Structural Materials – LANL

The Additive Manufacture of Titanium Zirconium Molybdenum to Provide a New Manufacturing Methodology for a Promising Material

Update on Work Package: AT-23LA080410

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Why Titanium – Zirconium – Molybdenum?

- Short Term (FY22-23) – Develop the manufacturing, generalized mechanical behavior, and timeline for maturation for AM TZM (TRL <=3)
- ORNL/ANL/INL/LANL collaborative effort:
  - Material (manufacturing processes)
  - 316 SS (powder metallurgy (PM) / additive manufacturing (AM))
    - Purpose: Applicability of current code requirements to new manufacturing processes
  - Grade 91 (wrought / AM)
    - Purpose: Provide material option with enhanced high temperature strength / higher creep strength (thinner ligaments)
  - **Molybdenum Alloys (AM)**
    - Purpose: Provide material option with higher potential operating temperature
  - Graphite (AM)
    - Purpose: Provides material option to combine moderator with structural material

Impact: Enable new manufacturing methods

Impact: Disruptive for Engineering Design

Impact: Disruptive for Operating Temperature Design

Impact: Disruptive from a Neutronic Design

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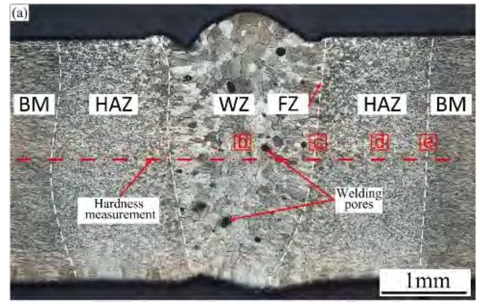
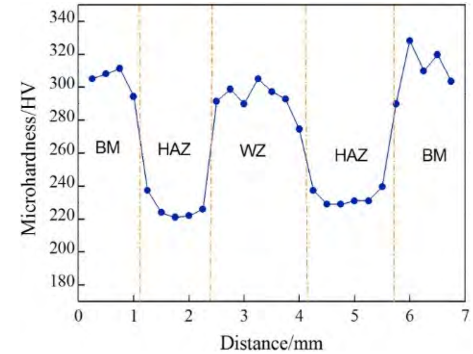
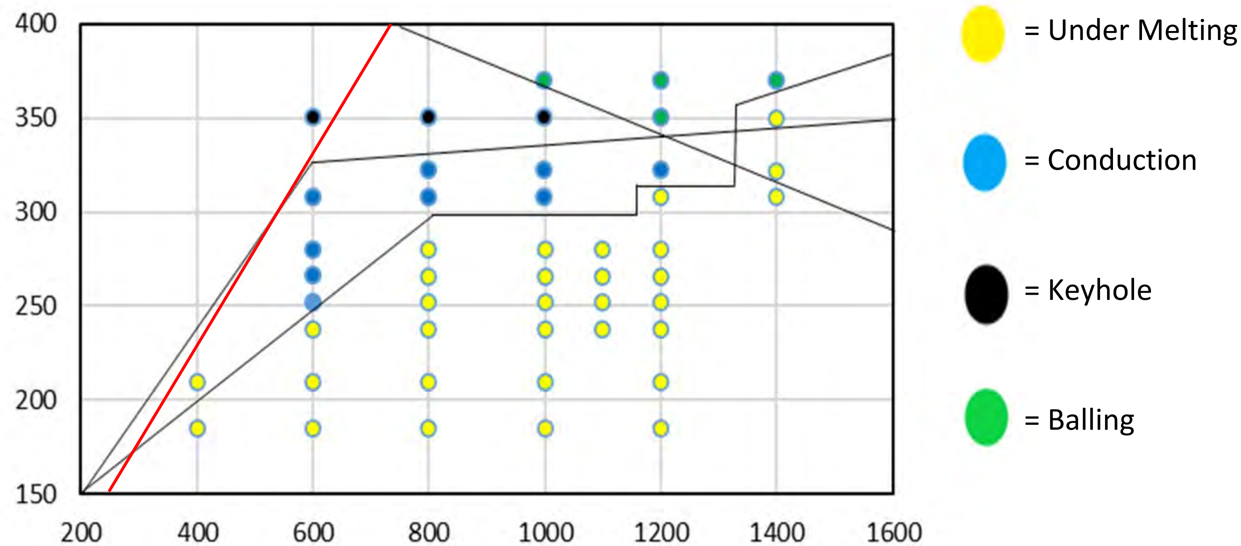
Why Additive Manufacturing?

- Material is challenging to both machine and weld
- Limited AM literature points to success when using customized machines
- Achieve net or near-net shape allows for potential deployment of this material using commercially applicable AM machines







References:

1) L. Kaserer, et al., *Int. J. Ref. Met. & Hard Mater., DOI 10.1016/k.ijrmhm.2020.105369.*

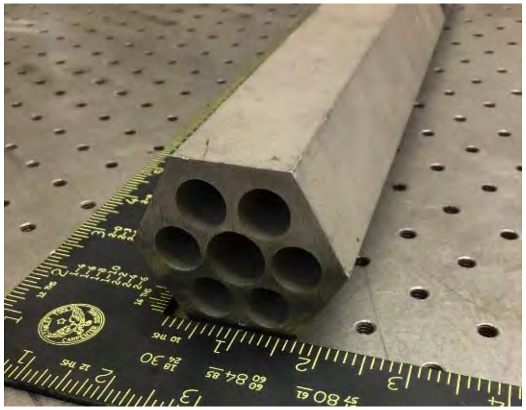
2) Brand MJ, Pacheco RM, Winter WP, Tegtmeier EL, Carpenter JS, 'Progress Towards a Titanium-Zirconium-Molybdenum Alloy Coreblock Prototype Using Powder Bed Fusion', a Level 4 milestone report for the Department of Energy-Nuclear Energy Microreactors Program, LA-UR-22-29612 (2022).

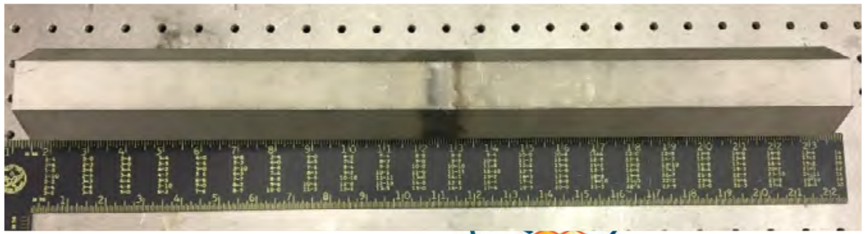
3) Y. Zhang, et al., *Mater. Sci. Eng. A, DOI: 10.1016/j.msea.2017.05.076*

Milestones and Future Work

- M4 Milestone (9/30/2022) Completed. Outcome: Report (LA-UR-22-29612) titled "Progress towards a Titanium-Zirconium-Molybdenum Alloy Coreblock Prototype Using Powder Bed Fusion"
- M3 Milestone (5/17/2023) In Progress. Goal: Fabricated an AM TZM 7 hole block prototype
- Prior to investing in larger amounts of powder, AM process will be proven out by building a shorter section of 7 hole block material.
- The next step would be to create a test object for SPHERE

Images show objects made of 316L SS





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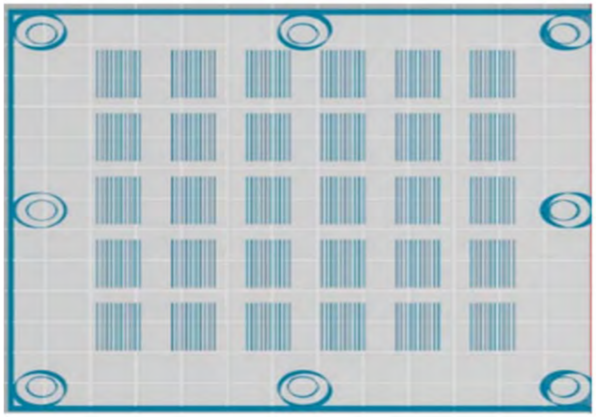
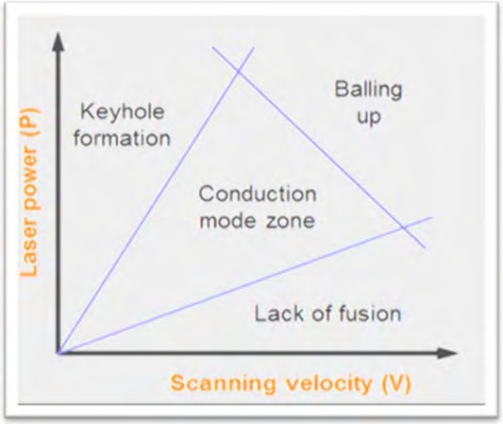
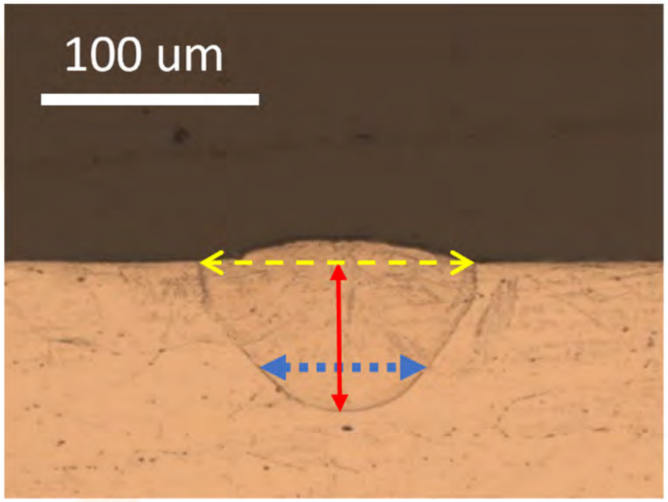
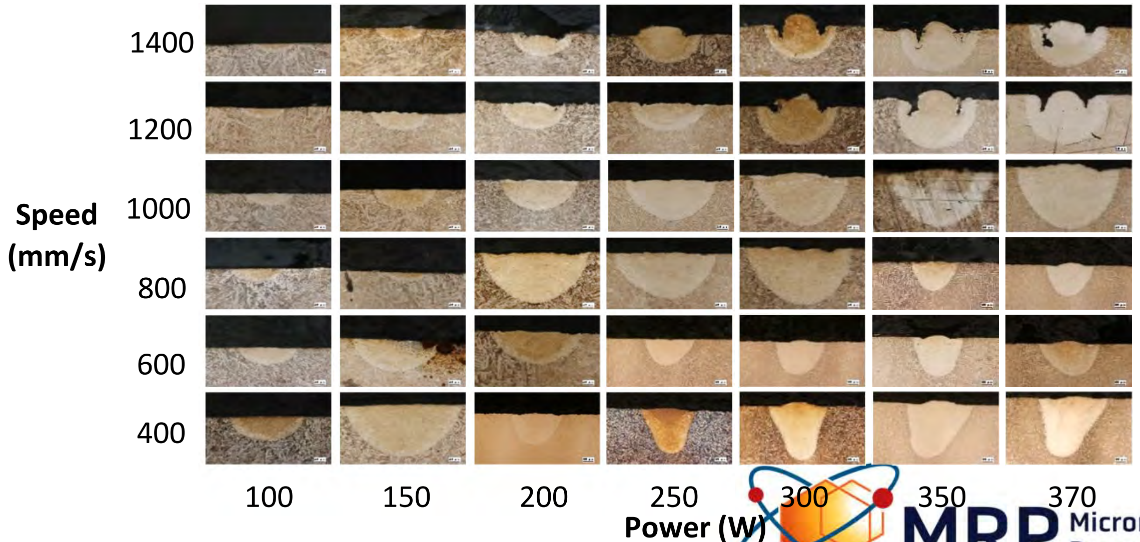
Process Parameter Development Methodology

- Reducing porosity is tied to improving the stability and predictability of the molten pools
- Example of 4340 steel in conjunction with Worcester Polytechnic Institute









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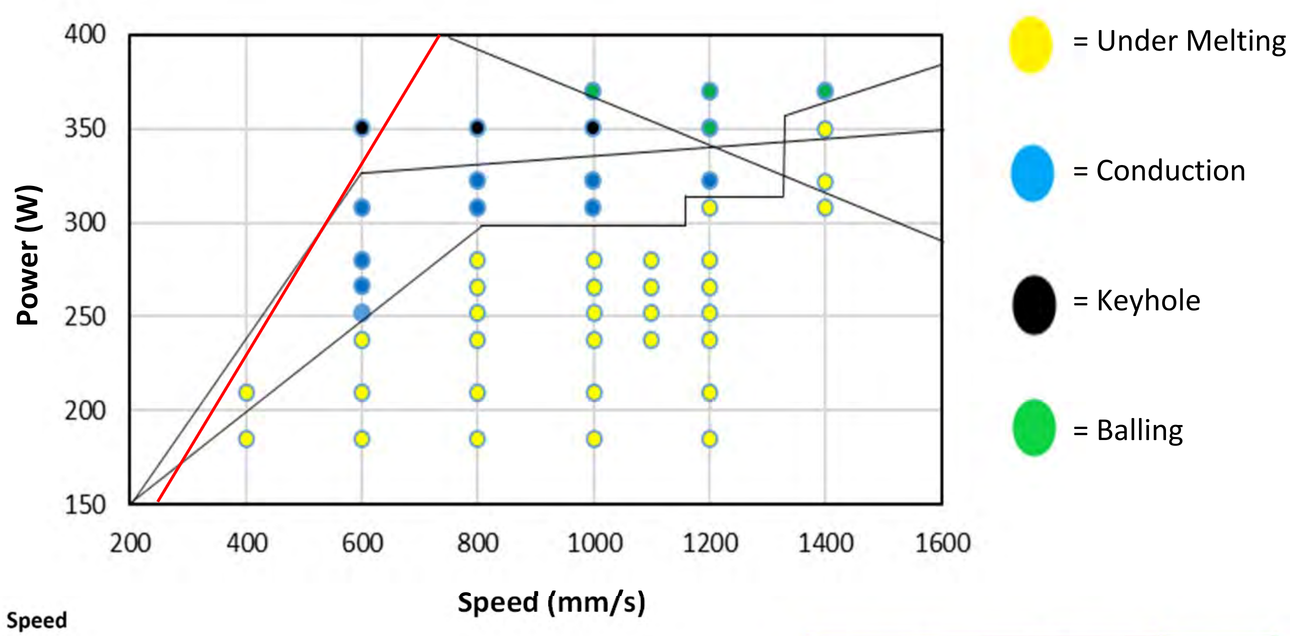
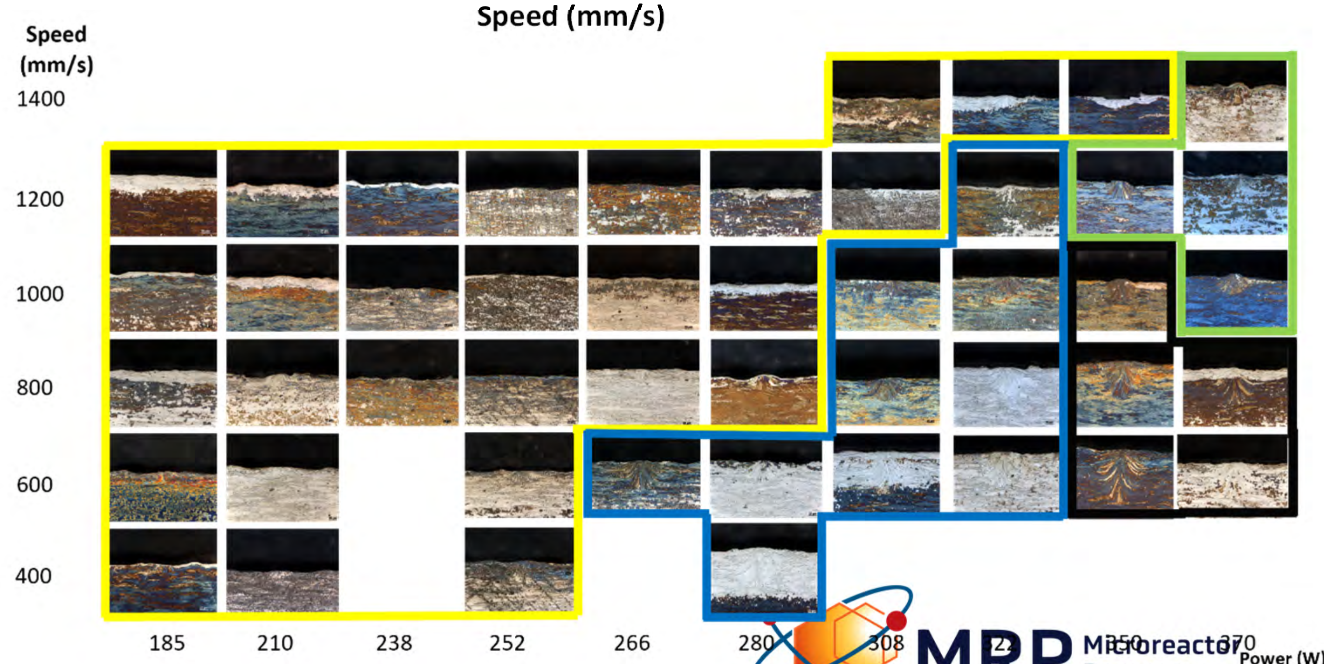
Application to Titanium – Zirconium – Molybdenum (TZM)

- First results on an industrially scalable system
- TZM has a much higher melting point (2623°C) than 4340 steel (1427°C)
- Wider band of conduction mode welding than initially expected (bigger images on following slide)
- Conclusion: Porosity should be controllable





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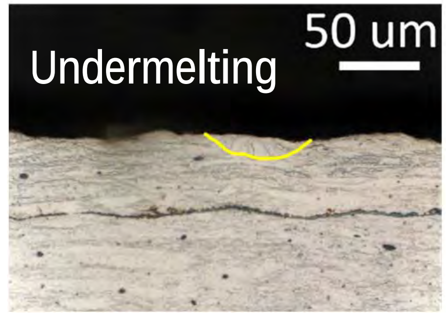
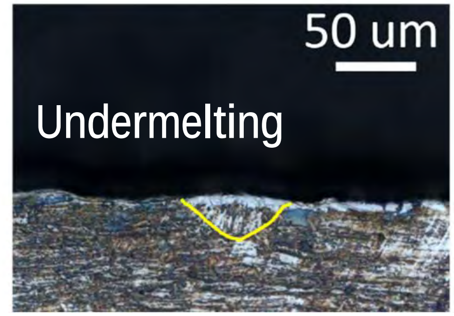
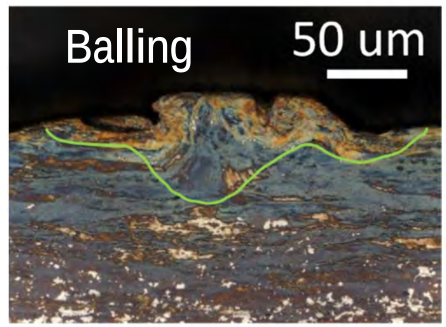
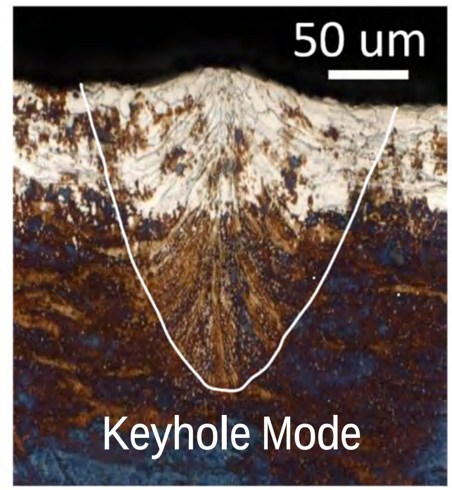
Results of TZM Process Development

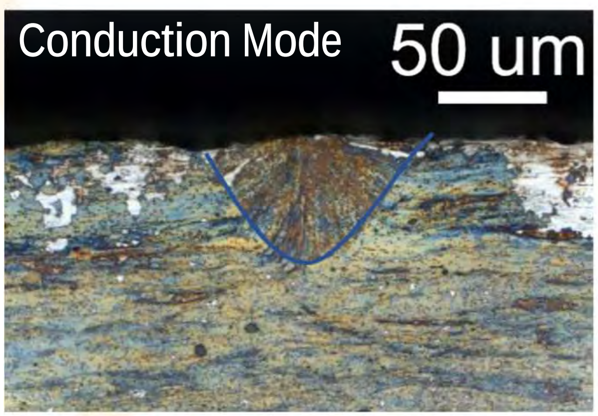
- Non-stable, ineffective molten pools shown to the right; predictable, effective molten pools shown below
- Significant change in microstructure noted
- In welding studies, this change in microstructure lead to severe cracking

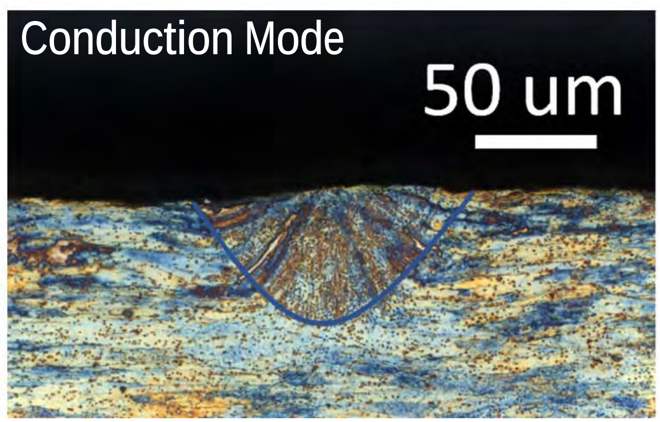












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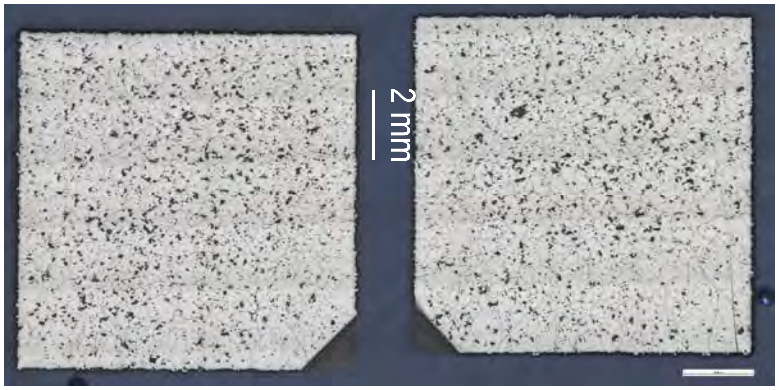
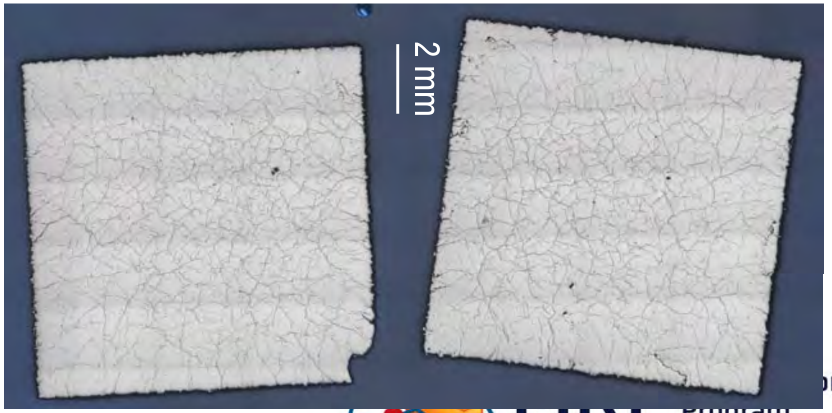
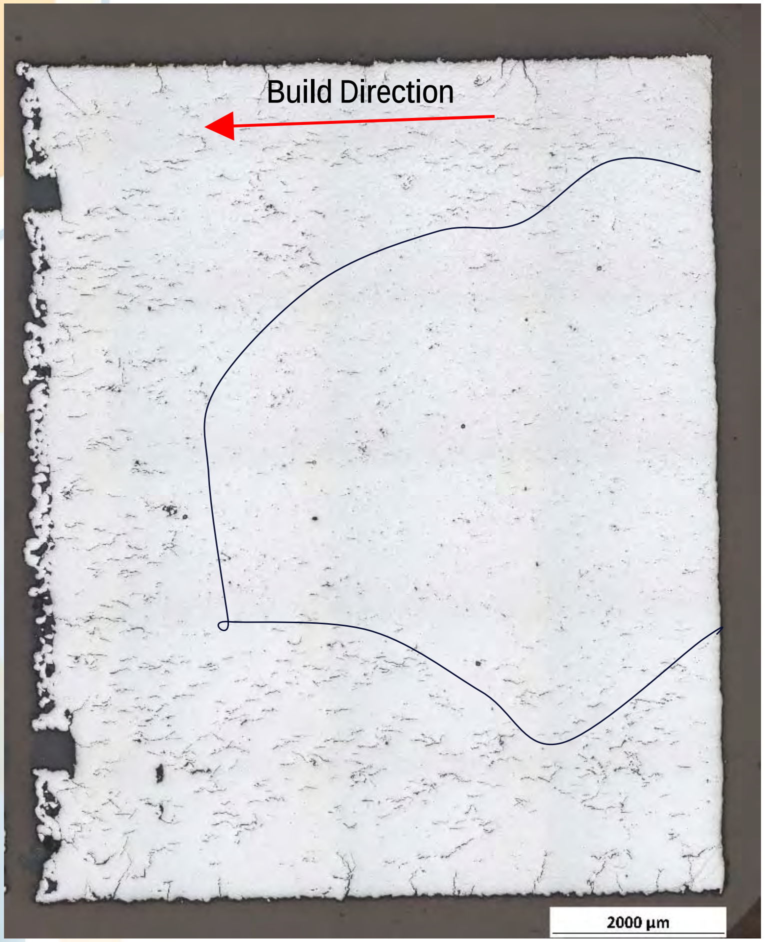
Stepping Towards 3-Dimensional Builds

- Range of parameters used includes hatch spacing
- Optimal parameters identified for reducing porosity (bottom image)





Reducing Cracking by Controlling Thermal History



- Note that challenges are still present in areas close to the surface of the build
- Further development can point towards ‘over-building’ and machining back to test out material properties **<u>or</u>** fine-tuning of process parameters for outside edges
- Microhardness of volume with minimal cracks provides a value of 400 VHN which is slightly higher than for wrought material.

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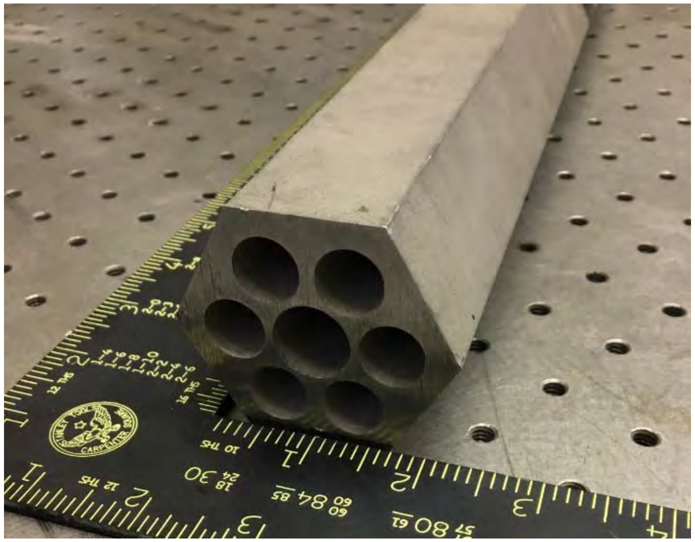
Next Steps

- Perform third build to fabricate tensile specimens
- Perform mechanical testing
- Fabricate seven hole prototype



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