CANFSA

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

Project 45-L: Additive Manufacturing Feasibility of Refractory Alloys

Semi-annual Fall Meeting

April 2022

- Student: Abby Miklas (Mines)
- Faculty: Amy Clarke, Jonah Klemm-Toole (Mines)
- Industrial Mentors: Andy Deal (Kansas City National Security Campus), Andrew Kustas (Sandia National Laboratories), Noah Phillips (ATI)

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Project 45-L: Additive Manufacturing Feasibility of Refractory Alloys

- Student: Abby Miklas (Mines)
- Advisor(s): Amy Clarke and Jonah Klemm-Toole (Mines)

Project Duration

Masters: August 2020 to August 2022

- Problem: Opportunity exists to produce refractory alloys for performance in extreme environments (e.g., ultrahigh temperatures).
- Objective: Understand solidification and microstructure development in refractory alloys under additive manufacturing conditions.
- Benefit: Strategies for alloying and microstructure development by additive manufacturing to achieve tailored microstructures.

Recent Progress

- Second trial of laser track melts have been performed on material
  - Binary alloys: Mo30Nb, Nb7.5Ta
  - Nb C103
  - MoNbTaTi
- CET modeling
- Initial SYSWELD simulations
- Metallography
- Literature review

Metrics

Description	% Complete	Status
1. Literature review	60%	●
2. Provide samples to KCNSC and acquire laser track melts	100%	●
3. Microstructure characterization by scanning electron microscopy (SEM) and electron backscatter diffraction (EBSD)	25%	●
4. Perform thermal gradient modeling of melt tracks	50%	●
5. Columnar-to-equiaxed transition (CET)/solidification modeling	75%	●

Refractory Multi-Principal Element Alloys (RMPEAs)

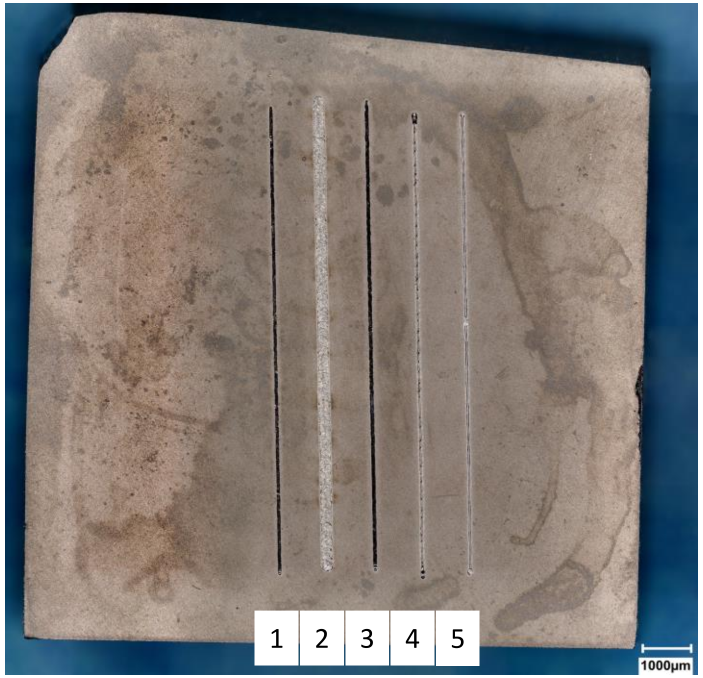
- Refractory elements are those that can maintain their properties above 1200 °C and are used as structural materials for extreme environments (i.e., W, Mo, Ta, Nb, etc.) [1]
- RMPEAs are defined as an MPEA containing refractory elements as principal constituents [2]
- RMPEAs suffer from low ductility at room temperature and are challenging from a workability standpoint (i.e., difficult to thermomechanically process) [3]
- Additive manufacturing (AM) has the potential to be an attractive alternative processing pathway for refractory alloy and RMPEA fabrication (e.g., avoids thermomechanical processing and post-process machining) [3, 4]

Laser Track Melts

Parameter Set	Power (W)	Speed (m/s)
1	162	0.8
2	243	0.2
3	162	0.5
4	405	1.7
5	324	1.7

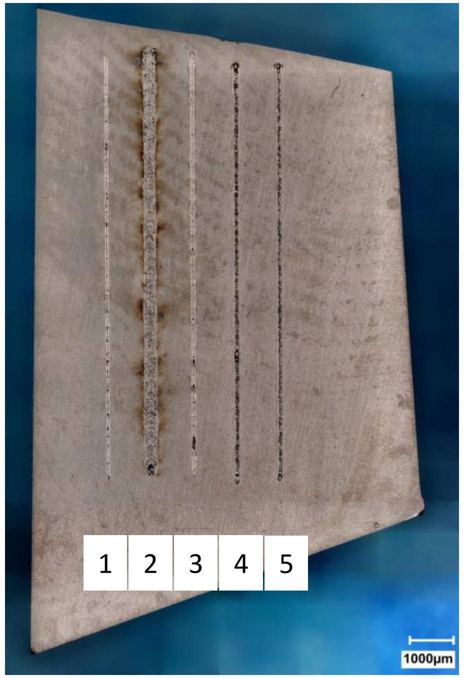
Mo30Nb

Nb7.5Ta



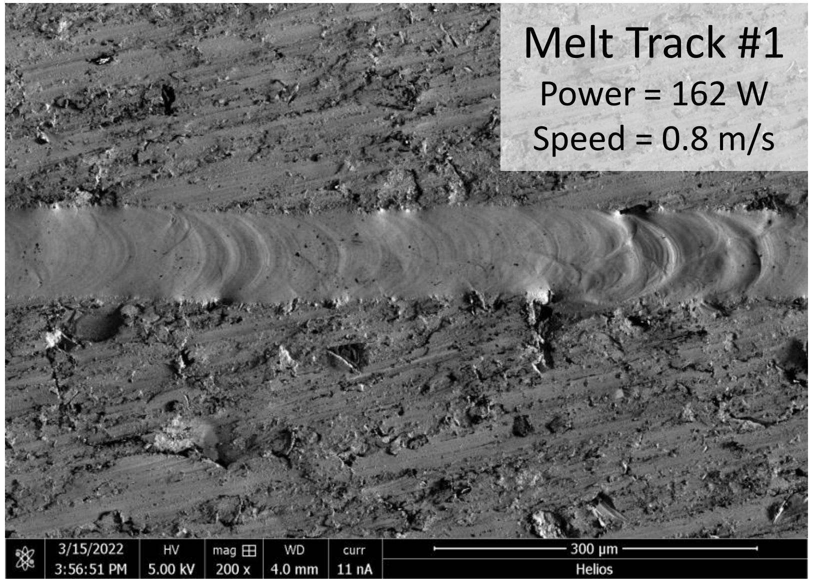
C103

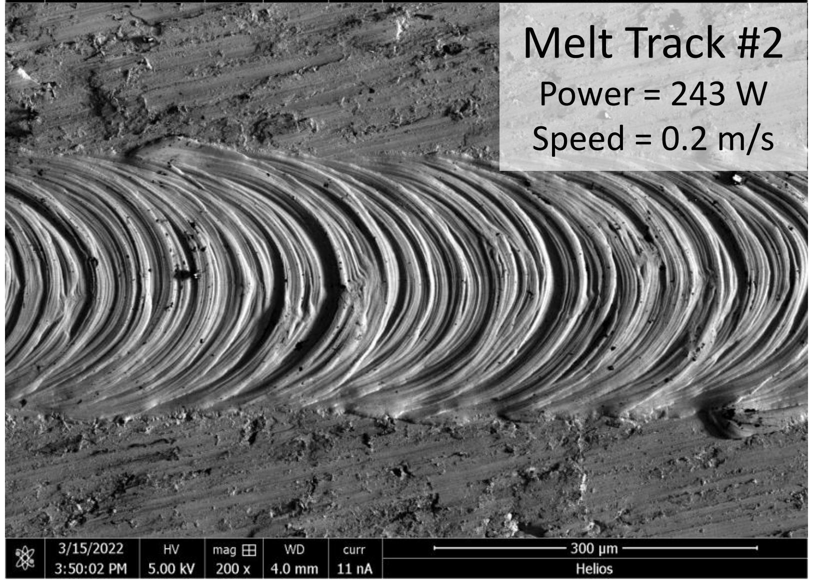
NbMoTaTi

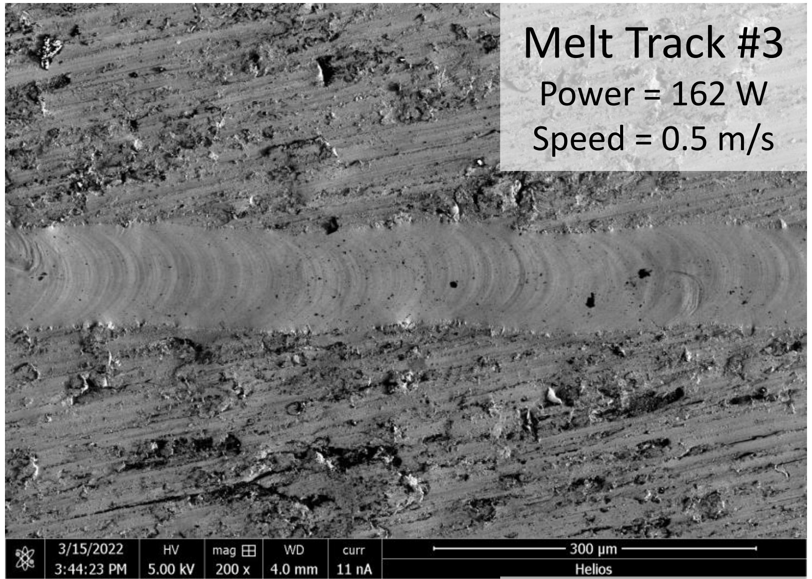


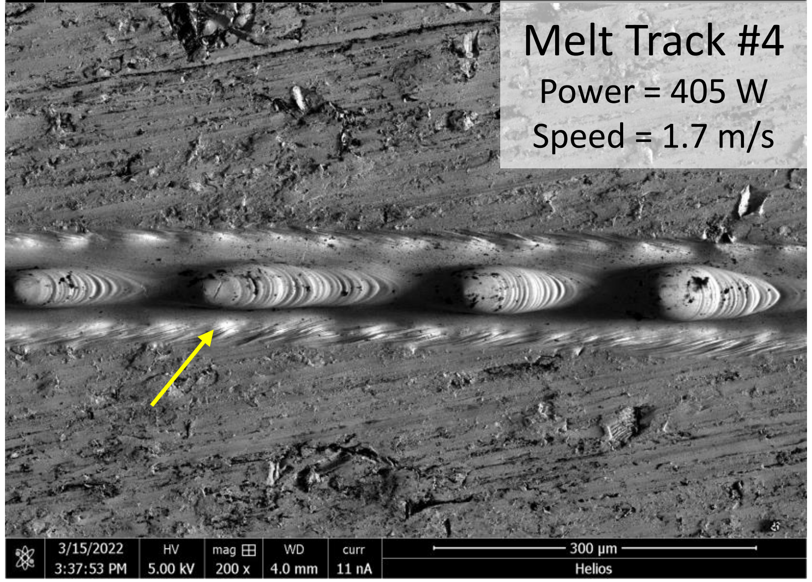
Laser behavior is consistent within a single track.

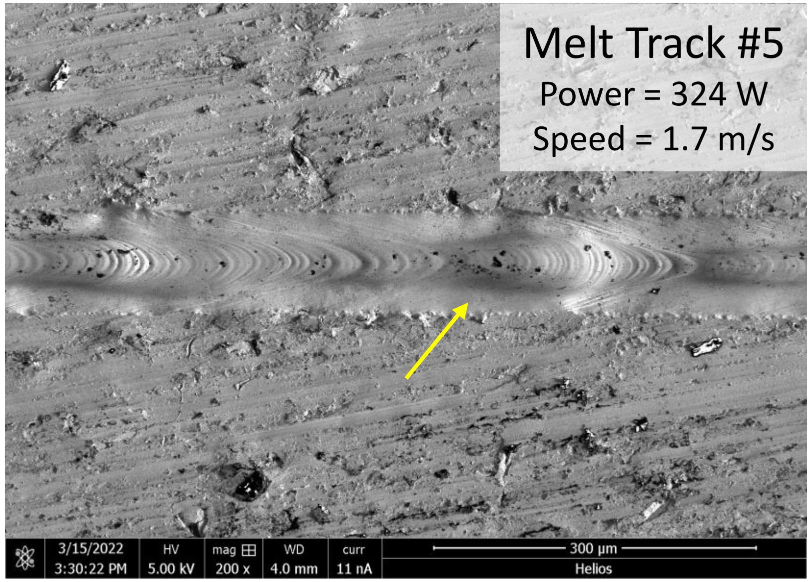
Top-Down Imaging – C103


Melt Track #1
Power = 162 W
Speed = 0.8 m/s

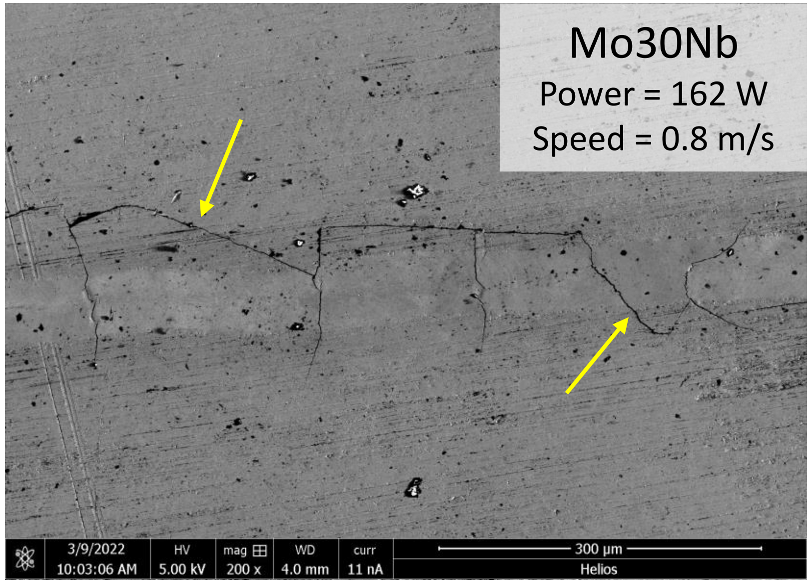

Melt Track #2
Power = 243 W
Speed = 0.2 m/s

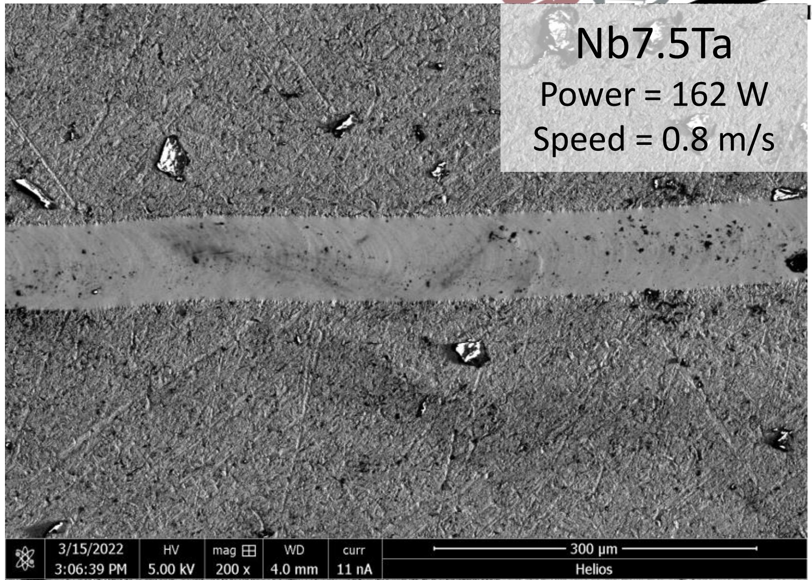

Melt Track #3
Power = 162 W
Speed = 0.5 m/s

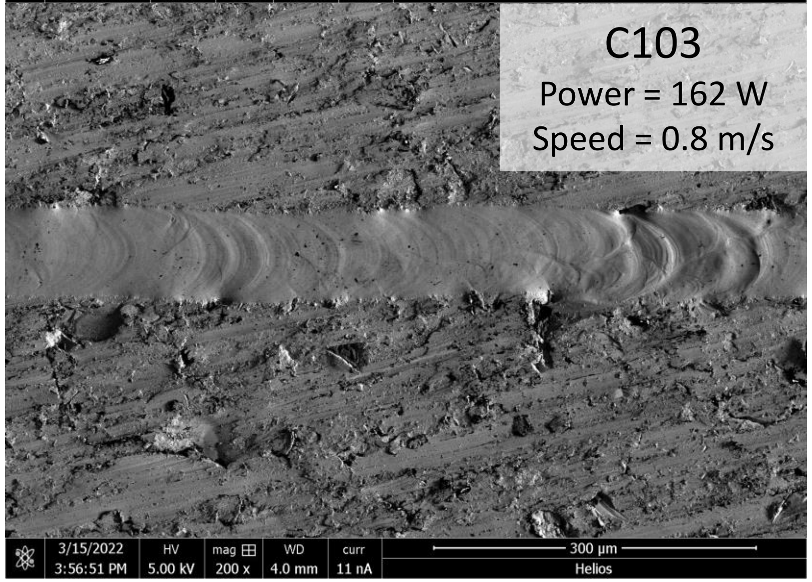

Melt Track #4
Power = 405 W
Speed = 1.7 m/s

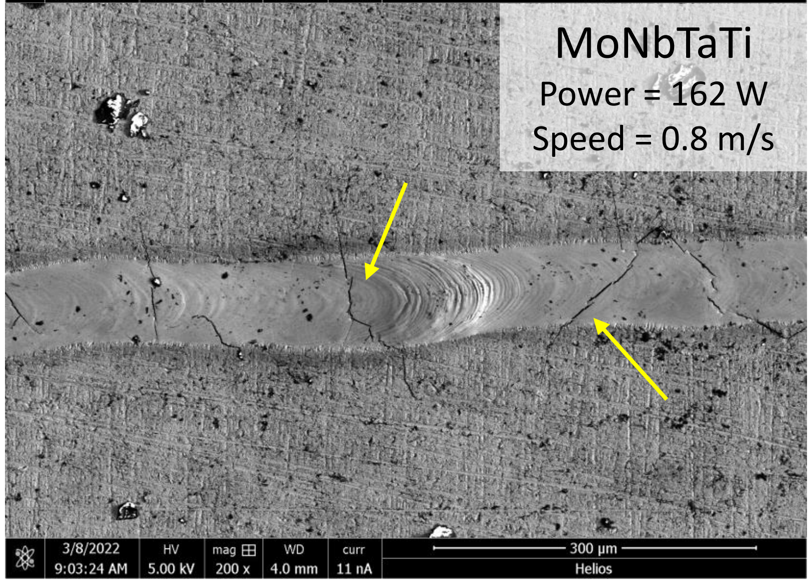

Melt Track #5
Power = 324 W
Speed = 1.7 m/s

Top-Down Imaging – Melt Track #1


Mo30Nb
Power = 162 W
Speed = 0.8 m/s

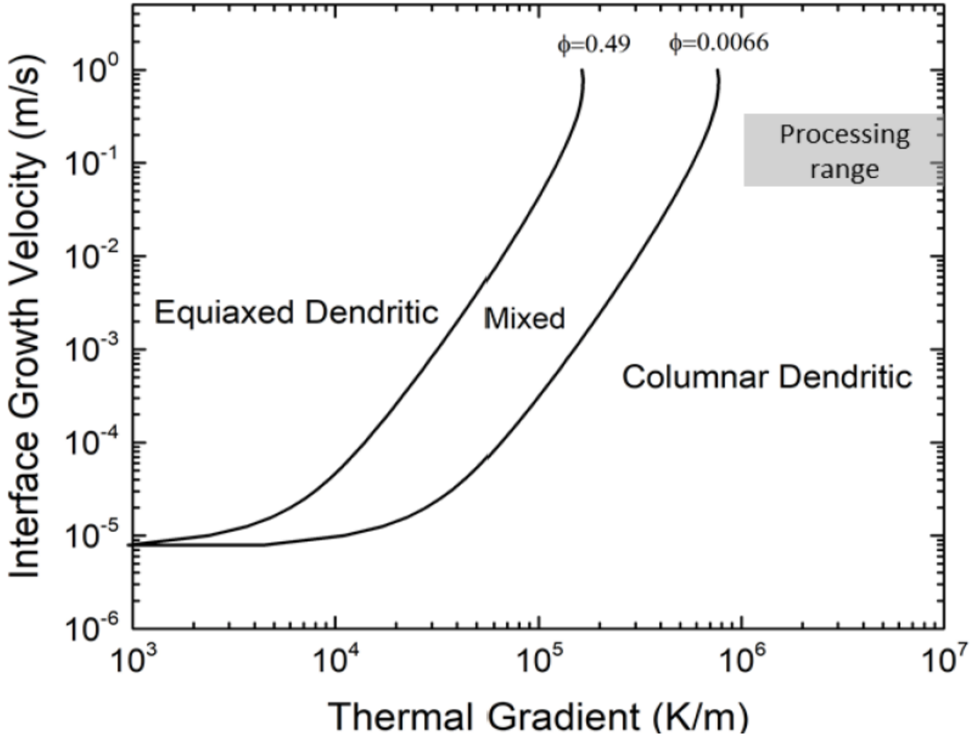

Nb7.5Ta
Power = 162 W
Speed = 0.8 m/s


C103
Power = 162 W
Speed = 0.8 m/s

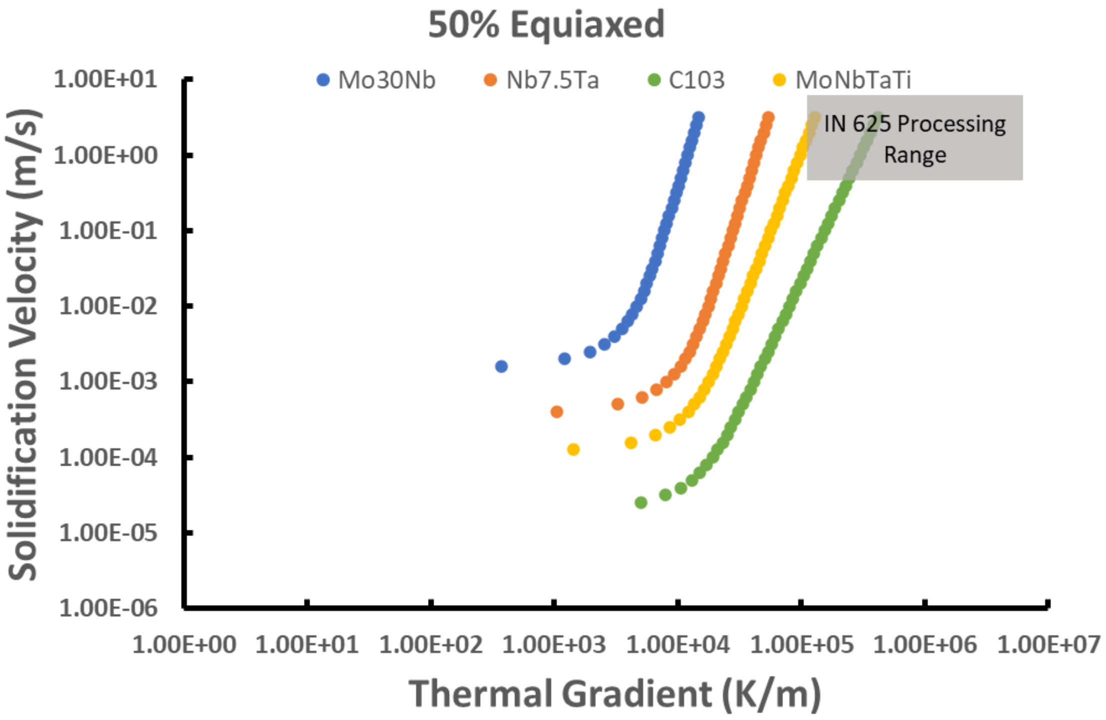

MoNbTaTi
Power = 162 W
Speed = 0.8 m/s

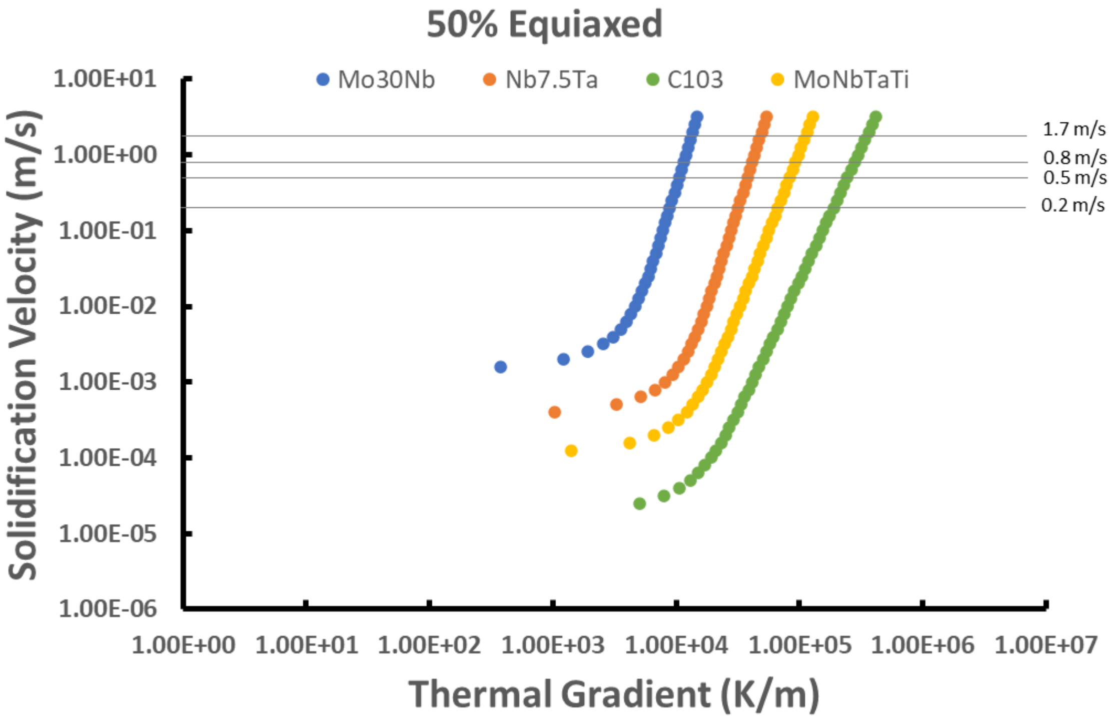
CET Modeling

- Using a simplified Kurz, Giovannola, Trivedi (KGT) model [5,6]
- Inputs needed for this model:
  - Gibbs-Thomson coefficient of matrix element, Γ
  - İnitial solute concentration, C
  - Diffusivity of solutes, D
  - Partitioning coefficient of solutes, k
  - Liquidus slopes of solutes, m
- Models can be further refined with information gathered from evaluation of melt track cross sections and thermal gradient modeling



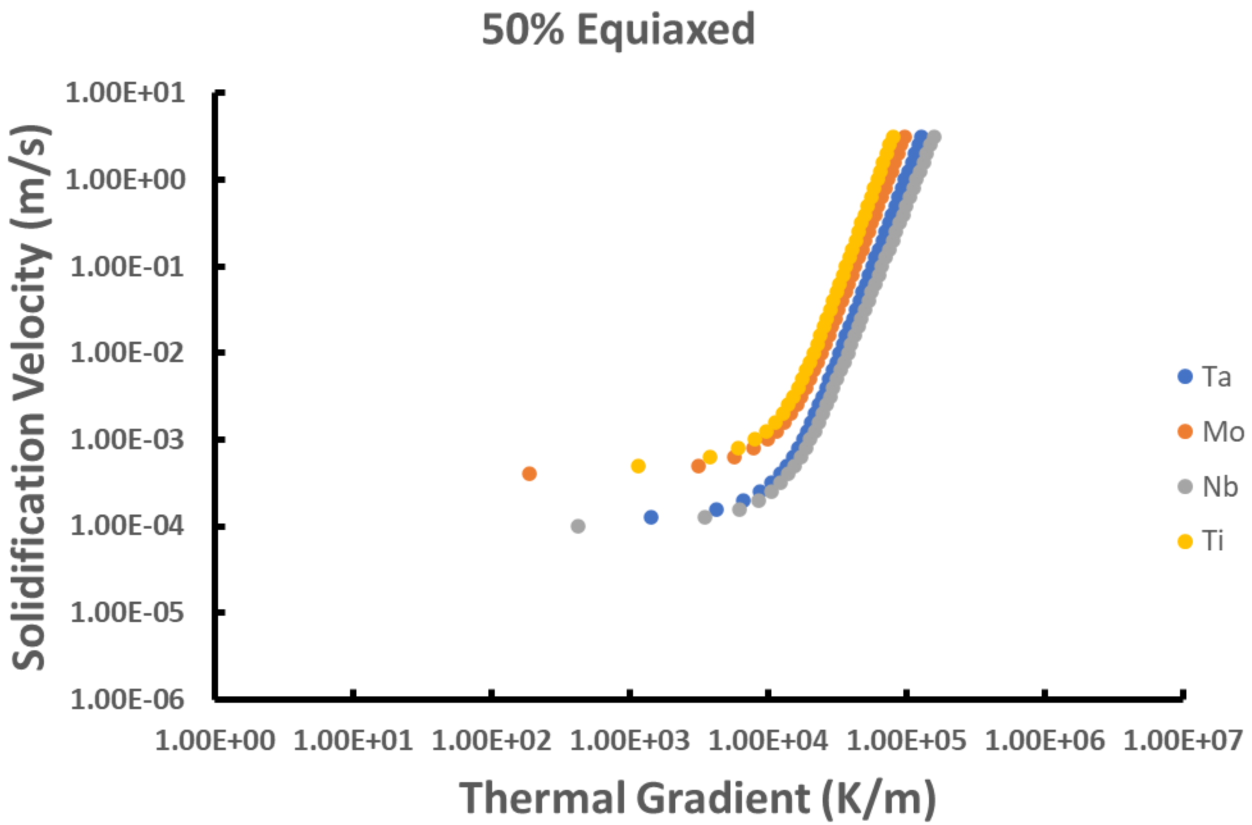
CET Modeling





C103 will have the highest amount of equiaxed grains.

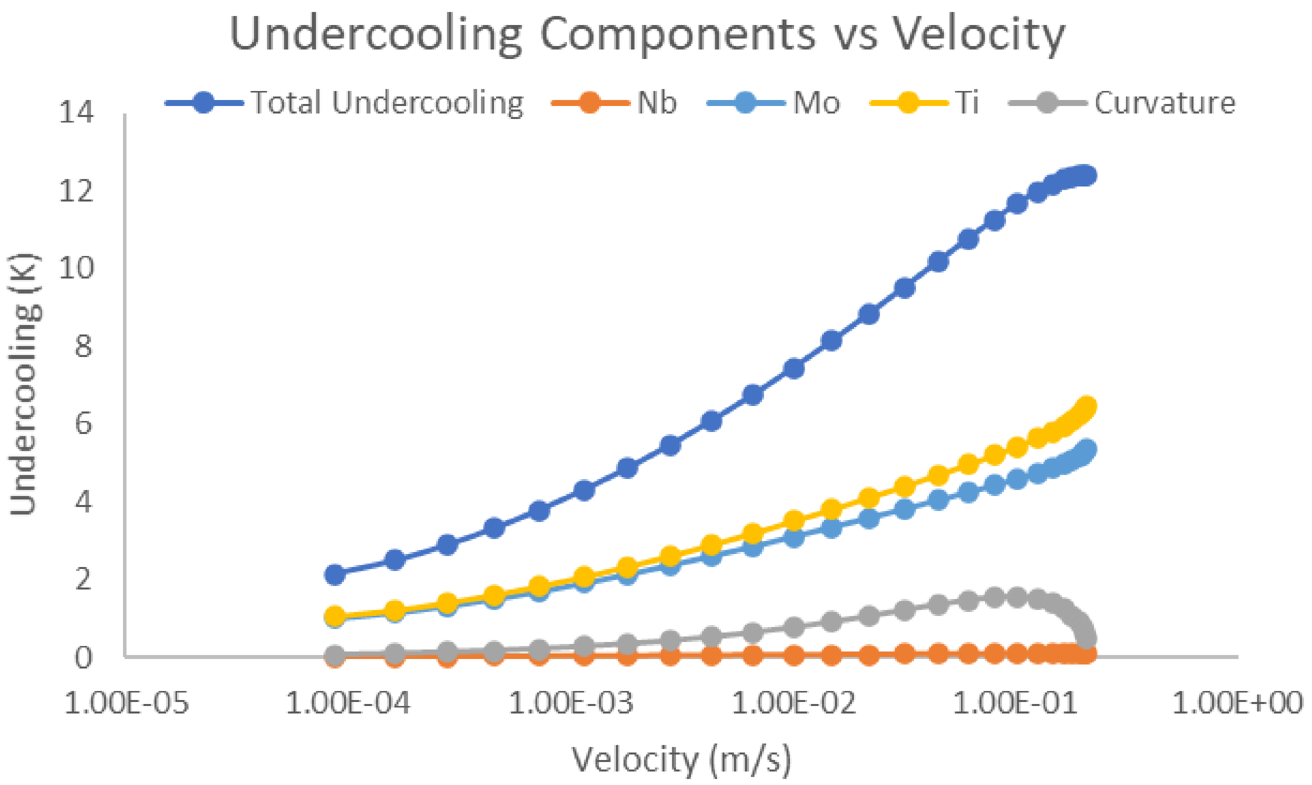
CET Modeling of an Equiatomic Alloy



Evaluating differing predictions for the MoNbTaTi system, assuming different "base" elements.

Contributions to Total Undercooling

- Determining the undercooling contribution of each solute to the constitutional undercooling can guide in alloy design and selection for AM



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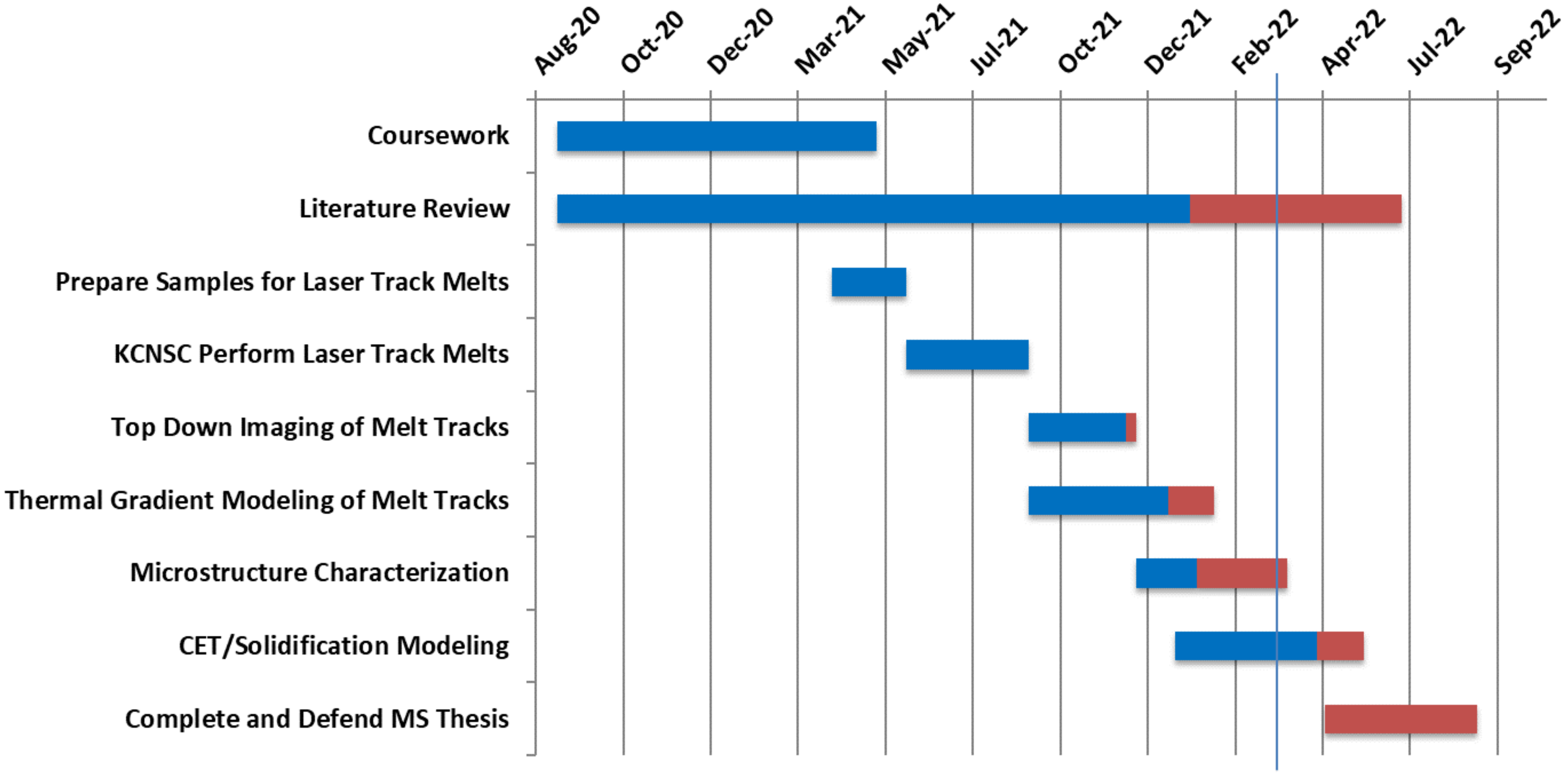
Gantt Chart


Aug-20
Oct-20
Dec-20
Mar-21
May-21
Jul-21
Oct-21
Dec-21
Feb-22
Apr-22
Jul-22
Sep-22
Coursework
Literature Review
Prepare Samples for Laser Track Melts
KCNSC Perform Laser Track Melts
Top Down Imaging of Melt Tracks
Thermal Gradient Modeling of Melt Tracks
Microstructure Characterization
CET/Solidification Modeling
Complete and Defend MS Thesis

Upcoming Work

- Evaluate the laser tracks metallographically
  - SEM
  - EBSD
- Perform thermal gradient modeling of laser melt tracks with commercially available software (SYSWELD)
- Compare CET/solidification with thermal gradients and microstructure characterization results

Challenges & Opportunities

- Inconsistent material preparation behavior
- Learning metallographic analysis and modeling techniques that are new to me

Thank you!
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References

[1] M. C. Gao, J. W. Yeh, P. K. Liaw, Y. Zhang, High Entropy Alloys: Fundamentals and Applications, Switzerland: Springer International Publishing, 2016

[2] B. S. Murty, J. W. Yeh, and S. Ranganathan, “Chapter 1 - A Brief History of Alloys and the Birth of High-Entropy Alloys,” in High-Entropy Alloys, London: Butterworth-Heinemann, 2014.

[3] N. R. Philips, M. Carl, and N. J. Cunningham, “New Opportunities in Refractory Alloys,” Metallurgical and Materials Transactions A, 14-May-2020. [Online]. Available: https://link.springer.com/article/10.1007/s11661-020-05803-3. [Accessed: 25-Mar-2021].

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[5] W. Kurz, B. Giovanola, and R. Trivedi, “Theory of microstructural development during Rapid Solidification,” Acta Metallurgica, vol. 34, no. 5, pp. 823–830, 1986.

[6] P. Mohammadpour and A. B. Phillion, “Solidification microstructure selection maps for laser powder bed fusion of multicomponent alloys,” IOP Conference Series: Materials Science and Engineering, vol. 861, no. 1, p. 012005, 2020.