CANFSA

Center for Advanced Non-Ferrous Structural Alloys
An Industry/University Cooperative Research Center

Project 36F-L: Microstructure and Processing Links in Beta-Titanium during Additive Manufacturing

Semi-annual Spring Meeting

April 2022

- Student: Chris Jasien (Mines)
- Faculty: Amy Clarke (Mines)
- Industrial Mentors: John Foltz (ATI), Lee Semiatin (AFRL)
- Other Participants: Jonah Klemm-Toole (Mines)

COLORADO SCHOOL OF MINES NSF IOWA STATE UNIVERSITY

Project 36F-L: Microstructure and Processing Links in Beta-Titanium during Additive Manufacturing

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- Student: Chris Jasien (Mines)
- Advisor(s): Amy Clarke (Mines)

Project Duration
PhD: August 2020 to August 2024

- Problem: Common titanium alloys for additive manufacturing (AM) undergo solid-state phase transitions during cooling that inhibit understanding of solidification.
- Objective: Subject beta-titanium alloys to conditions representative of AM and understand retention of the metastable beta phase and microstructure evolution.
- Benefit: The development of solidification models and knowledge base of titanium alloys for AM.

Recent Progress

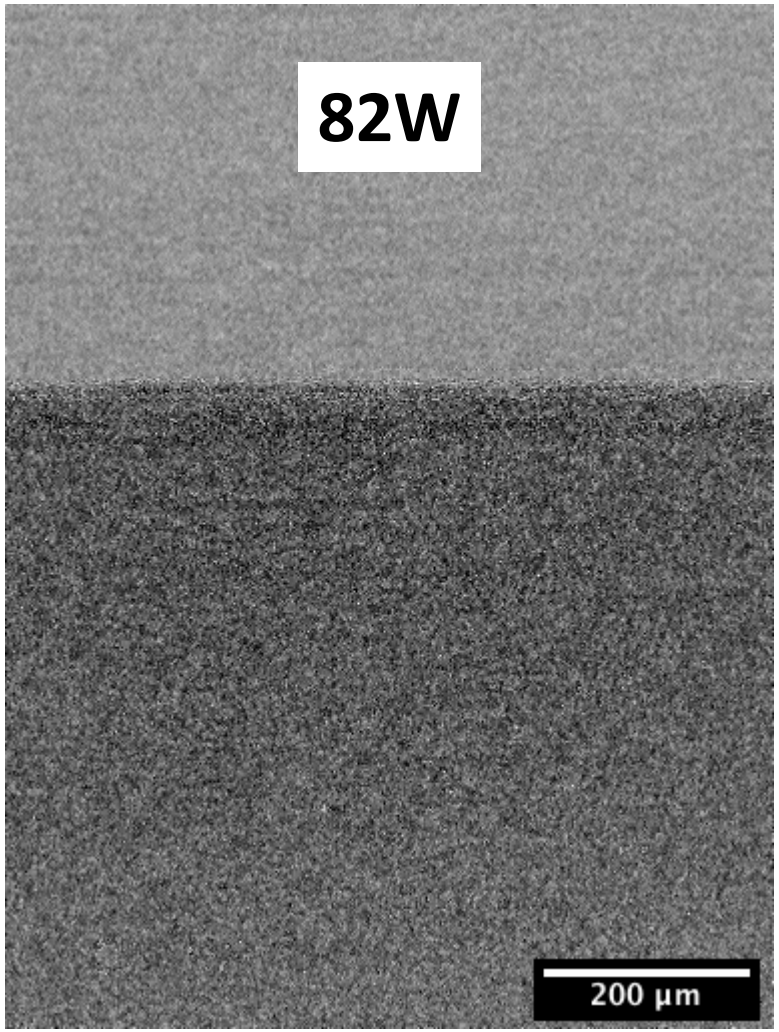
- Completion of dilatometry on as-built LPBF Ti-5553 samples
- Optical microscopy on cross-sections of Ti-1023 Advanced Photon Source (APS) samples
- Initial attempts of EBSD on Ti-1023 cross-sections

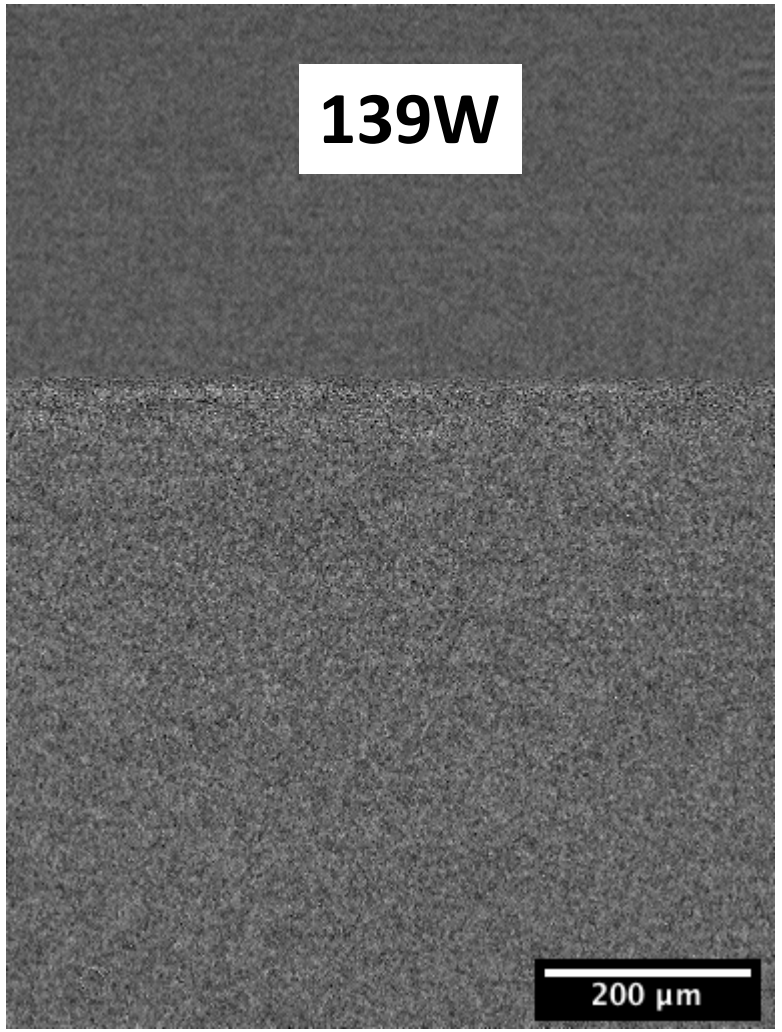
Metrics		
Description	**% Complete**	**Status**
1. Literature review	50%	●
2. Analyze APS data (solidification velocities)	100%	●
3. Determination of thermal history using simulations	100%	●
4. Supporting material characterization	25%	●
5. Laser processing of novel Beta-Ti alloys with various AM process parameters	0%	●

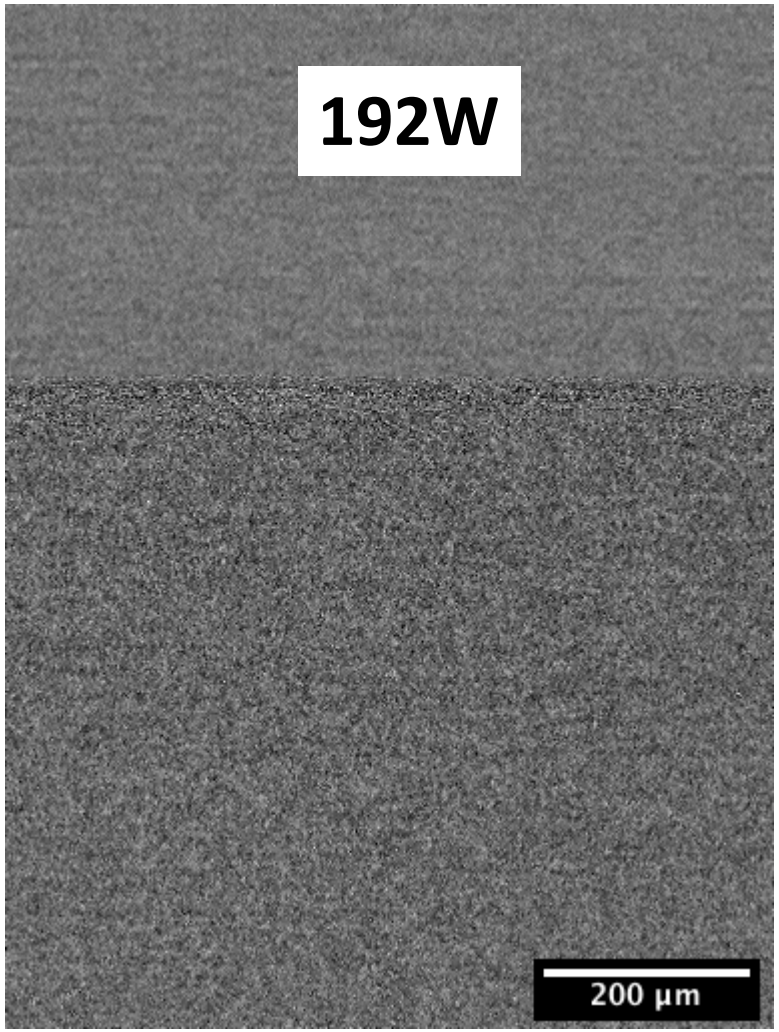
Previous Simulation Work
Ti-10V-2Fe-3Al (Ti-1023) APS Experiments

Simulations - Spot Melts

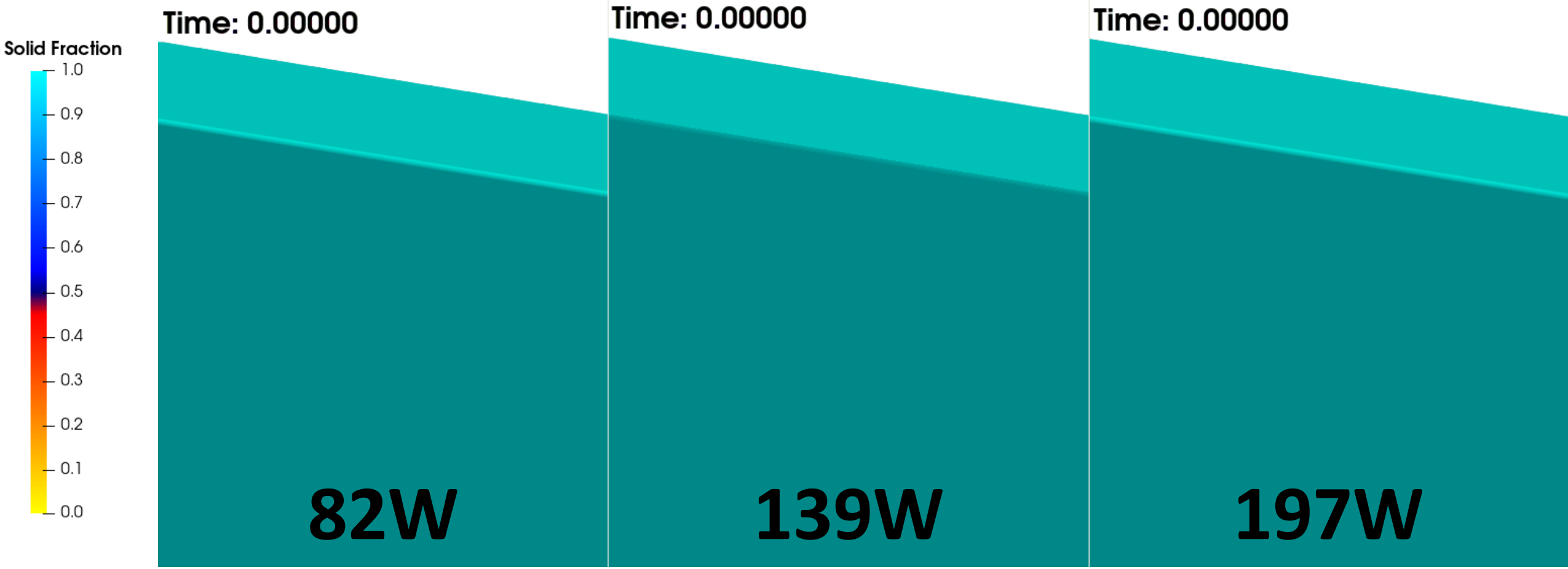
1ms Dwell



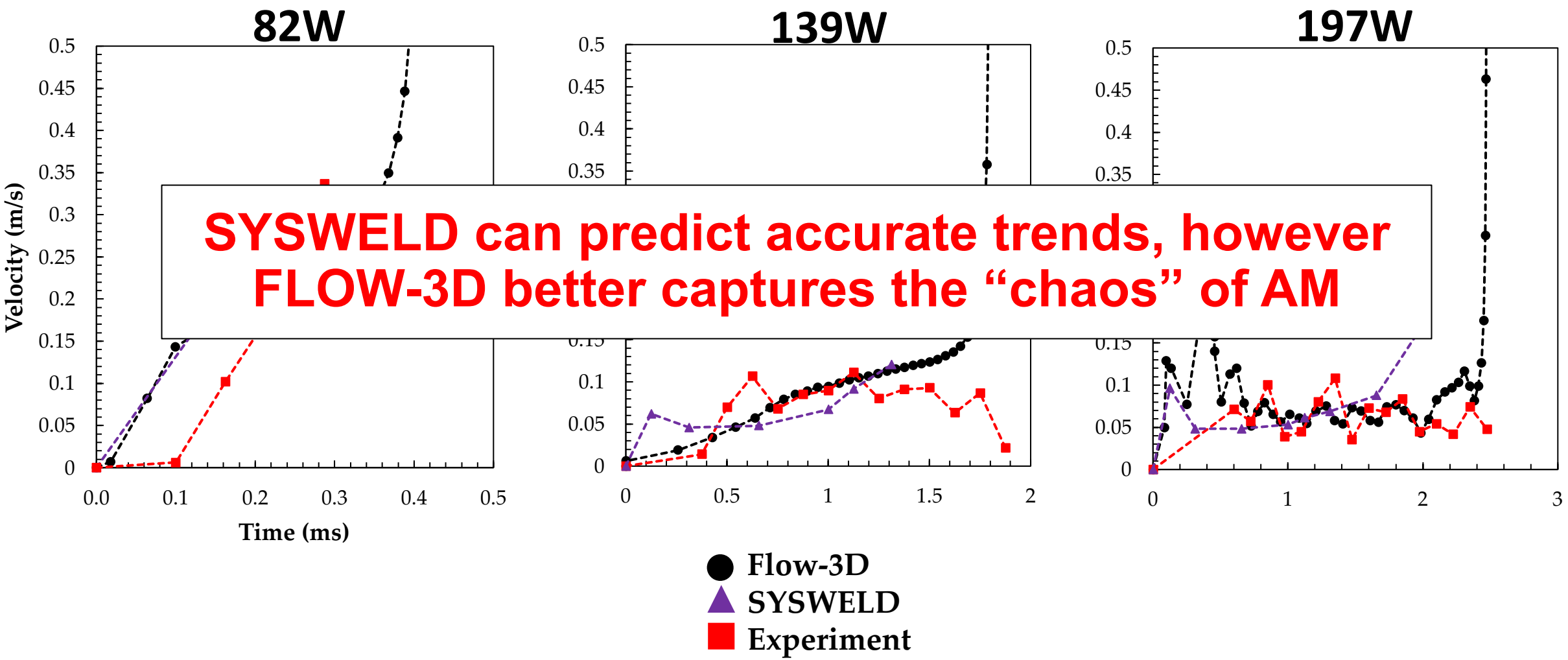




Simulations - Spot Melts



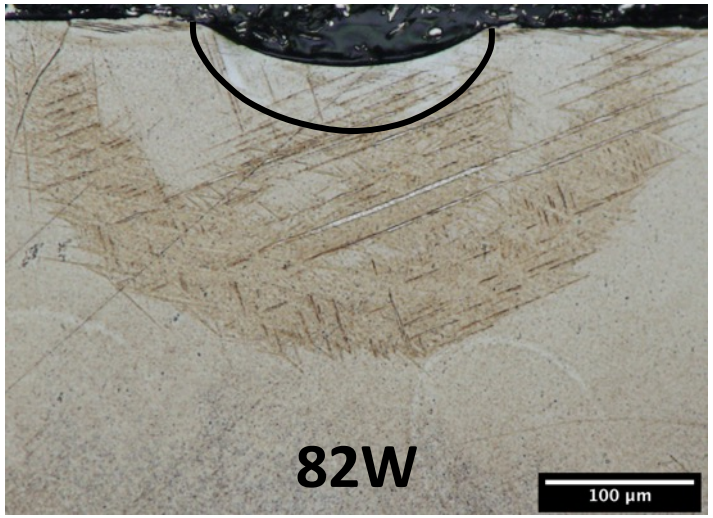
Simulations - Spot Melts



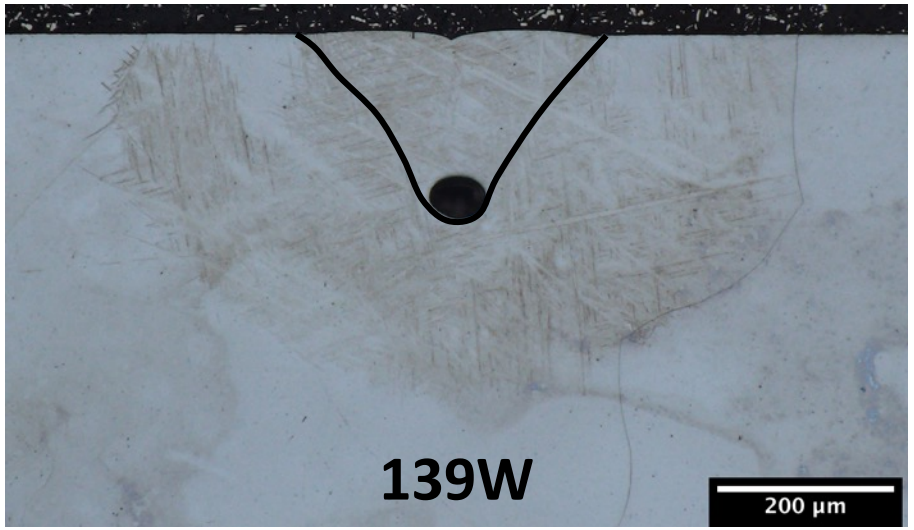
SYSWELD can predict accurate trends, however FLOW-3D better captures the "chaos" of AM

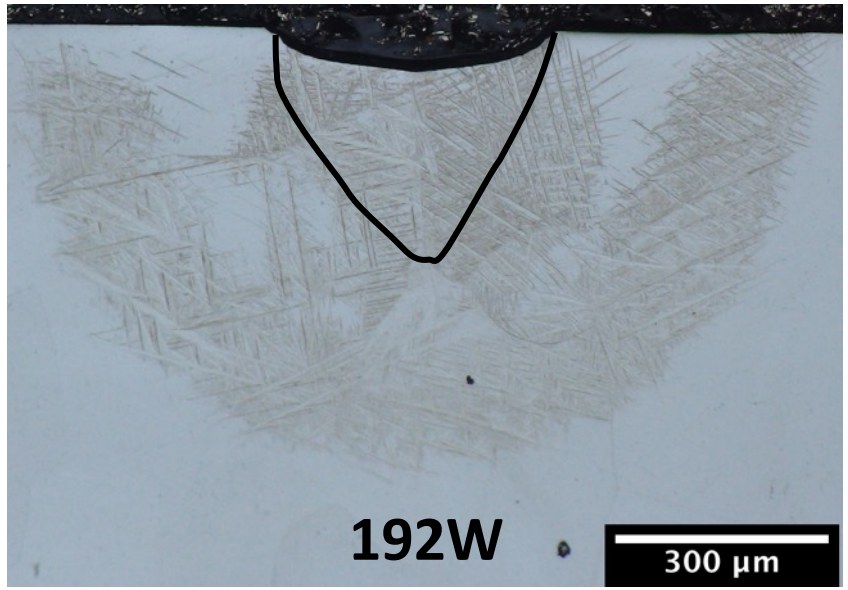
Cross-Section Optical Images
Ti-1023 APS Experiments

Cross-Sections Spot Melts

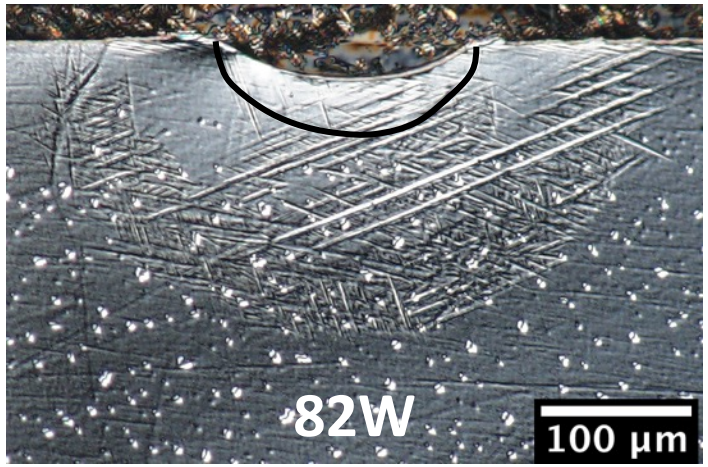


Increasing Power

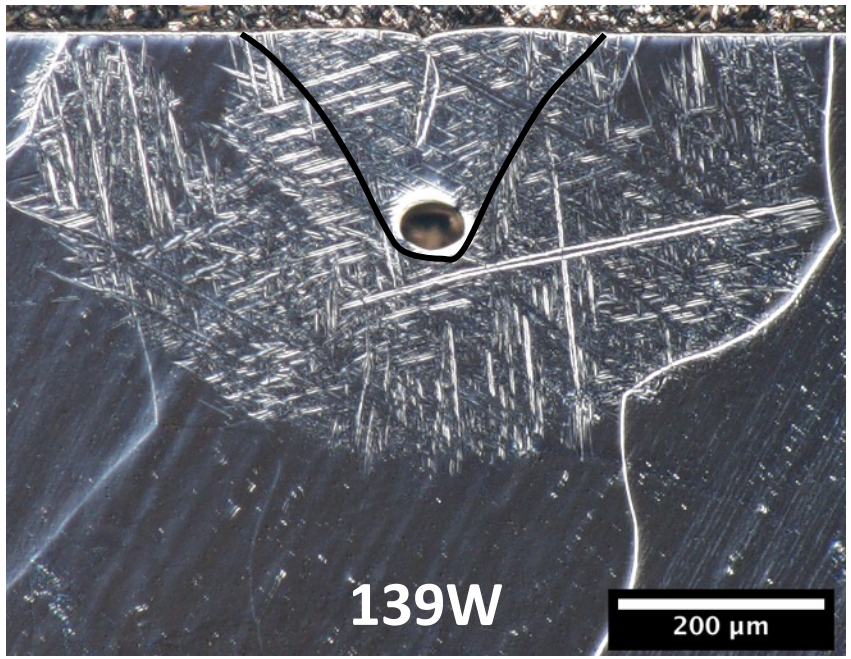


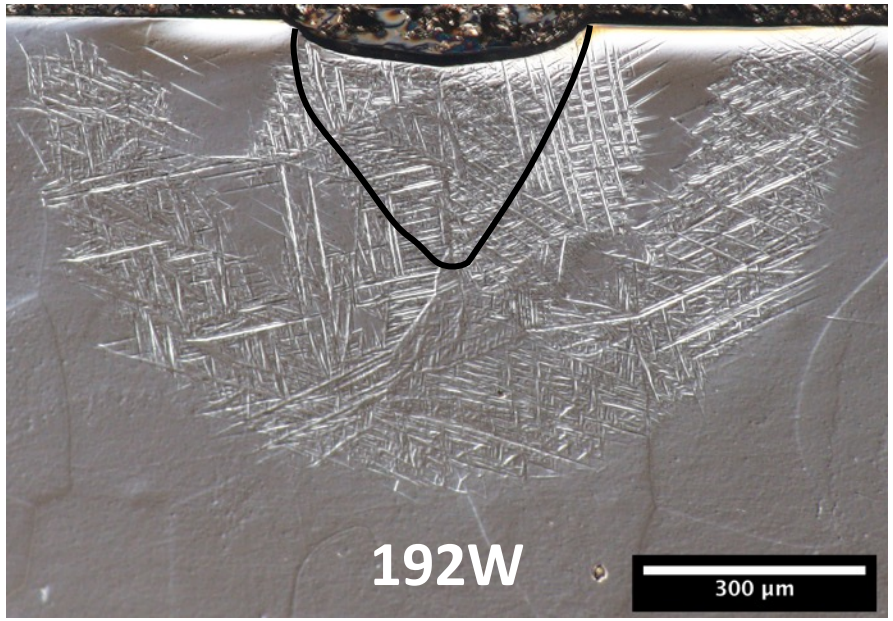


Cross-Sections Spot Melts

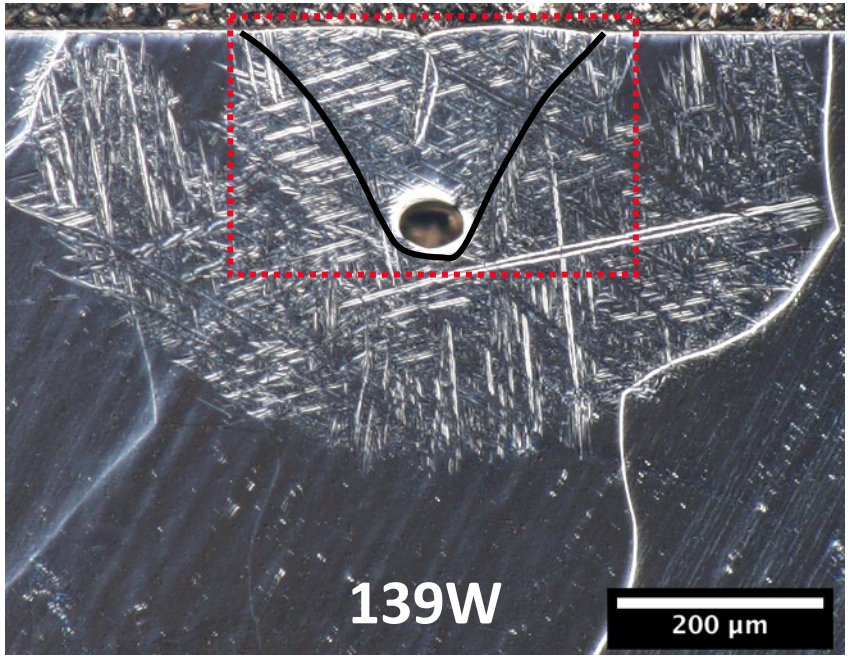


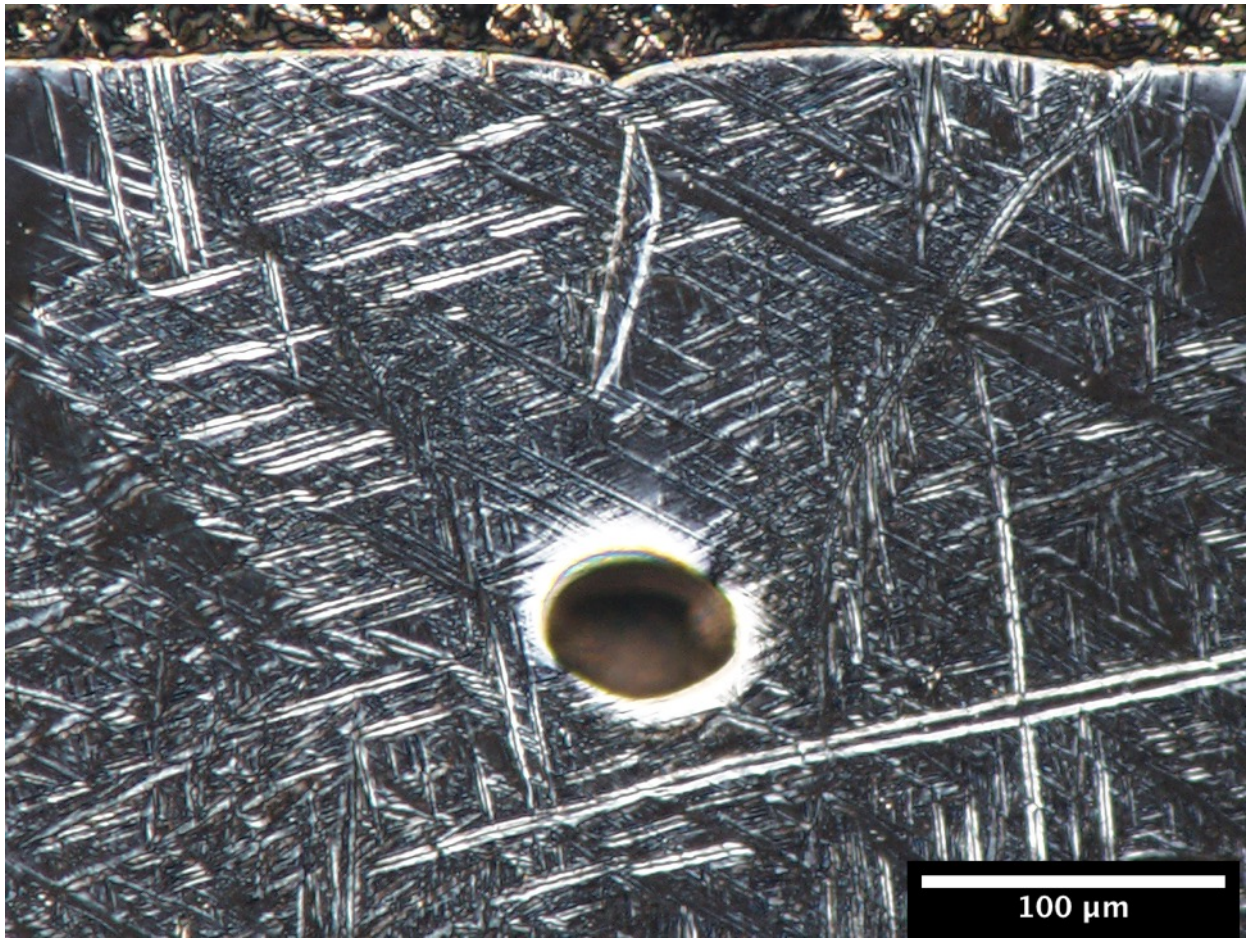
Increasing Power



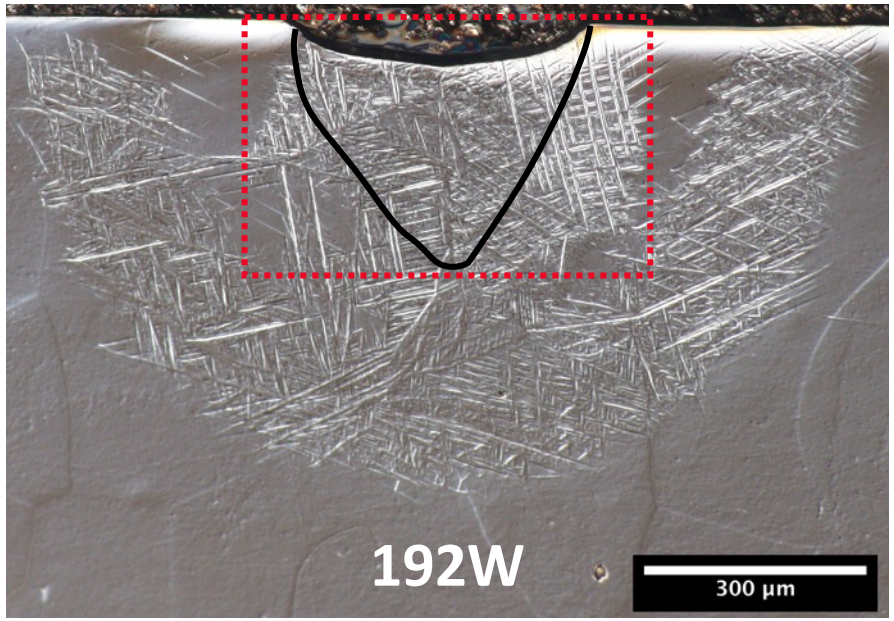


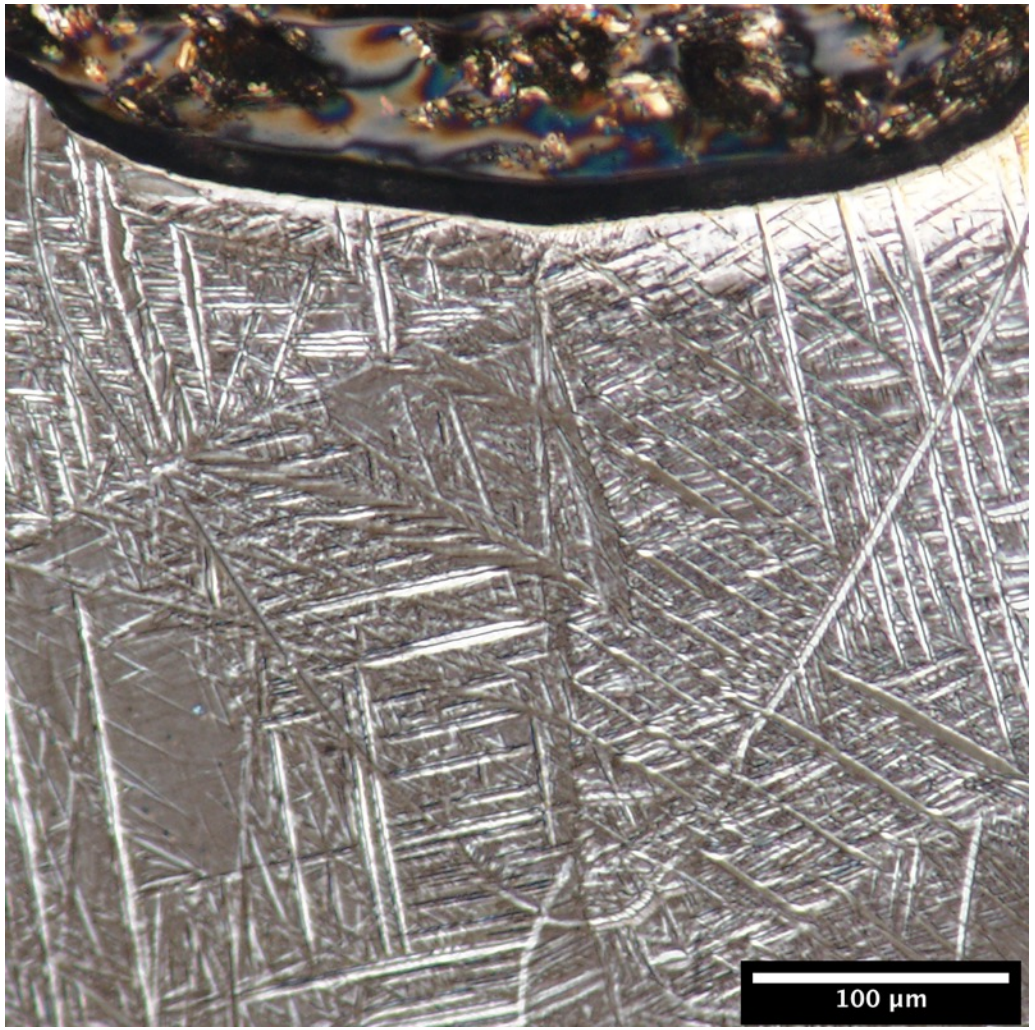
Cross-Sections Spot Melts





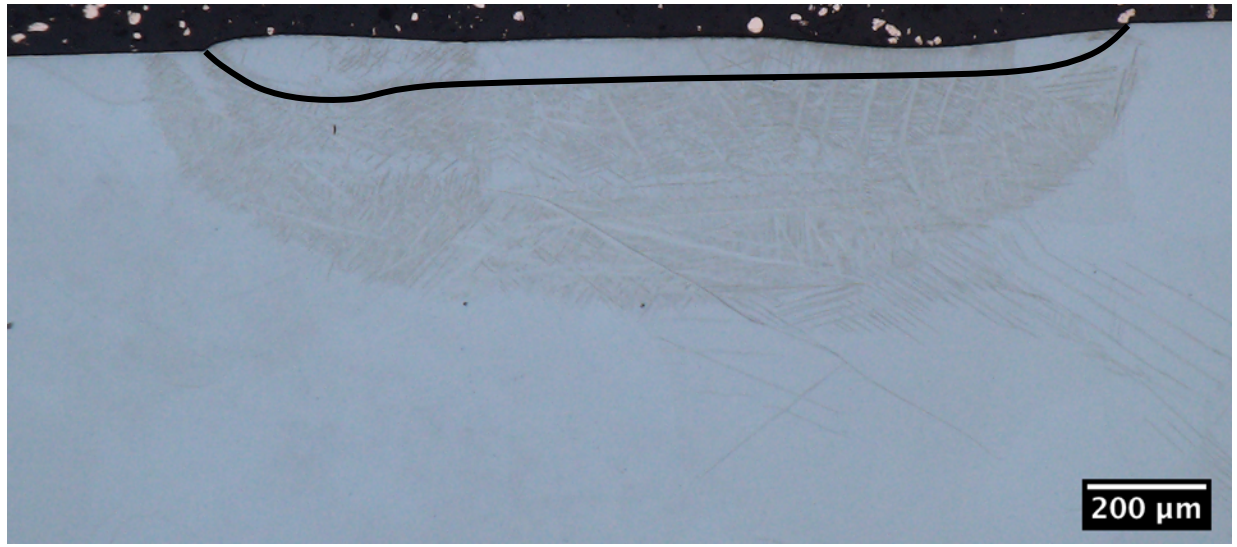
Cross-Sections Spot Melts



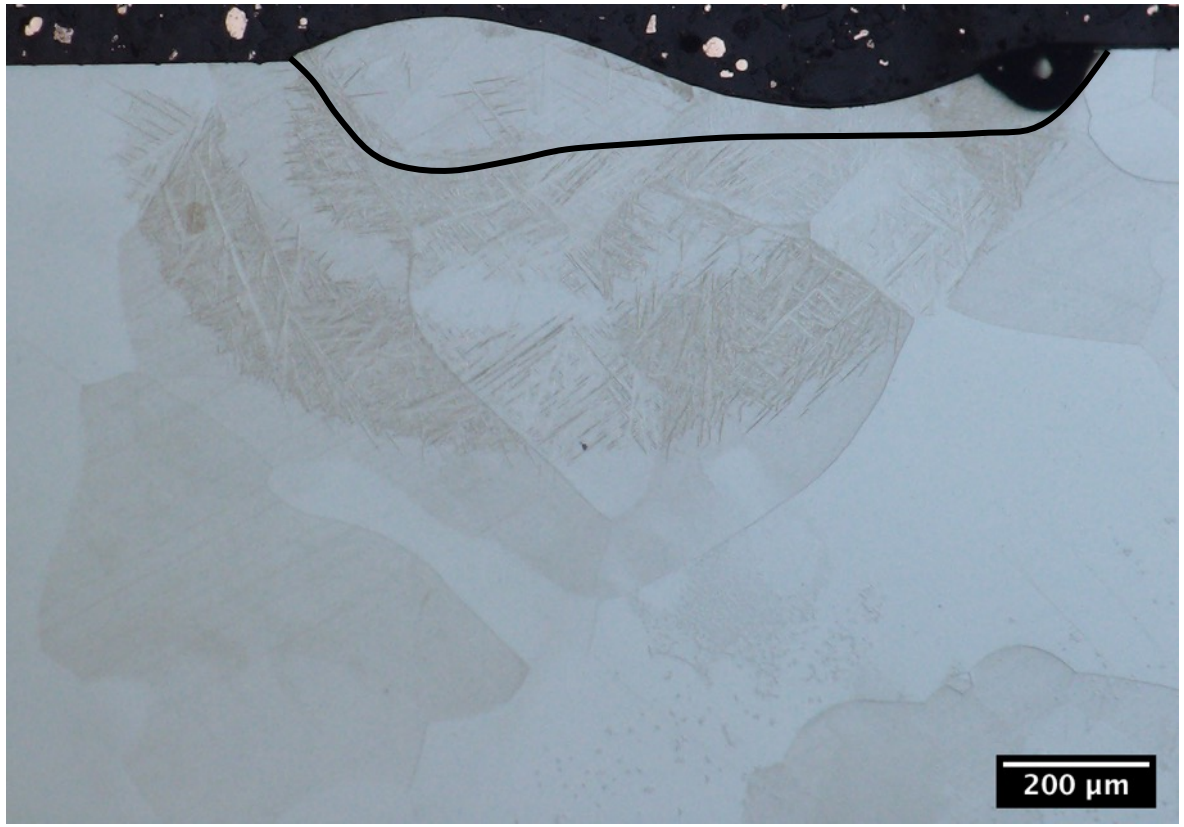


Cross-Sections Rasters

139W & 0.5 m/s



192W & 0.5 m/s

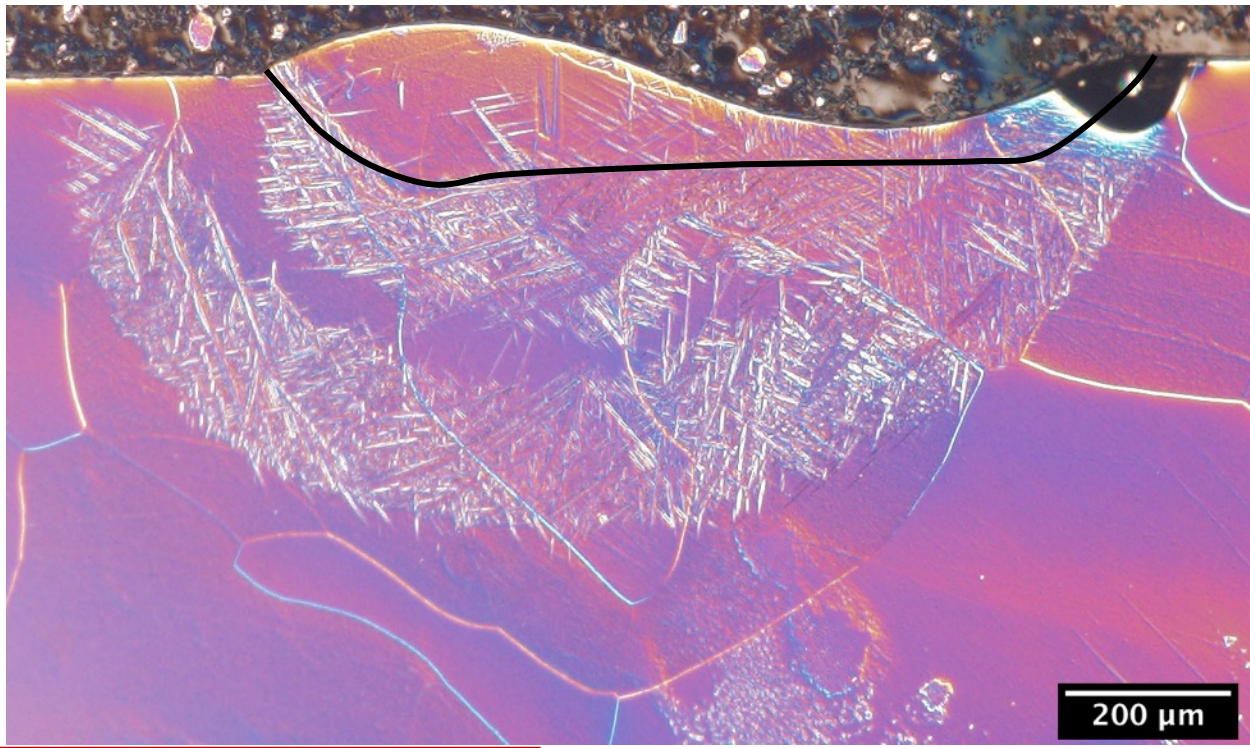


Travel Direction ➡

Cross-Sections Rasters

139W & 0.5 m/s

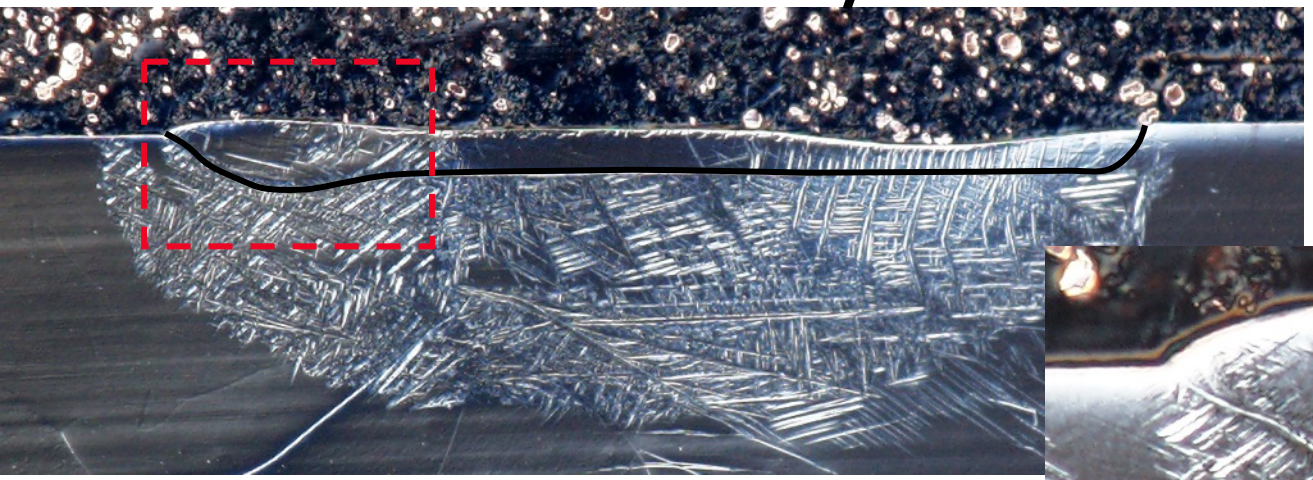
192W & 0.5 m/s

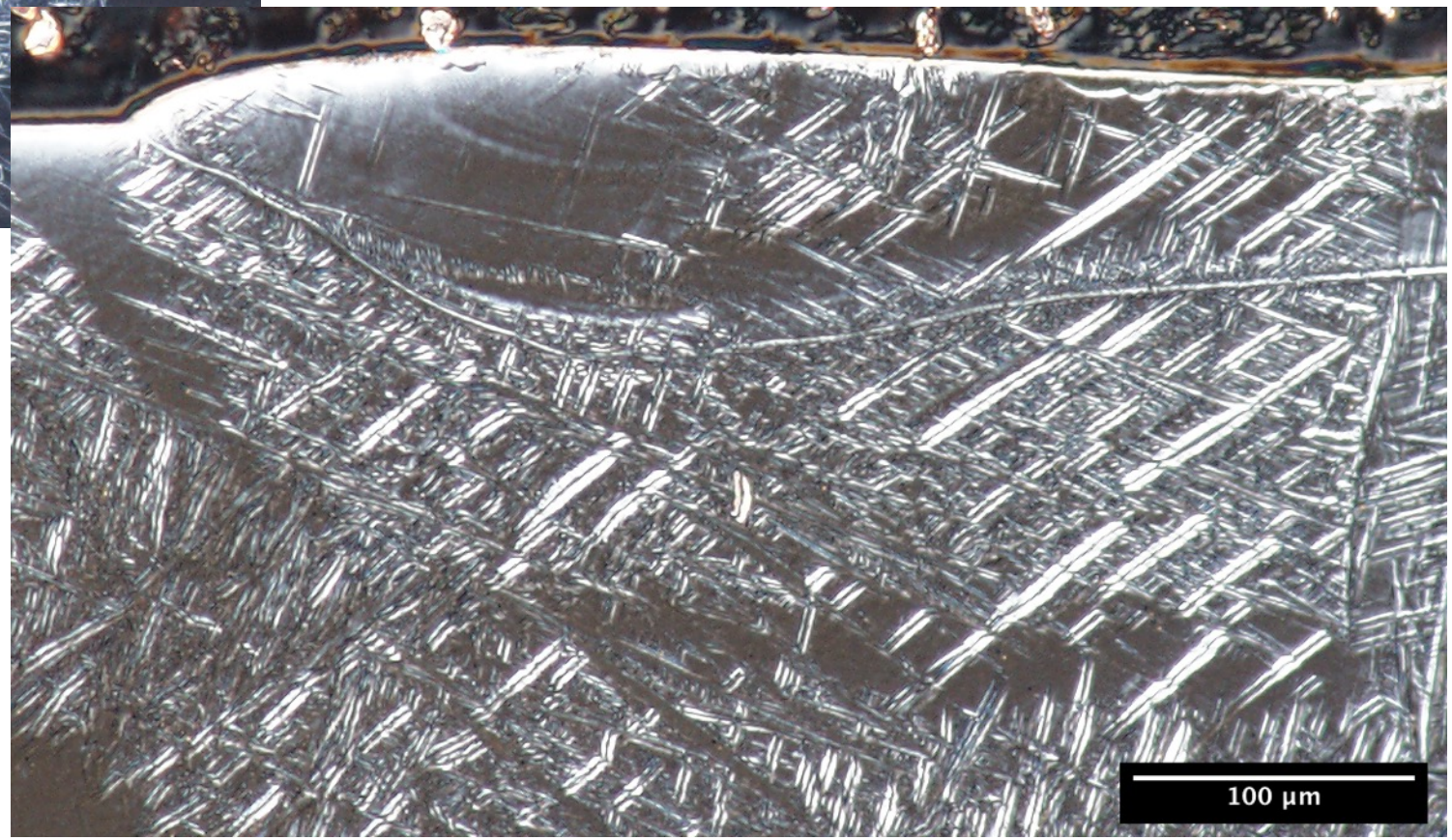


Travel Direction ➡

Cross-Sections Rasters

139W & 0.5 m/s

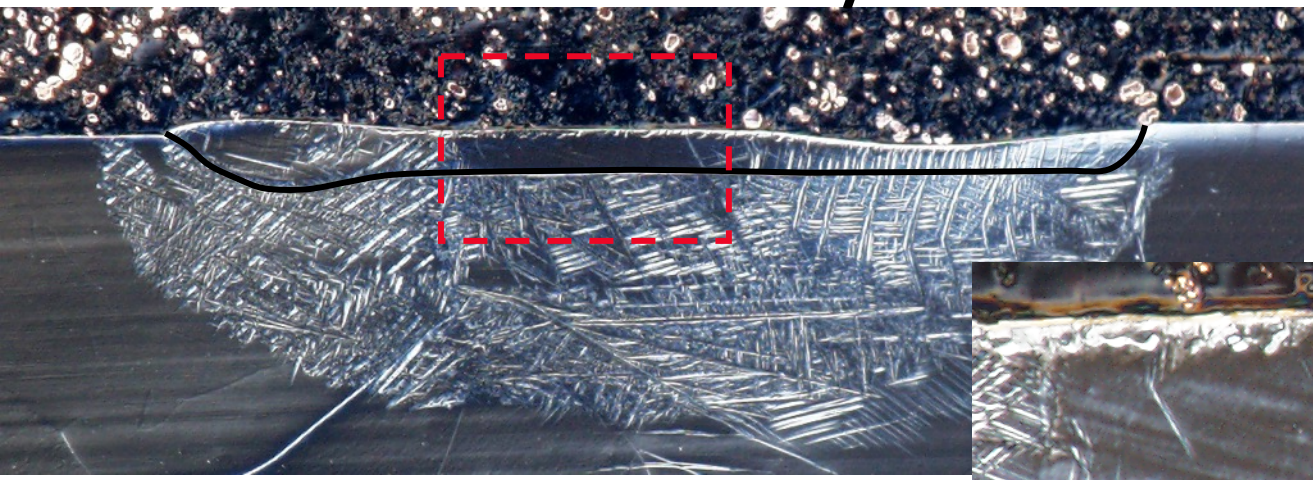




Travel Direction →

Cross-Sections Rasters

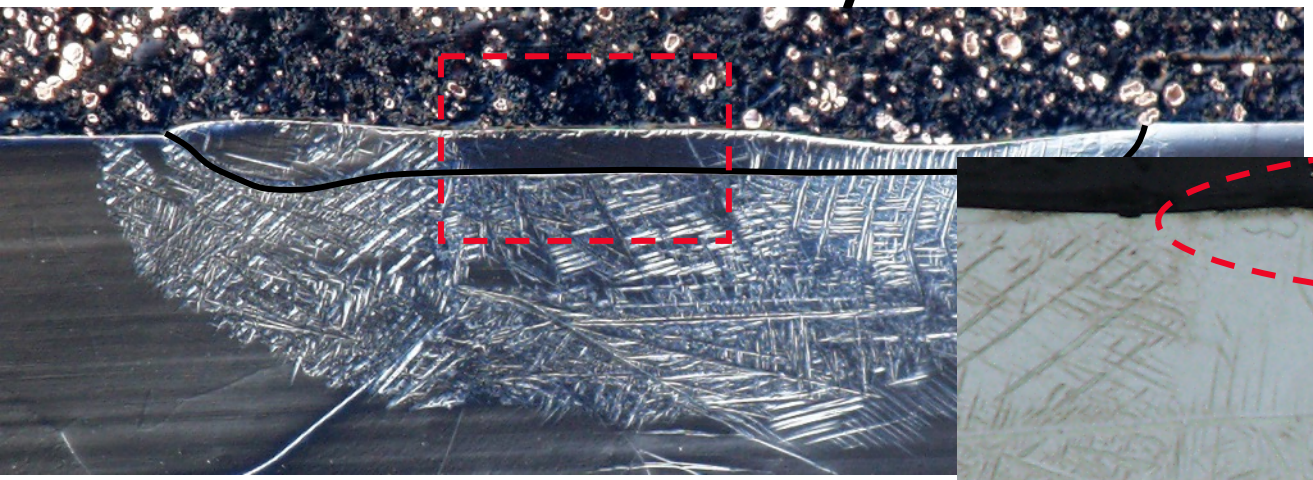
139W & 0.5 m/s

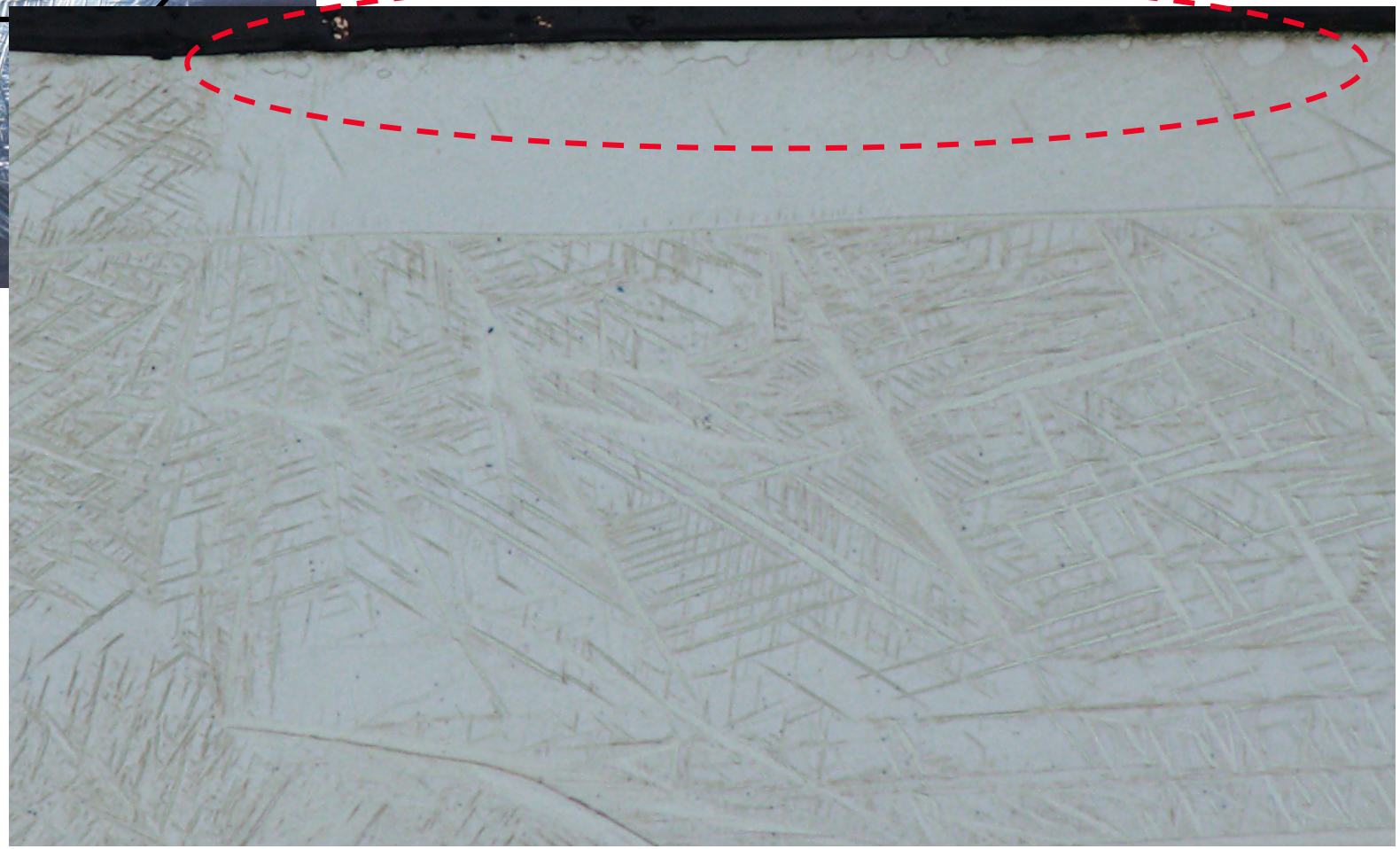


Travel Direction ➡

Cross-Sections Rasters

139W & 0.5 m/s

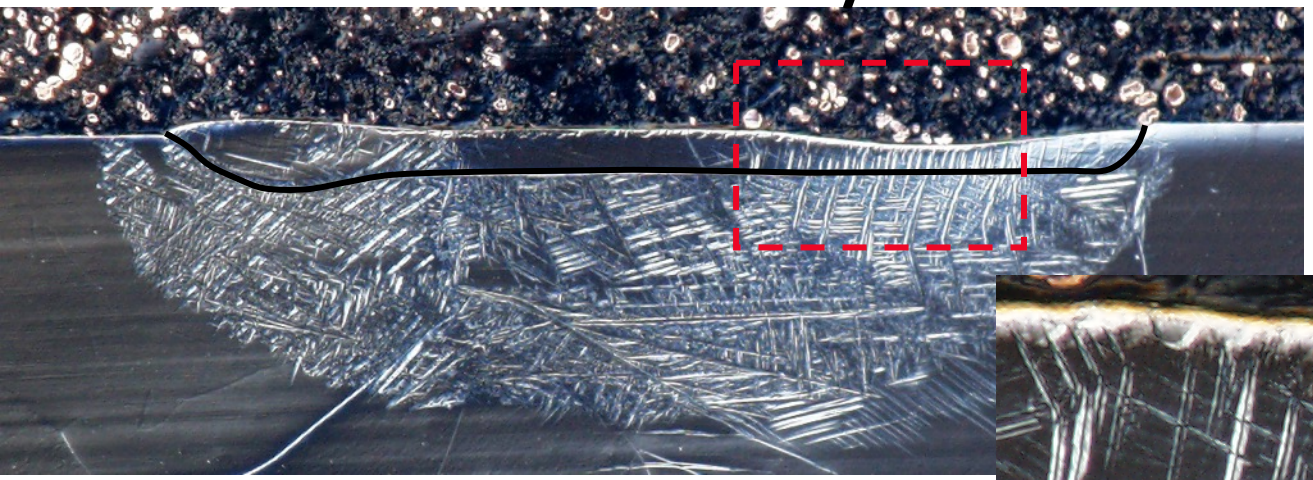


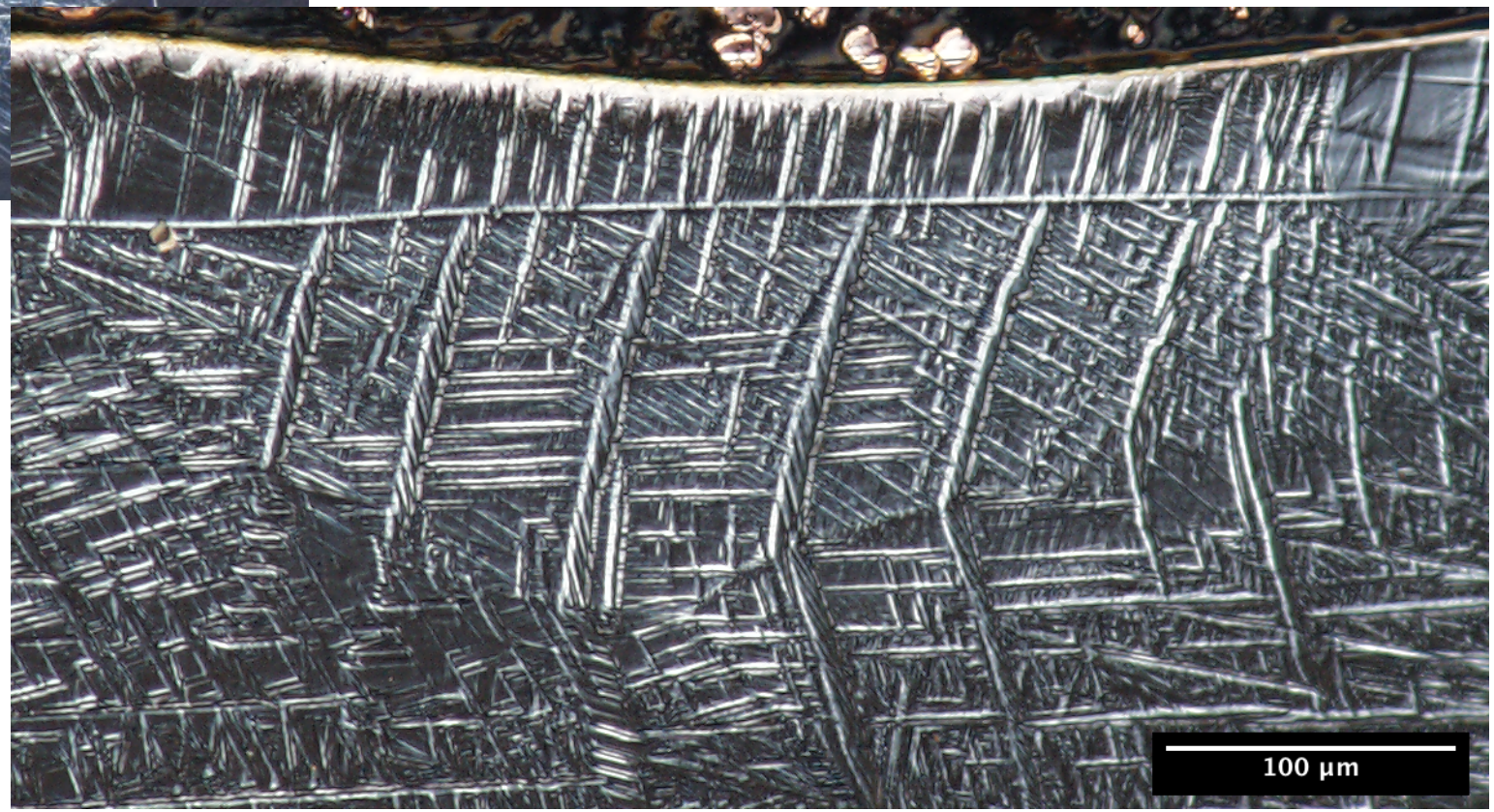


Travel Direction ➡

Cross-Sections Rasters

139W & 0.5 m/s

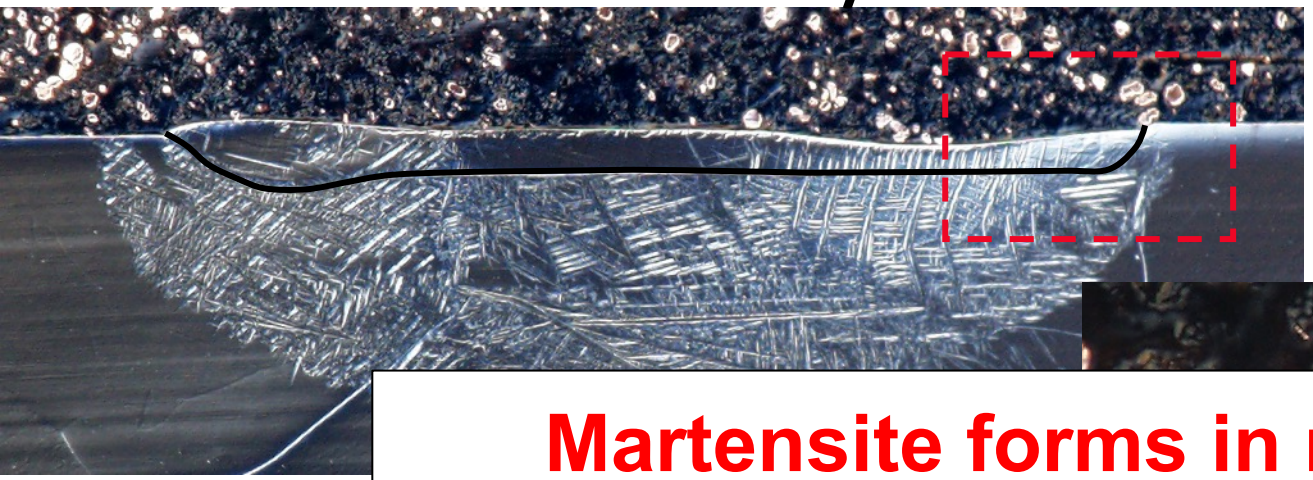




Travel Direction ➡

Cross-Sections Rasters

139W & 0.5 m/s

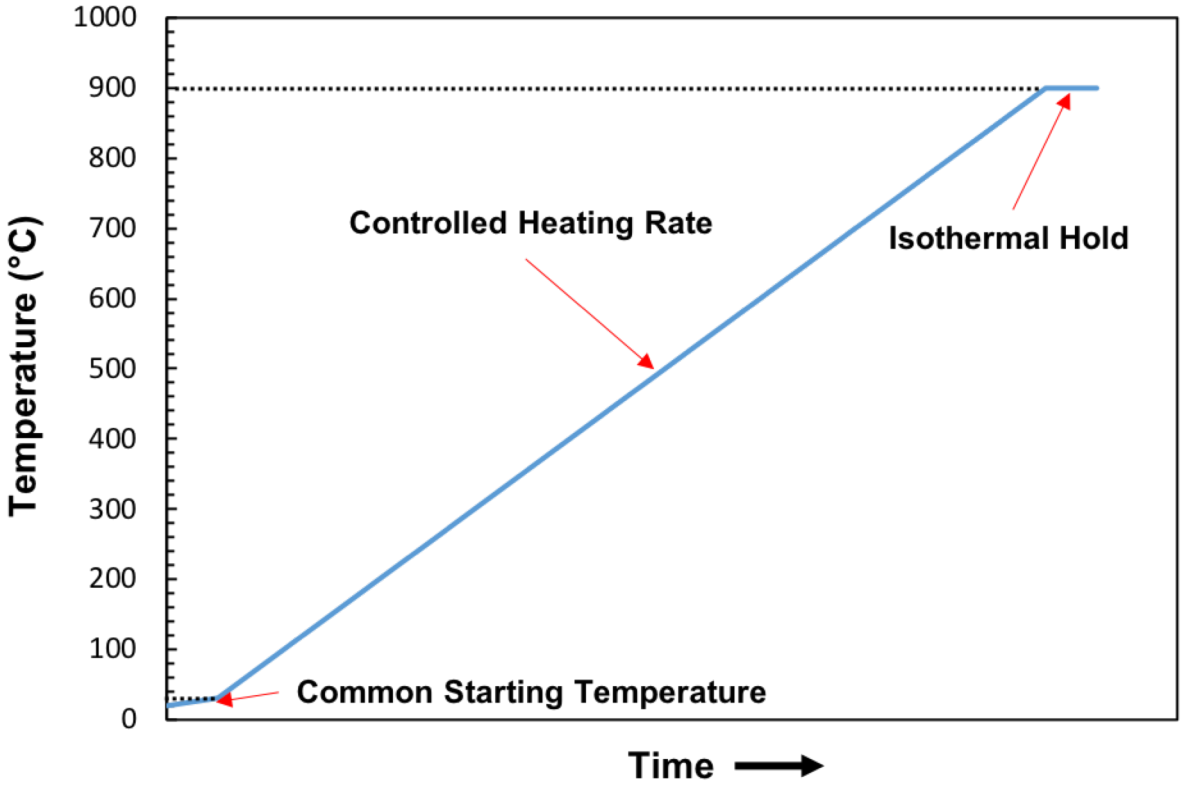


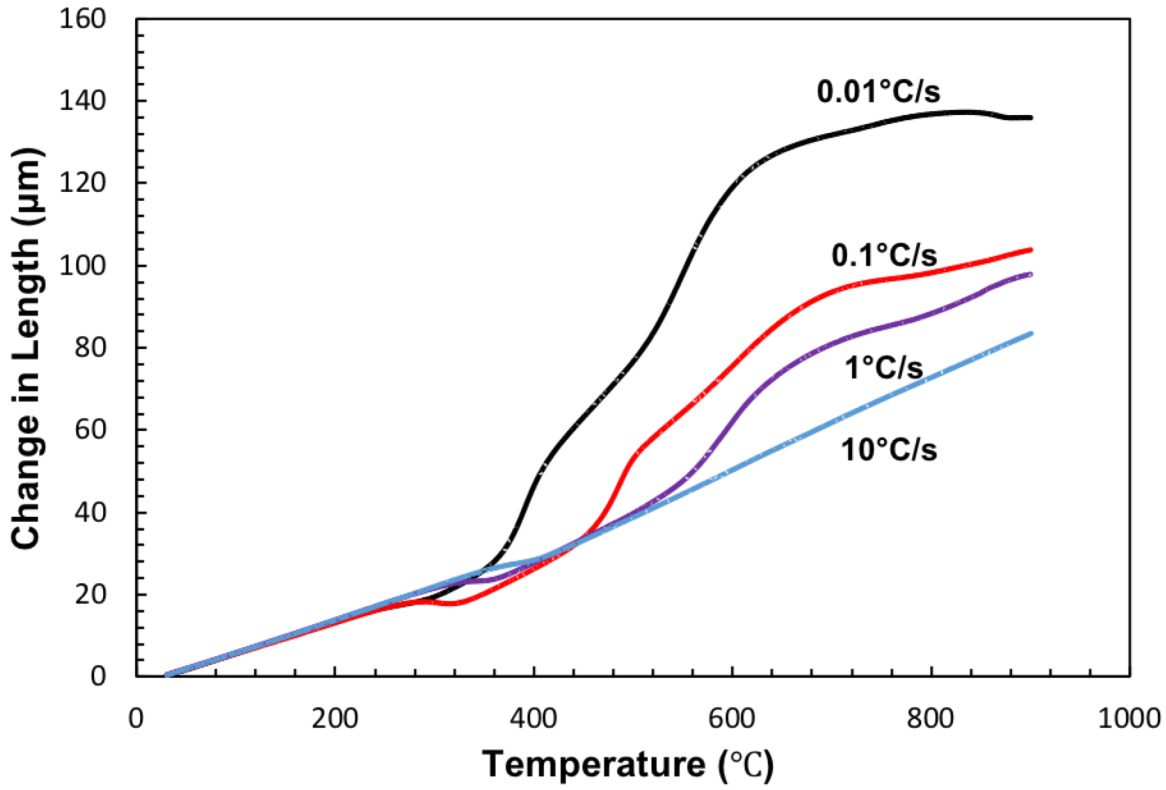
Martensite forms in melt-pool and HAZ regardless of laser processing condition

Travel Direction ➡

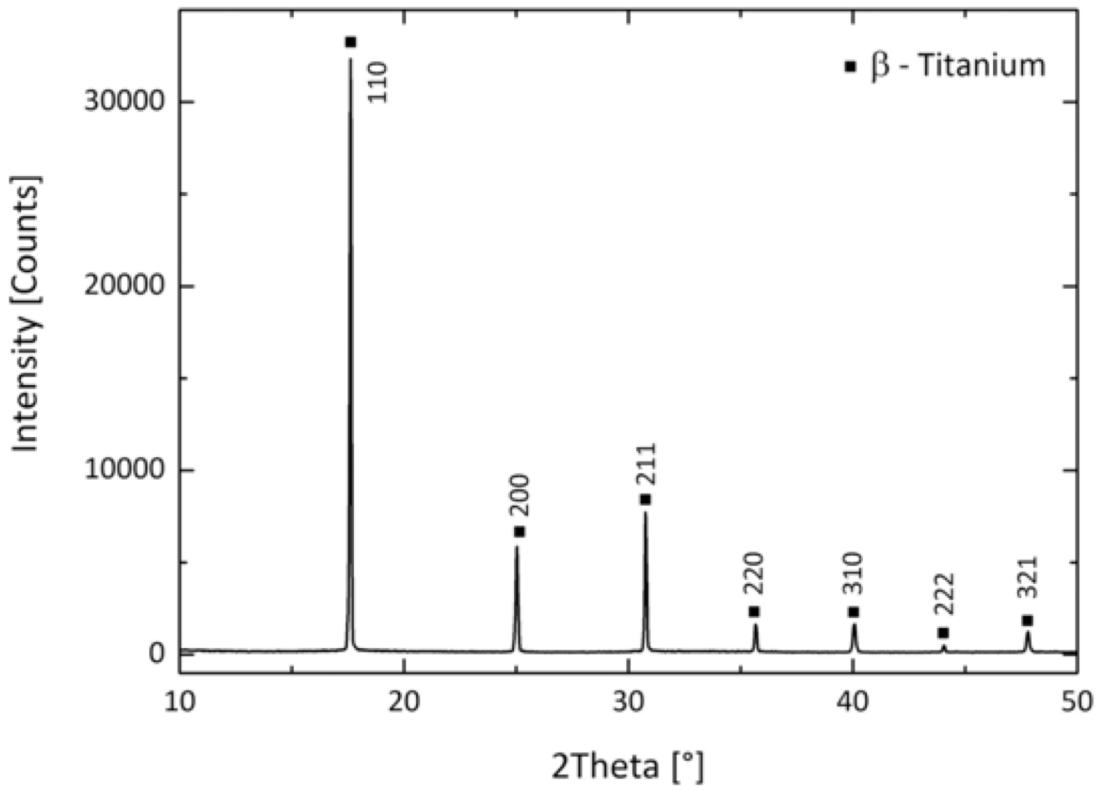
Equilibrium Alpha-Transus
Ti-5Al-5V-5Mo-3Cr (Ti-5553)

Ti-5553 Equilibrium Alpha-Transus

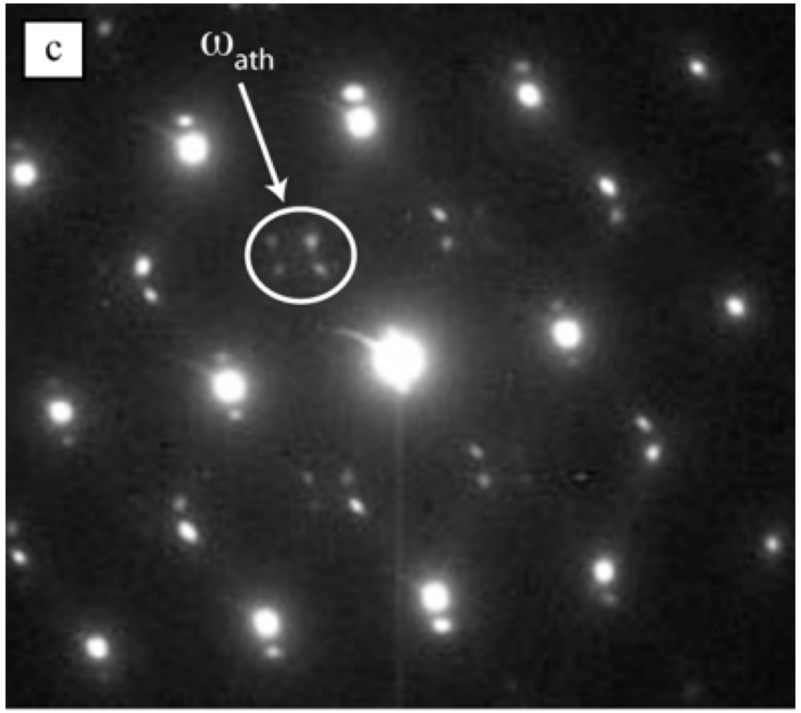




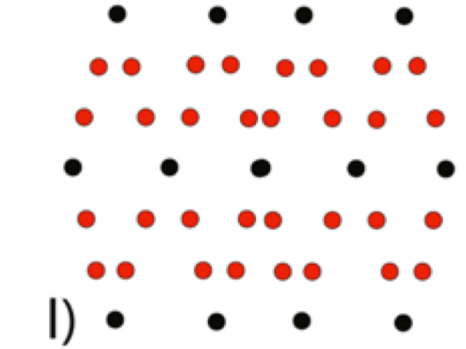
Ti-5553 Equilibrium Alpha-Transus



H. Schwab, F. Palm, U. Kühn, and J. Eckert, "Microstructure and mechanical properties of the near-beta titanium alloy Ti-5553 processed by selective laser melting," *Mater. Des.*, vol. 105, pp. 75–80, Sep. 2016, doi: 10.1016/j.matdes.2016.04.103

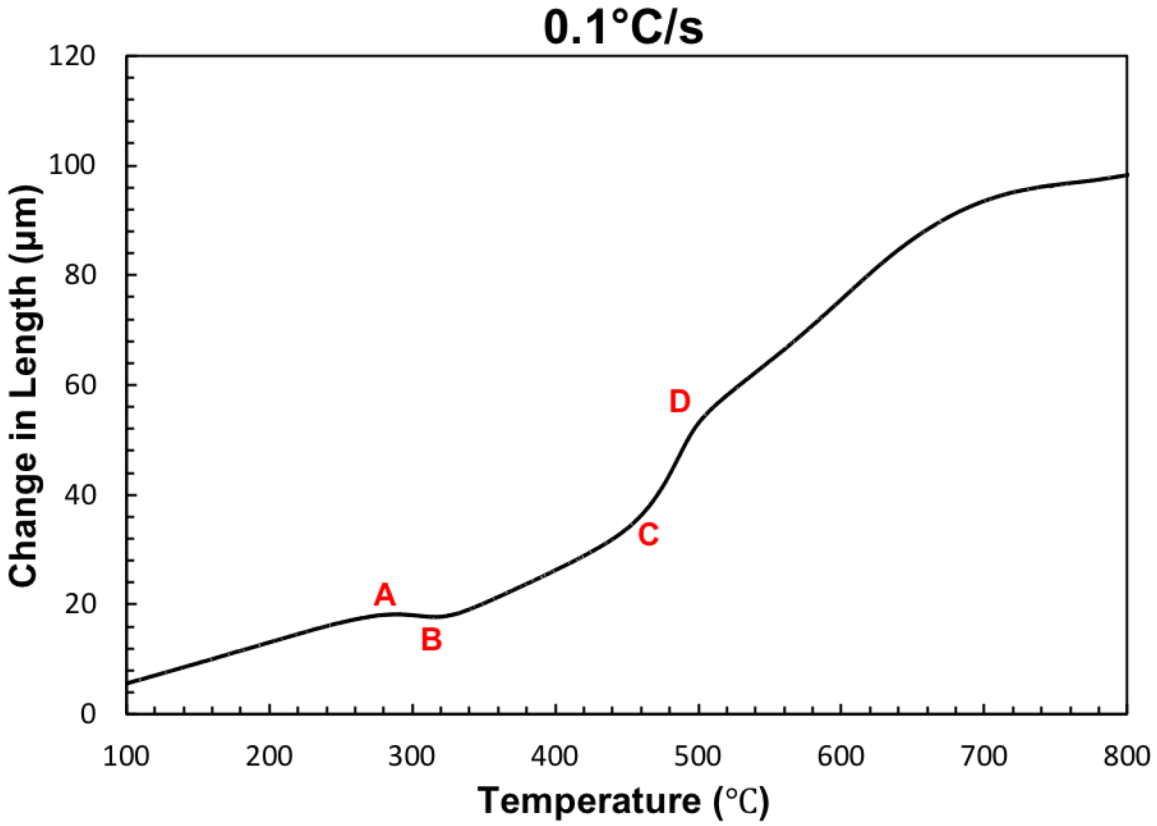


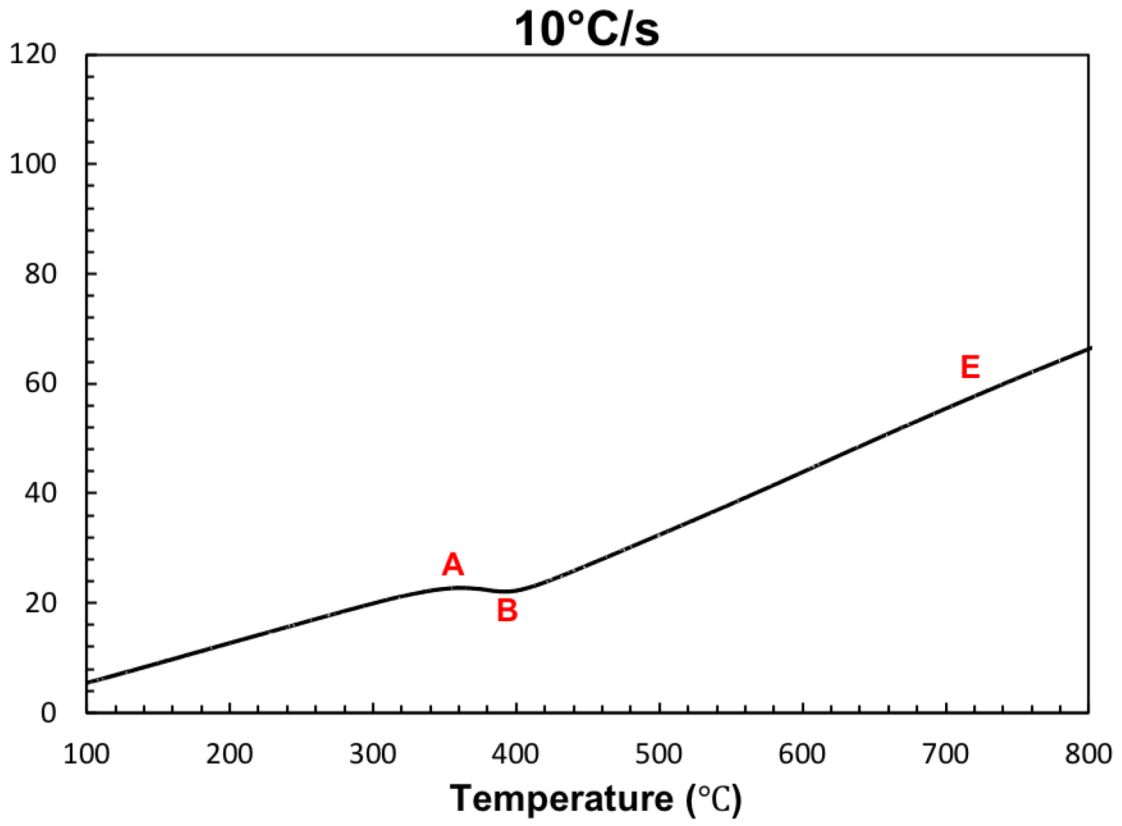
Settefrati, Amico, et al. "Precipitation sequences in beta metastable phase of Ti-5553 alloy during ageing." *Proceeding of the 12th World Conference on Titanium (Ti-2011). Science, Beijing*. 2012.



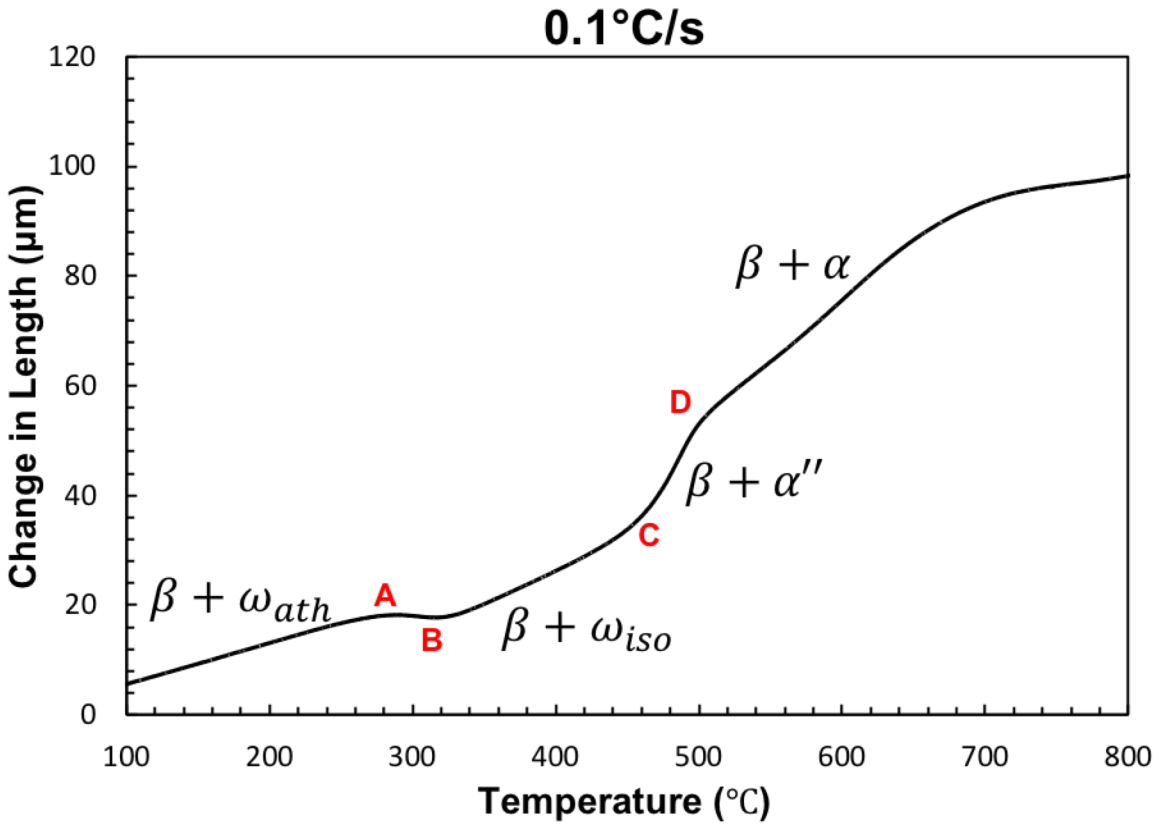
J. Coakley *et al.*, "Precipitation processes in the Beta-Titanium alloy Ti–5Al–5Mo–5V–3Cr," *J. Alloys Compd.*, vol. 646, pp. 946–953, Oct. 2015, doi: 10.1016/j.jallcom.2015.05.251

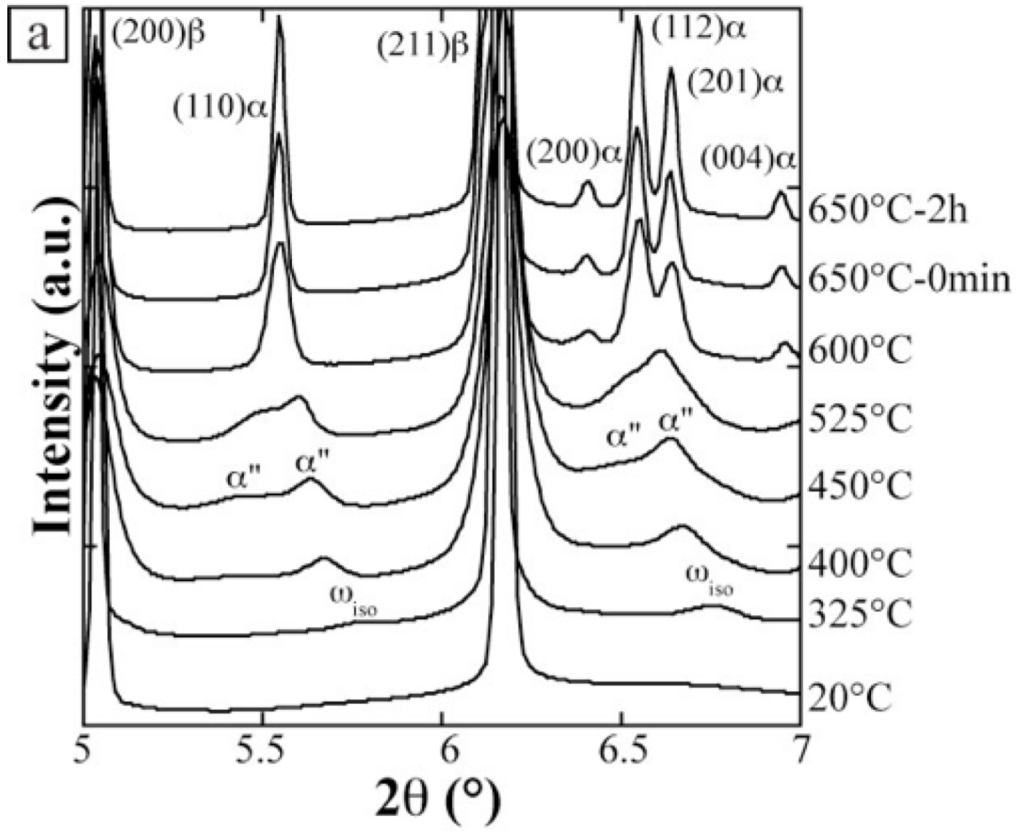
Ti-5553 Equilibrium Alpha-Transus





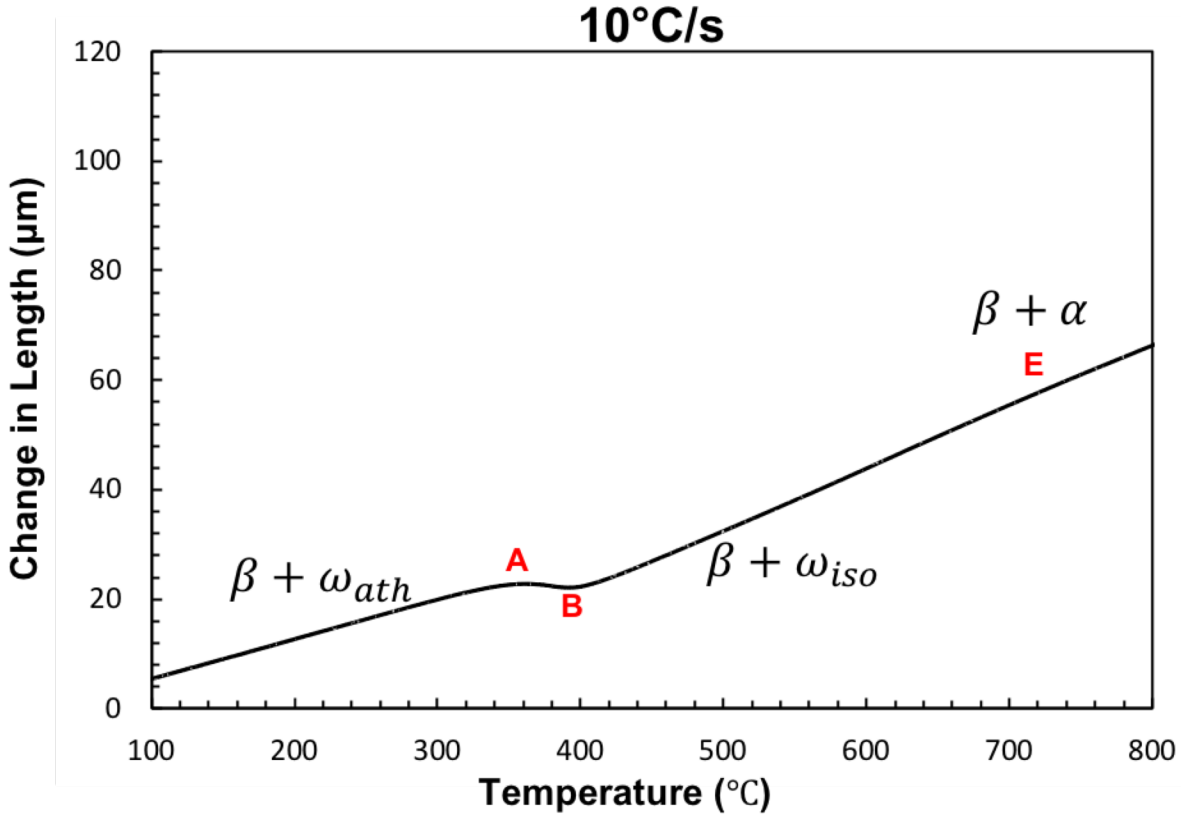
Ti-5553 Equilibrium Alpha-Transus

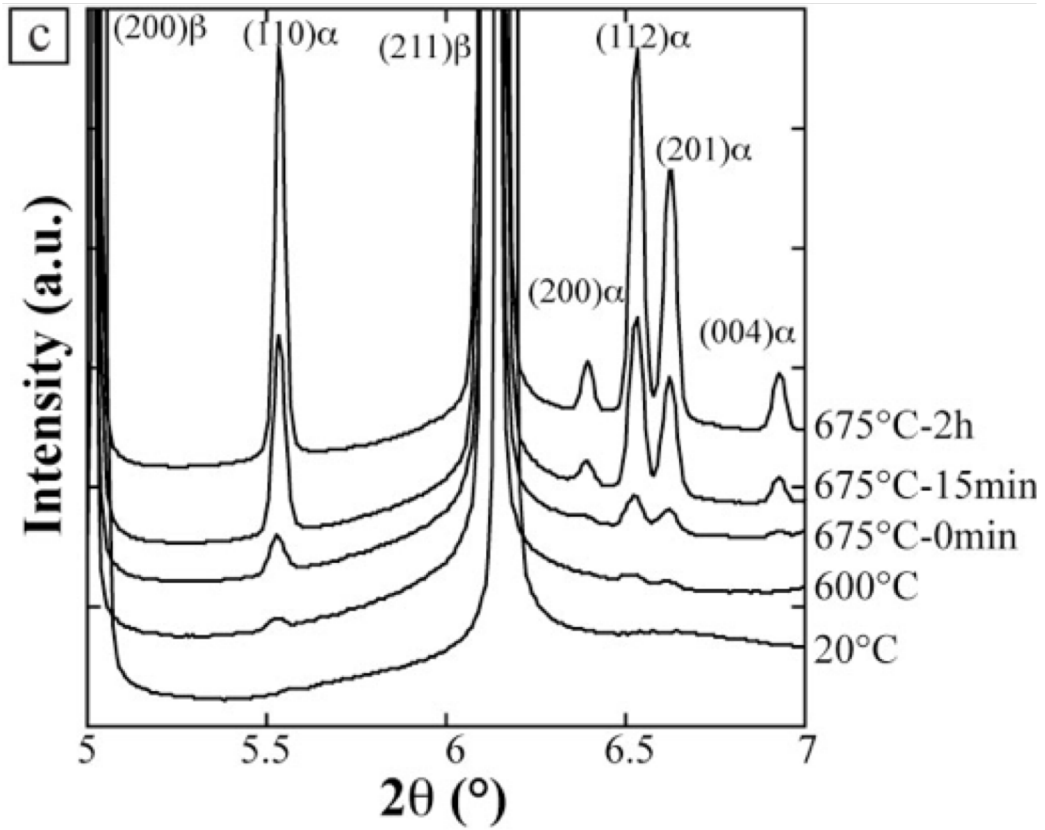




Settefrati, Amico, et al. "Precipitation sequences in beta metastable phase of Ti-5553 alloy during ageing." *Proceeding of the 12th World Conference on Titanium (Ti-2011). Science, Beijing*. 2012.

Ti-5553 Equilibrium Alpha-Transus





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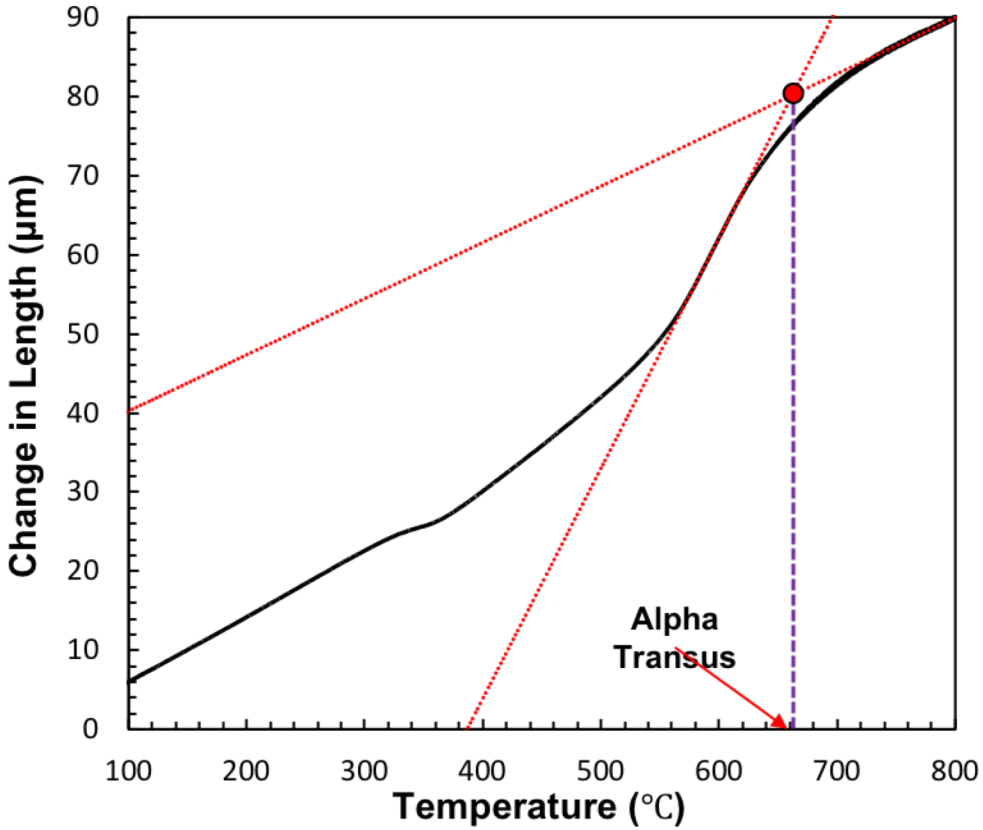
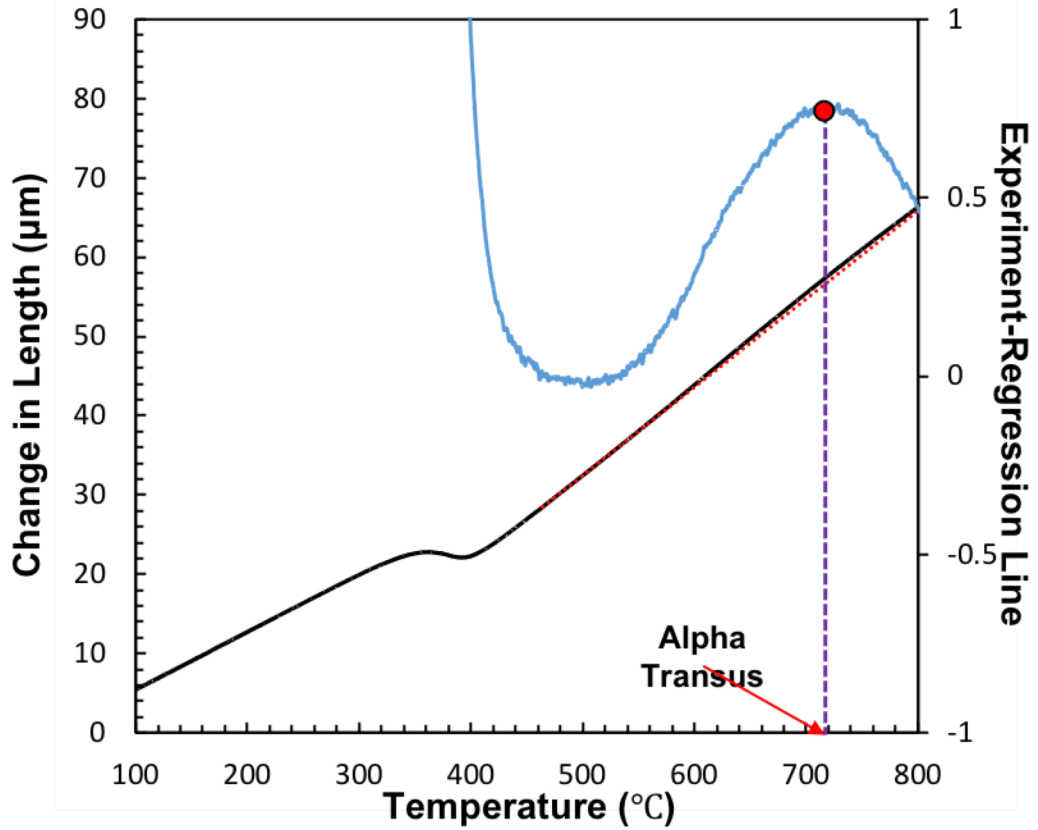
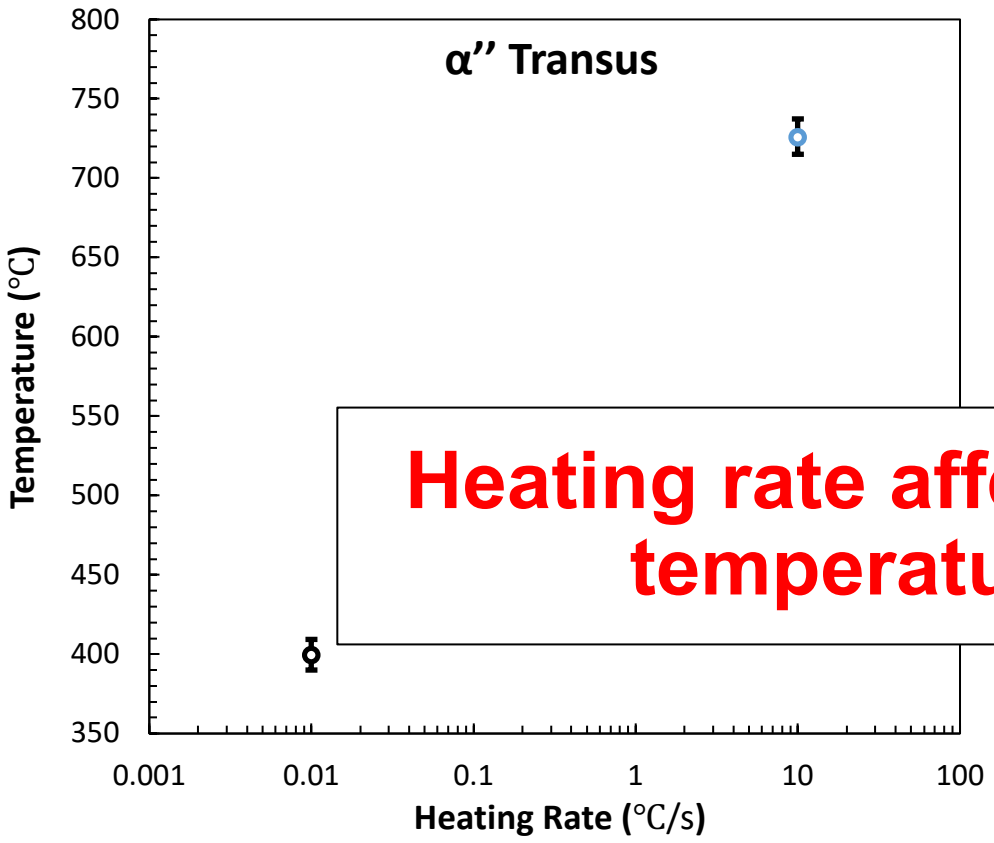
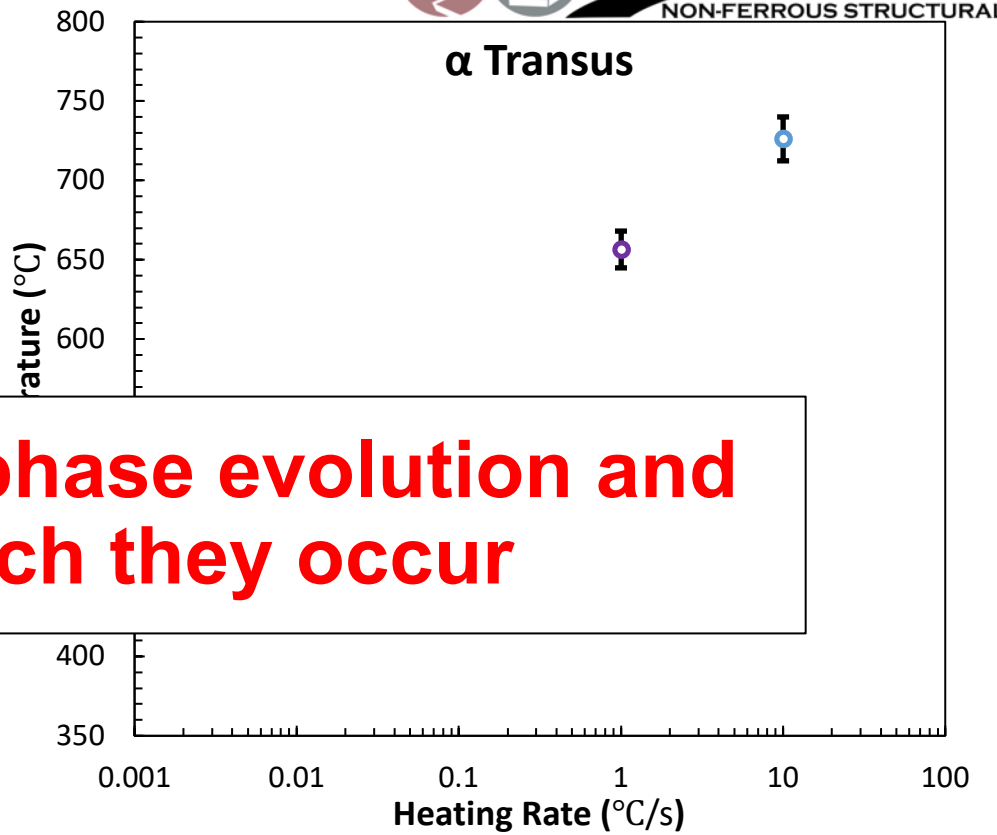
Ti-5553 Equilibrium Alpha-Transus





Ti-5553 Equilibrium Alpha-Transus

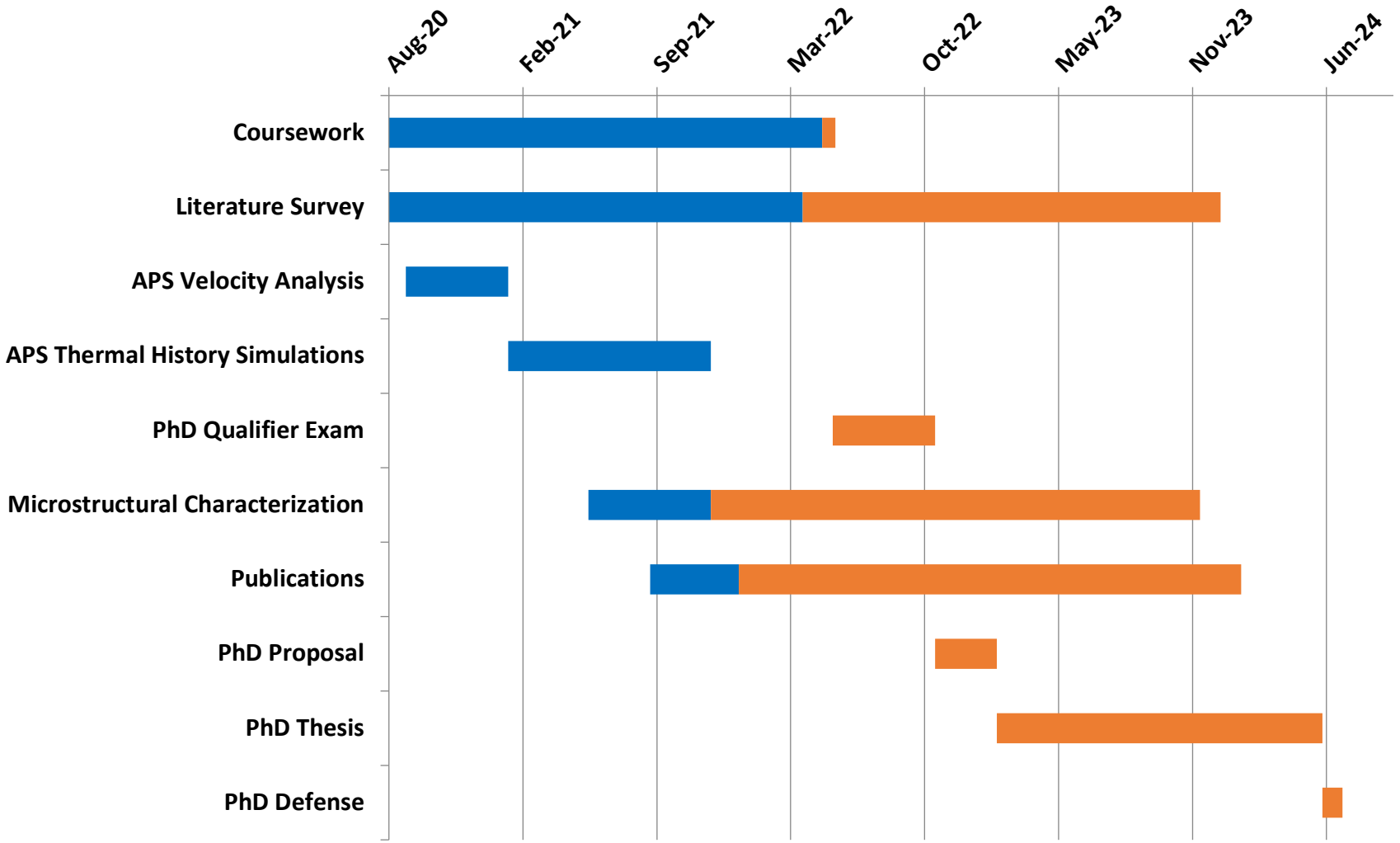




Heating rate affects the phase evolution and temperature at which they occur

Heating Rate (°C/s)	α'' Transus (°C)	Alpha Transus (°C)
10	-	726.16±13.84
1	493.52±6.34	656.47±11.59
0.1	424.06±4.12	496.22±5.67
0.01	399.66±4.13	516.52±6.75

Gantt Chart



Challenges and Opportunities

- Thin sample geometry of APS samples has complicated the metastable beta-Ti preparation process
  - No electropolishing
- Difficulty in obtaining useful EBSD scans from Ti-1023 APS samples
  - Highly deformed martensite structure interferes
- Procedure has been developed for “electropolishing-less” EBSD prep of metastable beta-Ti (with no martensite)
  - Useful for future work of this project which involves other alloys in this class

Future Work

- Ion milling of the melt pool region
  - Potential solution to current EBSD problems
- Further optical microscopy of Ti-1023 for varying process conditions
  - Overlapping spots and rasters (effect of thermal cycling)
- LPBF processing and subsequent microstructural characterization of novel metastable beta-Ti alloys
- Possible heat treatments of AM metastable beta-Ti alloys to exploit unique microstructural features for exceptional mechanical properties

Conclusions

- Martensite forms within the melt-pool and heat affected zone for both simple spot-melts and rasters in Ti-1023
  - Ability to accommodate stress without cracking
  - Steady-state region in raster not exhibit this

- Heating rate plays a large in role in phase evolution and temperatures at which they form in Ti-5553
  - Informs future optimization of heat treatments for metastable beta-Ti

Thank you!

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