Project 49-L: Microstructure-property relationships of additively manufactured Ti-5553

Semi-annual Fall Meeting

October 2021

- Student: Andrew Temple (ISU)
- Faculty: Dr. Peter Collins (ISU)
- Industrial Mentors: KCNSC Honeywell FM&T (Camille Baker, Ben Sikora, Ben Brown, Seth White, Andy Deal)

Project 49-L: Microstructure-property relationships of AM Ti-5553

- Student: Andrew Temple (ISU)
- Advisor(s): Peter Collins (ISU)

Project Duration
PhD: January 2018 to May 2022

- Problem: Microstructure-property relationships of heat treated AM Ti-5553 are currently not well understood.
- Objective: Develop a predictive yield strength model for AM Ti-5553 similar to the equation developed for Ti-64
- Benefit: The understanding of microstructure-property relationships as they relate to heat-treated AM Ti-5553. Enables future alloy and process design.

Recent Progress

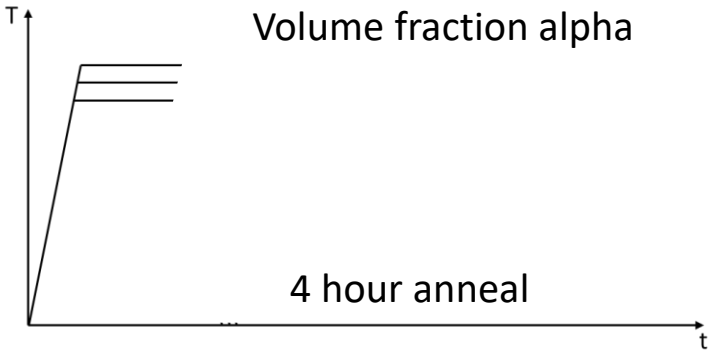
- Completed initial SEM characterization and MIPAR quantification for 12 of 27 samples
- Identified qualitative and quantitative microstructure-property relationships
- Started on dissertation writing

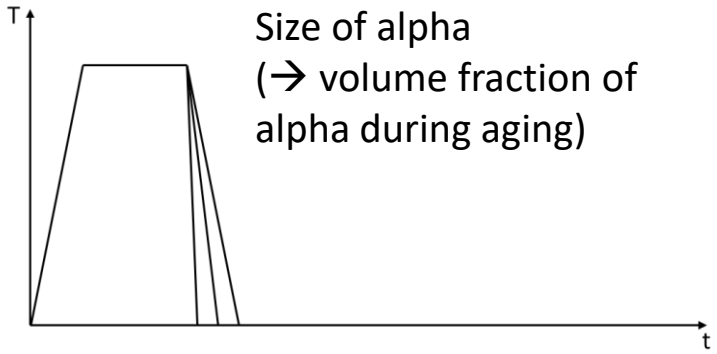
Metrics		
Description	**% Complete**	**Status**
1. Literature review	85%	●
2. Microstructural characterization	75%	●
3. Image analysis and quantification	75%	●
4. Dissertation writing	15%	●
5. PhD Final Oral Examination	0%	●

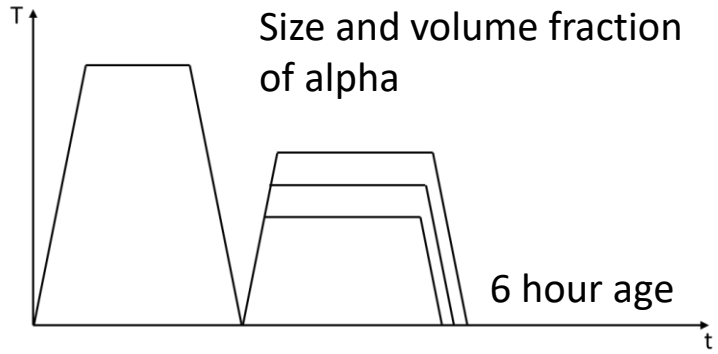
Heat treatments of L-PBF Ti-5553

Variables	Levels		
	Low	Mid	High
Annealing temperature (°C)	700	745	785
Cooling rate (°C/min)	5	50	500
Aging temperature (°C)	500	575	650

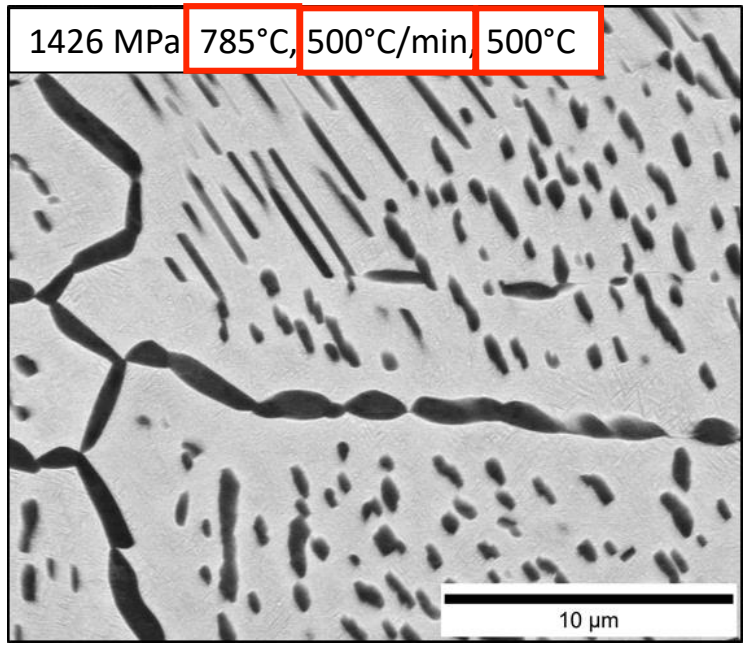
Beta transus is about 845°C

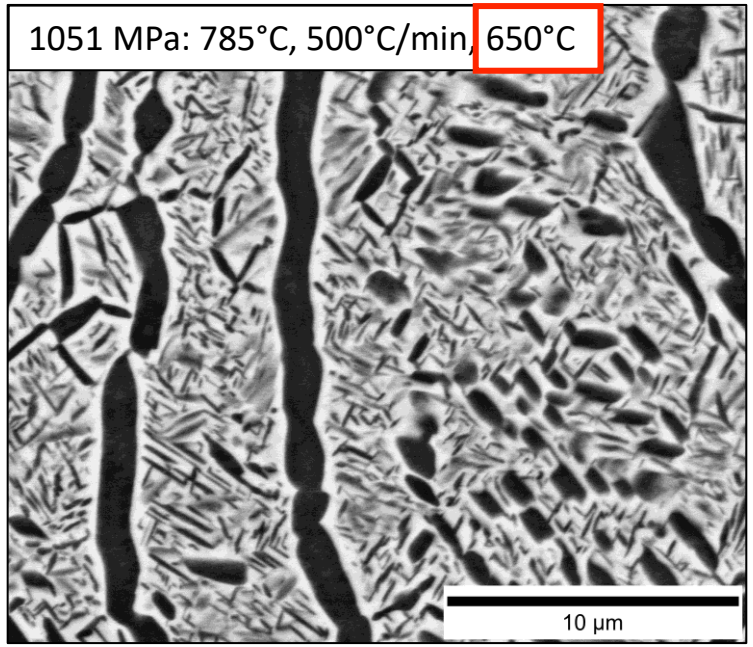


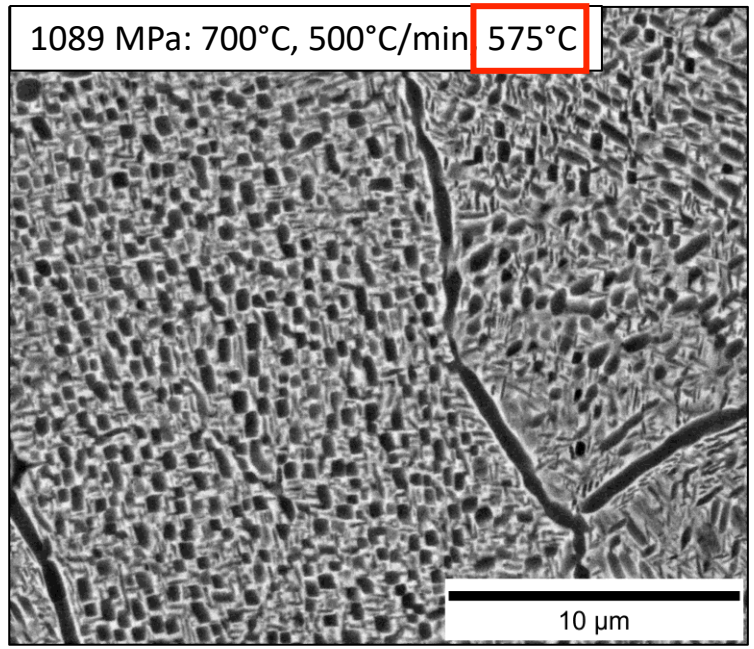


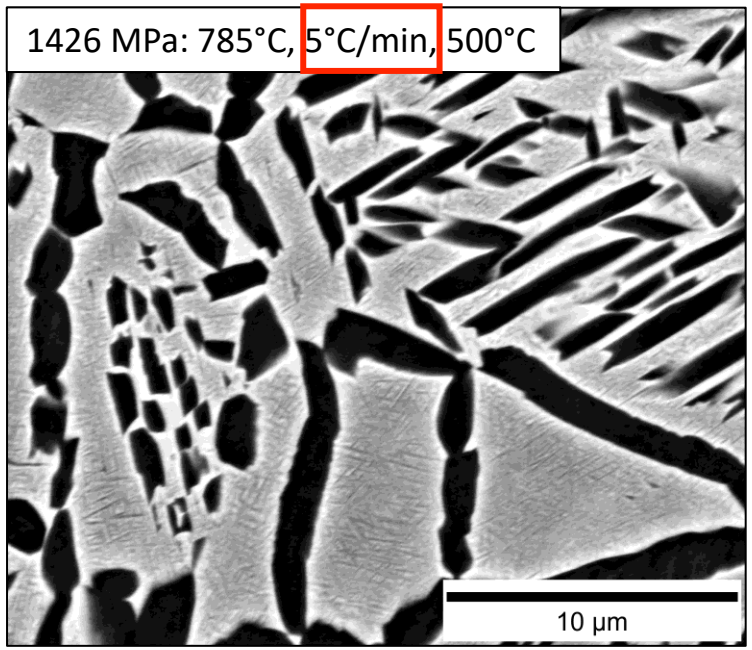


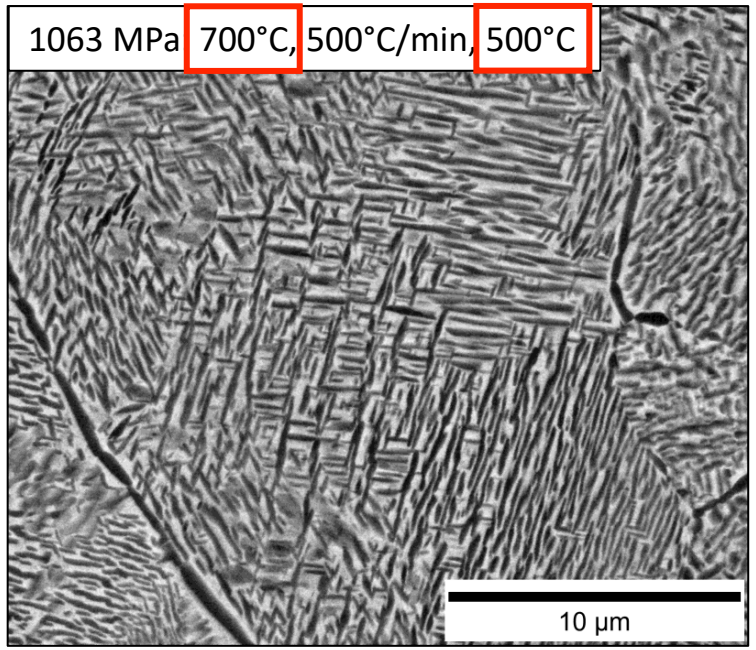
Heating/cooling rates of 5°C/min unless otherwise specified



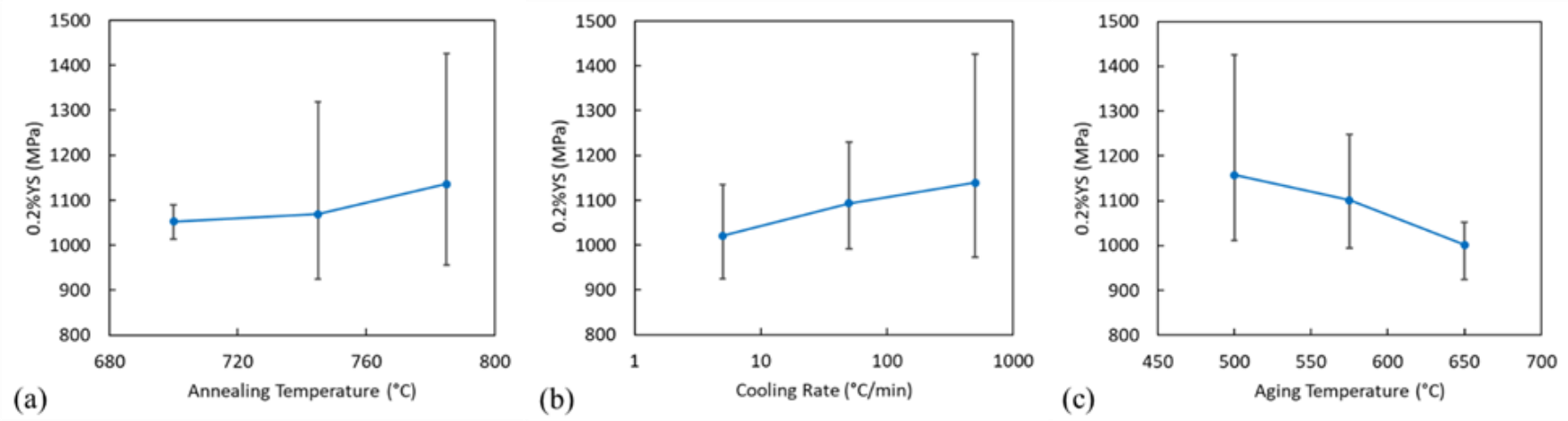




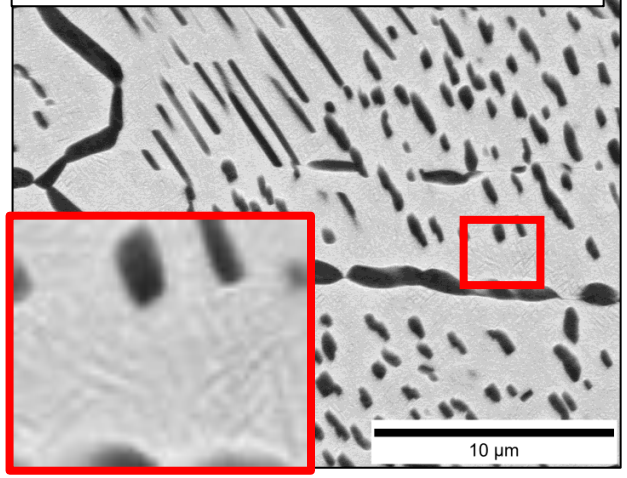




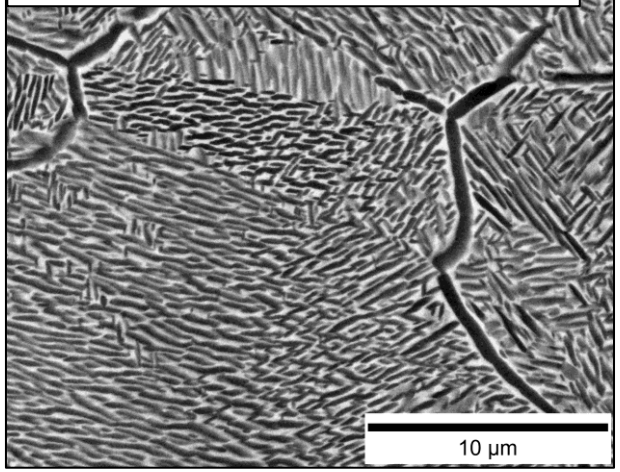
Tensile testing of L-PBF Ti-5553



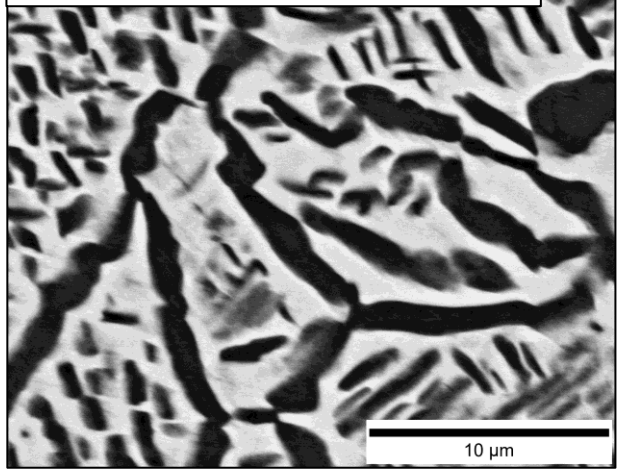
1426 MPa: 785°C, 500°C/min, 500°C



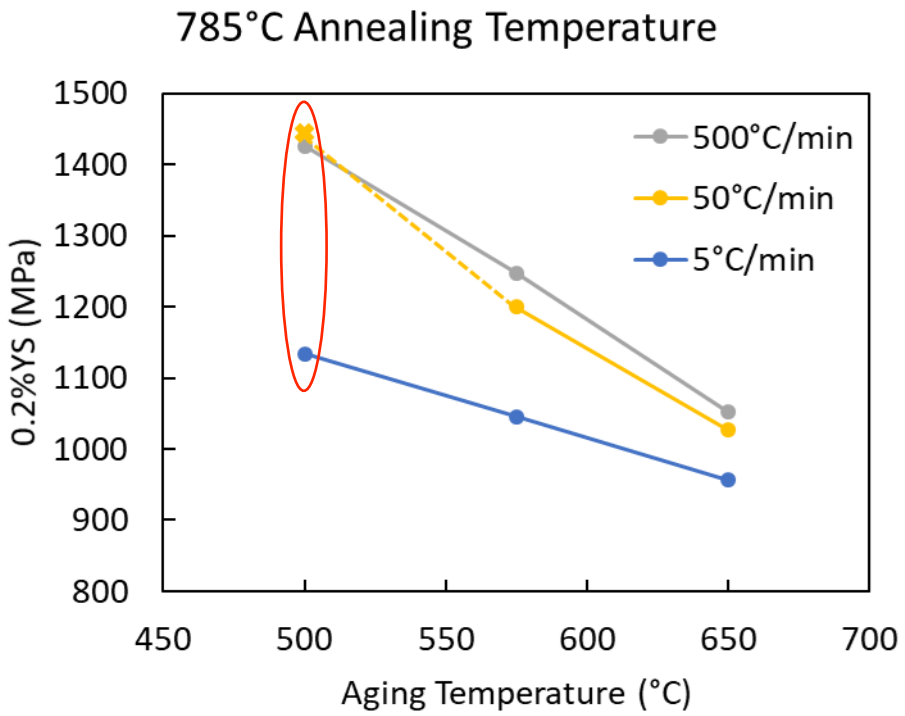
1080 MPa: 700°C, 50°C/min, 575°C

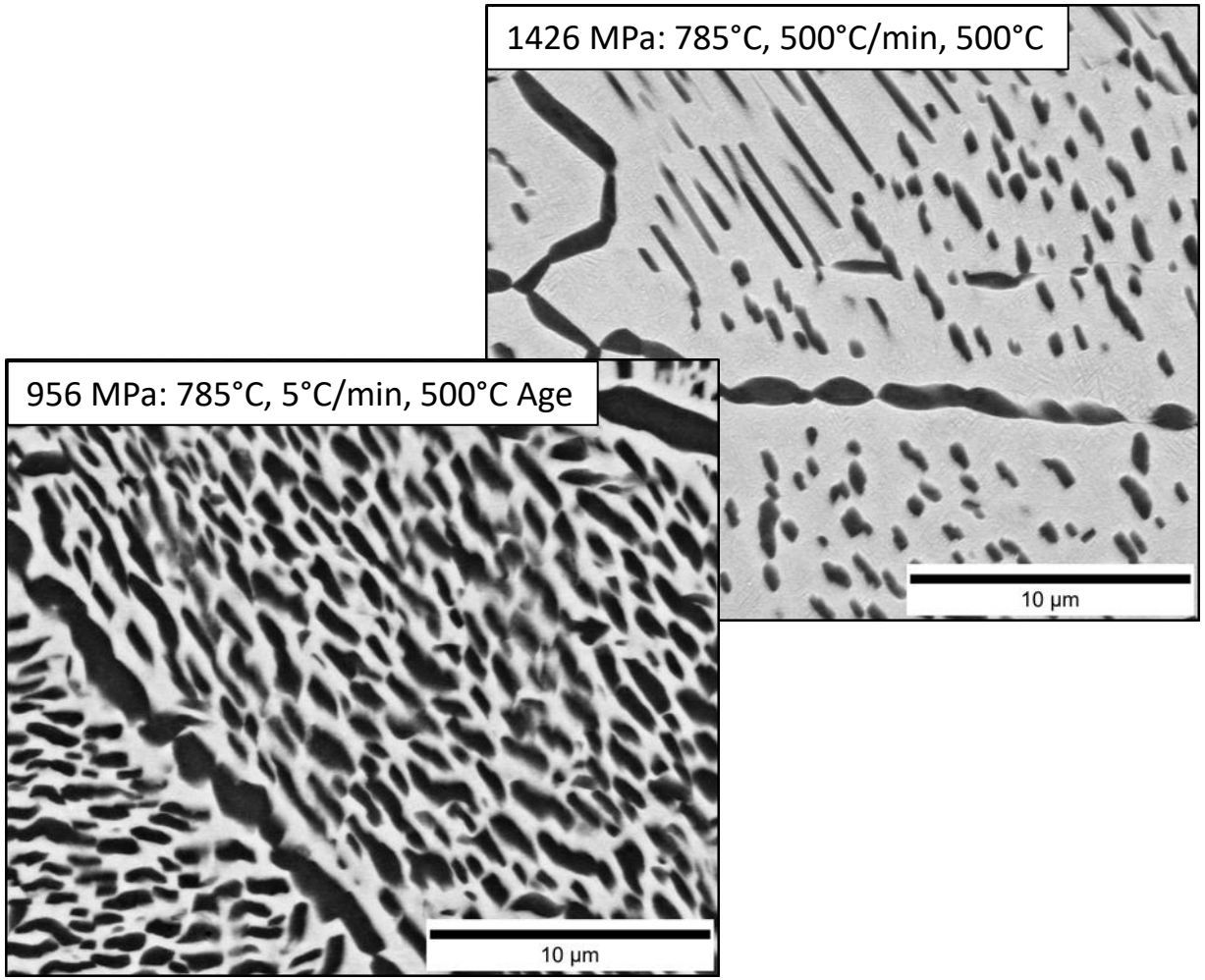


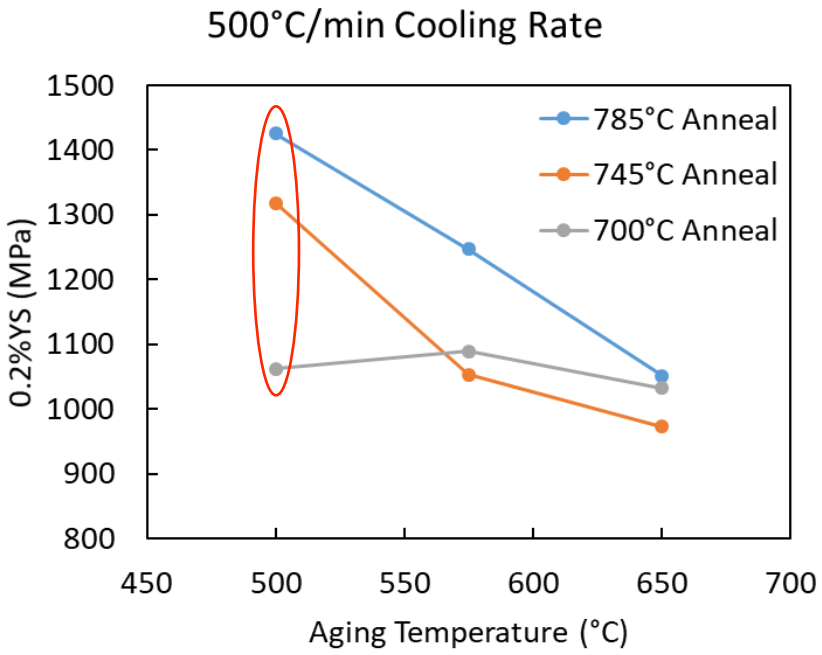
925 MPa: 745°C, 5°C/min, 650°C

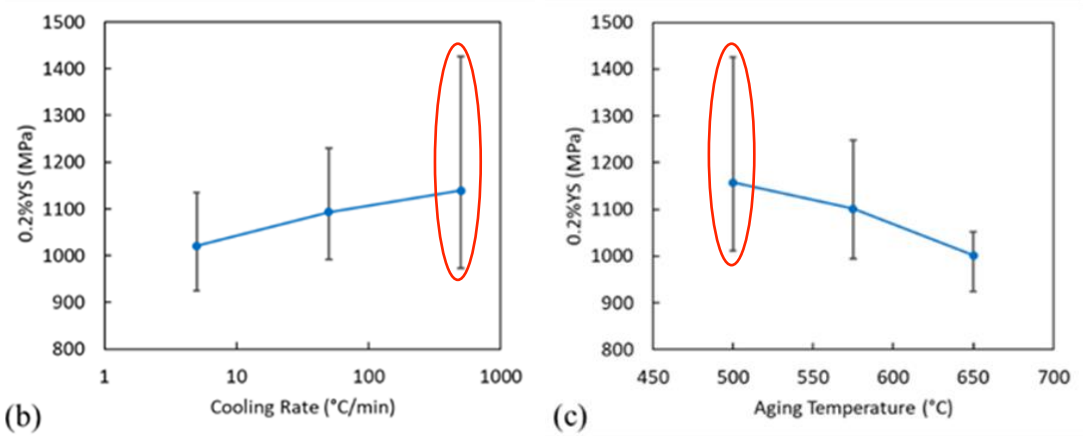


The influence of cooling rate

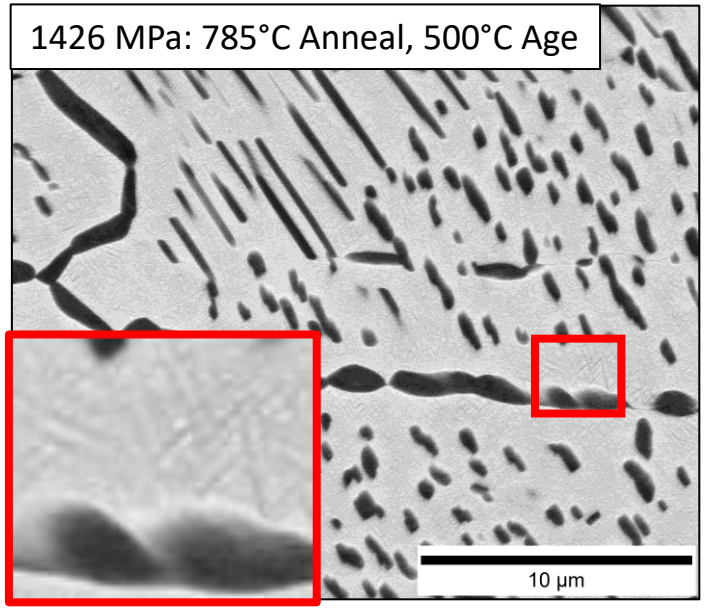




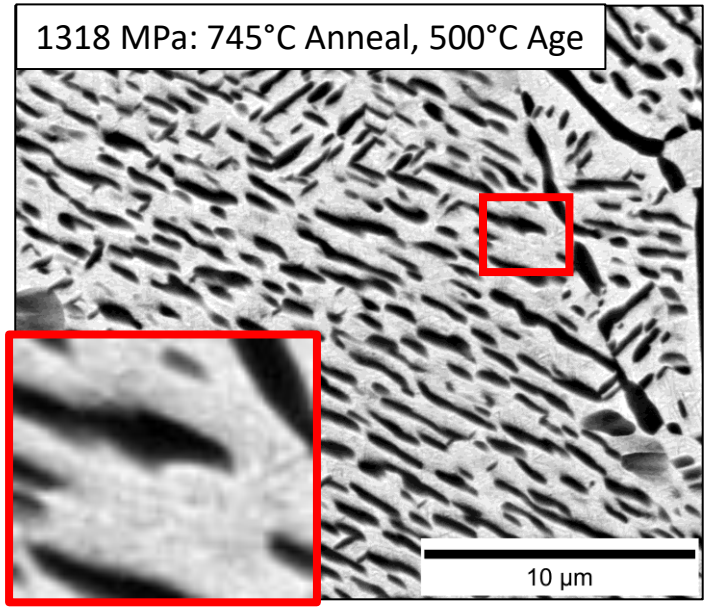




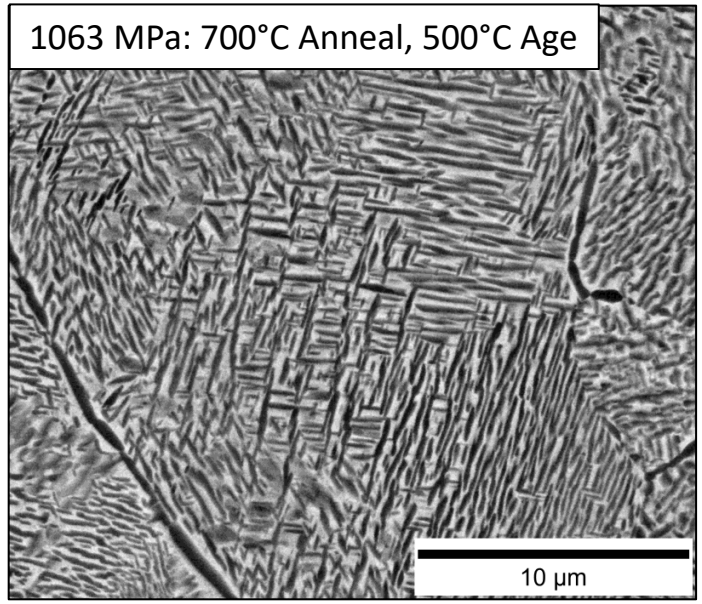
1426 MPa: 785°C Anneal, 500°C Age

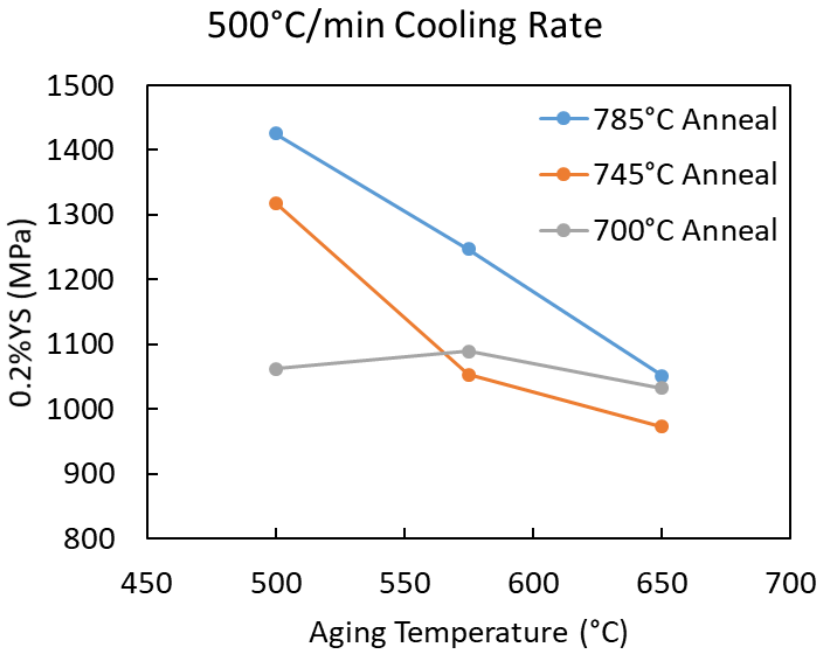


1318 MPa: 745°C Anneal, 500°C Age



1063 MPa: 700°C Anneal, 500°C Age





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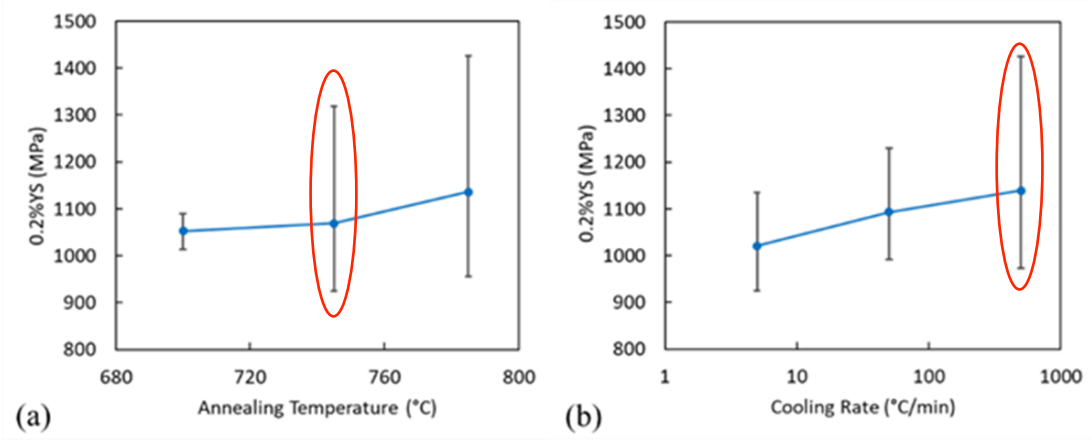
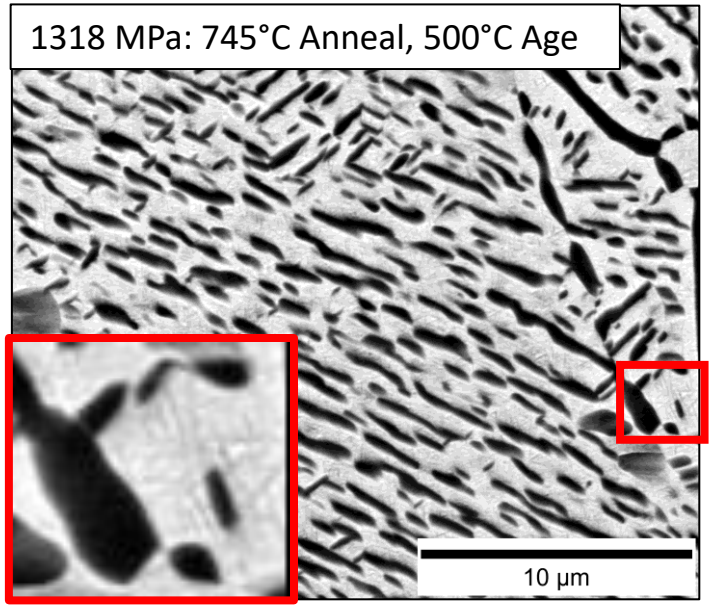
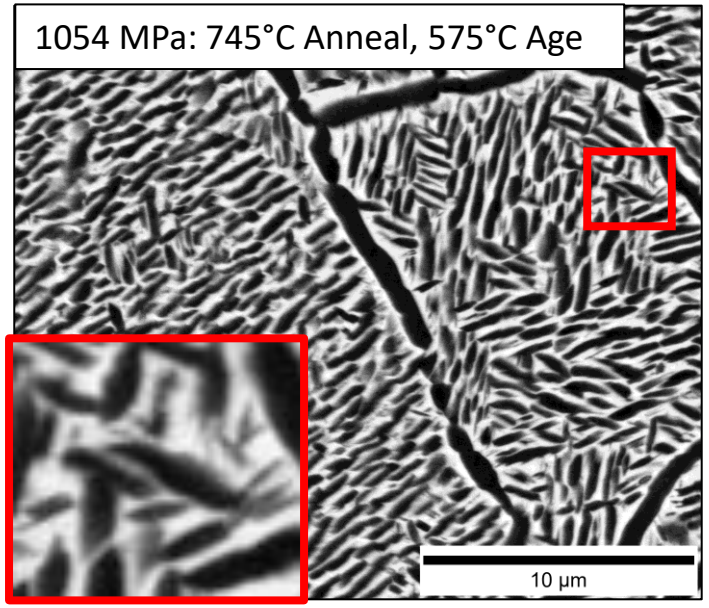


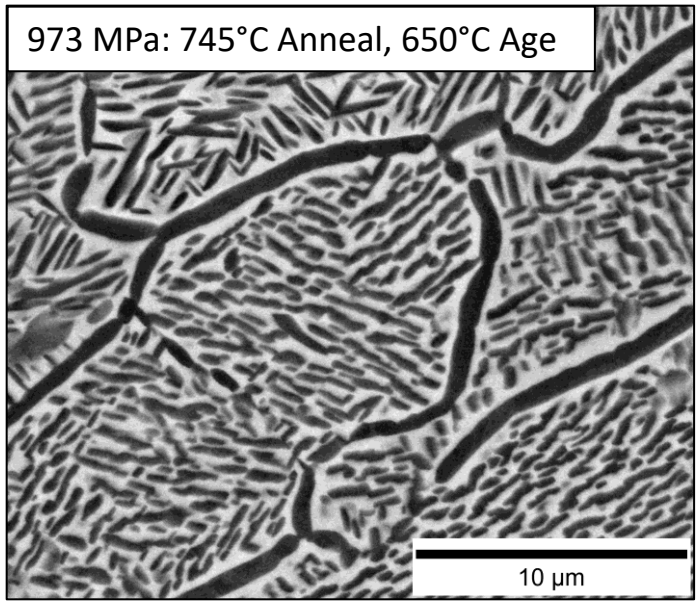
1318 MPa: 745°C Anneal, 500°C Age



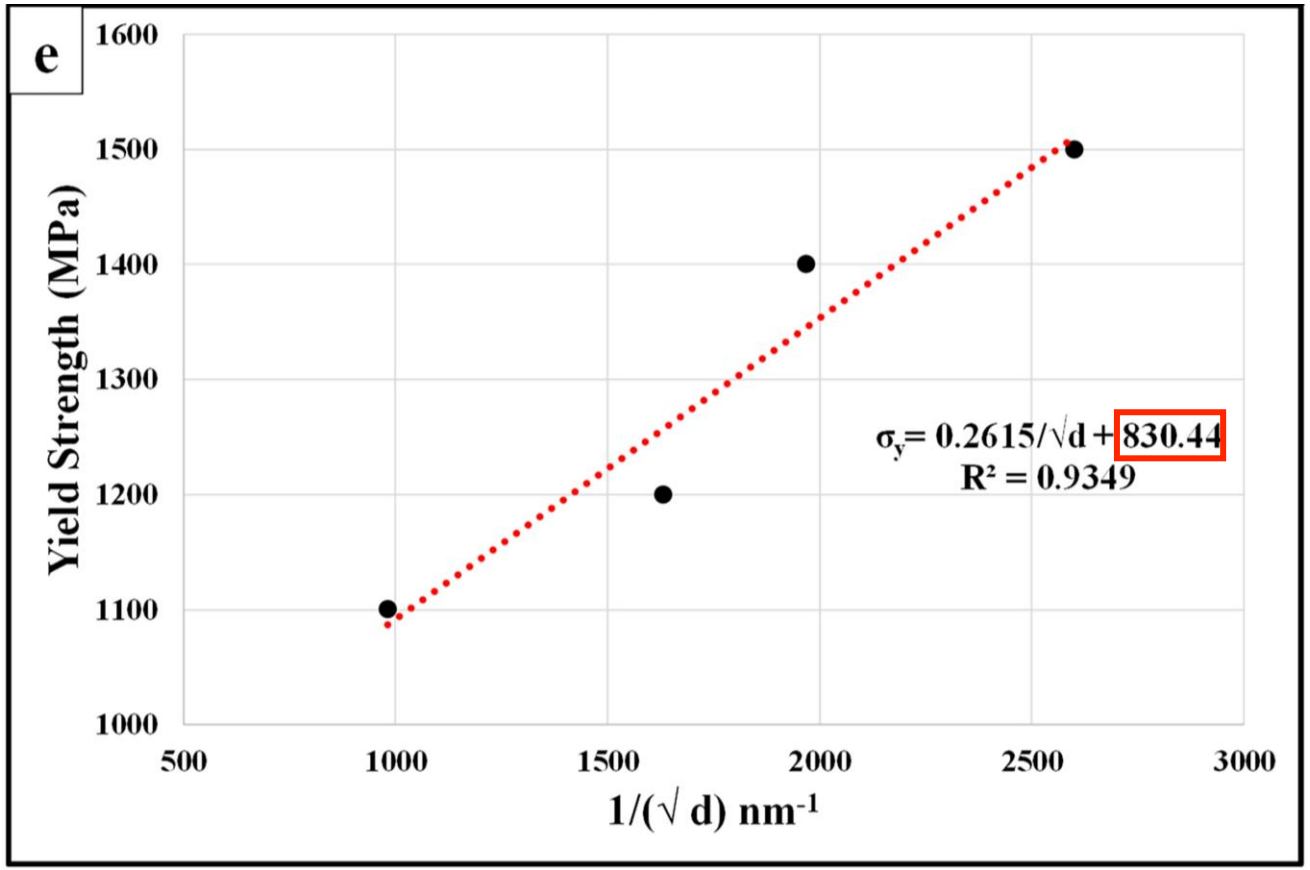
1054 MPa: 745°C Anneal, 575°C Age

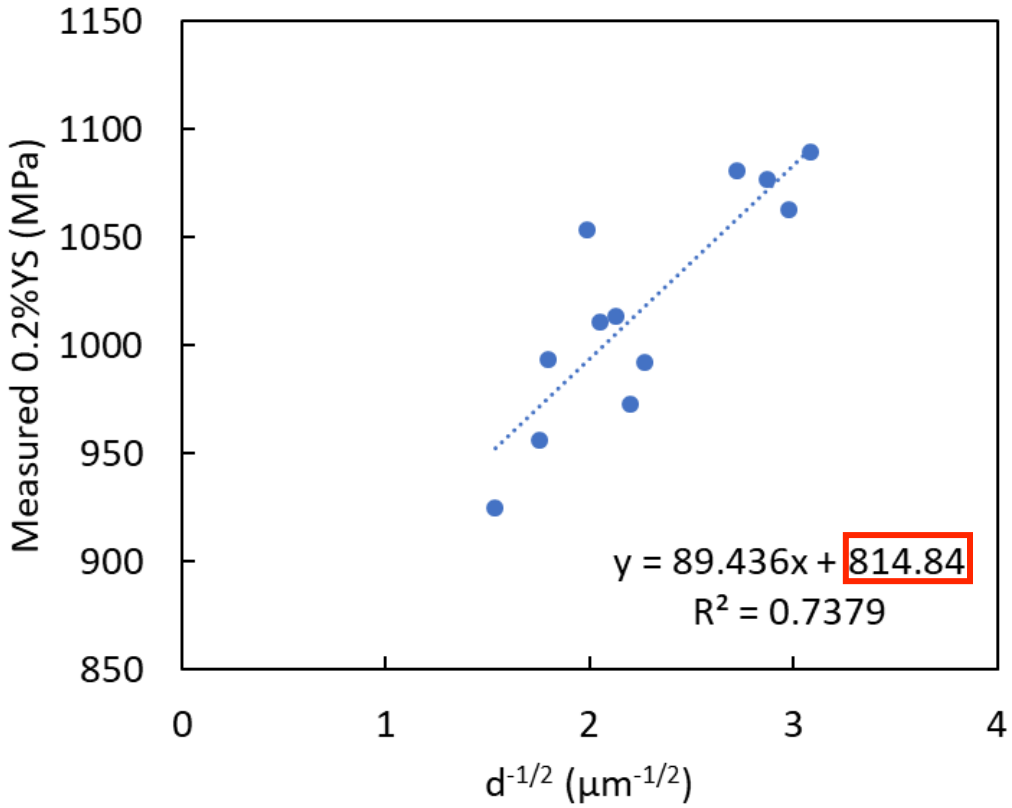


973 MPa: 745°C Anneal, 650°C Age



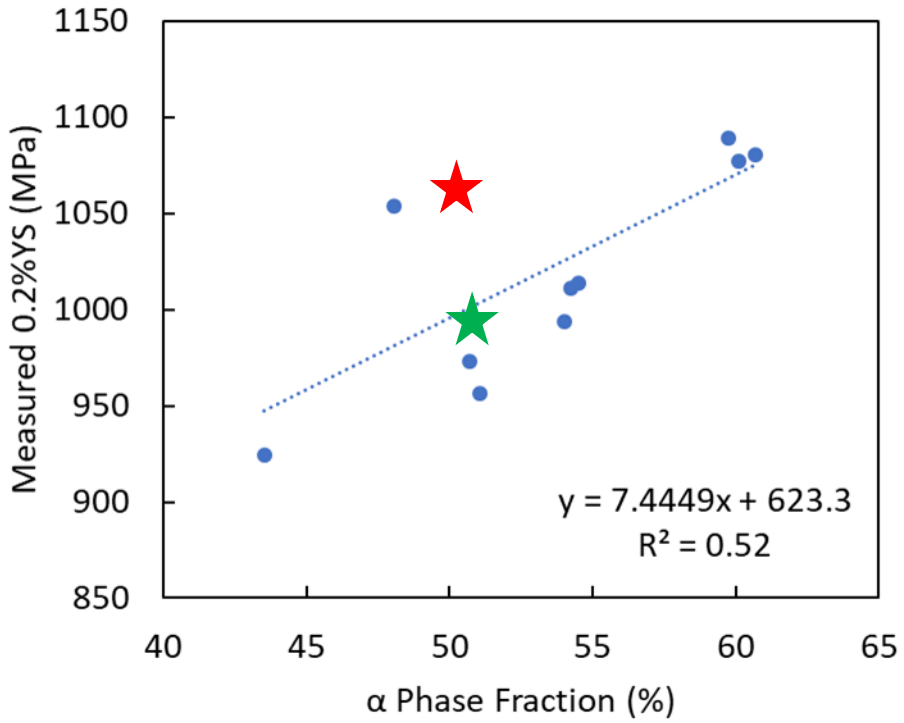
Microstructure-property relationships

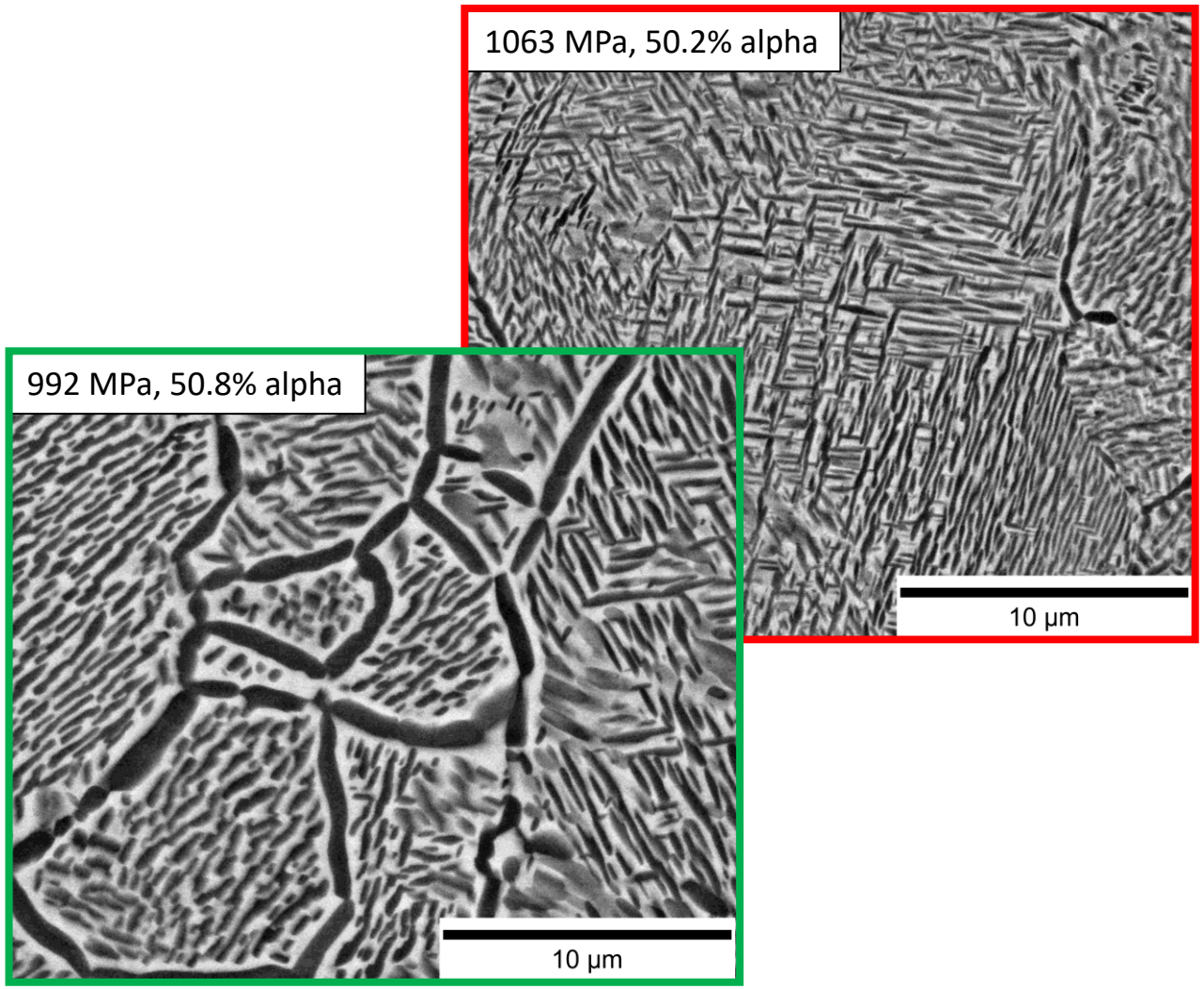




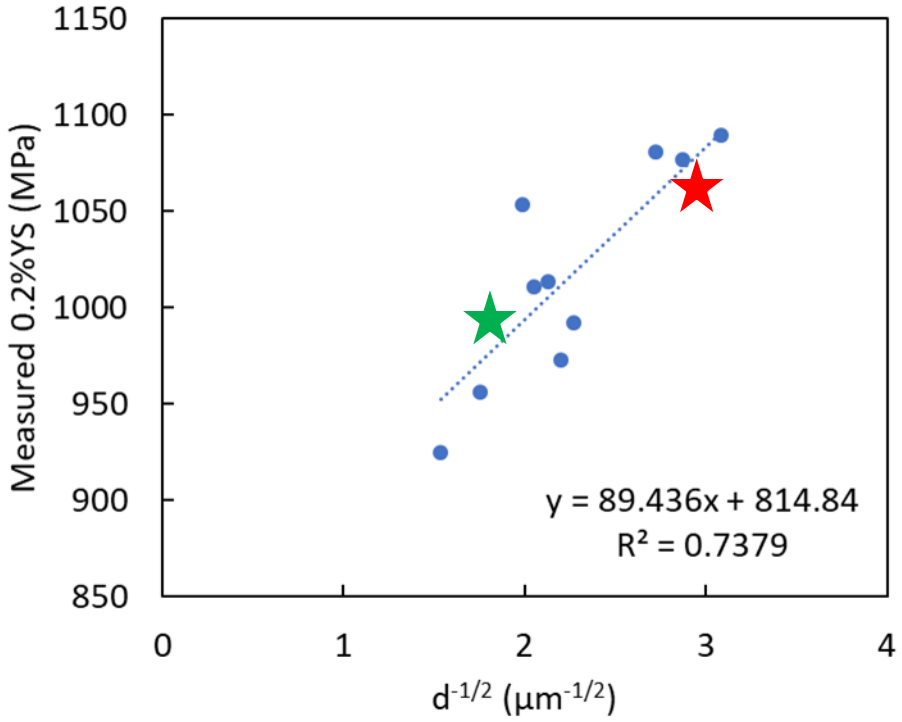
S. A. Mantri et al., Tuning the scale of α precipitates in β-titanium alloys for achieving high strength. Scripta Materialia. 154, 139–144 (2018). https://doi.org/10.1016/j.scriptamat.2018.05.040

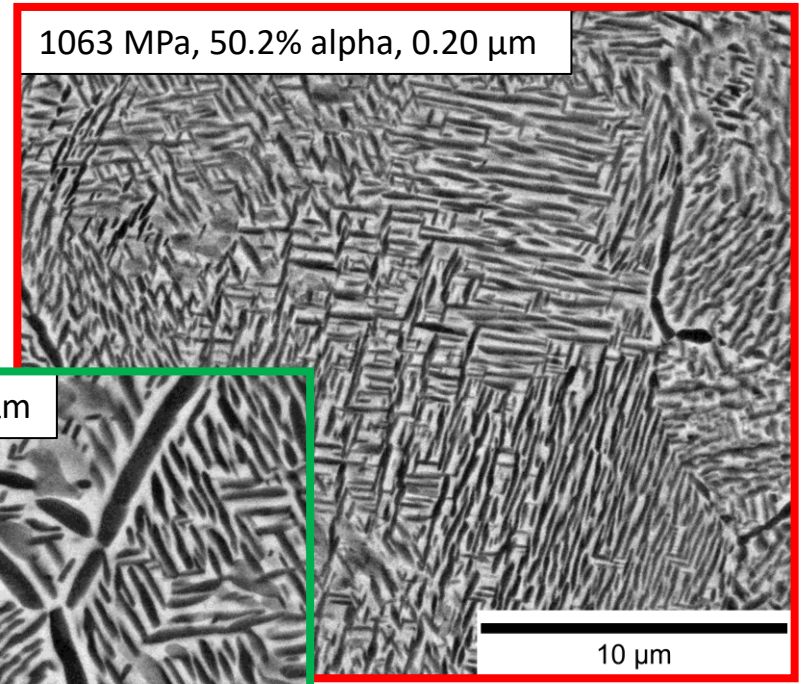
Alpha phase fraction

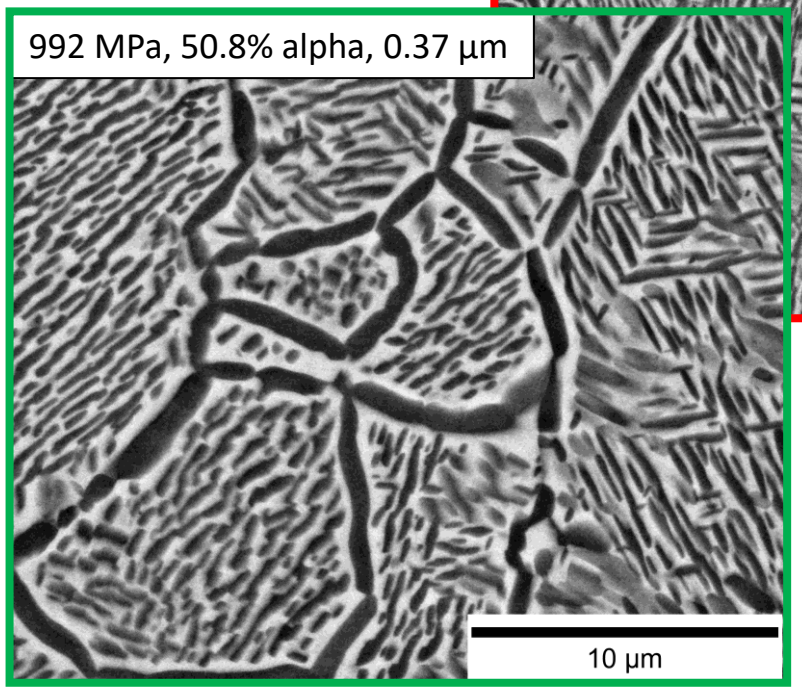




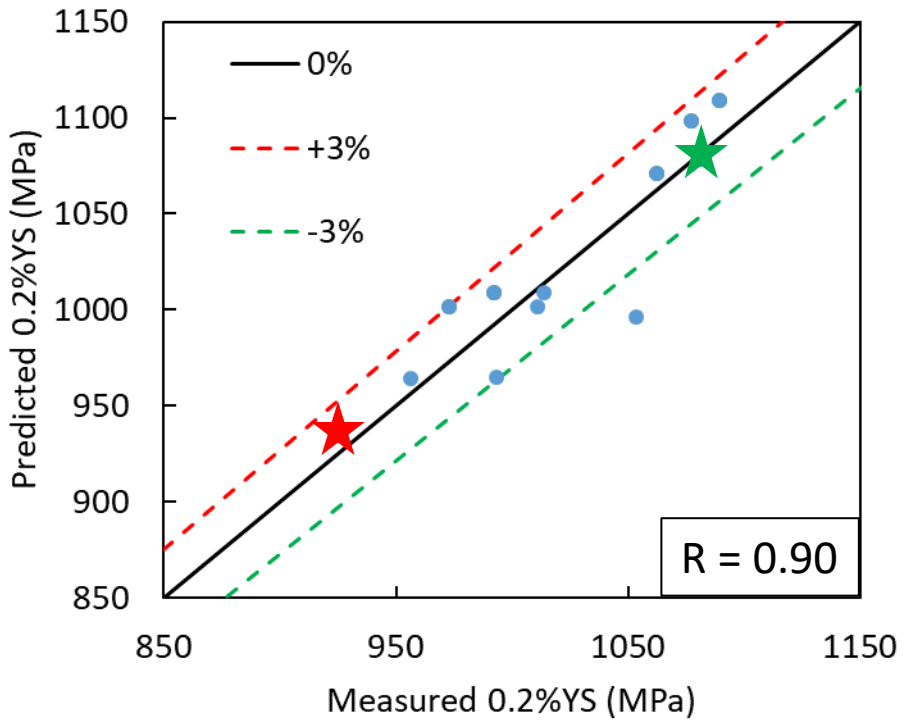
Alpha-to-alpha inter-precipitate spacing



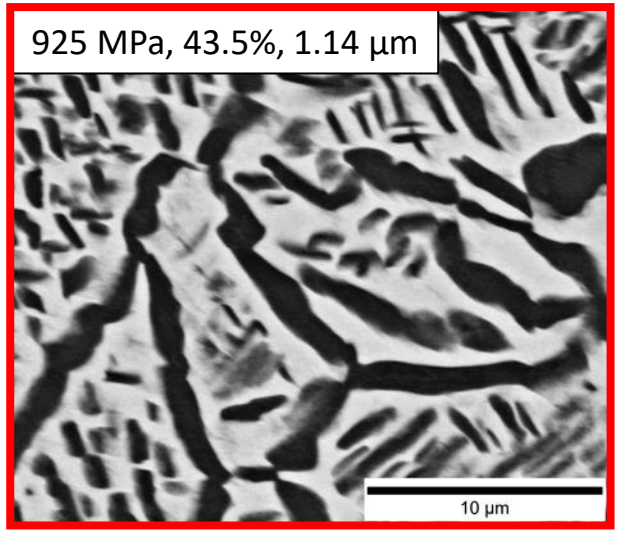


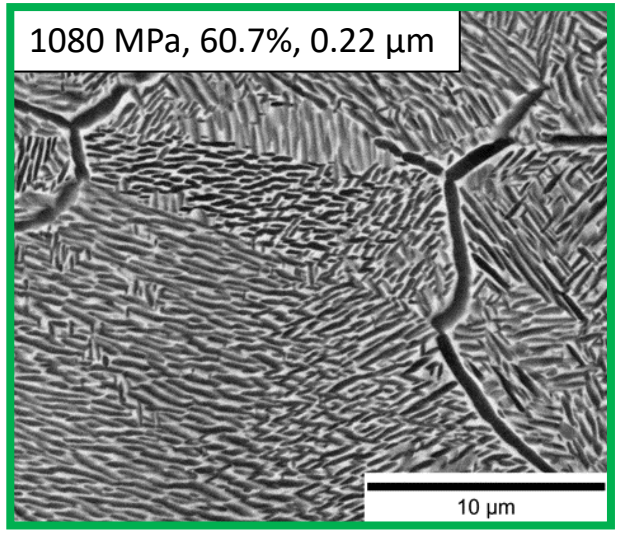


Yield strength predictions of L-PBF Ti-5553



$$YS = F_V^{\alpha} \cdot \left(149 \cdot x_{Al}^{0.667} + 759 \cdot x_O^{0.667}\right) + F_V^{\beta} \cdot \left(\left((22 \cdot x_V^{0.7})^{0.5} + \left(247 \cdot x_{Cr}^{0.7}\right)^{0.5}\right)\right)^2 + F_V^{\alpha} \cdot 220 \cdot \frac{1}{\sqrt{d}}$$





Solid solution – 793-847 MPa

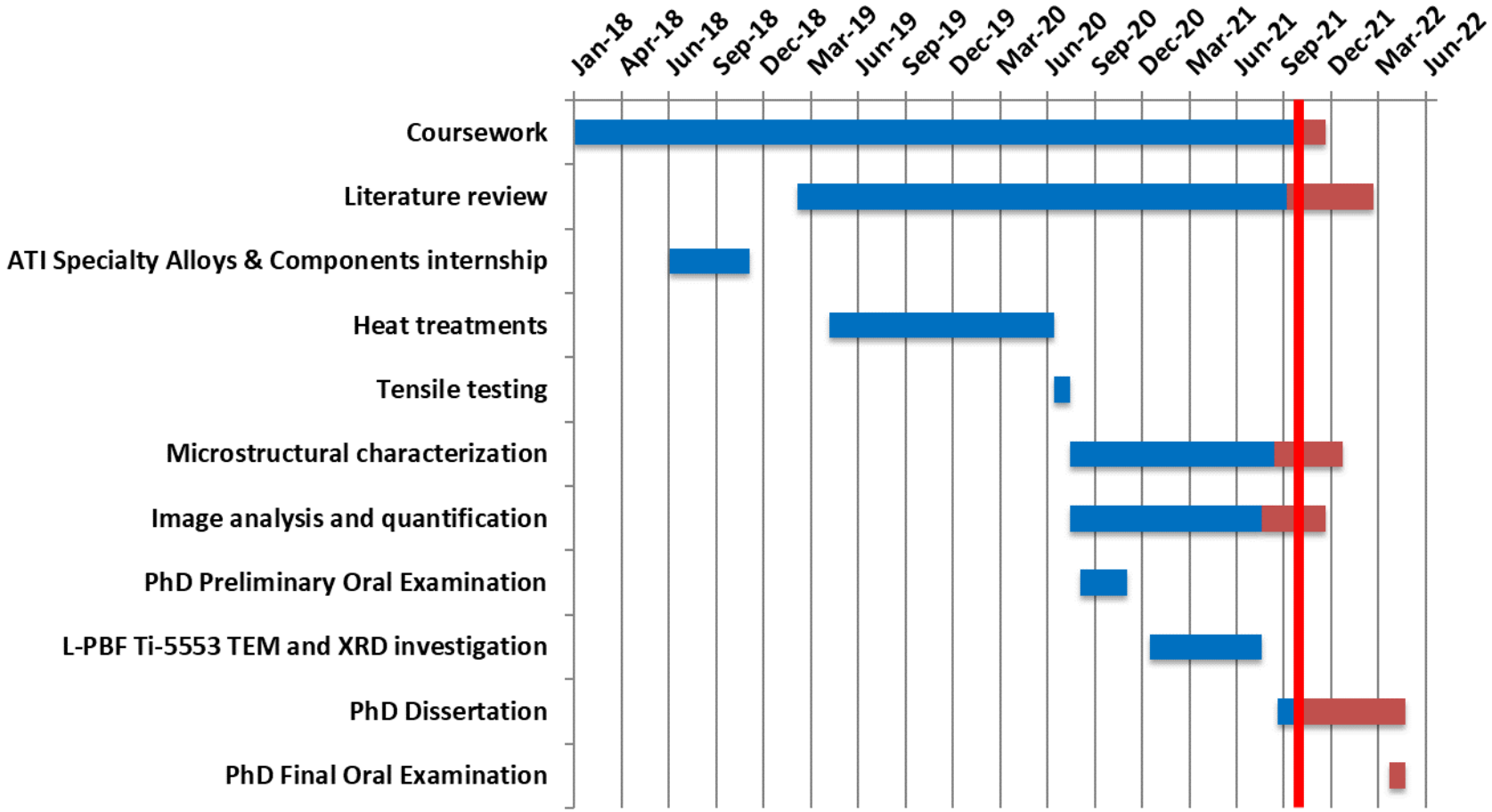
Mean free slip path – 89-313 MPa

	α Phase Fraction (%)	α-to-α Distance (µm)	0.2%YS (MPa)
Average	53.14	0.4288	1019
Max	60.69	1.147	1089
Min	43.51	0.1767	925

Summary

- Strength increases with shorter distance between alpha laths
- Strength increases with increased alpha phase fraction
- Base strength is set by solid solution strengthening (chemistry and phase fraction)

PhD Progress



Challenges & Opportunities

- Microstructural analysis and quantification
  - Fine secondary alpha laths for prediction of yield strengths > 1150 MPa

- Dissertation writing

Thank you!

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