Development and Fabrication of AM TZM

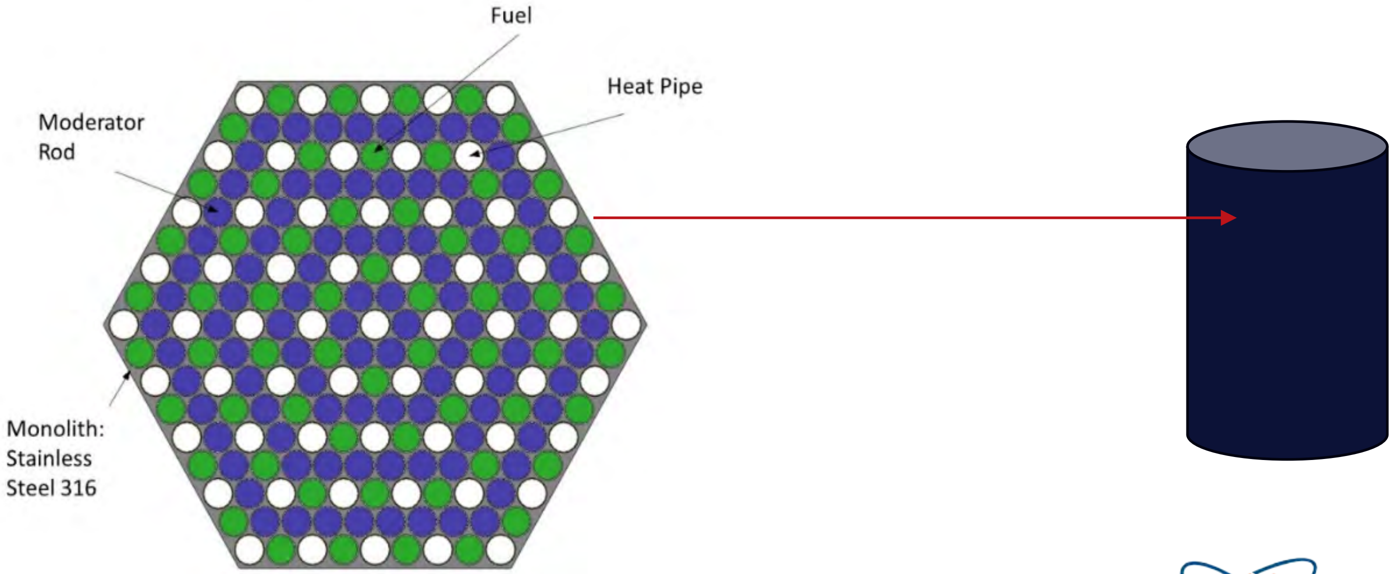
Michael Brand, John Carpenter, Robin Montoya, Omar Mireles, Peter Beck Nick Barta and Rose Bloom

March 6th, 2024

INL Idaho National Laboratory
Oak Ridge National Laboratory
MRP Microreactor Program
Los Alamos National Laboratory
Argonne National Laboratory

Structural Material is used for a variety of purposes in a microreactor

- For a small system, material is needed to contain fuel, heat pipes, and/or moderator material (see grey below) or for containment of the system itself.
- Traditional materials have been proposed in the past (i.e. stainless steel), but new materials such as refractory metals offer potential for expanded operations with higher temperatures.
- Molybdenum alloys are one example.



MRP Microreactor Program

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

MRP Microreactor Program

Why Titanium – Zirconium – Molybdenum?

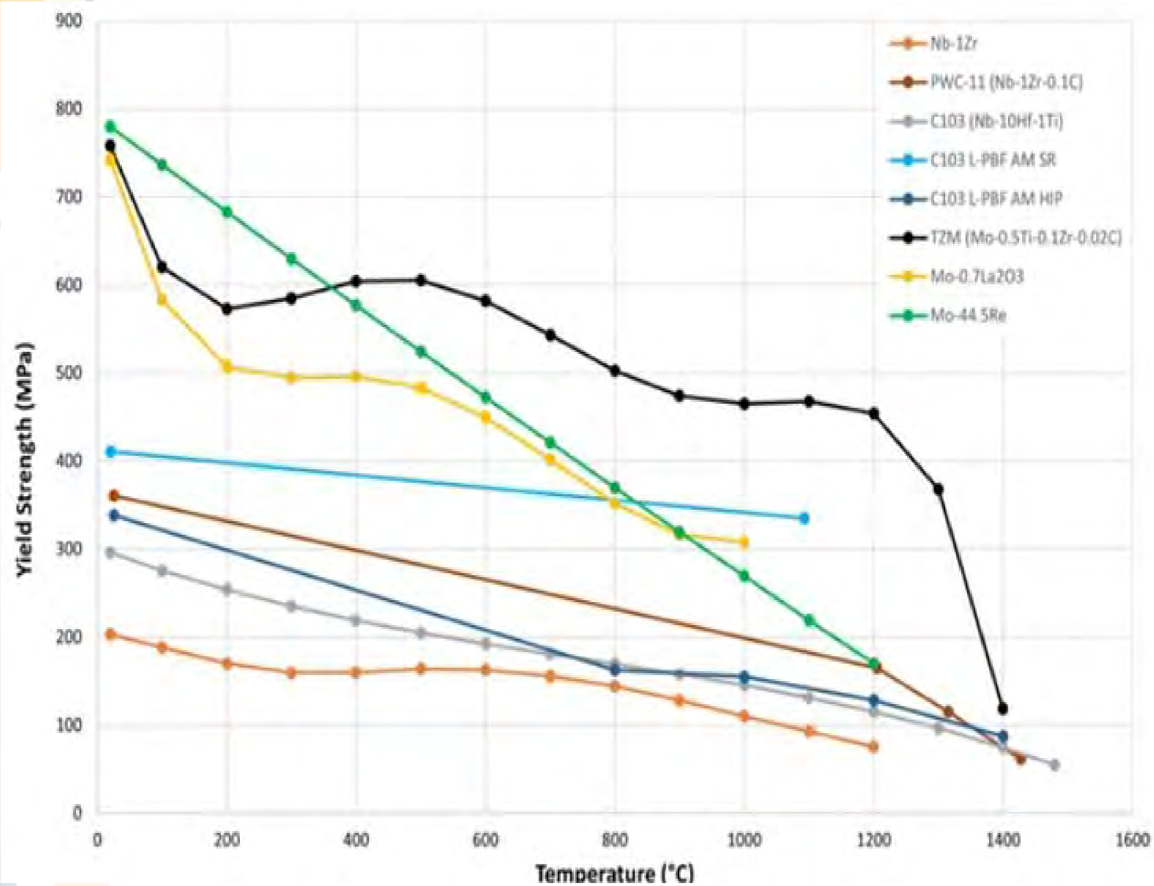
- Short Term (FY22-24) – Develop the manufacturing, generalized mechanical behavior, and timeline for maturation for AM TZM (TRL <=3)
    - Zirconium alloys are the main material used in casings containing uranium oxide (UO_2) pellets- High erosion and corrosion resistance in water. Generate heat in water- accelerate the degradation of casings.

Molybdenum Alloy (AM)

- Offers high corrosion resistance and higher thermal conductivity.
- Reduce thermal constraint of fuel elements for light water and fast reactors
- Increase safety and reliability, sustainability, increase reactor life and profitability.
- Drawback-more expensive and difficult to work with

MRP Microreactor Program

R&D approach: Other Mo Alloys being used for AM purpose



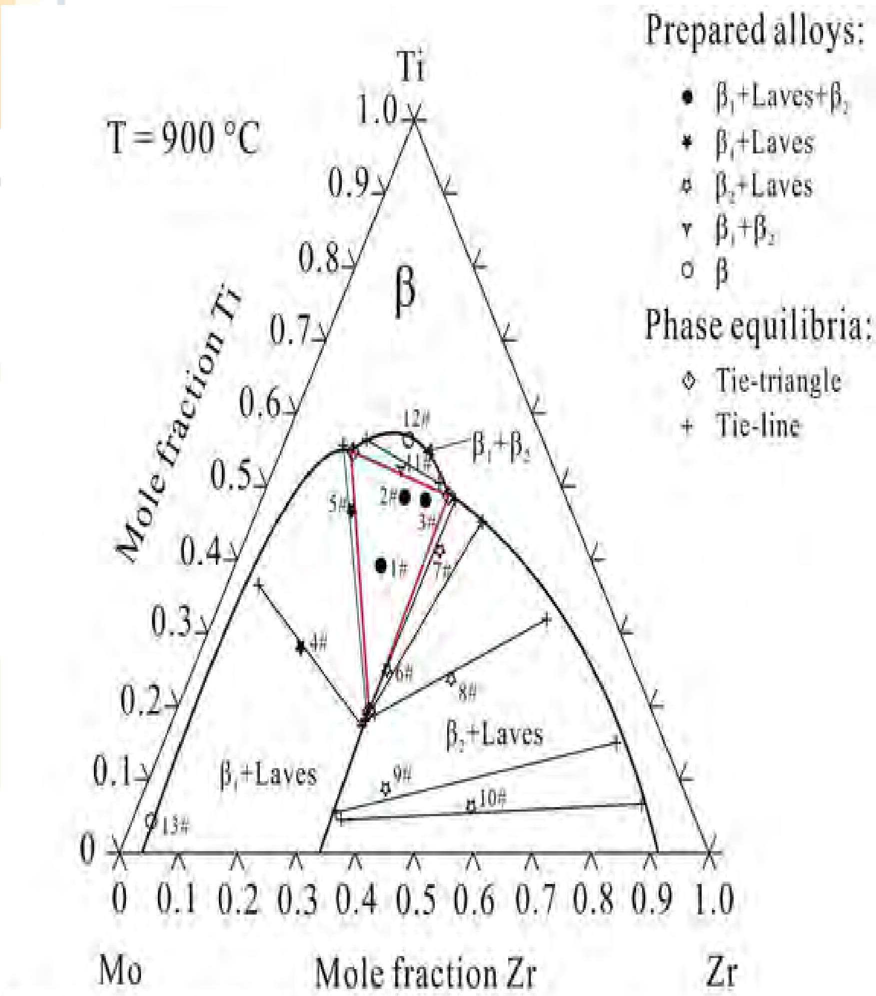
Refractory Metal Yield Strength Comparison courtesy of Omar Mireles

- Mo exhibits great physicochemical properties
  - Melting pt = 2623° C
  - Low CTE = 4.8µm/m*K @ 25°C
  - High electrical & thermal conductivity = 138W/mK
- Mo recrystallization temp = 1100°C
- Mo DBTT =
  - Melting pt = 2623° C
  - Low CTE = 4.8µm/m*K @ 25°C
  - High electrical & thermal conductivity = 138W/mK

MRP Microreactor Program

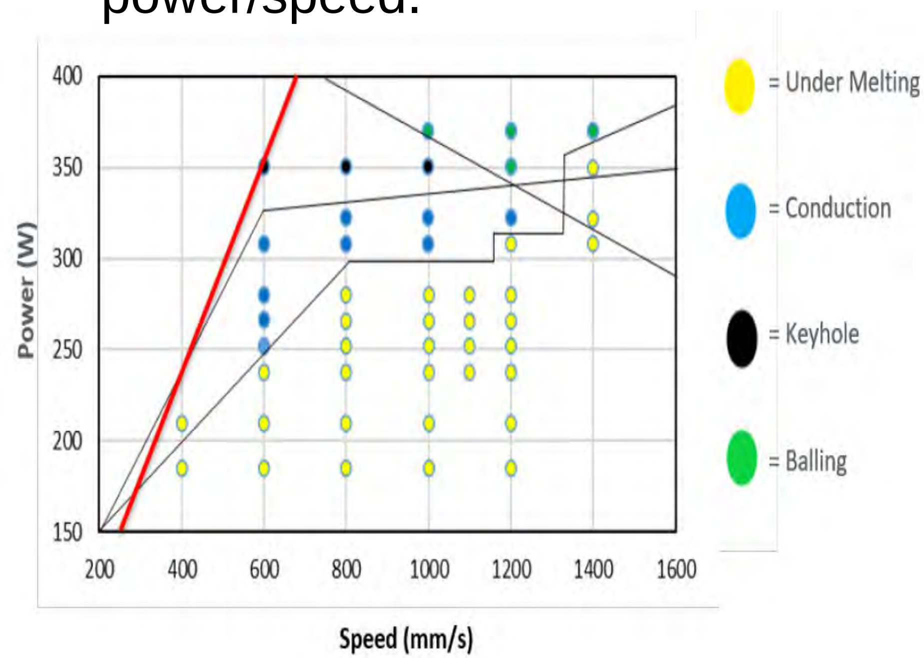
R&D approach: Understanding TZM for AM

TZM = 0.5wt% Ti + 0.08wt% Zr + 0.01-0.04wt% C



The experimental isothermal section of the Mo–Ti–Zr system at 900 °C

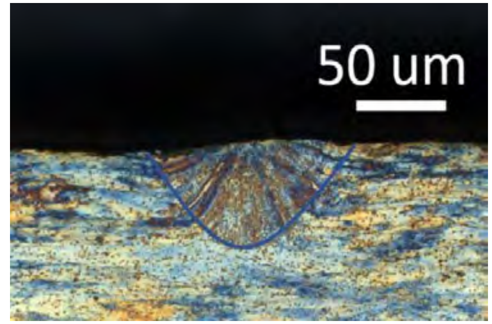
- Processing map of 47 combinations of laser power and laser speed
- Identified operating window from Kaserer et al.. The red line represents the possible favorable power/speed.

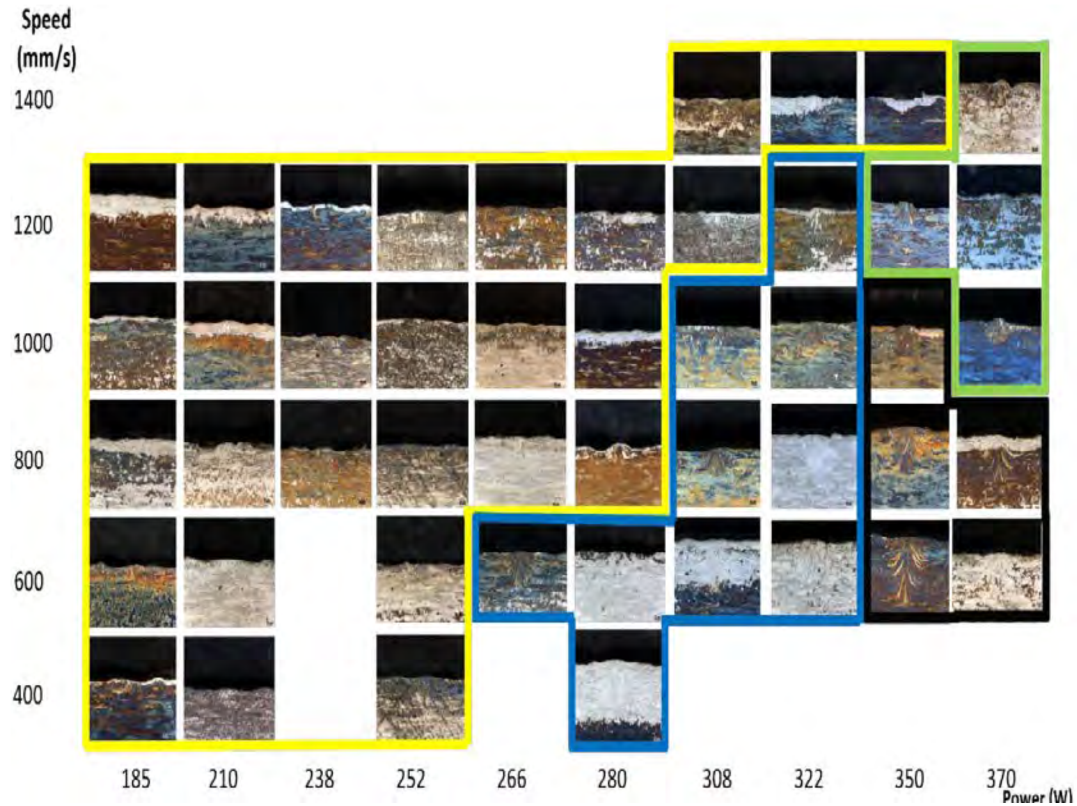


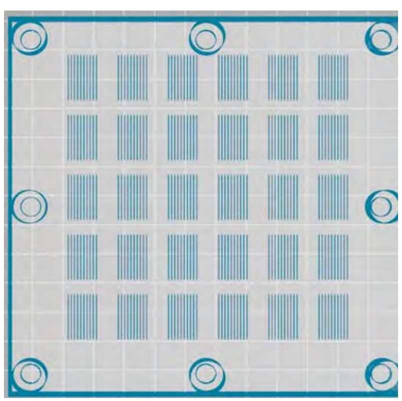
MRP Microreactor Program

Prior and Ongoing Work:

- Additive manufacturing of refractory alloys → overcomes difficulty in conventional fabrication & machining
- LANL Microreactor Program
  - Used single bead welds to elucidate relationship between scanning time and laser power
  - Demonstrated capability to AM TZM alloy





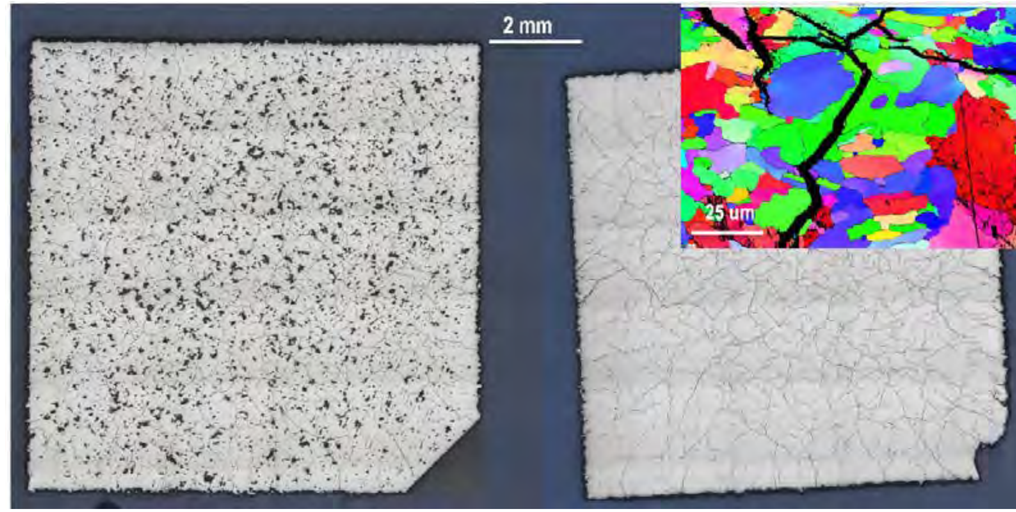


MRP Microreactor Program

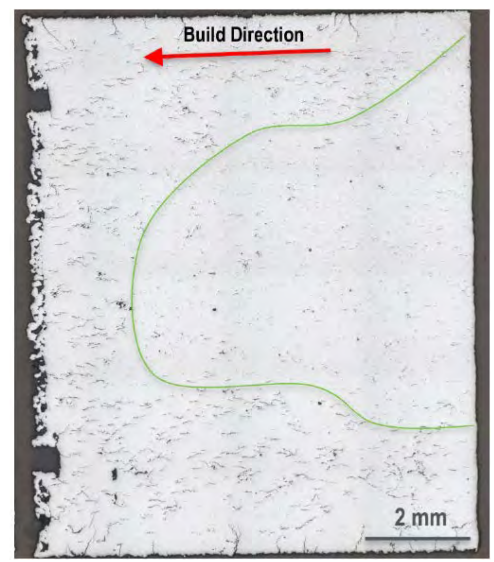
Results of a Variety of TZM parameters

Challenges:

- High solidification rate: 10^3-10^6K/s = High residual stresses
- Microcrack prone in L-PBF for refractories. Some improvement seen with:
    - o Nano-particle dispersoids usually high melting point intermetallic particles - still low TRL.



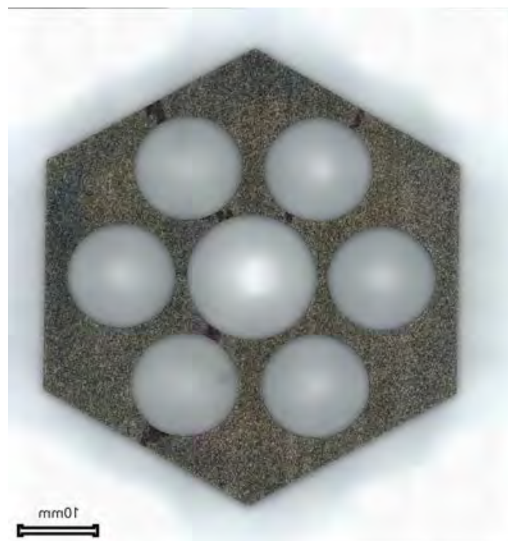
- Recent publications by Plansee of L-PBF at elevated temp (600^{o}C) and EB-PBF (ORNL) have shown demonstrated relatively micro-crack free AM but have other associated process constraints.



MRP Microreactor Program

7- Hole TZM Core Block

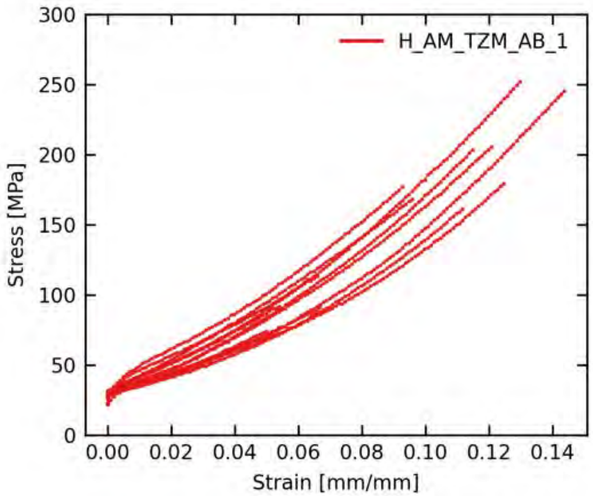
- No problems during process
- Short Build- 24hr
- Rough surface finish
- Cracking persistent throughout

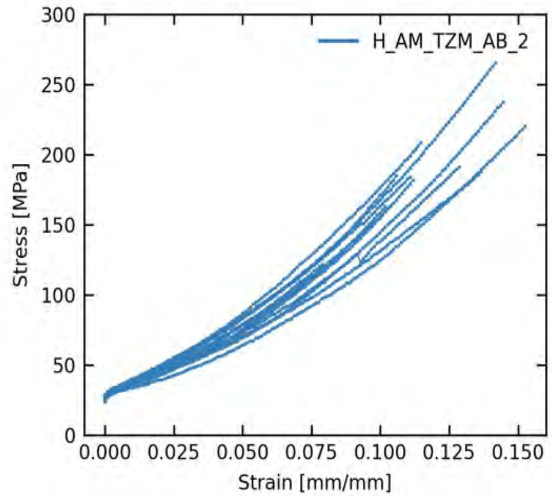


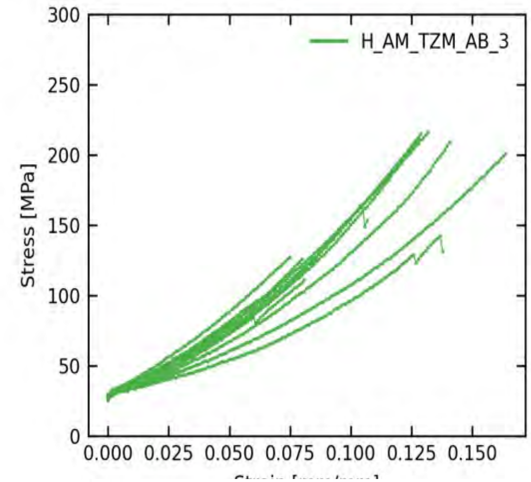
MRP Microreactor Program

TZM Tensile Data

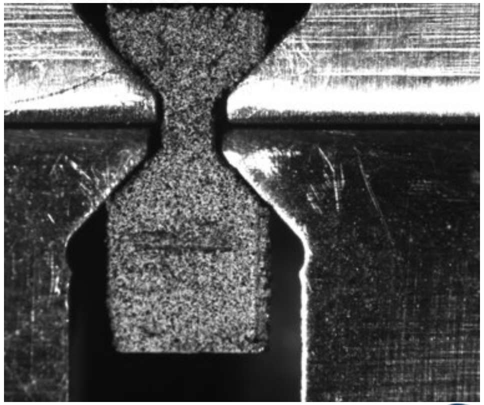
- With constant inputs (Poisson's ratio, Young's modulus), the tensile data can be used to model the strength behavior under different conditions
- Failure in gauge length. DIC images collected.
- Tested at room temperature.
- Wrought Strength is 830 MPa

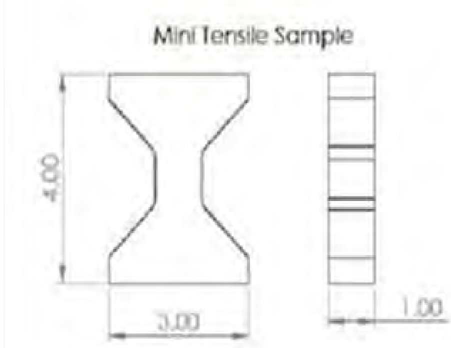






	Fracture Stress (MPa)		
Parameter Set	H_AM_TZM_AB _1	H_AM_TZM_AB _2	H_AM_TZM_AB _3
Mean	163.3	192.4	165.4
Stdev	57.2	35.9	44.2





MRP Microreactor Program

Summary and Future Proposed Work

There's now a better understanding of LPBF capabilities and limitations for TZM.

Based on the challenges and associated results, the following is suggested in order to successfully fabricate TZM, Mo, and create more accurate strength models:

- Add ZrC (400-1200nm, 80nm) and TiC (20nm, 300nm) dispersoids loading at 0.1-1mol%
  - Helps refine dentritic grains to make them respond to HIP process
- Increase C content to 2.3at%
- Need to change the material to be processable OR
- Get a machine capability that has a customizable heat chamber

  that can go higher than the DBTT but
  - Limited on build volume
    - Only seen an actual size be achievable on DED system
  - Working with Manufacturing Demonstration facility (MDF) at Oak Ridge National Lab
    - Aconity Machine capable of providing pre-heat of 800^{o}C
    - Will send materials for samples to be fabricated

MRP Microreactor Program

MRP Microreactor Program