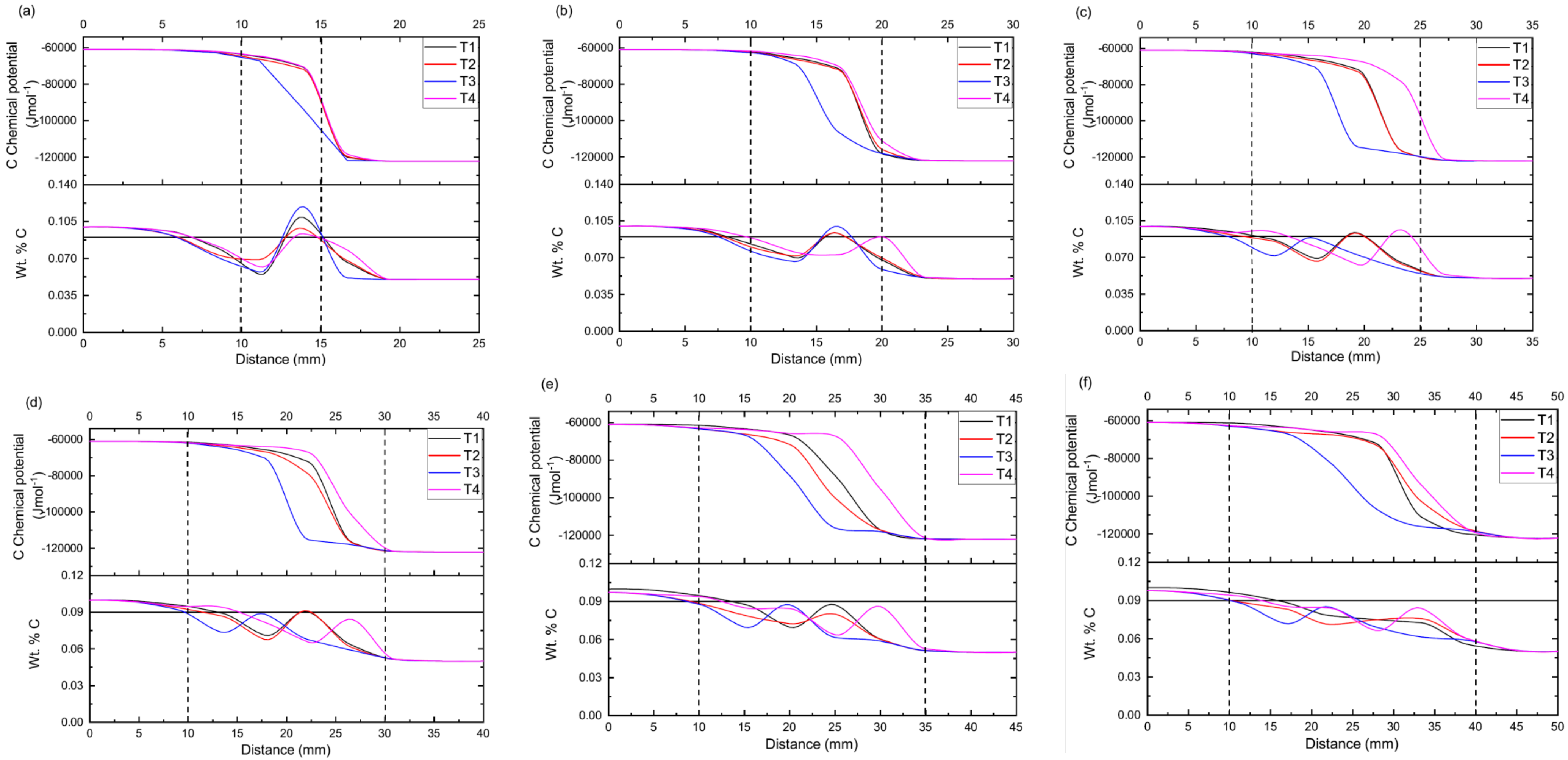
- Low $Cr_{eq.}/Ni_{eq.}$ ratio in 347H and low ferrite number, primary austenite solidification.
- High S+P in 347H resulting in the formation of low melting eutectics.
- 347H has high susceptibility to solidification cracking.
- Considering working with powder vendors to alter the composition to reduce cracking.

Non-linear transition zone configurations studied for diffusion simulations



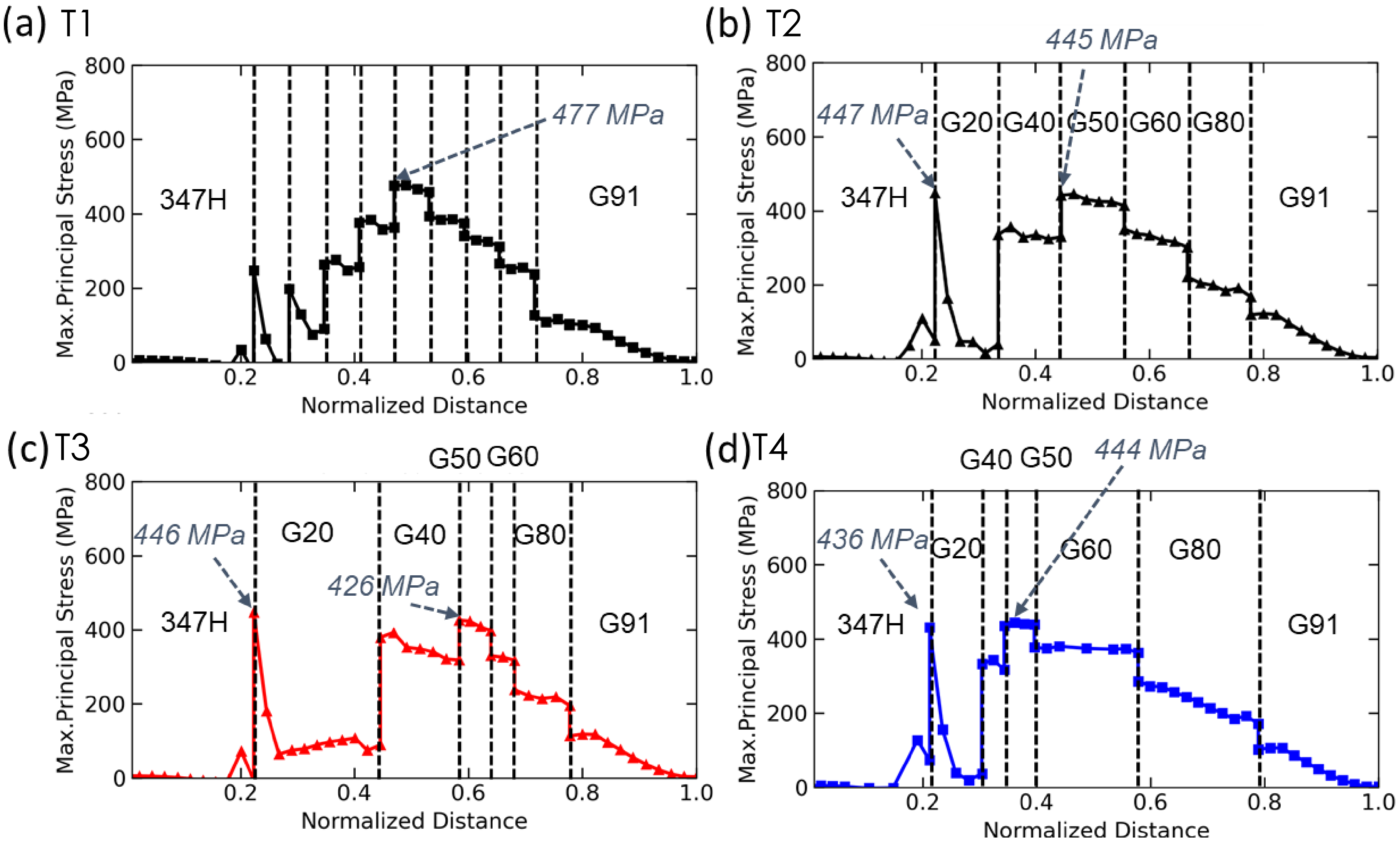
- Linear transition in terms of composition and width in the transition zone (T1).
- Non-linear transition in terms of composition linear in terms of width in the transition zone (T2).
- Non-linear variation in both composition and width in the transition zone (T3 and T4).

Identifying optimum transition zone length using kinetic simulations



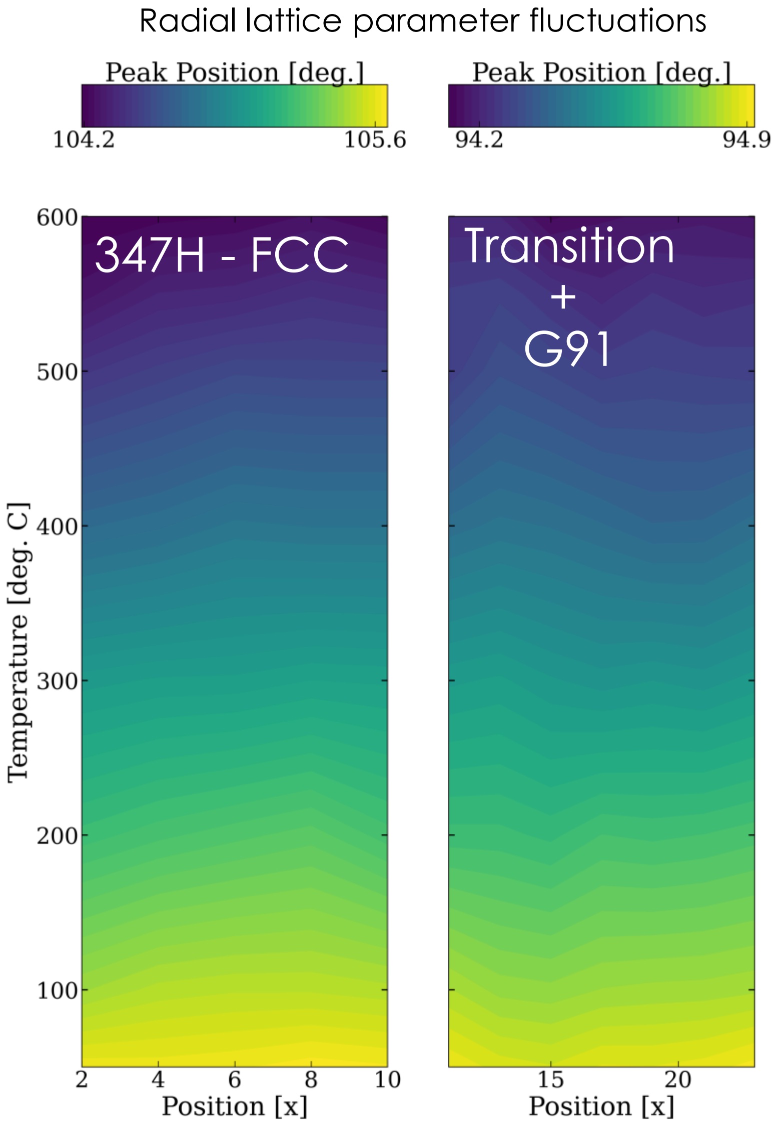
- The non-linear transition zone has a shallower chemical potential gradient and lower C depletion at grade 91/transition zone interface.
- Optimum transition zone length for the non-linear case is lower compared to the linear case.

Stress Evolution by Thermal Expansion Mismatch



- The non-linear transition zone (T4) has the lowest maximum principal stress compared to other transition zone configurations.

Next steps



- Neutron diffraction measurements data analysis (on-going).
- High-temperature tensile testing on the transition joints.
- Characterization of burst tested transition joint samples.
- Fabrication and testing of non-linear transition joints.