Development of Functionally Graded Transition Joints to Enable Dissimilar Metal Welds

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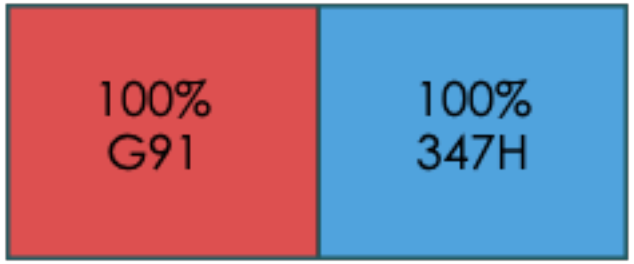
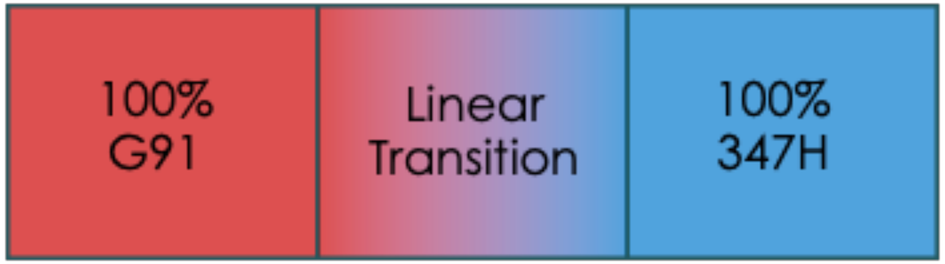
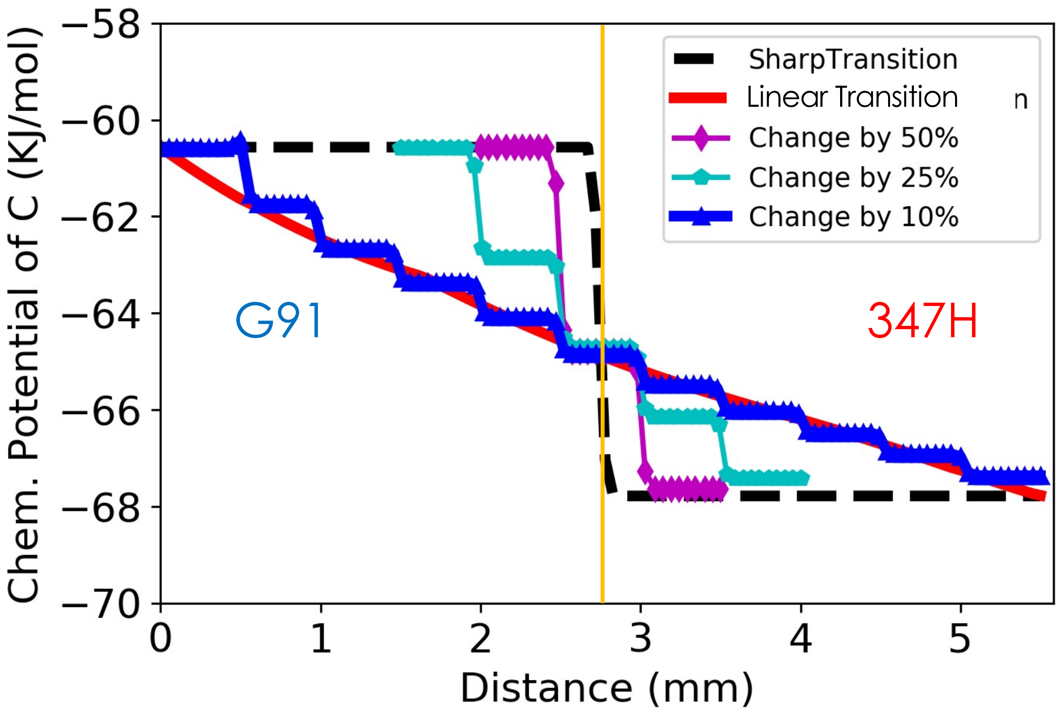
Background

- Fossil-fuel fired plants use low alloy Cr-Mo Ferritic (Grade 91) and high-alloy Austenitic steels (Stainless Steel 347H)
- Joining the ferritic and austenitic components necessitates the formation of a dissimilar metal weld
- Costs associated with premature failure of the joint: $250,000-$850,000 per day
- Challenges with dissimilar metal welds
  - High stresses in the joint – due to mismatch in coefficient of thermal expansion
  - Carbon migration – due to difference in carbon chemical potential across the interface
- Current solution – trimetallic joints result in some improvement in life but joints still fail in about half their expected life cycle
- Additive manufacturing (AM) – technologies like blown powder directed energy deposition allow for graded transition joints for dissimilar metal welds
  - Reduce differences in carbon chemical potential
  - Reduce stresses in the joint resulting from CTE mismatch

Chemical Potential: Identifying Composition Gradients in Transition Zone

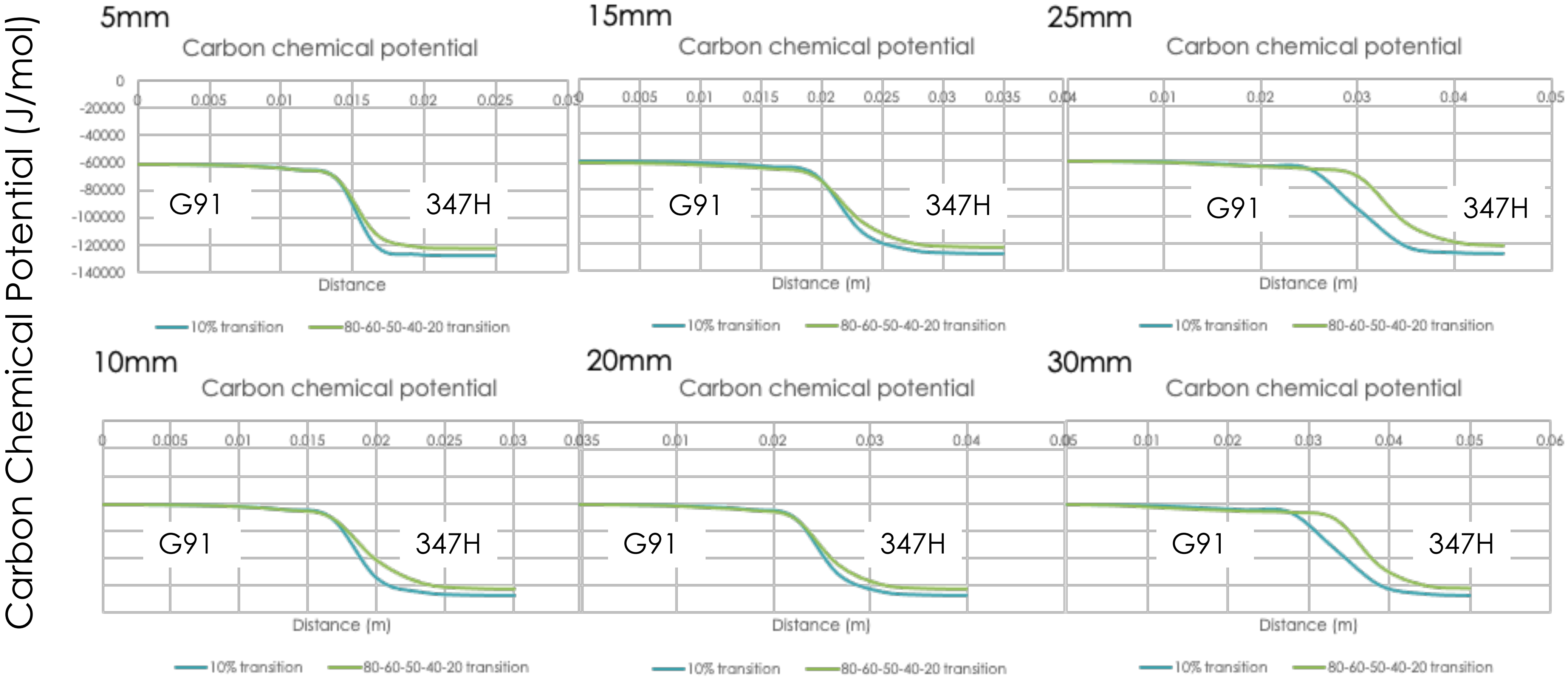






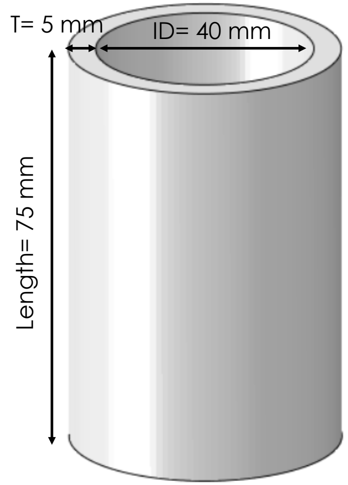
- A steeper transition gradient is associated with larger carbon chemical potential difference – joint likely to fail because of carbon depletion zone
- Linear transition has the shallowest gradient but not practical – will result in large transition zone thickness during fabrication since it takes ~3 layers to change the composition
- 10% transition appears to be practical!
- Is there a better composition profile?

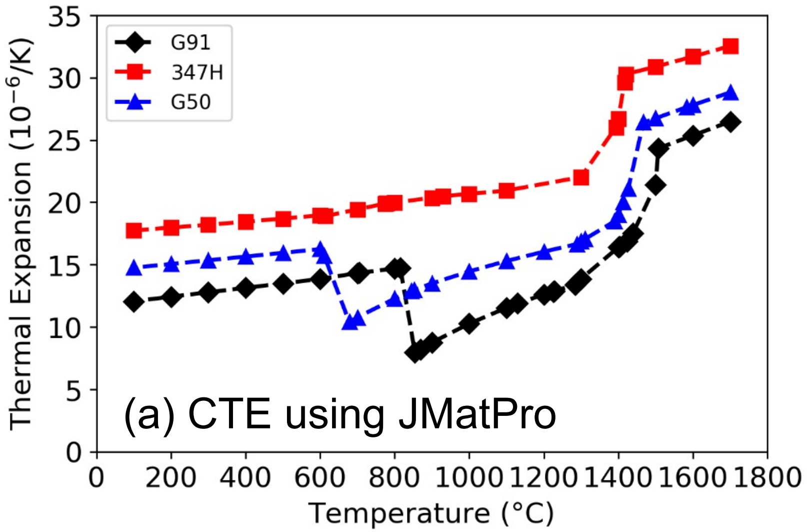
Alternate Composition Gradients & Impact on Length of Transition Zone

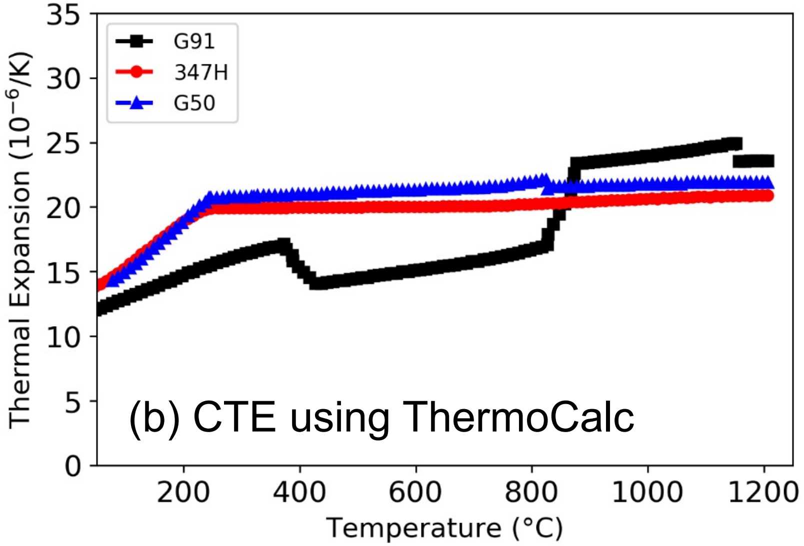


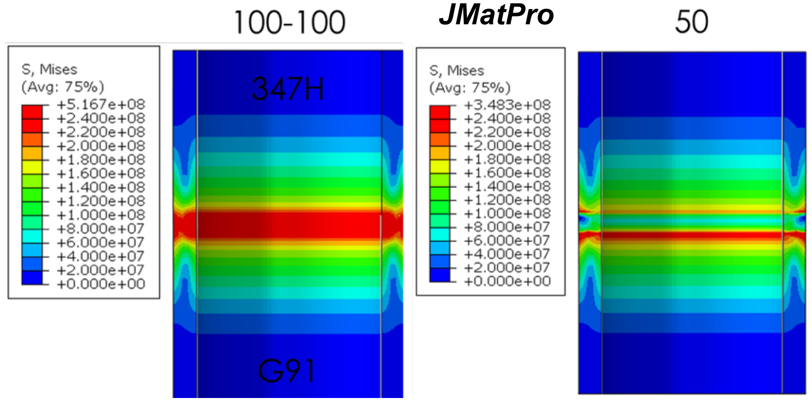
A transition of 80%G91-60%G91-50%G91-40%G91-20%G91 is shallower than the 10% transition in composition for all transition zone lengths at 650 °C

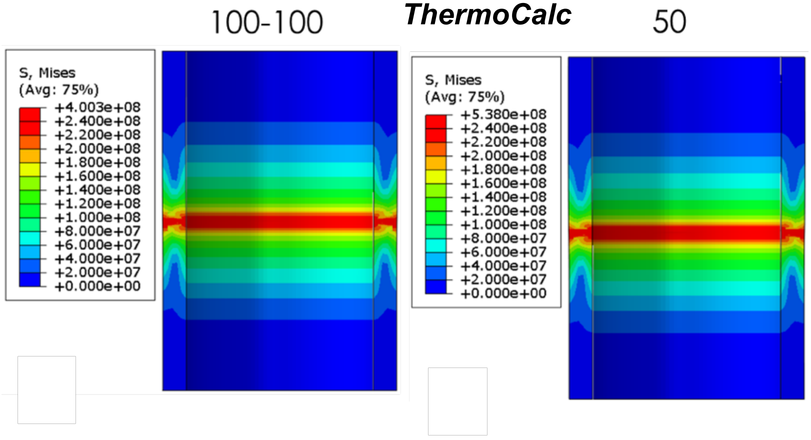
Stress in the Joint: Impact of Database on Calculations





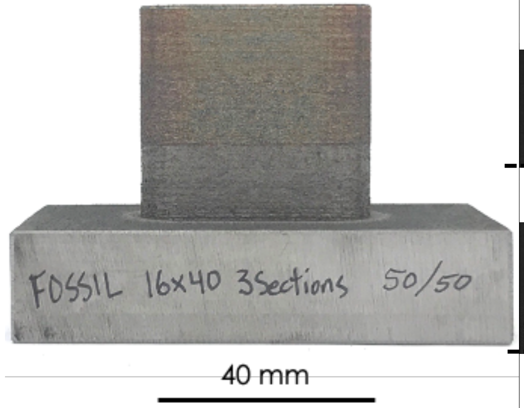


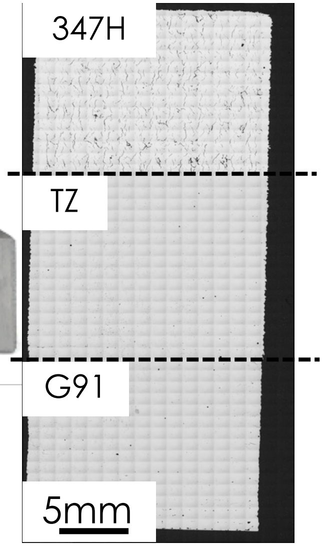


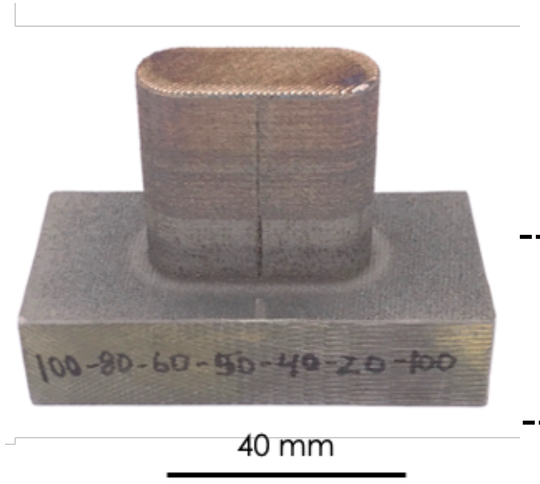


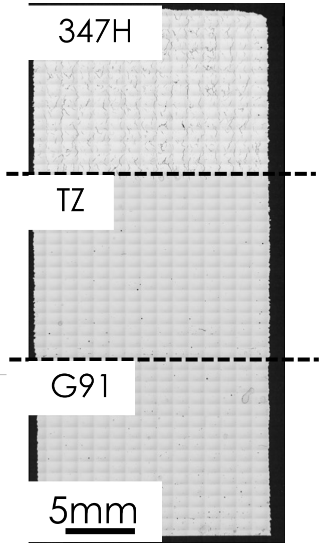
- For stress prediction,
  - 100/100 (516 MPa) > 50/50 (348 MPa) using CTE from *JMatPro*
  - 100/100 (400 MPa) < 50/50 (538 MPa) using CTE from *ThermoCalc*
- The trend in stress directly follows the difference in CTE
- Stress prediction relies on accuracy of CTE

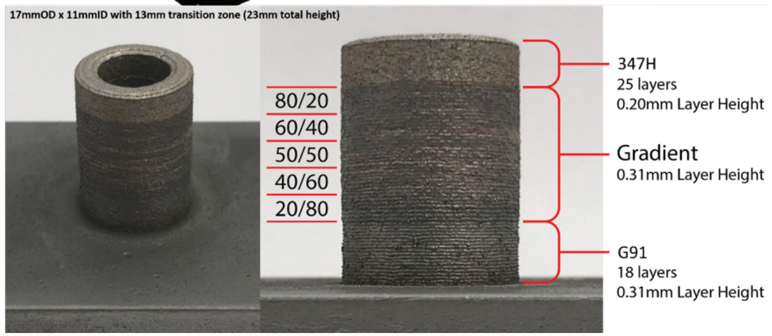
Fabrication of Transition Joint Samples









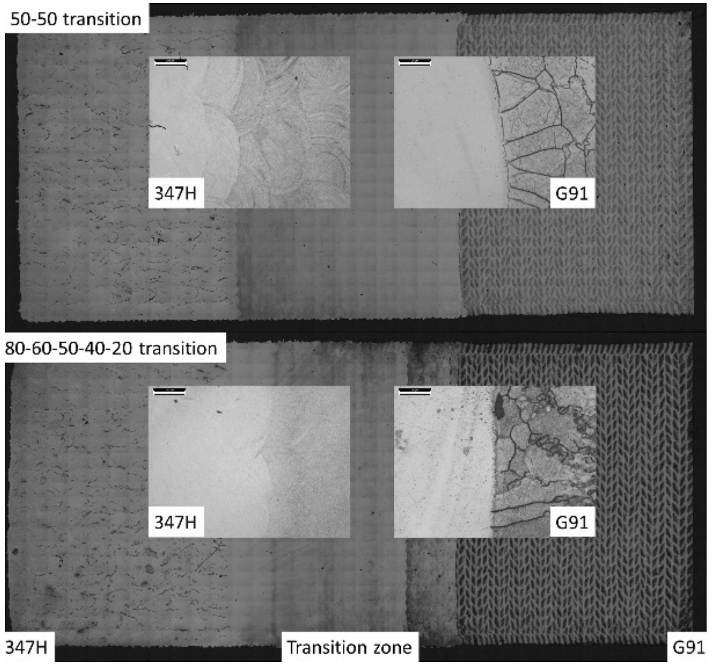


OD: 17mm
ID: 11mm
Total Height: 23mm

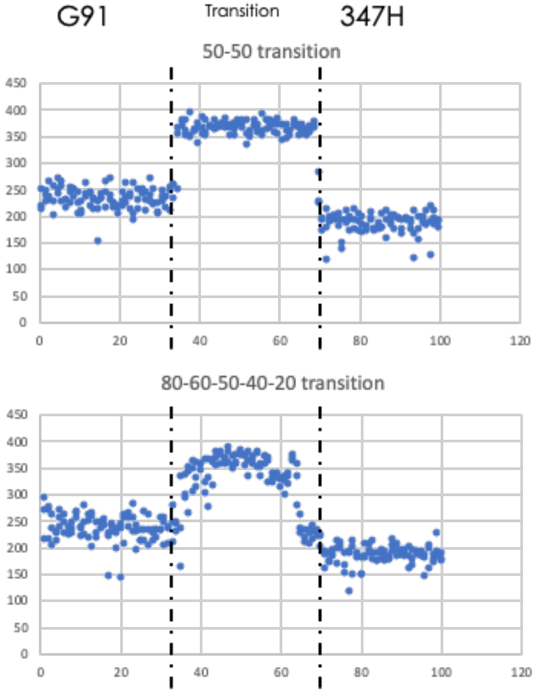
- Transition joints deposited using a BeAM Modulo 400 Blown Powder AM system
- Joints deposited with 50/50 (3 sections) transition zone or a gradation of 80/60/50/40/20 (7 sections)
- Cracking observed in 347H but not in the transition zone or G91
- Tubular geometry deposited and currently under evaluation for understanding geometry impacts on defects and microstructure

Transition Zone: Characterization

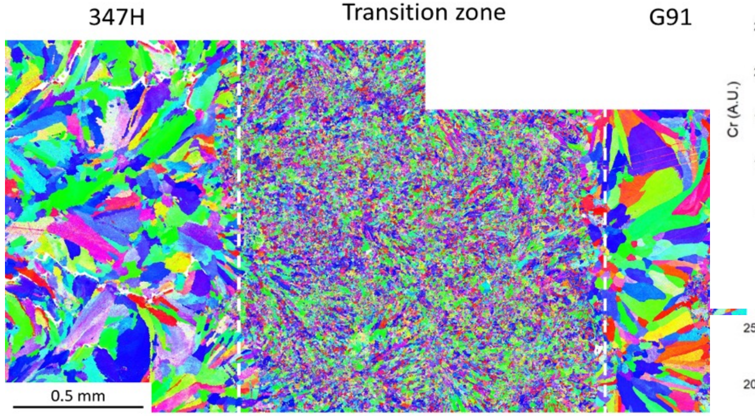
Optical Micrographs



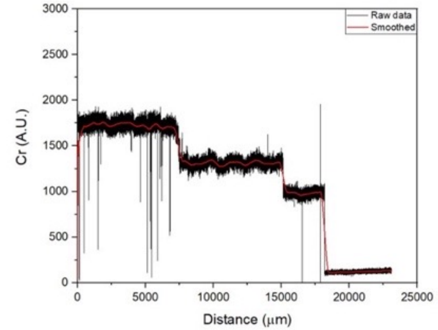
Hardness Profile

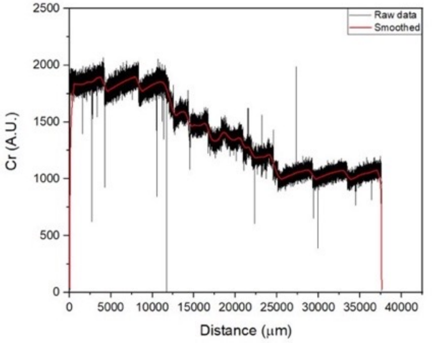


EBSD IPF Maps



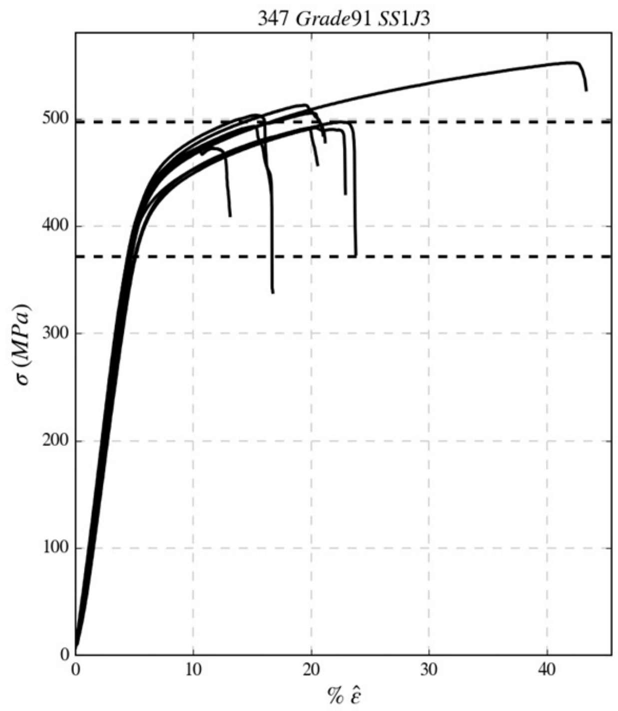
EDS Cr Profile

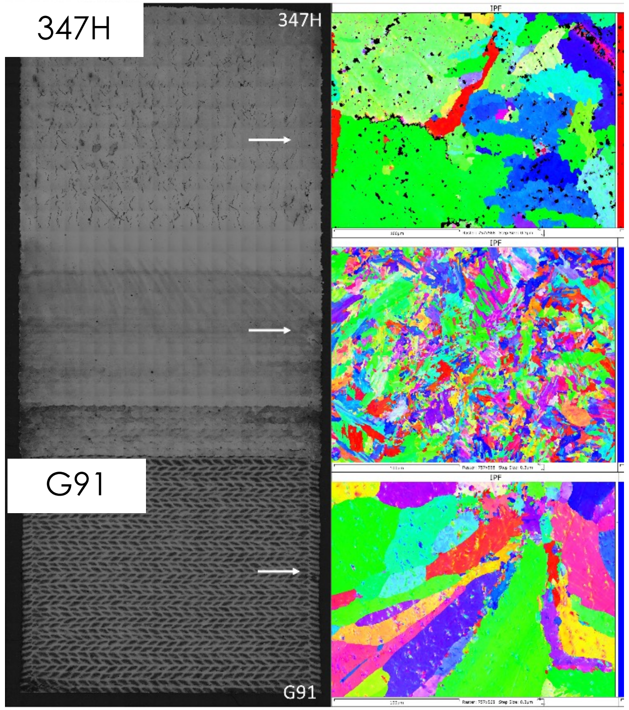


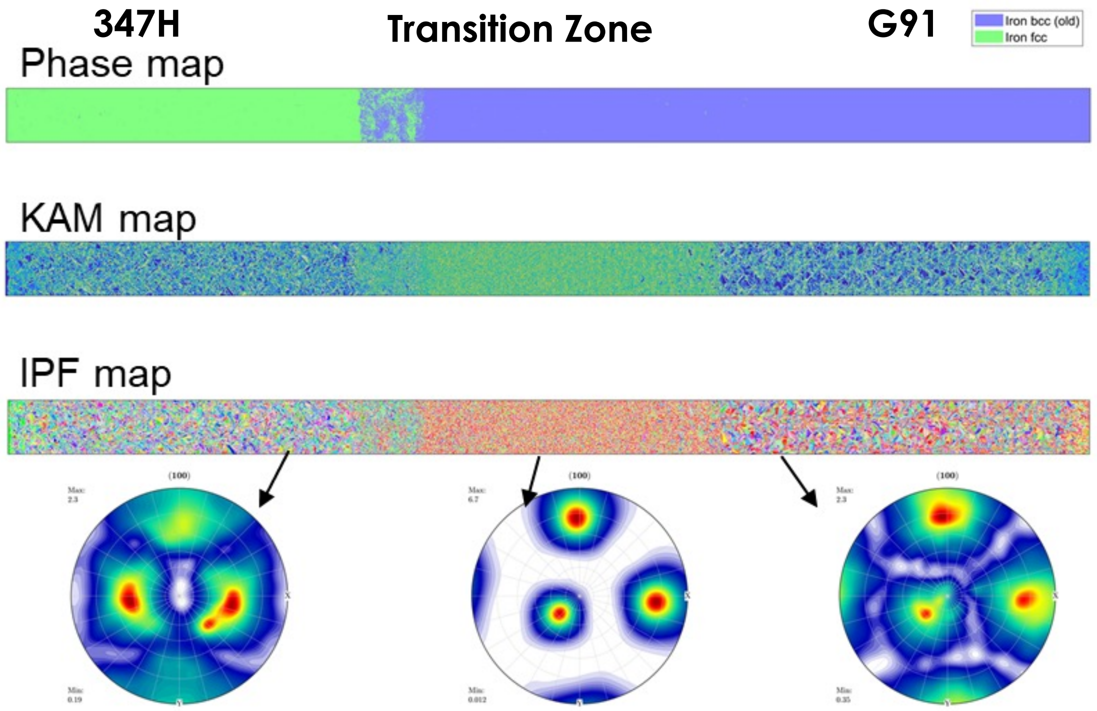


- ➢ Cracking visible in 347H side whereas a chevron pattern observed in G91 side of the joint
- ➢ Hardness peaks in the transition zone – tempered martensite at the bottom and coarser austenite grains at the top whereas microstructure in transition zone is significantly finer
- ➢ Composition changes in line with transition zones – as expected

Detailed Characterization of 80-60-50-40-20 Transition Joint

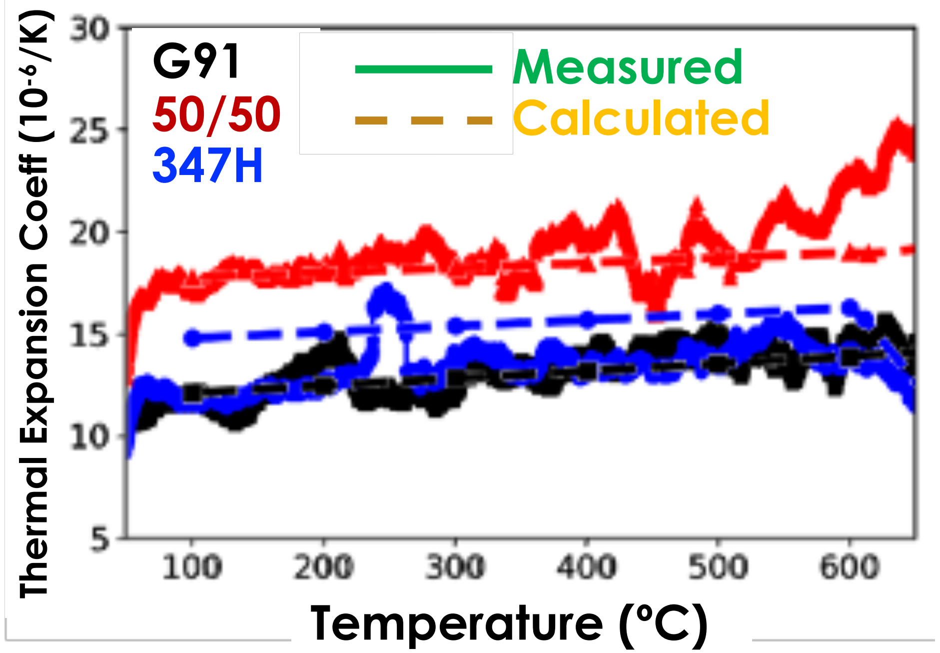




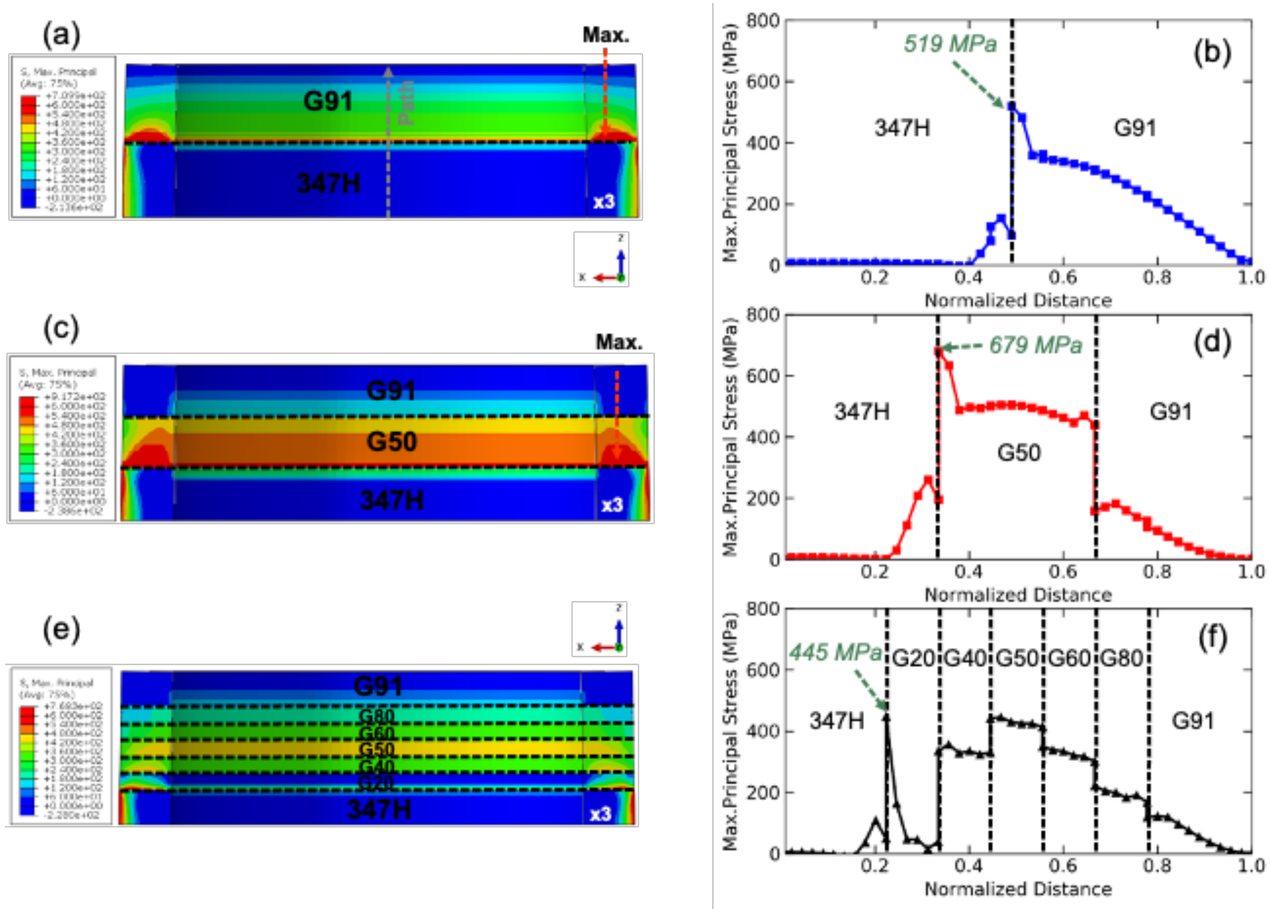


- ➢ Room temperature tensile properties between those of conventionally fabricated G91 and 347H
- ➢ Transition zone has finer structure than either of the base materials, explaining the higher hardness
- ➢ Texture changes from <001> in G91 and transition zone to <011> in 347H (under investigation)

Stress in the Joint: Based on Experimental Measurements

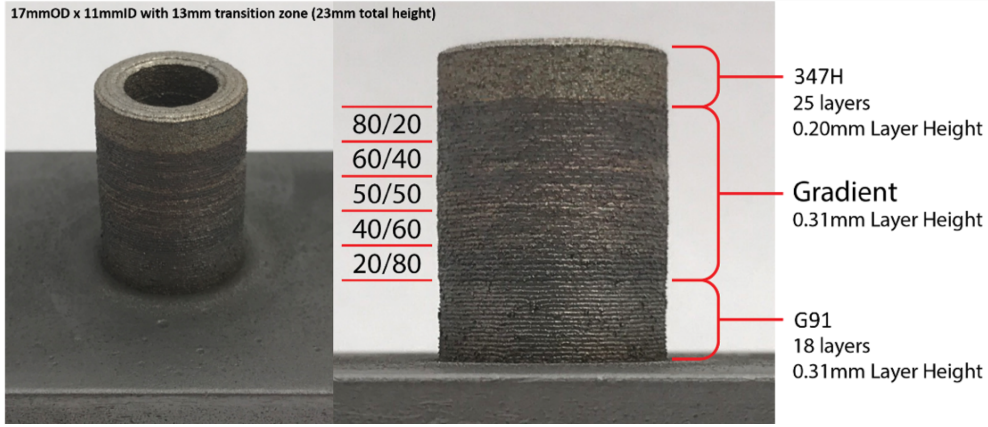


- Measured CTE values in close agreement with calculated values using JMAT
- Reveals stress larger for 50/50 transition compared to a sharp transition of 100/100: results from larger CTE difference at the 347H/TZ interface



- Lowest stress for 80/60/50/40/20 transition zone
- In all cases highest stress observed at the 347H interface

Next Steps

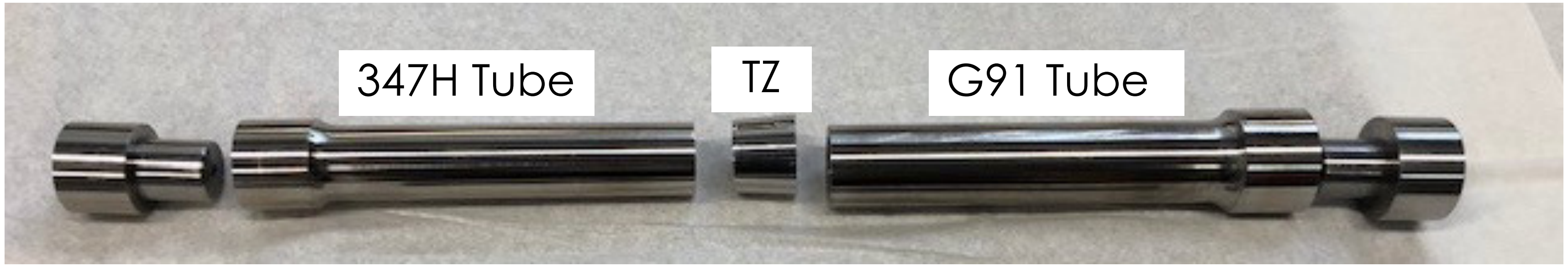


Residual stress measurements to be conducted at the High Flux Isotope Reactor (HFIR) and compared with the model

Burst testing underway

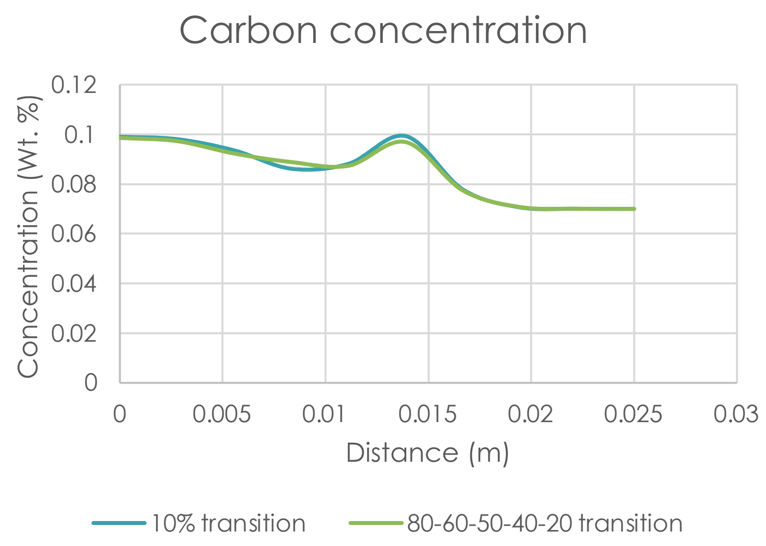
Ongoing study for process development to mitigate/minimize cracking in 347H

Samples being extracted for high temperature tensile testing and creep testing

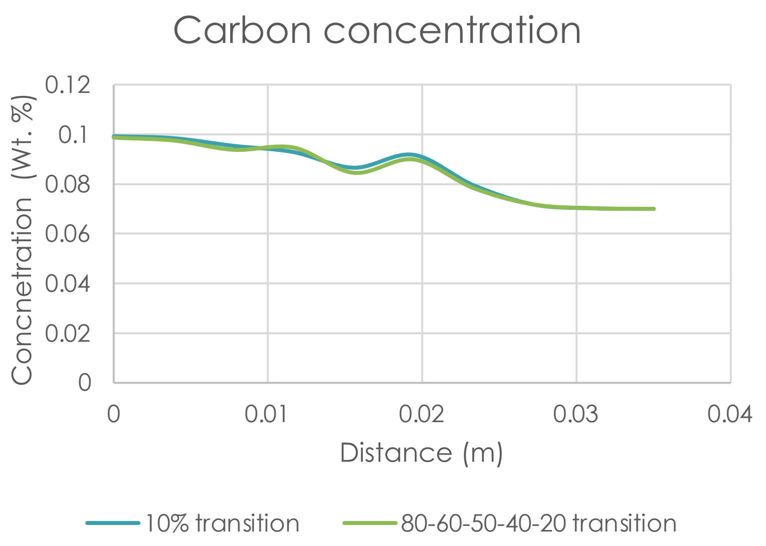


DICTRA simulations to identify carbon depletion at interface

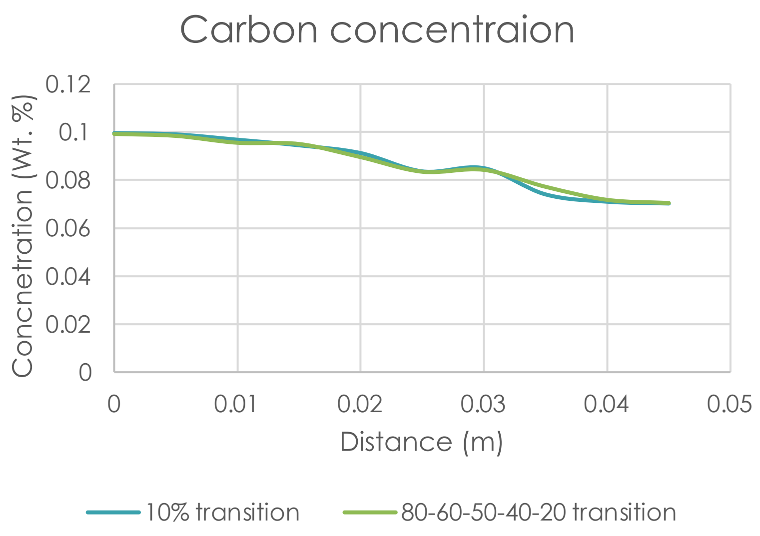
5mm



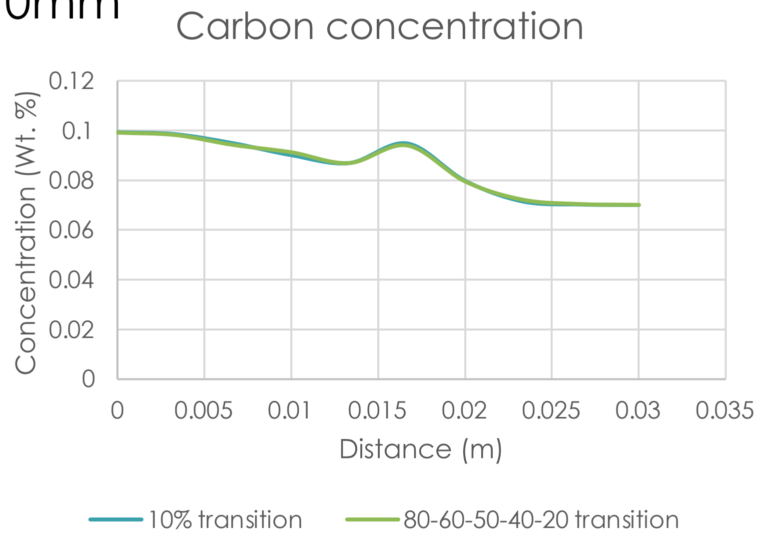
15mm



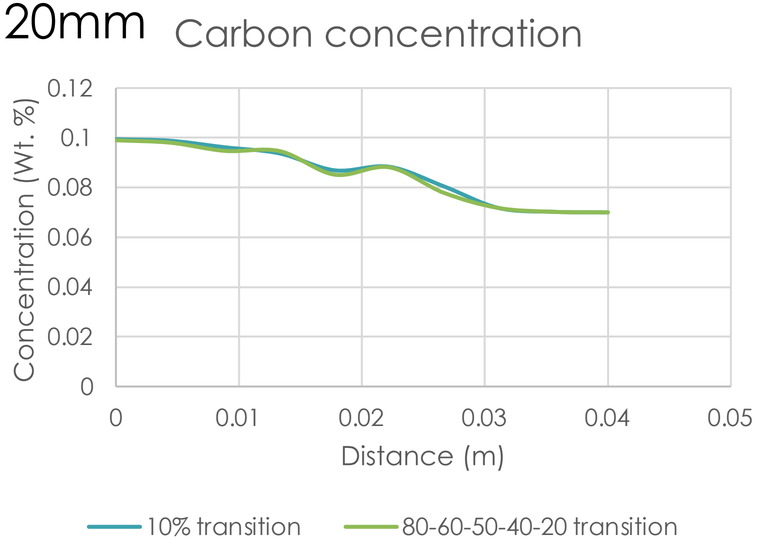
25mm



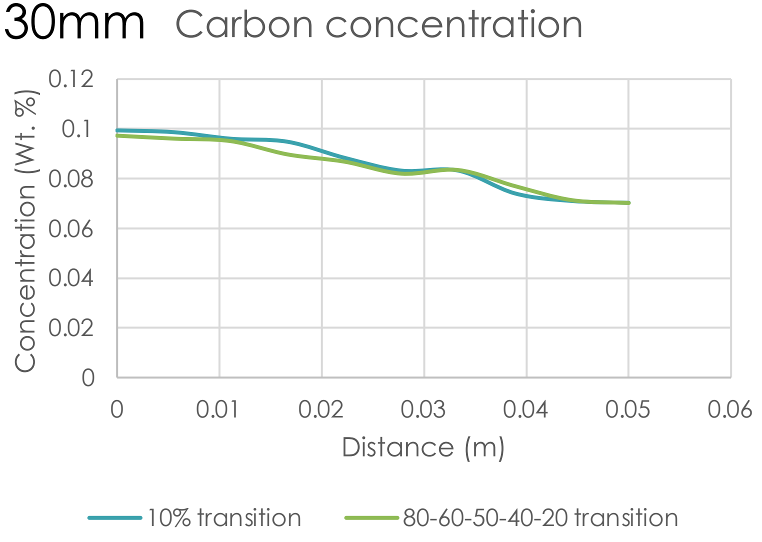
10mm



20mm

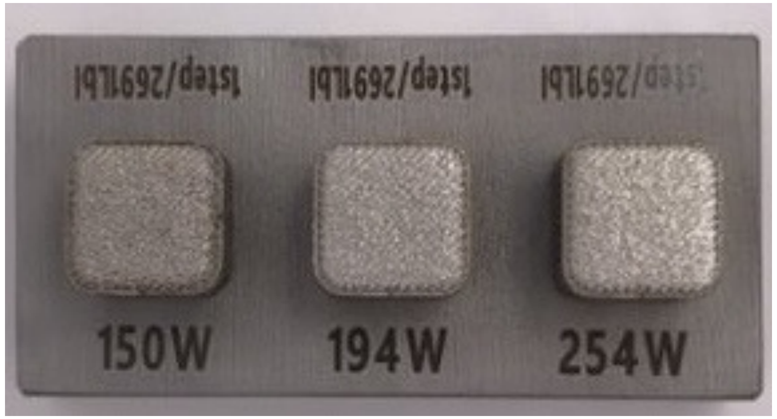


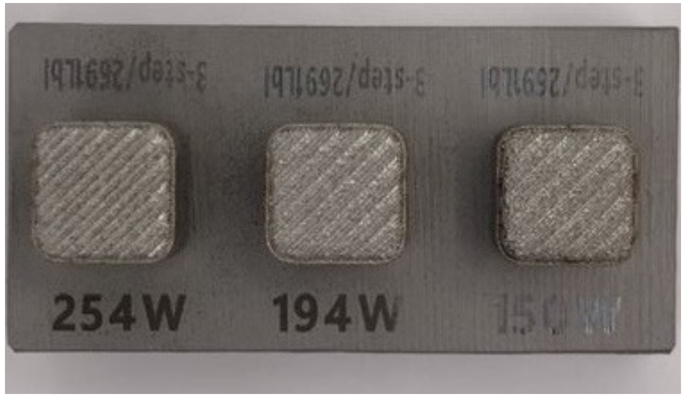
30mm



Process parameter studies on 347H to eliminate cracking

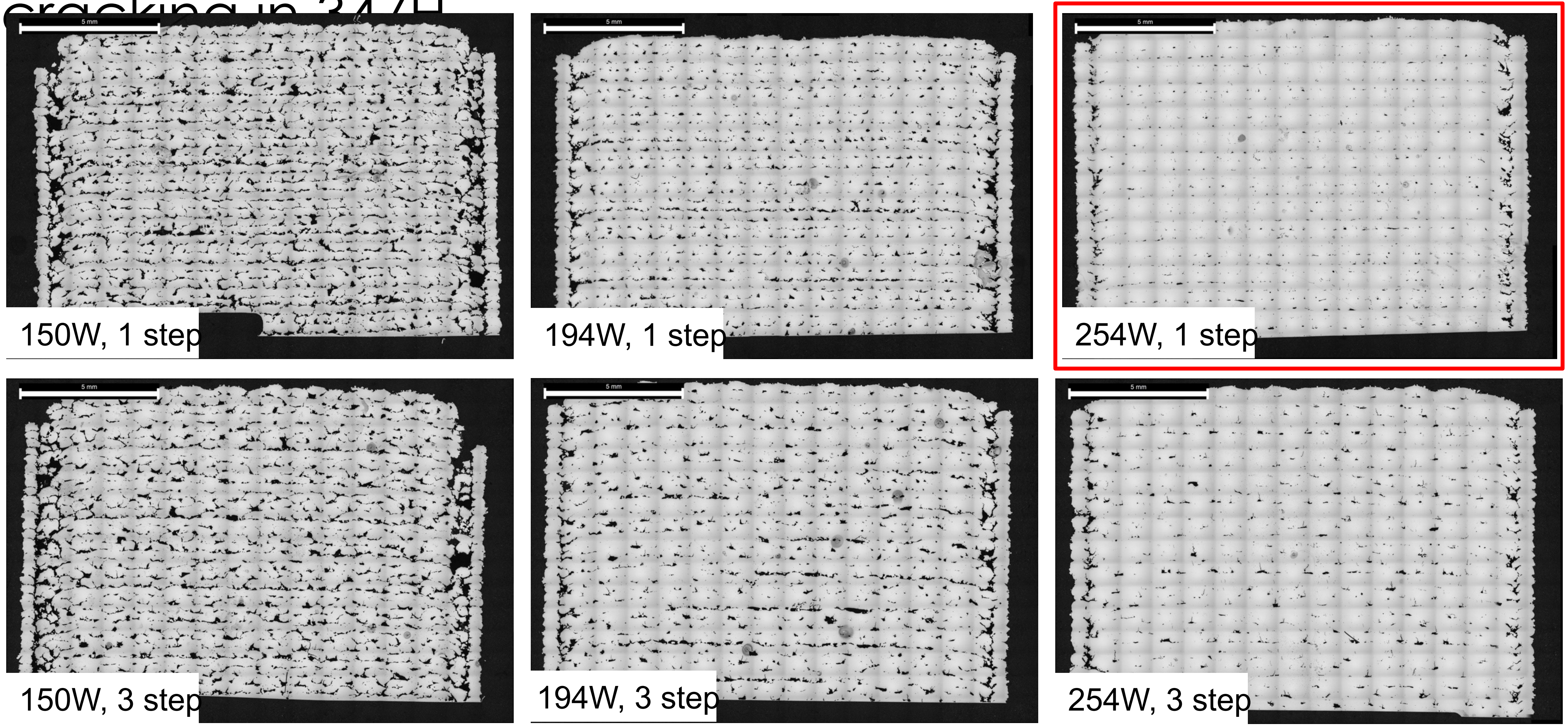
- Effect of scan strategy (1-step vs 3-step) and power



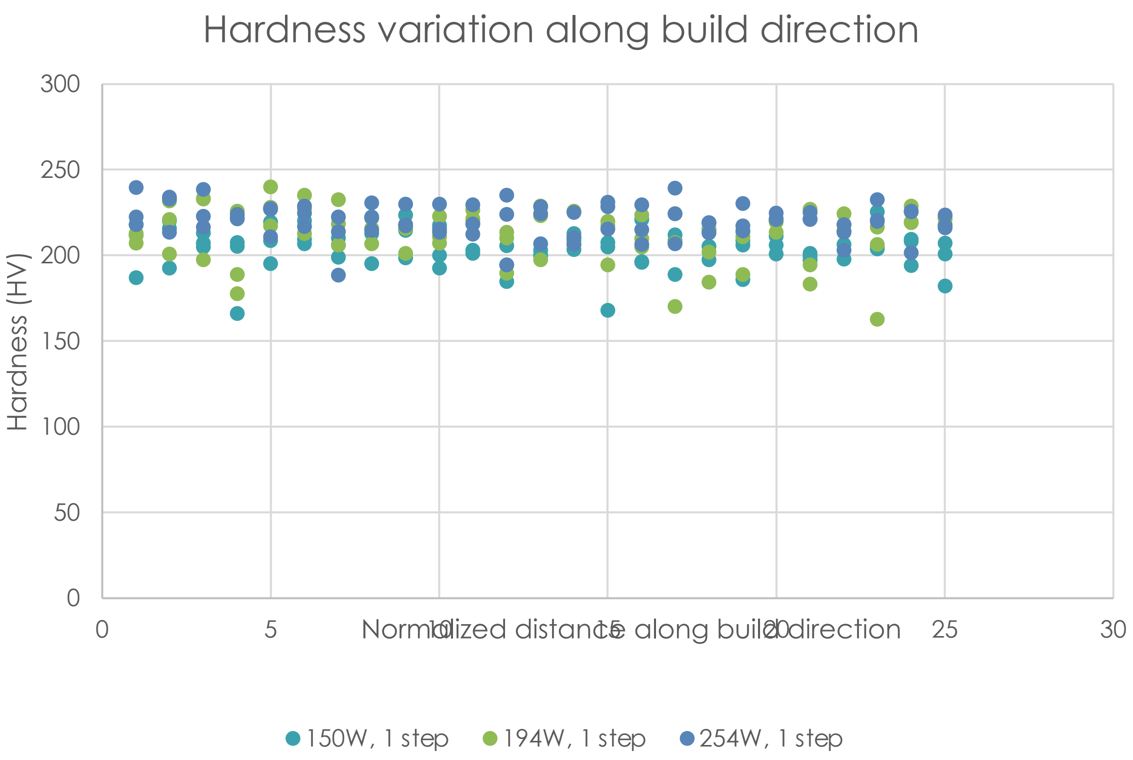


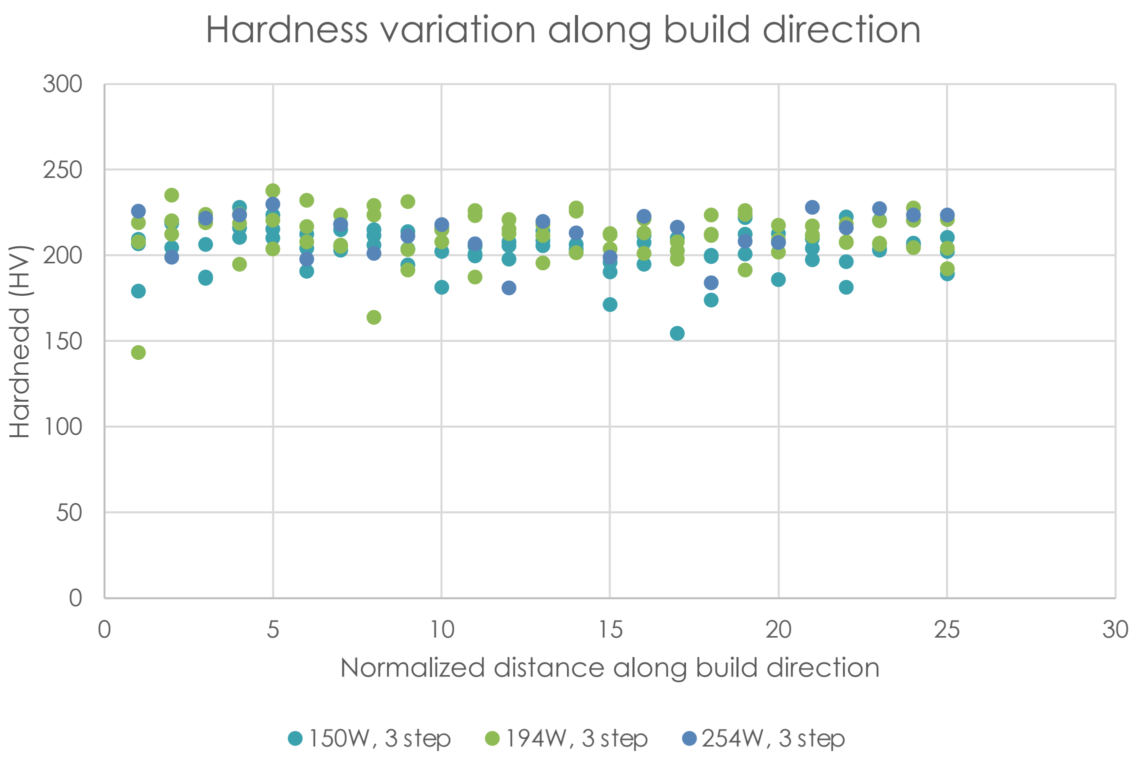
- Optical microscopy and hardness were carried out on these builds.

Effect of power and scan strategy on porosity and cracking in 347H



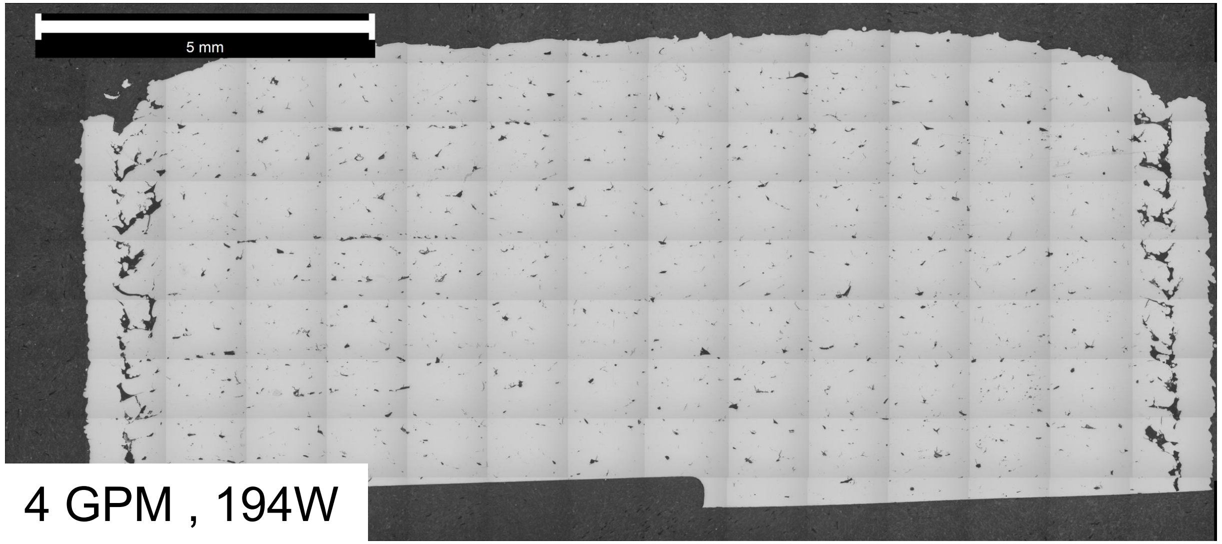
Effect of power and scan strategy on hardness in 347H



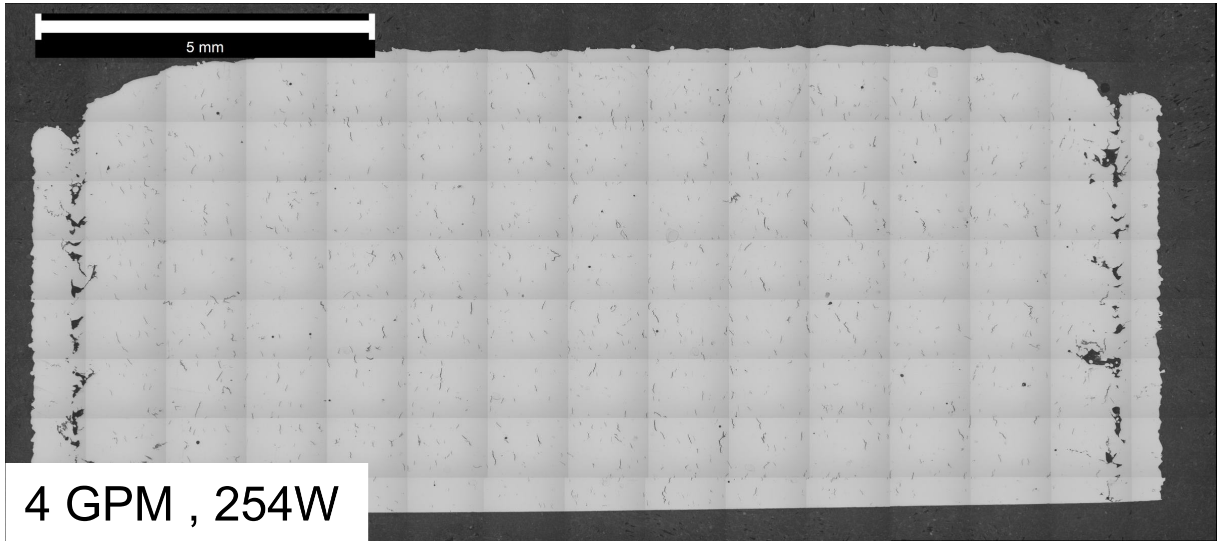


- No significant variations in hardness with changes in power, scan strategy.
- Considering minimal porosity for 254W and 1 step, subsequent builds were made by varying the powder flow ra

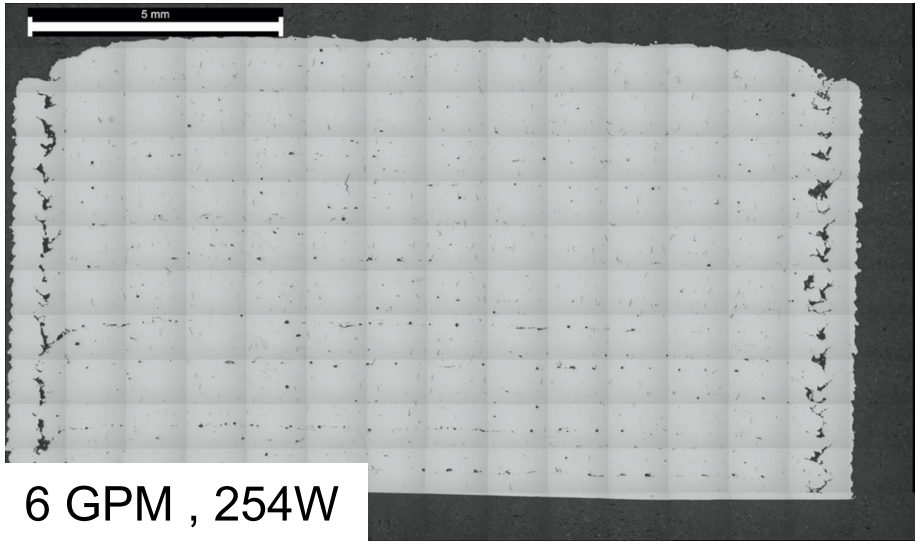
Process parameter studies on 347H to eliminate cracking – Effect of powder flow rate



4 GPM , 194W



4 GPM , 254W



6 GPM , 254W

- Higher power with 1 step scan strategy and intermediate powder flow rate seems to provide microstructure with a relatively lower number of cracks.
- Modelling the solidification cracking to achieve an optimized process parameter underway.