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

Characterization and Consolidation of a High Temperature Aluminum Transition Metal Powder Alloy

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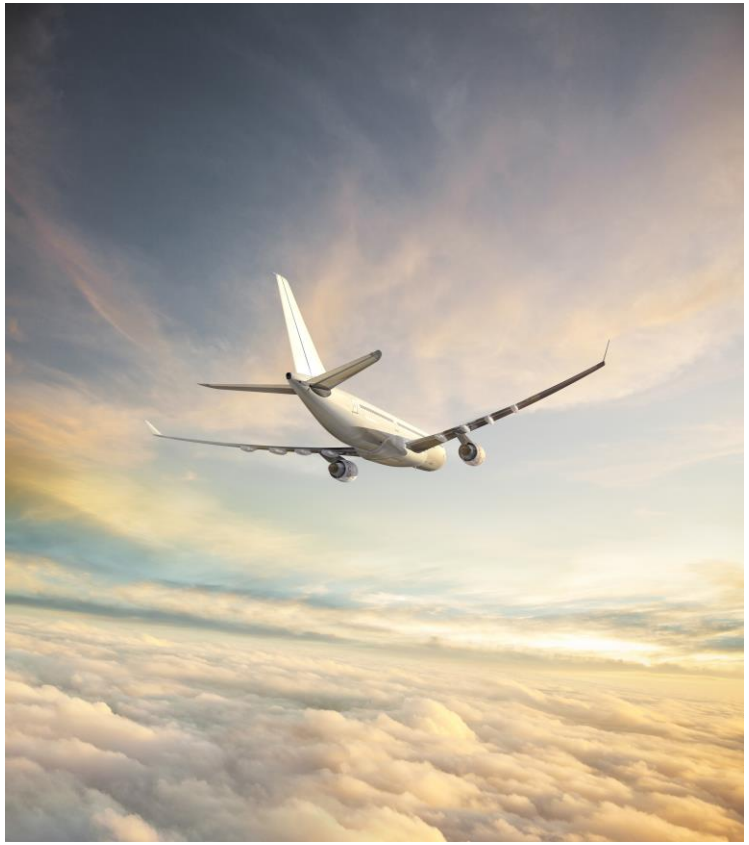
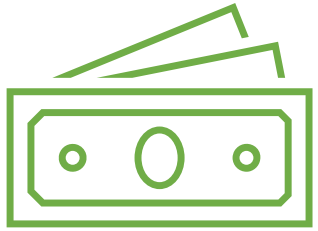
Faculty: Kester Clarke (Mines)

Industrial Mentors: Rob Mayer (Queen City Forge)

COLORADO SCHOOL OF MINES NSF IOWA STATE UNIVERSITY

High Temperature Aluminum

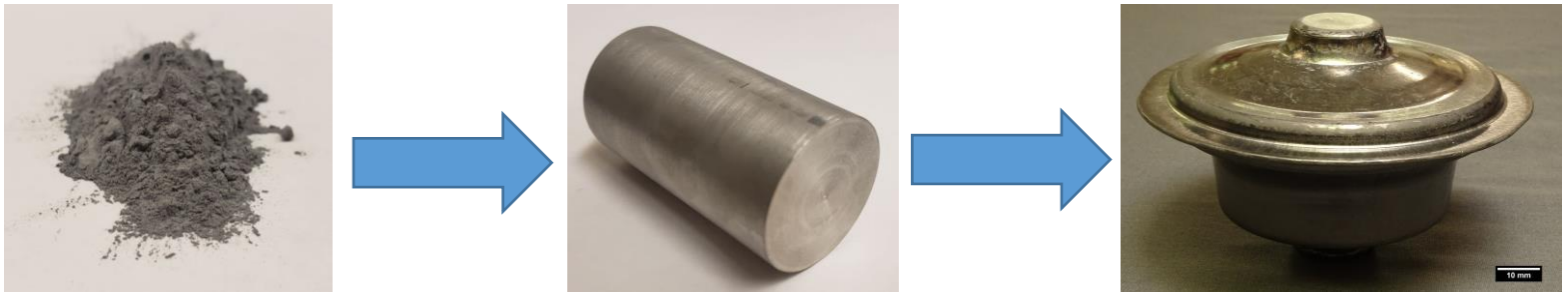




- Current alloys operate 200-300°C , 0.5-0.6 T_m
- Higher temperature alloys reduce protective fuel enrichment operation

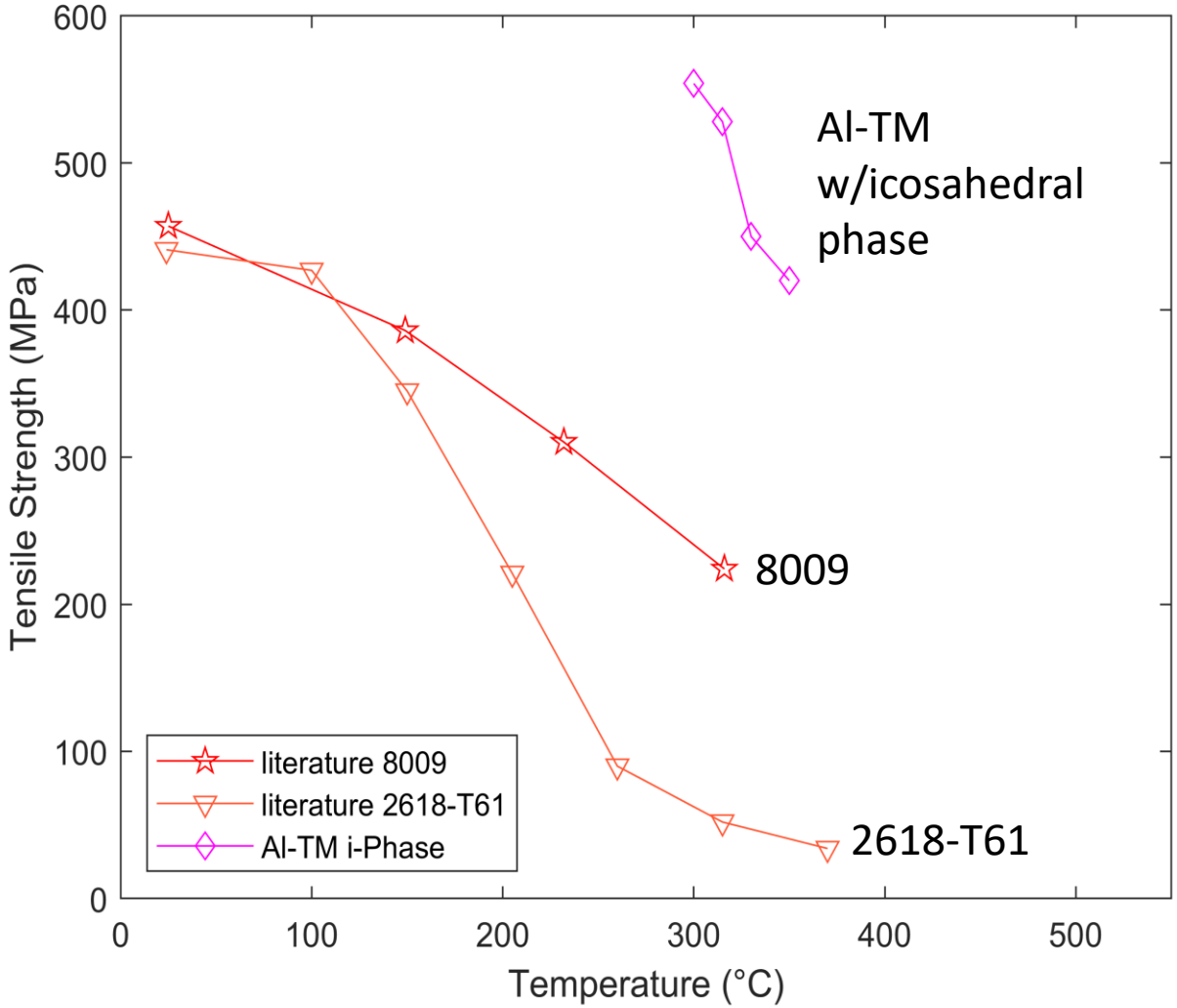
Outline

- Aluminum Transition Metal Alloys (Al-TM) Produced Through Rapid Solidification
- Powder Consolidation Pathways
- Characterization of Starting Powder
- Extrusion of Al-TM and Mechanical Properties
- Deformation Behavior



Al-TM Background

- Produced as a powder via melting and gas atomization
- Aluminum alloyed with Fe, Cr and Ti
  - Other alloys are Al-Fe-Cr-X
  - X; Ti, Nb, Ta, V [1]
- High temperature thermal stability
- Ductility
  - 15% elongation via ShAPE processing [2]
  - 4-9% elongation via extrusion [3]



Powder Consolidation

Al, Mg, Cu Alloys

Press and Sinter

Steel Alloys

Powder Forging and Hot Pressing

Titanium, etc

Hot Isostatic Pressing

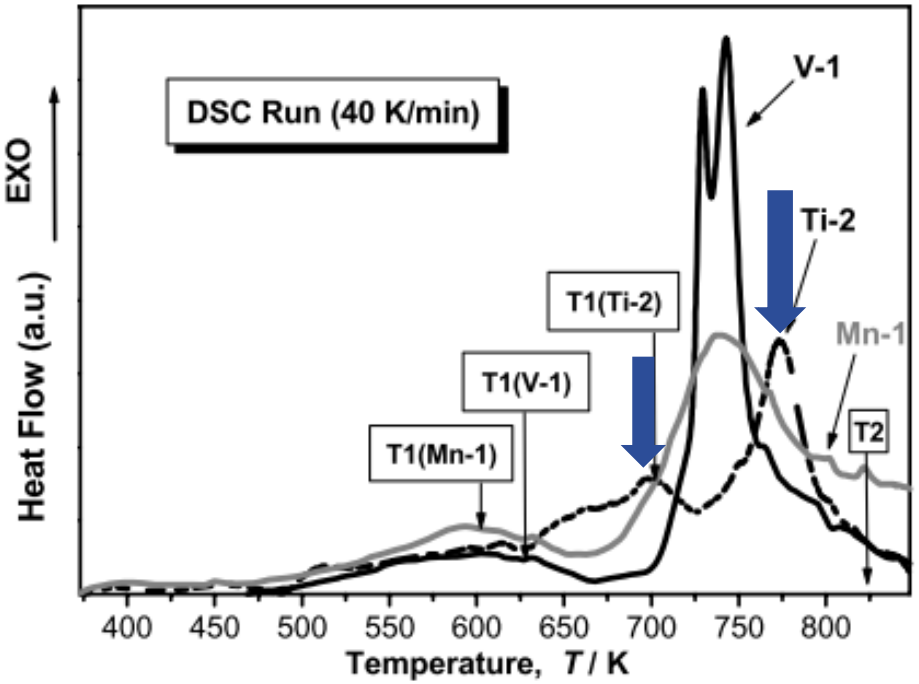
Higher Strength and Atmospheric Sensitivity

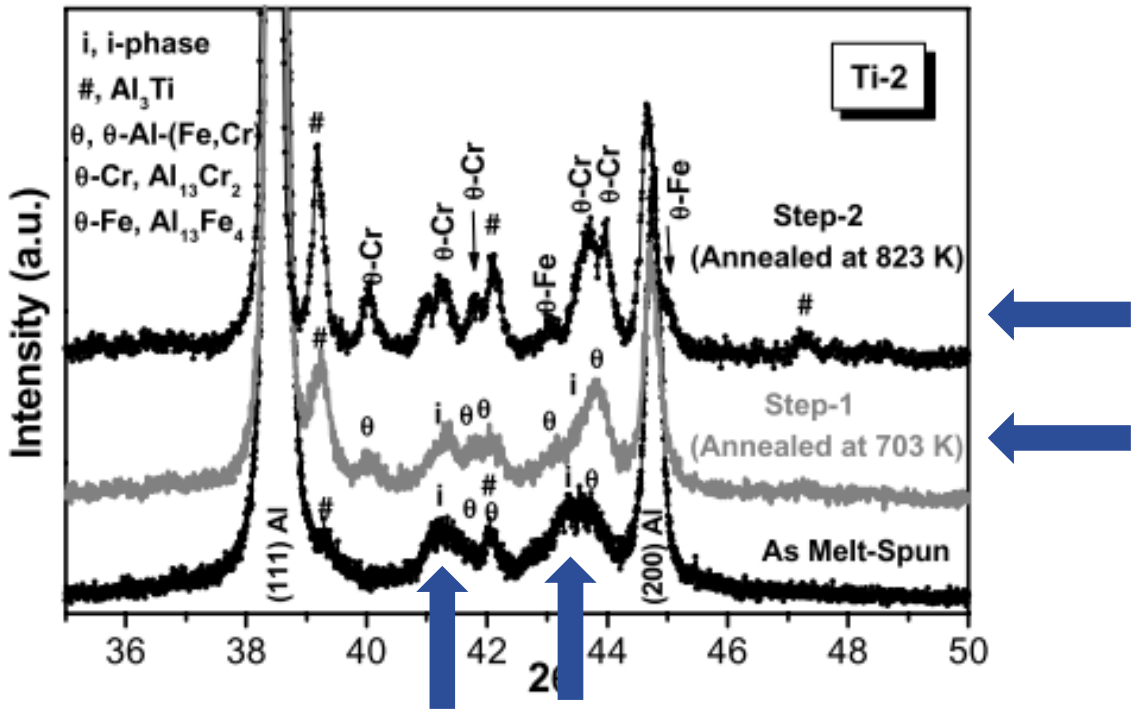
Adapted from [4-6]

Al-TM Phase Evolution

Strengthening Precipitates

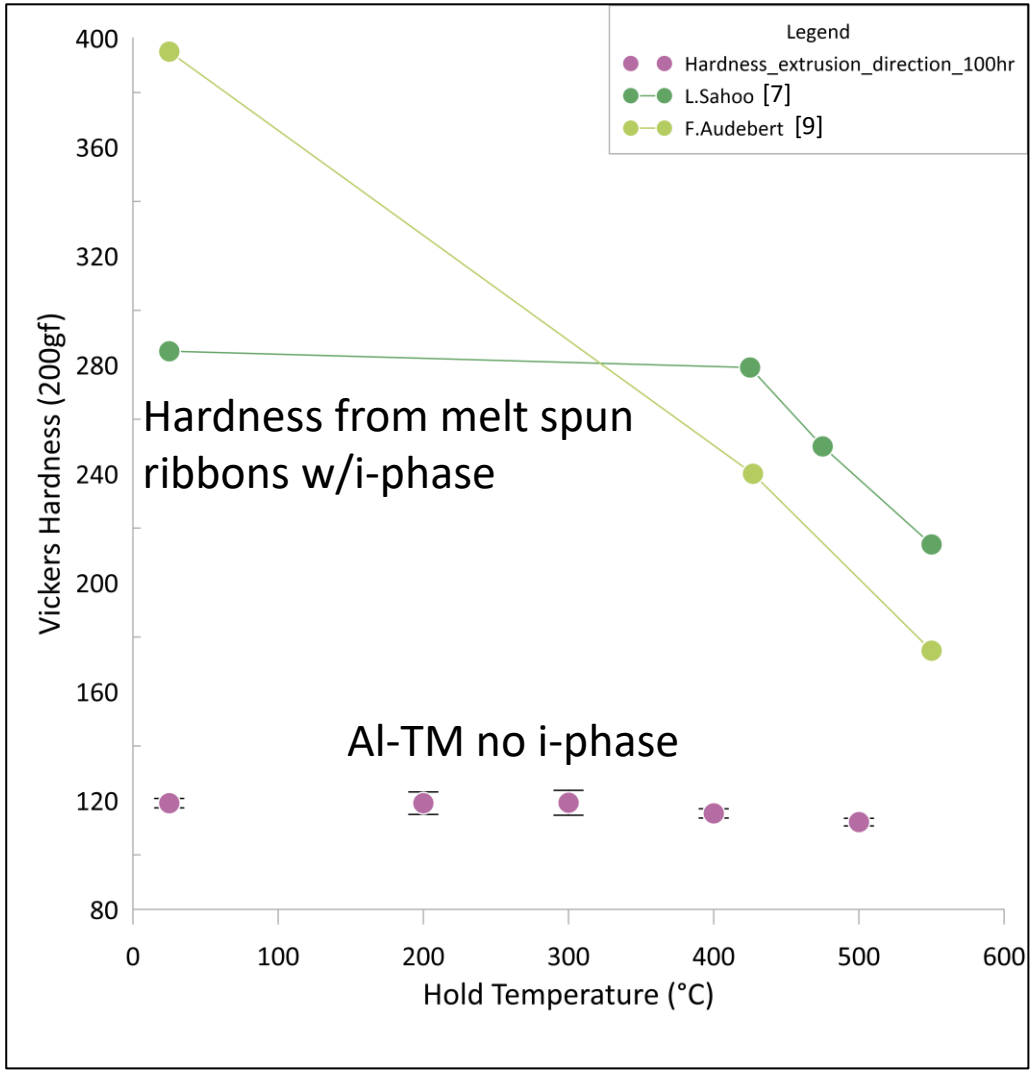
- Icosahedral Phase, a quasi-crystalline particles 50-80 nm [7]
- Coarsening at ~427°C (800°F) and transformation at ~500°C (932°F) [7,8]





Adapted from [5]

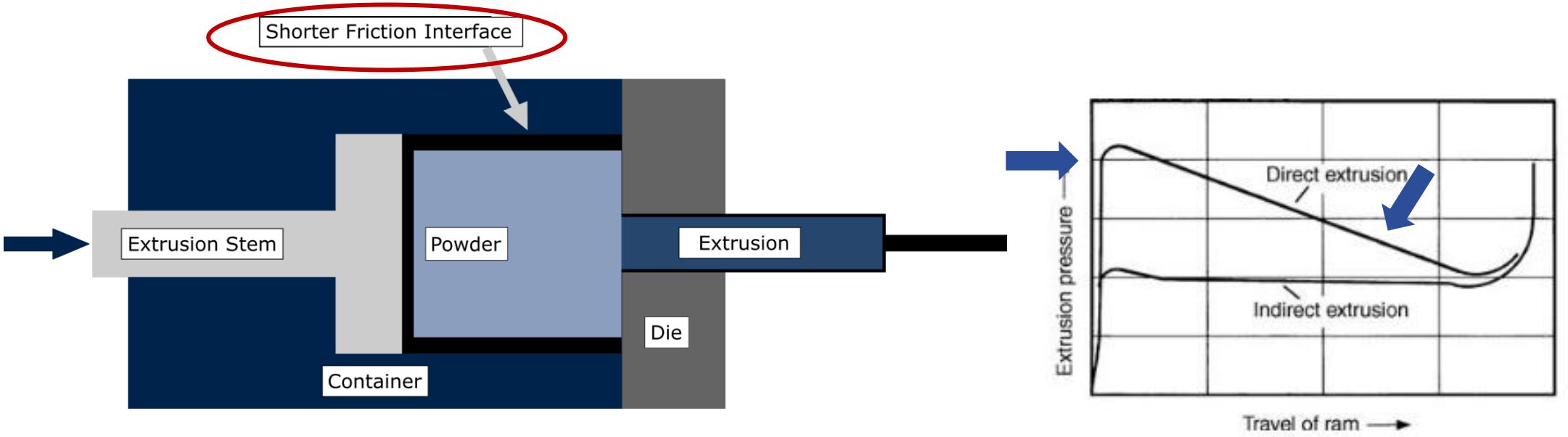
Thermal Stability



Motivation

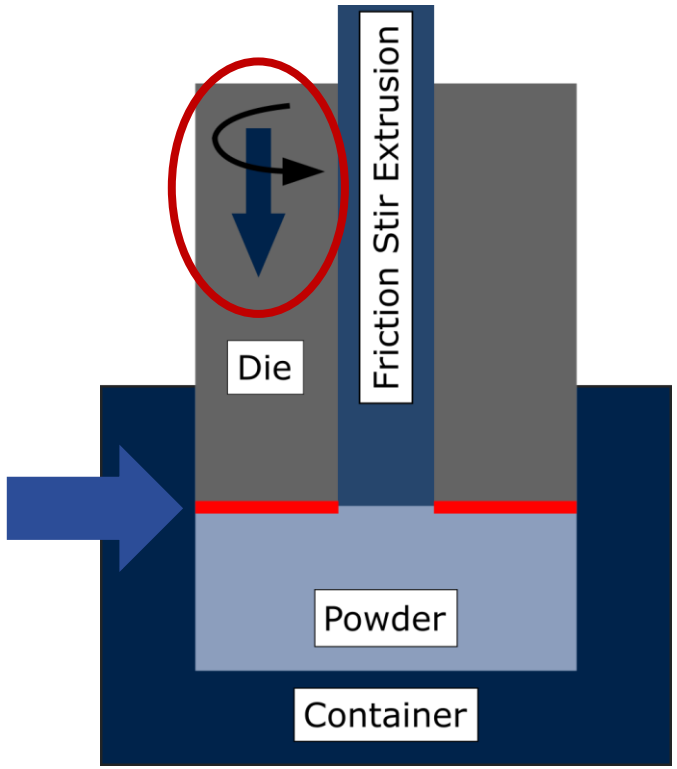
Direct Extrusion
Friction Stir Extrusion

Direct Extrusion

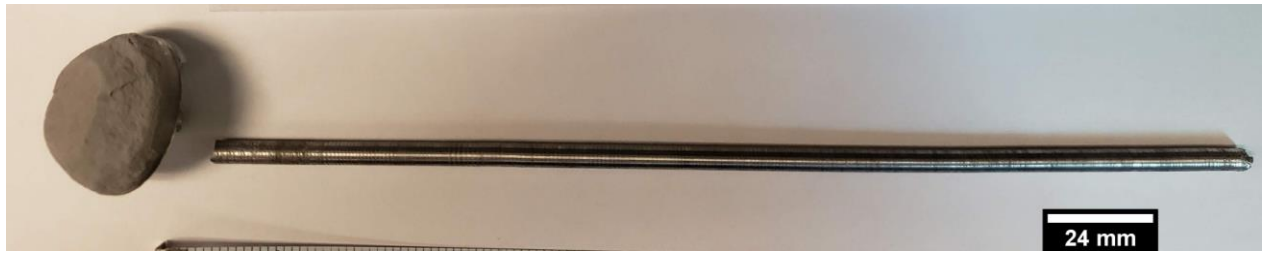


Adapted from [10]

Friction Stir Extrusion (FSE)



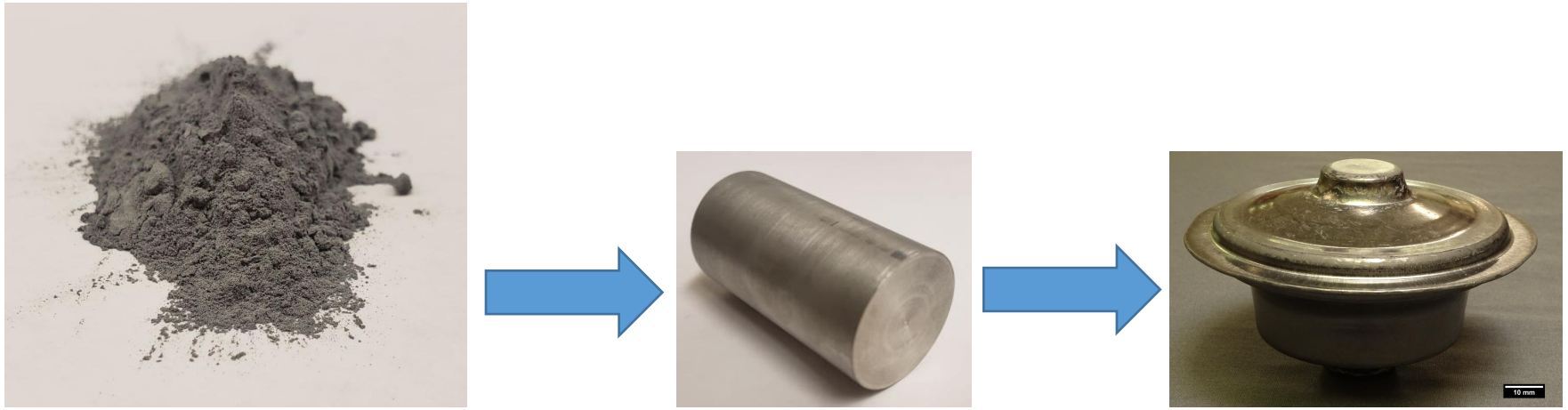
- Effective consolidation of fine powder size
- Consolidation of larger powder size demonstrates dependance on shear deformation for consolidation
- Retention of hardness at elevated temperature



FSE graciously provided by Scott Whalen of PNNL

Outline

- Al-TM alloys produced through Rapid Solidification
- Powder Consolidation Pathways
- **Characterization of Starting Powder**
- Extrusion of Al-TM and Mechanical Properties



Two Powder Sizes of Interest

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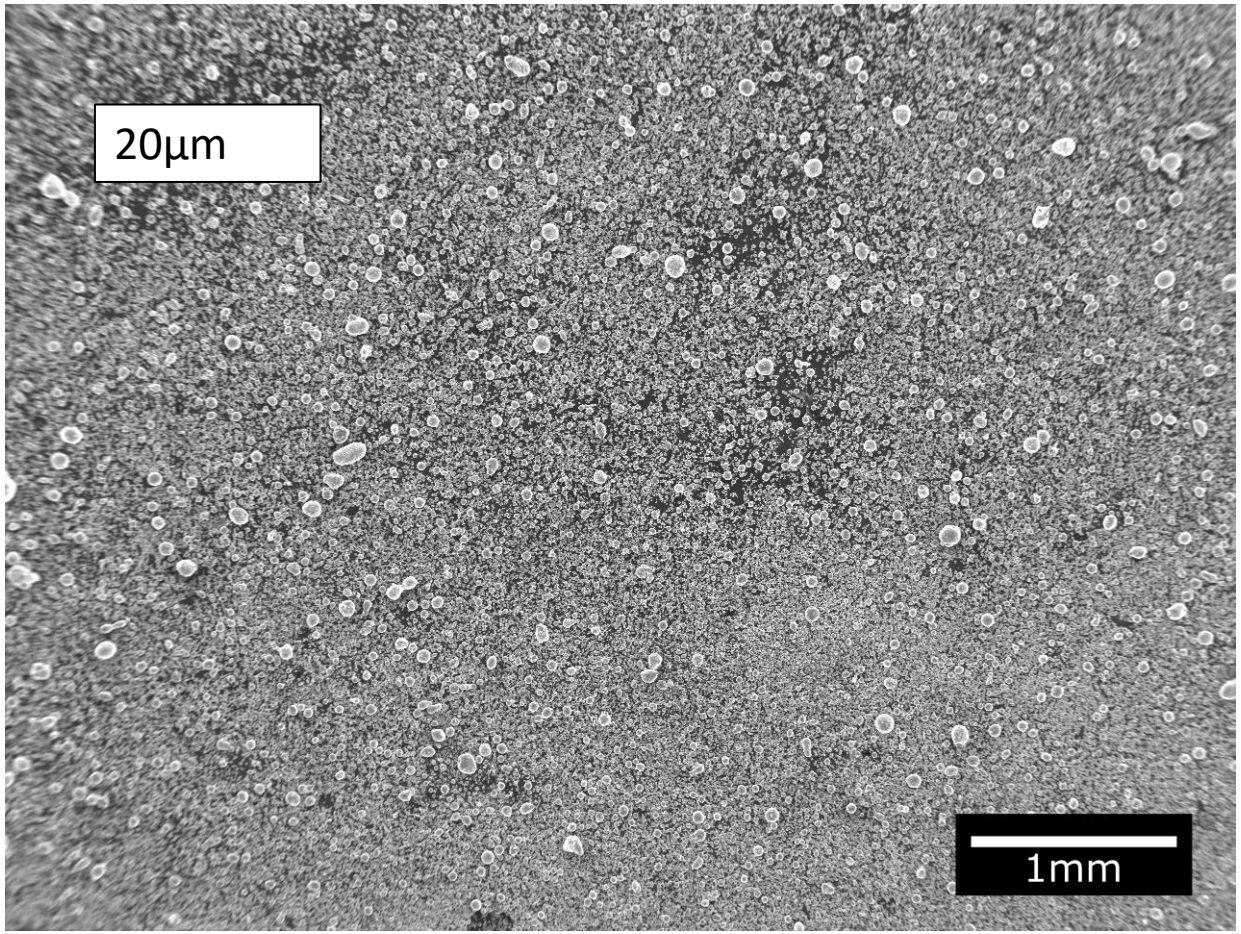

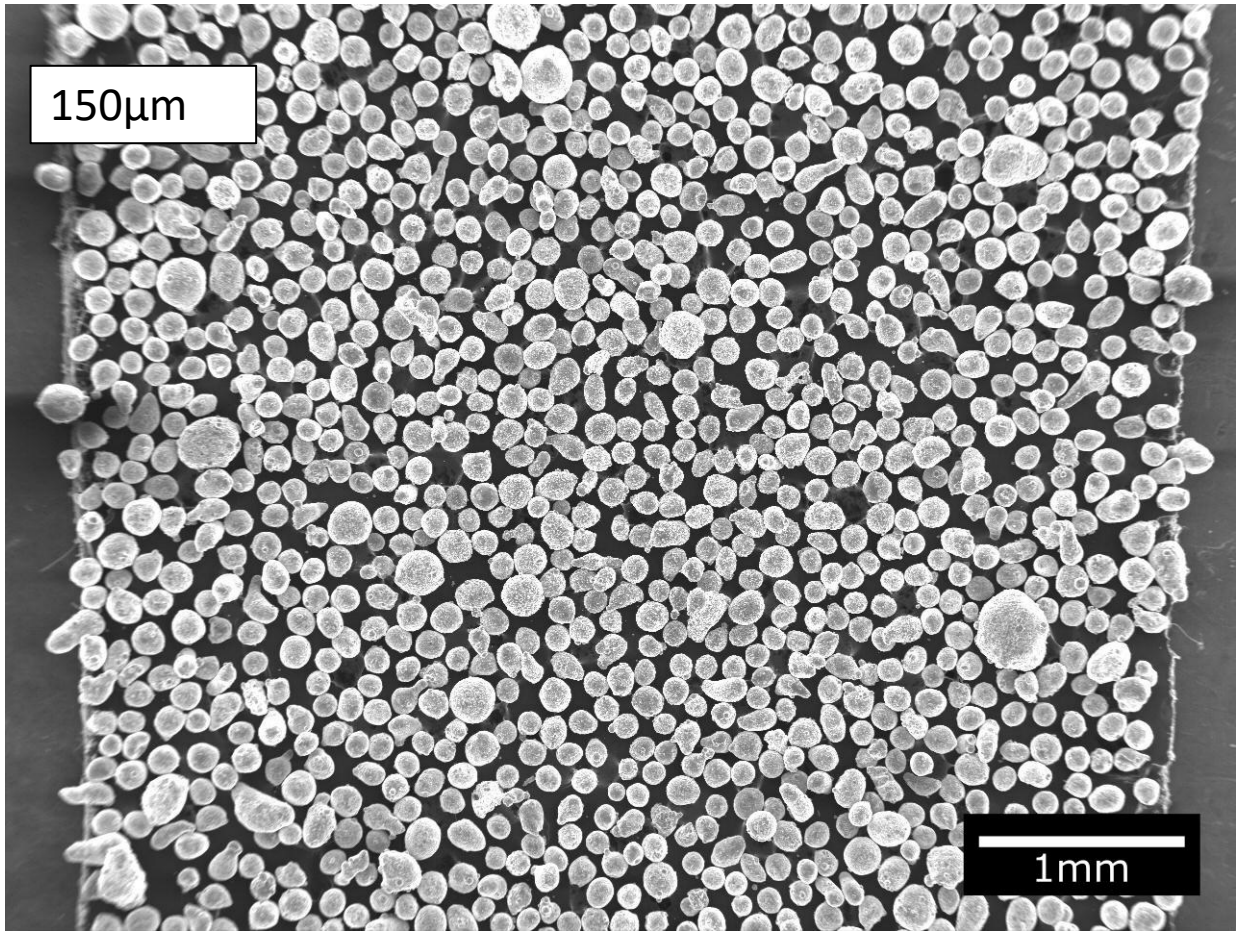

- Alloyed in the melt prior to atomization
- Spherical morphology typical of atomization

Phases Present Dictated by Powder Size

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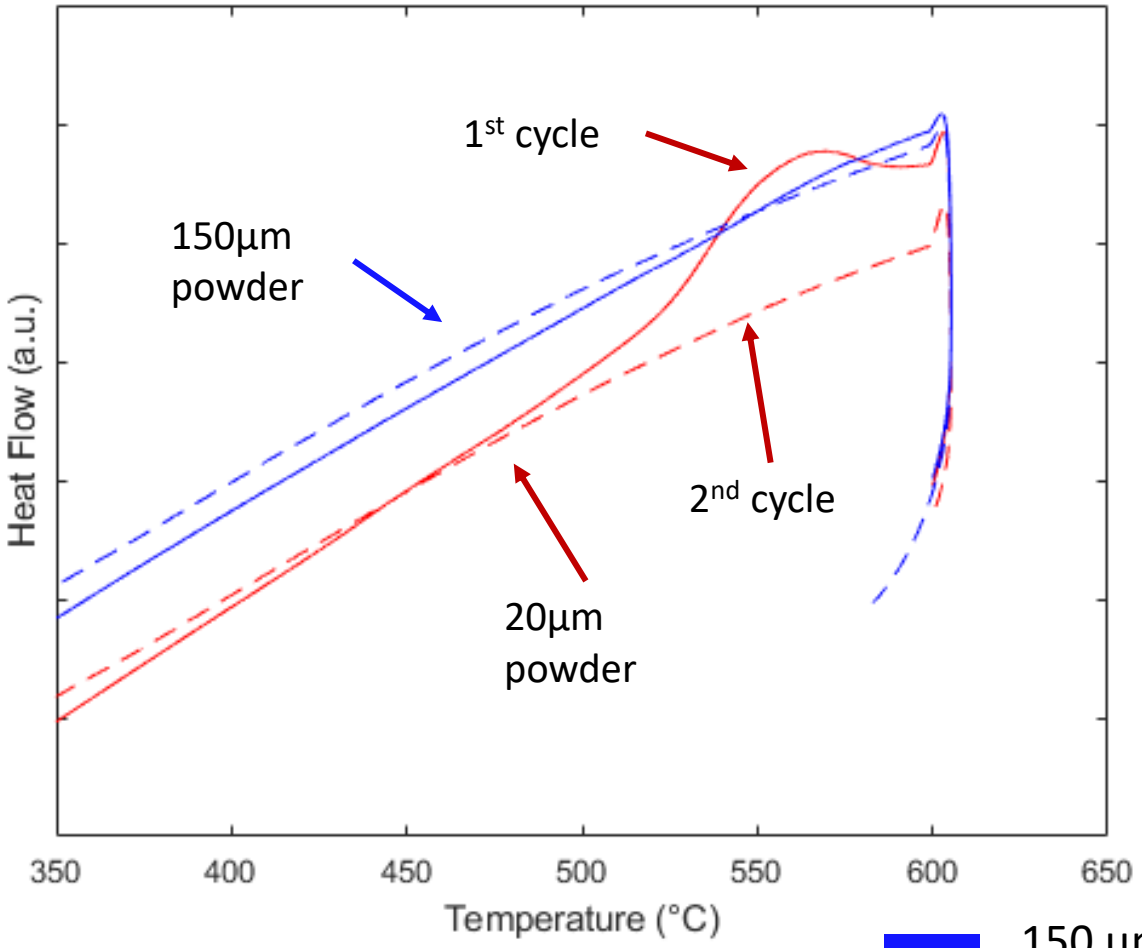
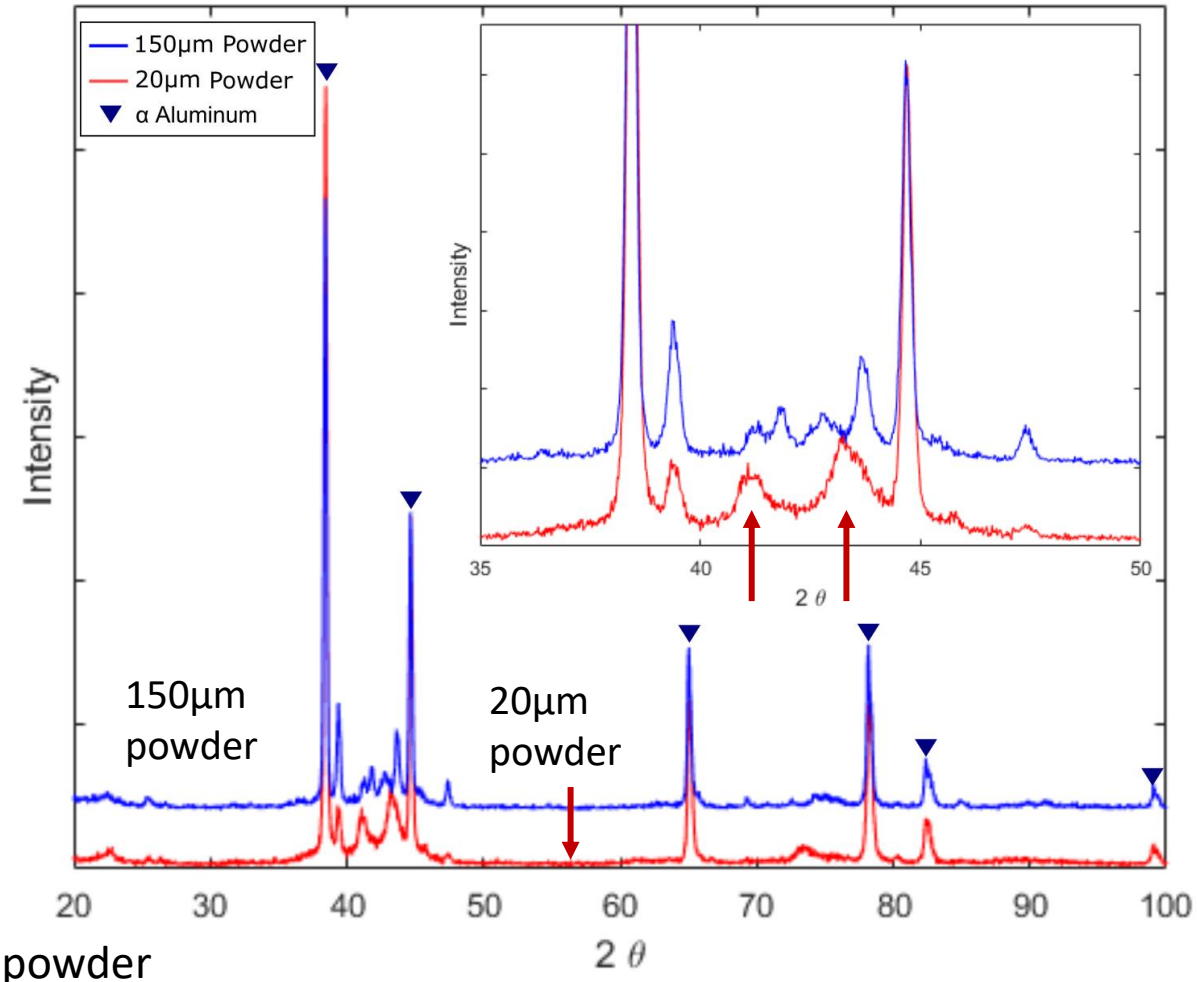
Differential Scanning Calorimetry (DSC)



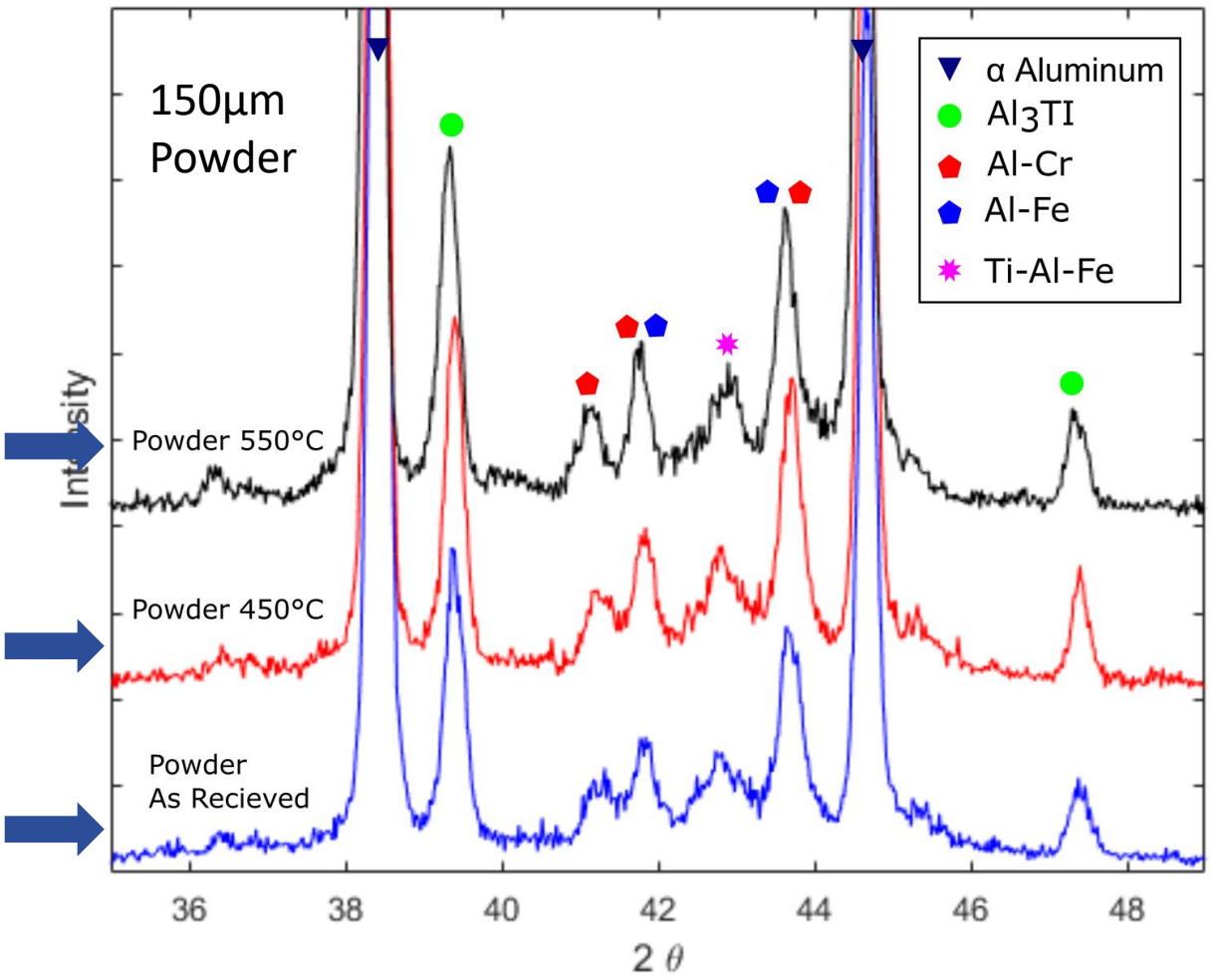
X-Ray Diffraction (XRD)



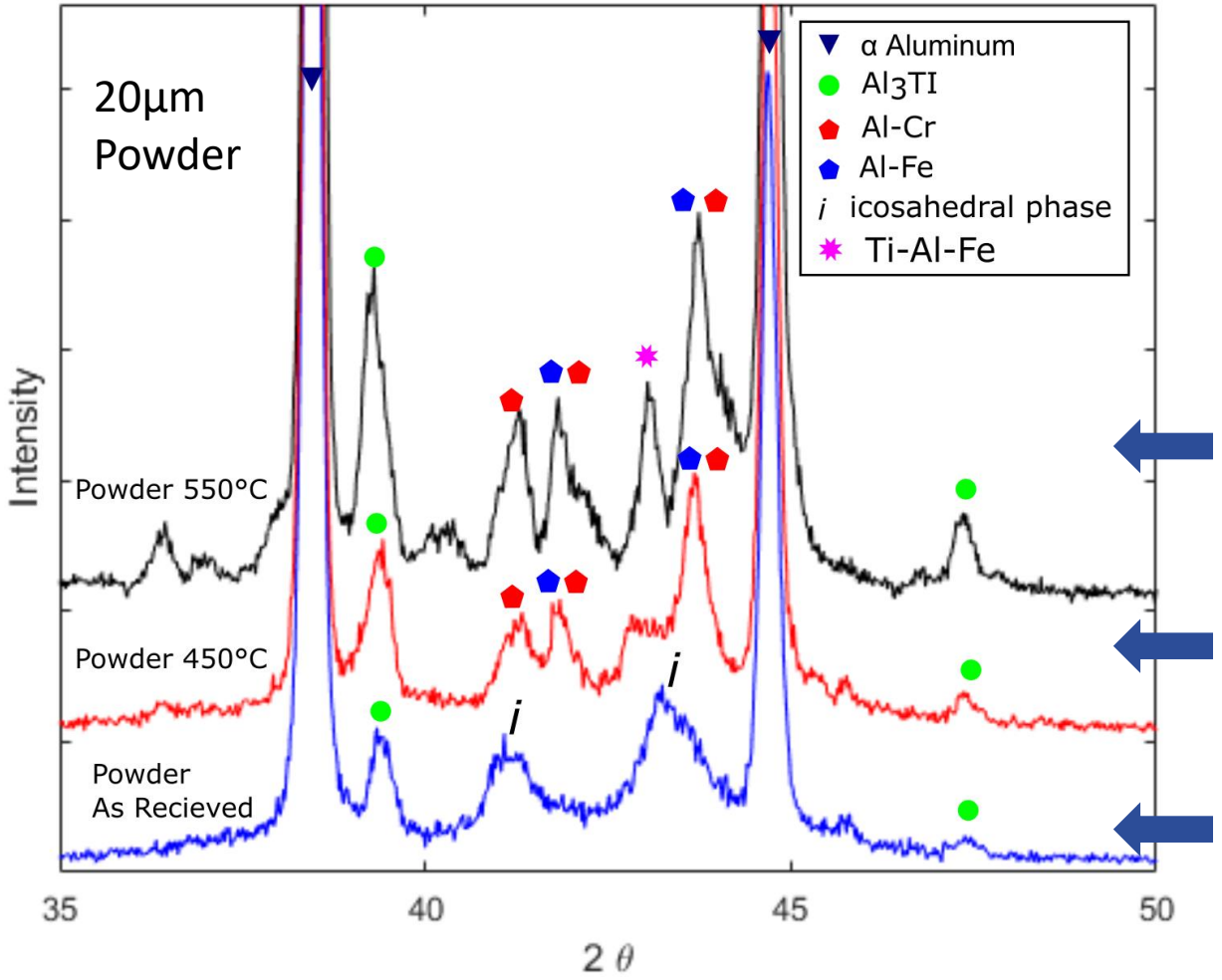
150 µm powder

20µm powder

Phase Transformation with Annealing



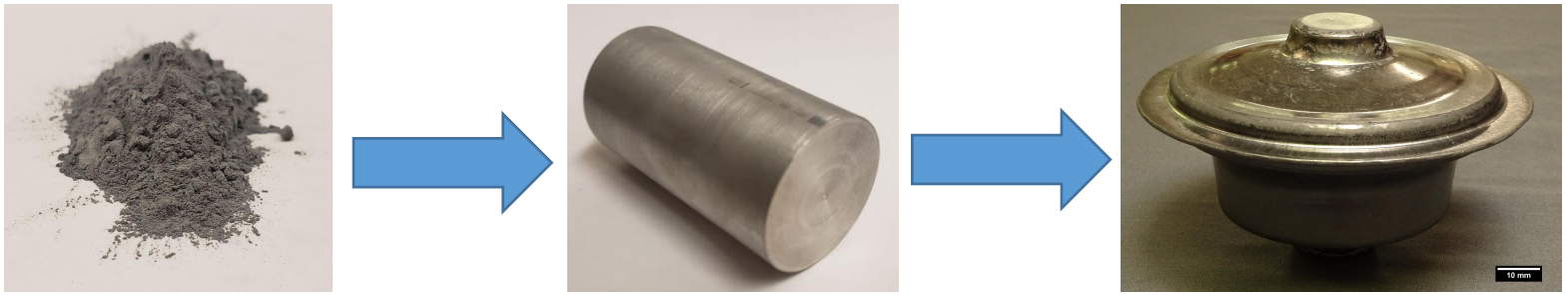
150 µm powder



20 µm powder

Outline

- Al-TM alloys produced through Rapid Solidification
- Powder Consolidation Pathways
- Characterization of Starting Powder
    - Icosahedral phase absent in 150µm
    - Transformation of the Icosahedral Phase at 450°C
- Extrusion of Al-TM and Mechanical Properties
- Deformation Behavior



Direct Extrusion Conditions

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Temperature (°C)	Extrusion Ratio	Exit Temp Contact Thermocouple	Exit Temp IR
350	10:1	360	390
400	16:1	390*	420*
425	16:1	410	440
450	16:1	410*	440*
550	25:1	Provided by Industrial Sponsor	

*Difficulties loading can into extrusion chamber, external thermocouple dropped 50C before loading

Fine Secondary Phases Present Following Extrusion

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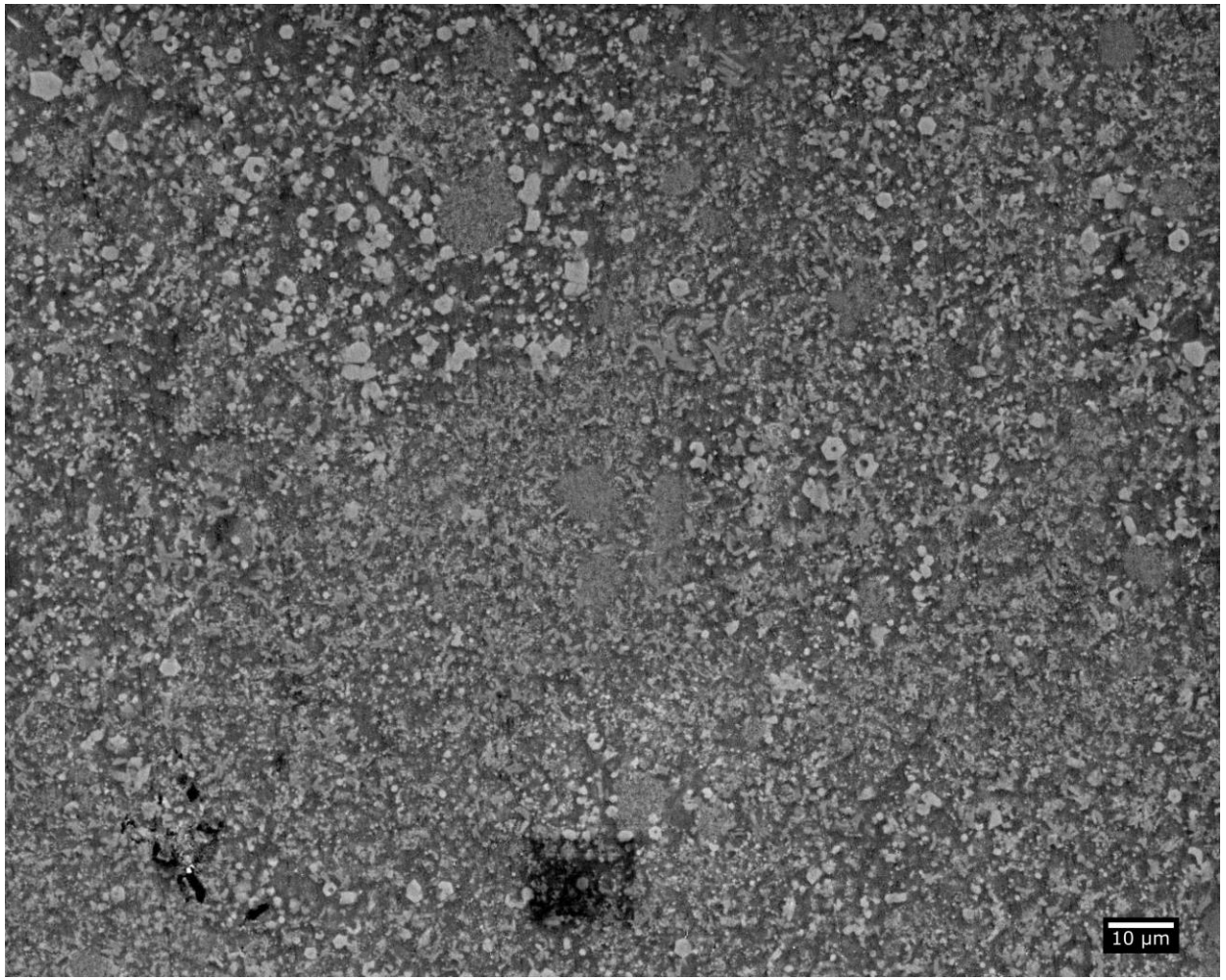
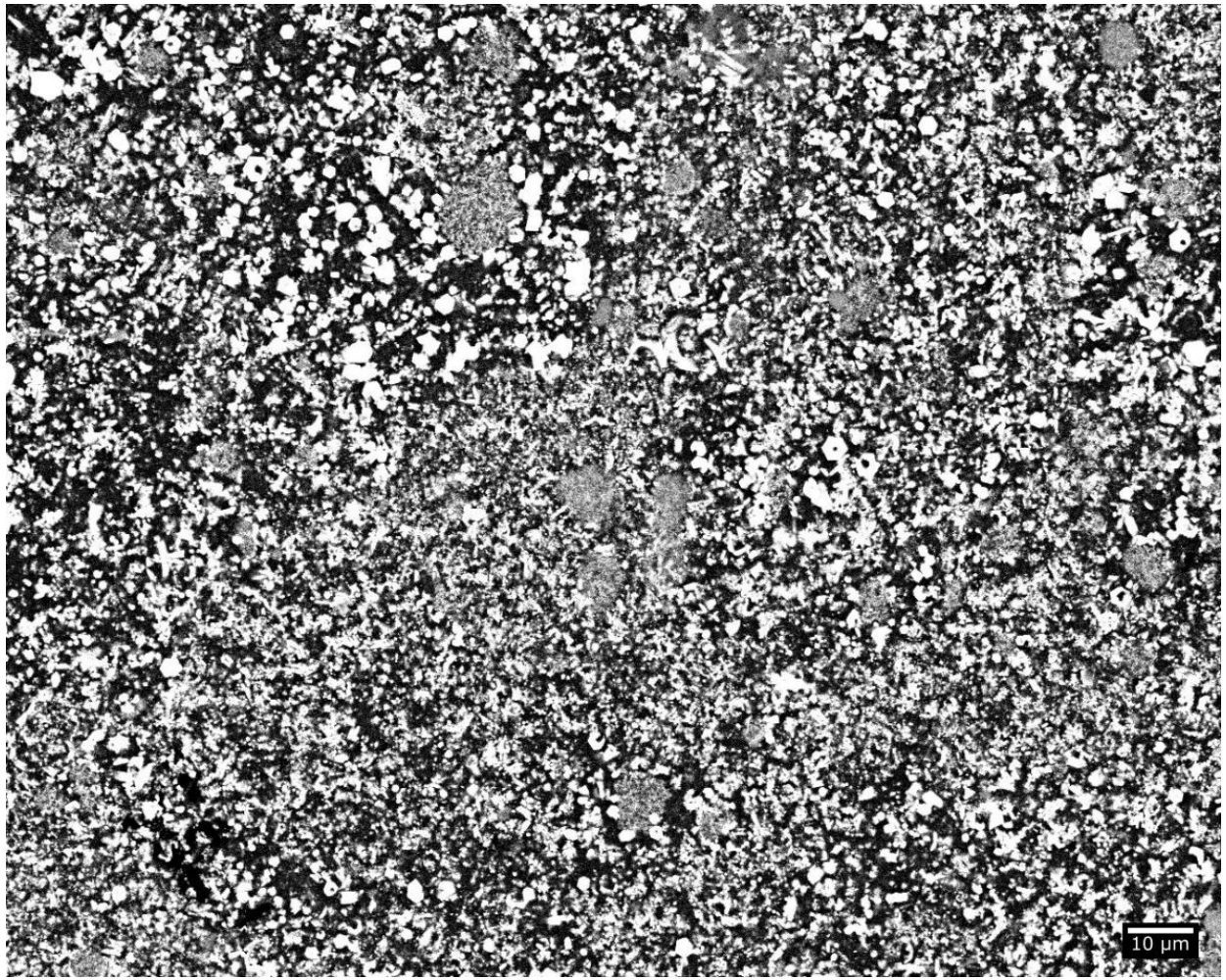
SEM SE

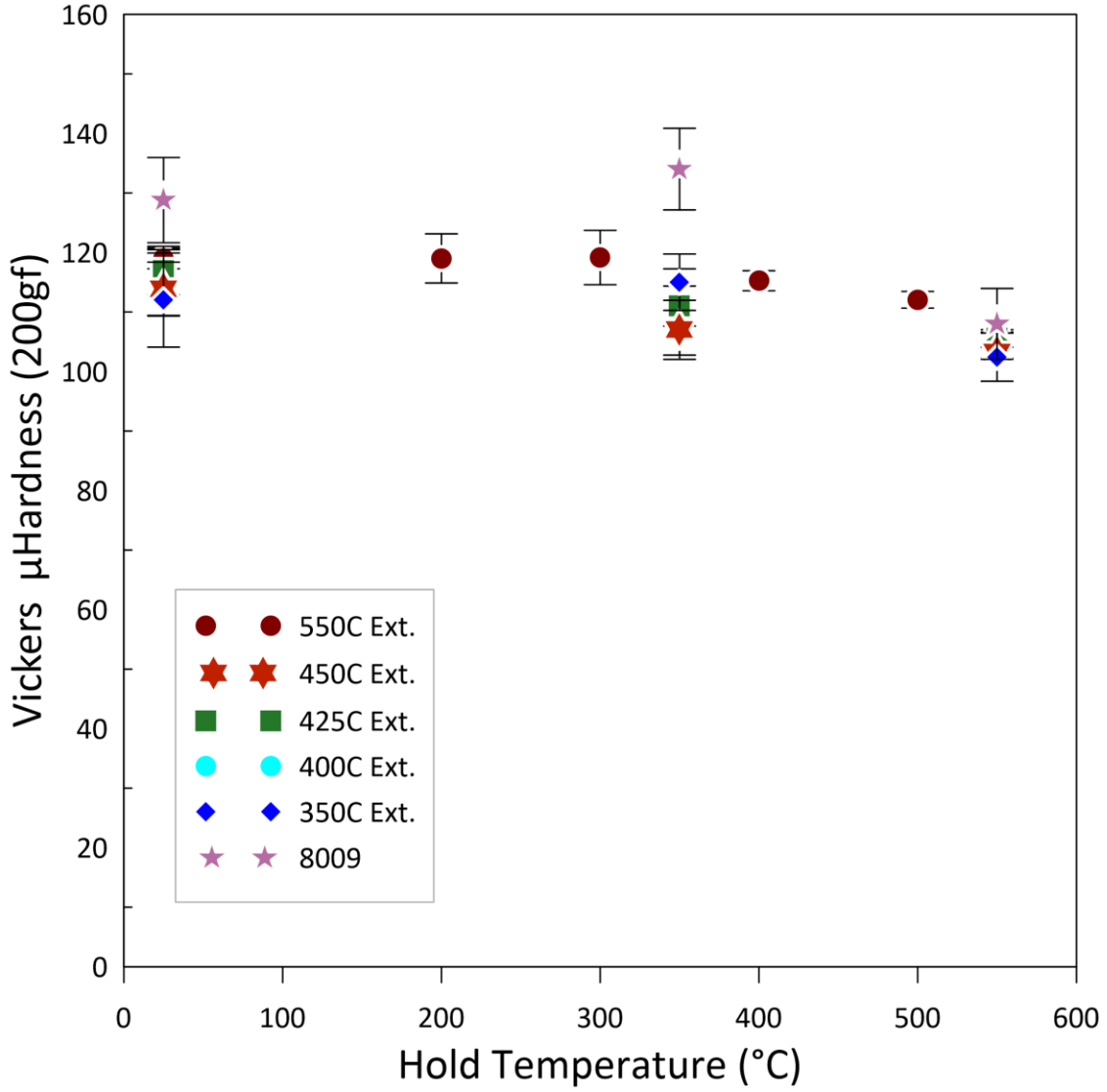


SEM BSE



As Extruded, 350°C extrusion Temperature, 10:1 extrusion ratio

Al-TM Alloys Maintain Hardness at 550C



Al-TM Microstructure minor coarsening

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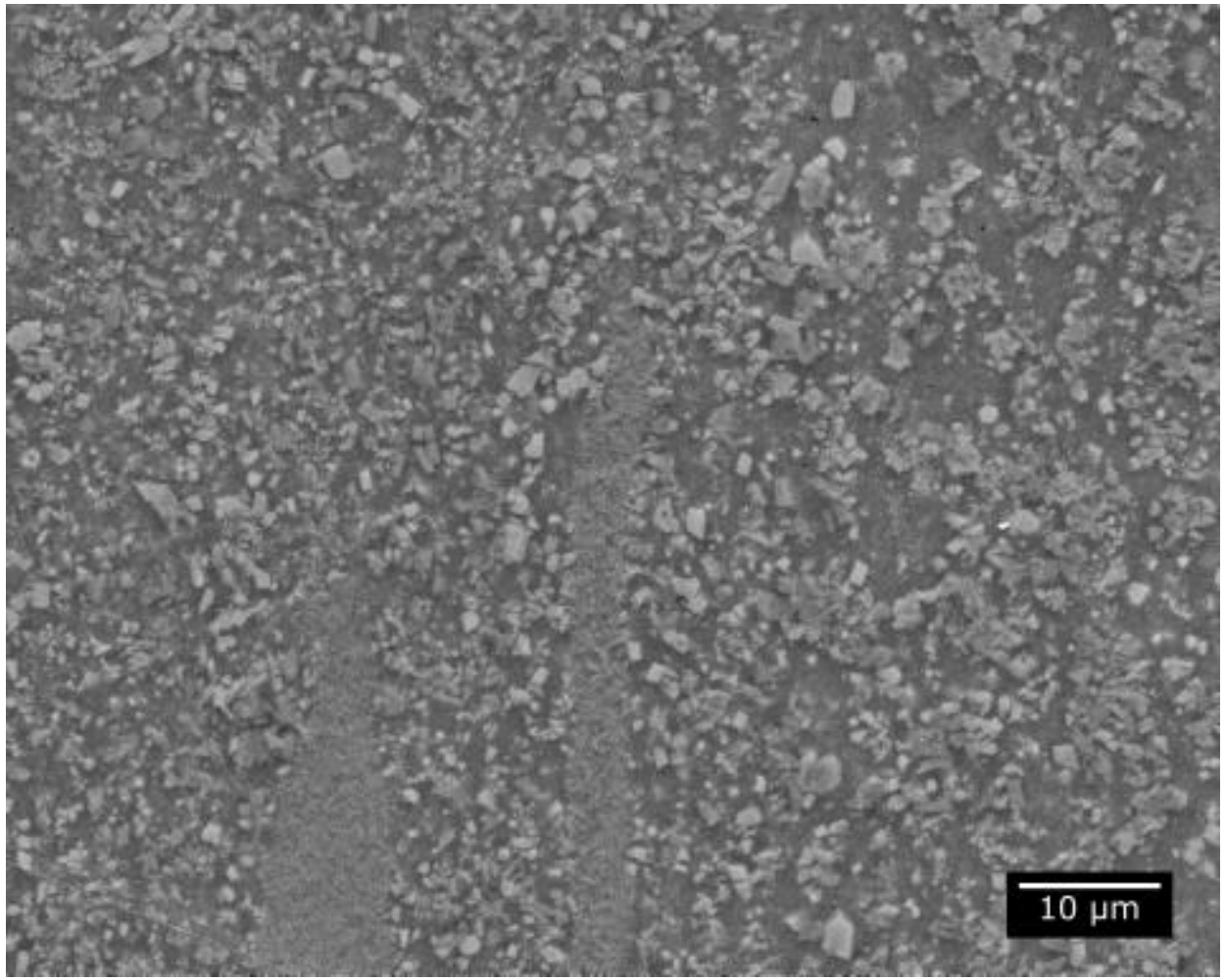
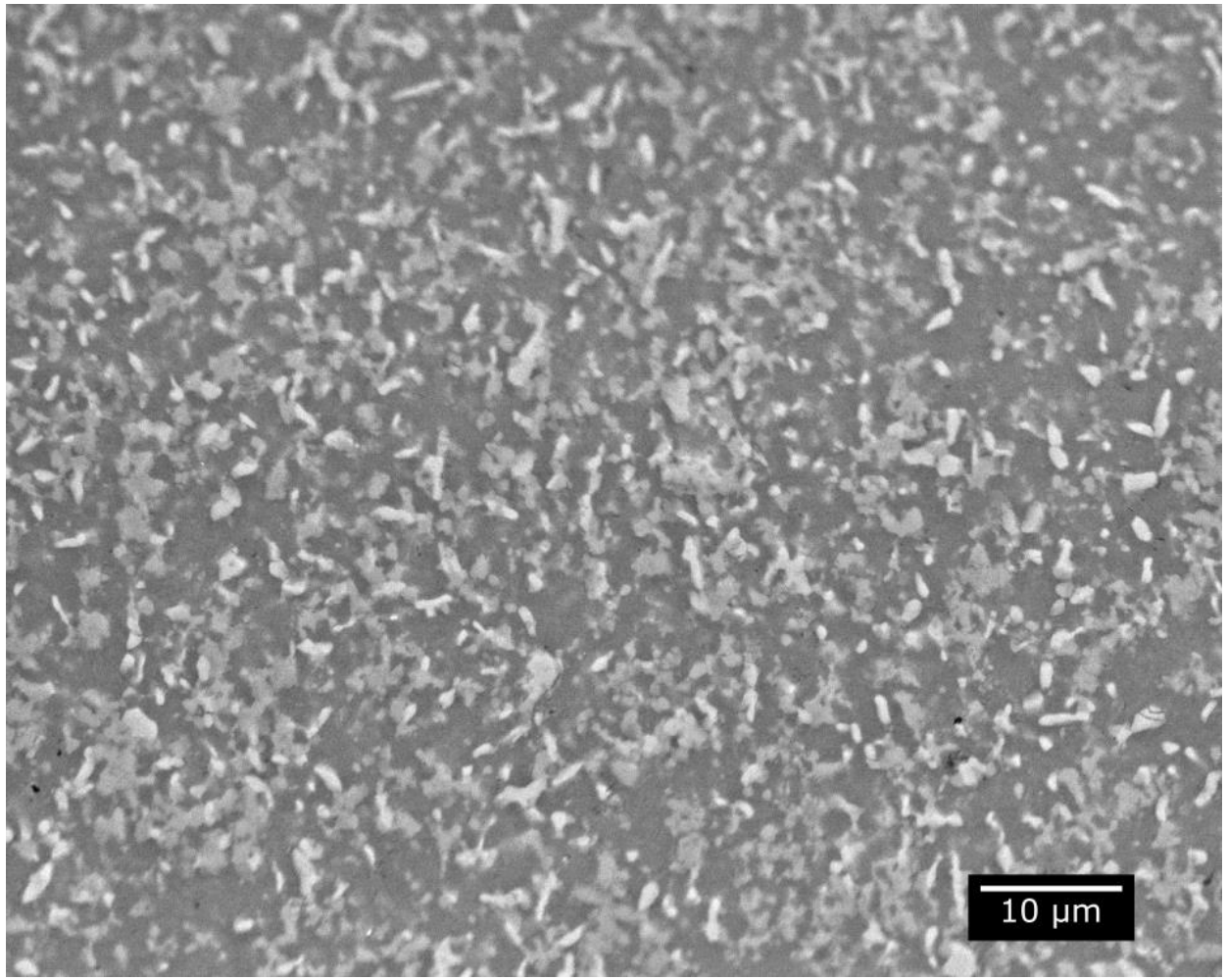
As Extruded



SEM SE

550°C Hold 100 hours



SEM SE

8009 Secondary Phases Significantly Coarsen

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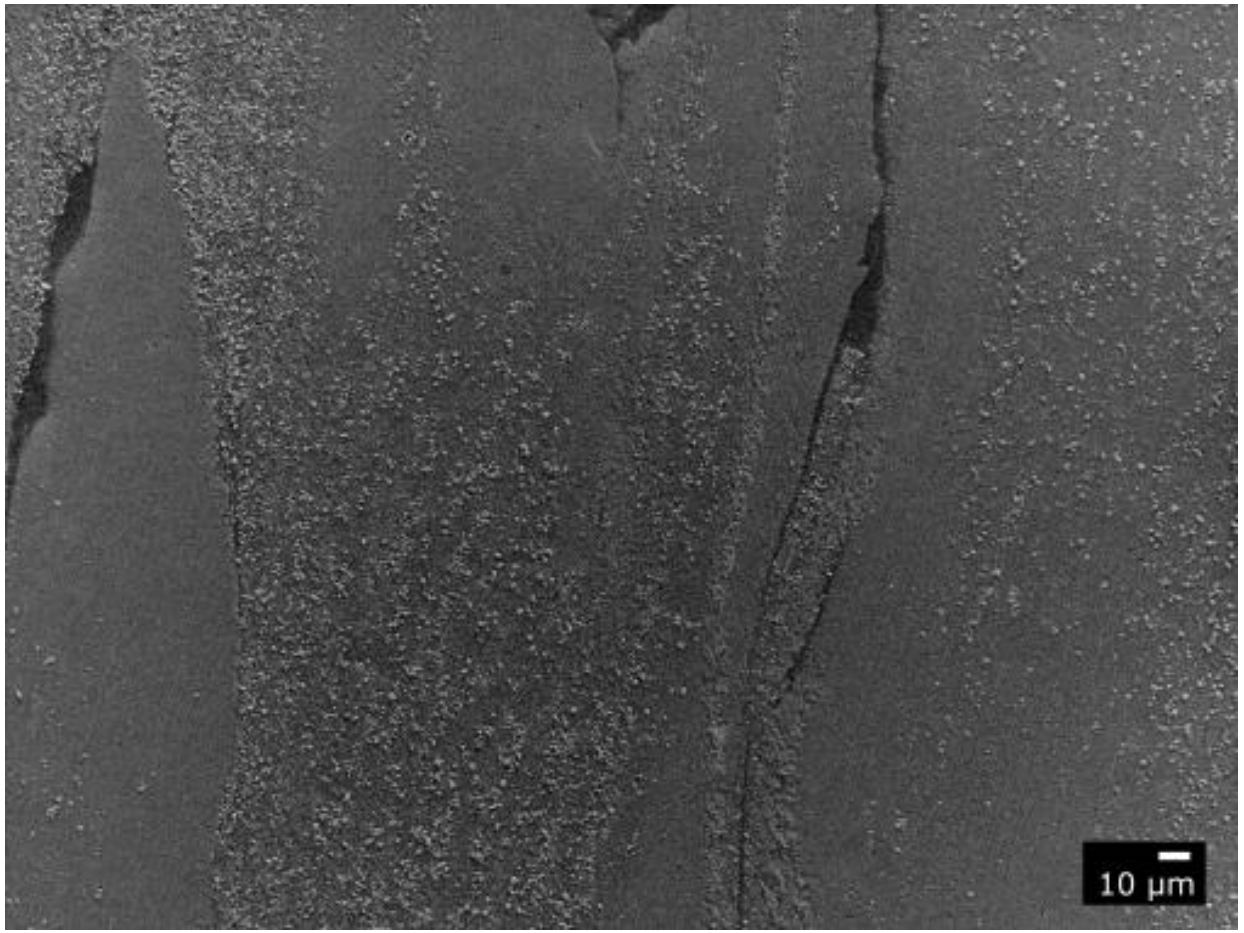
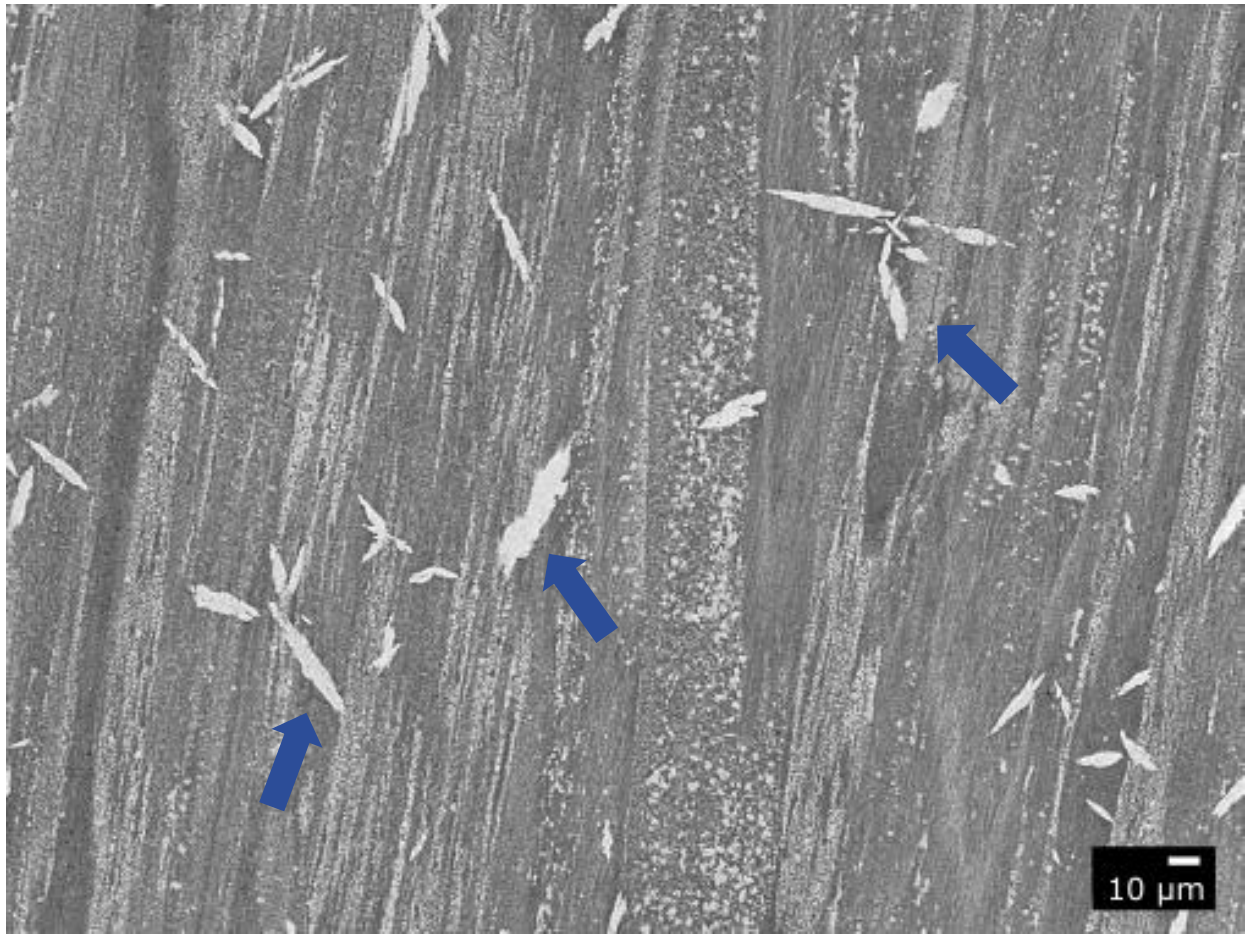
As Extruded



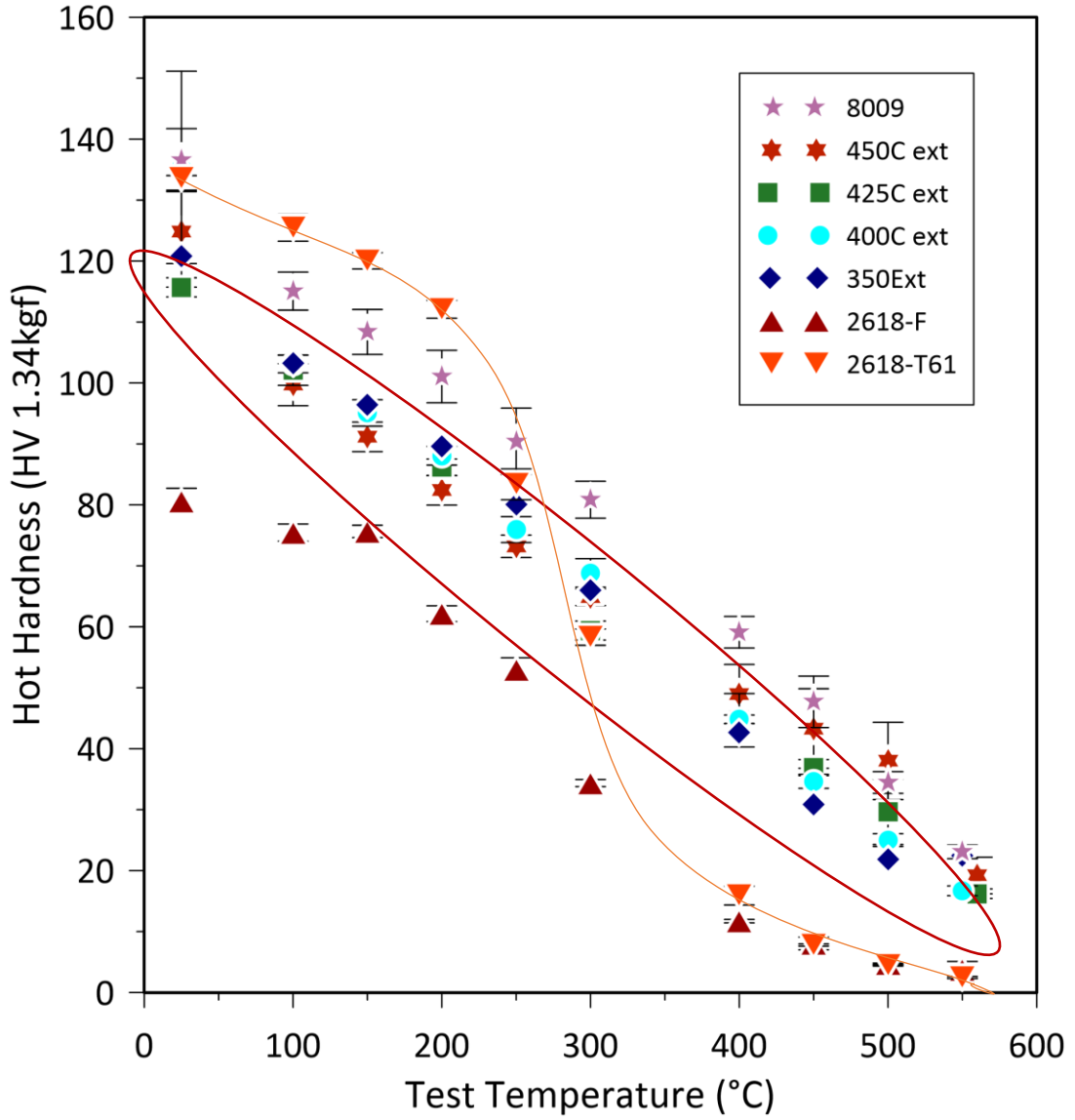
SEM SE

550°C Hold 100 hours



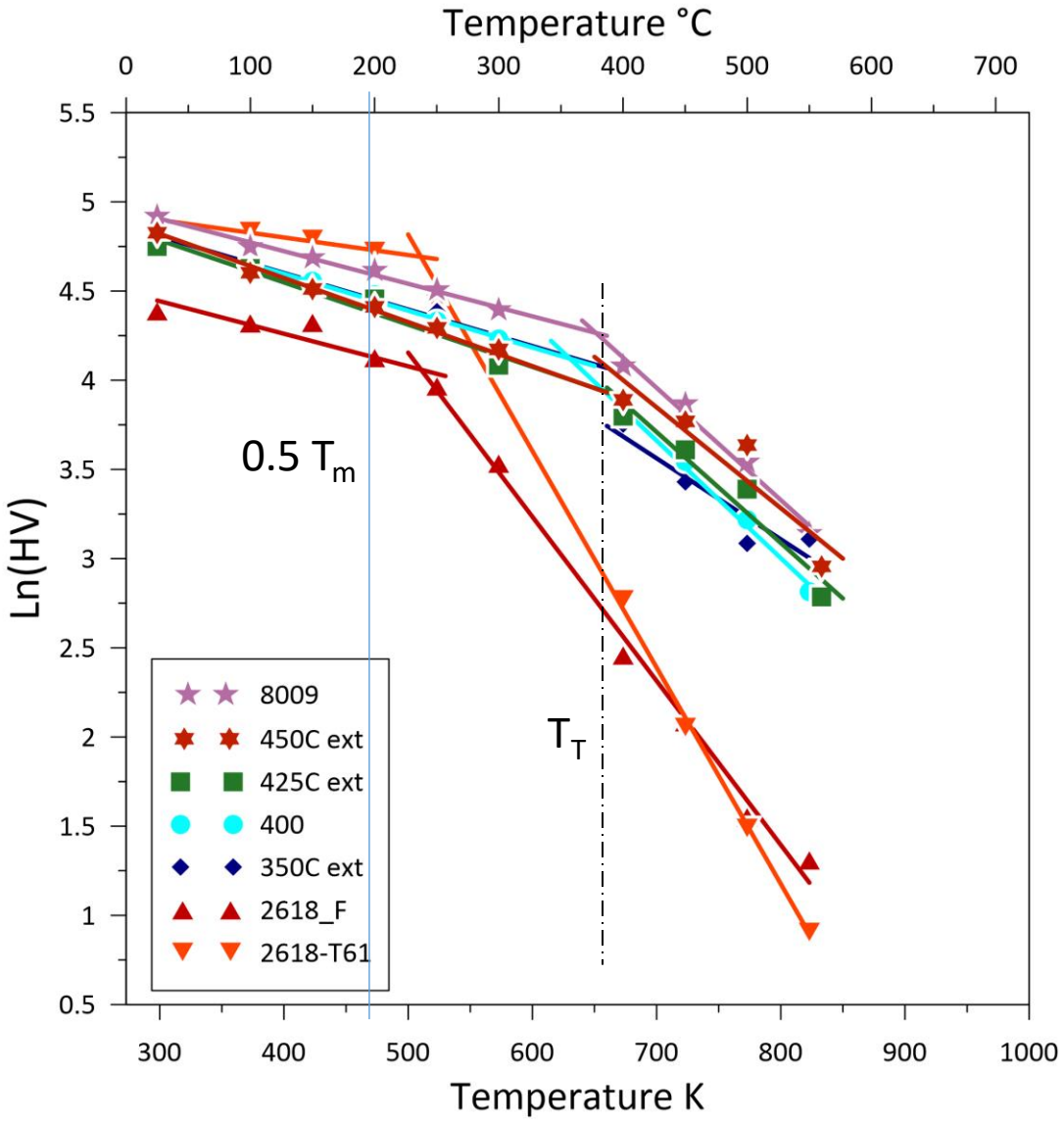
SEM SE

Hot Hardness

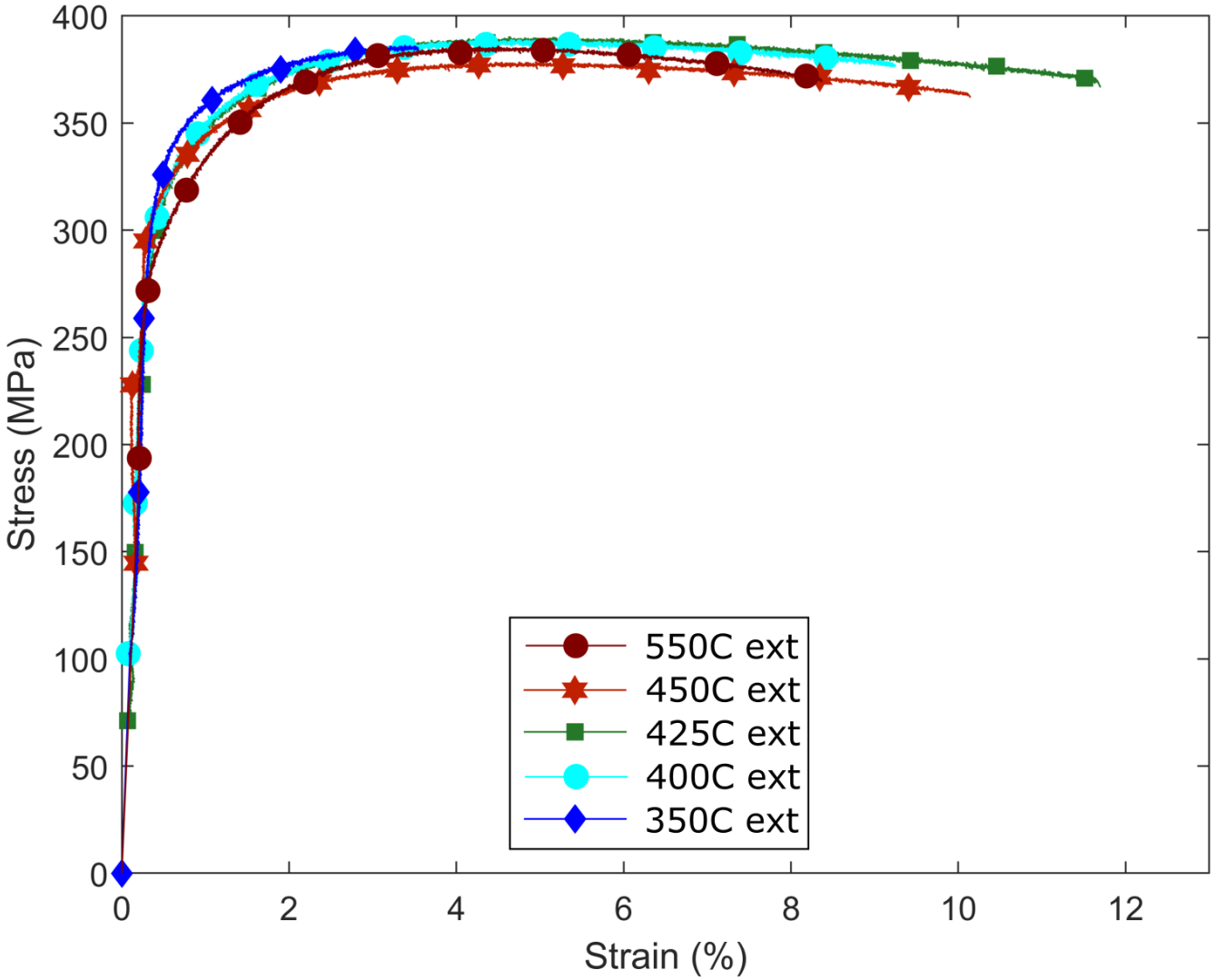


- Average of 10 indents
- One standard deviation

Al-TM Delays Deformation

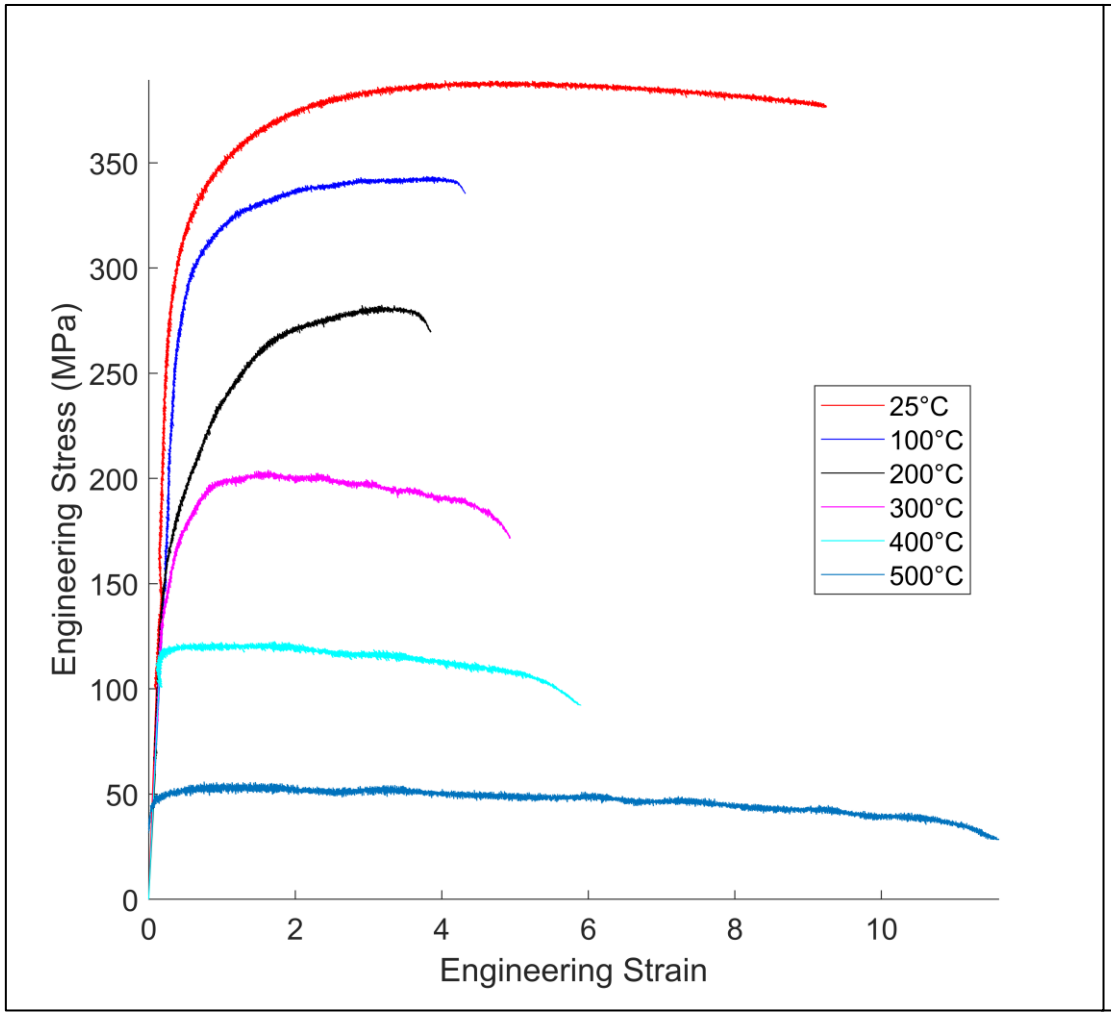


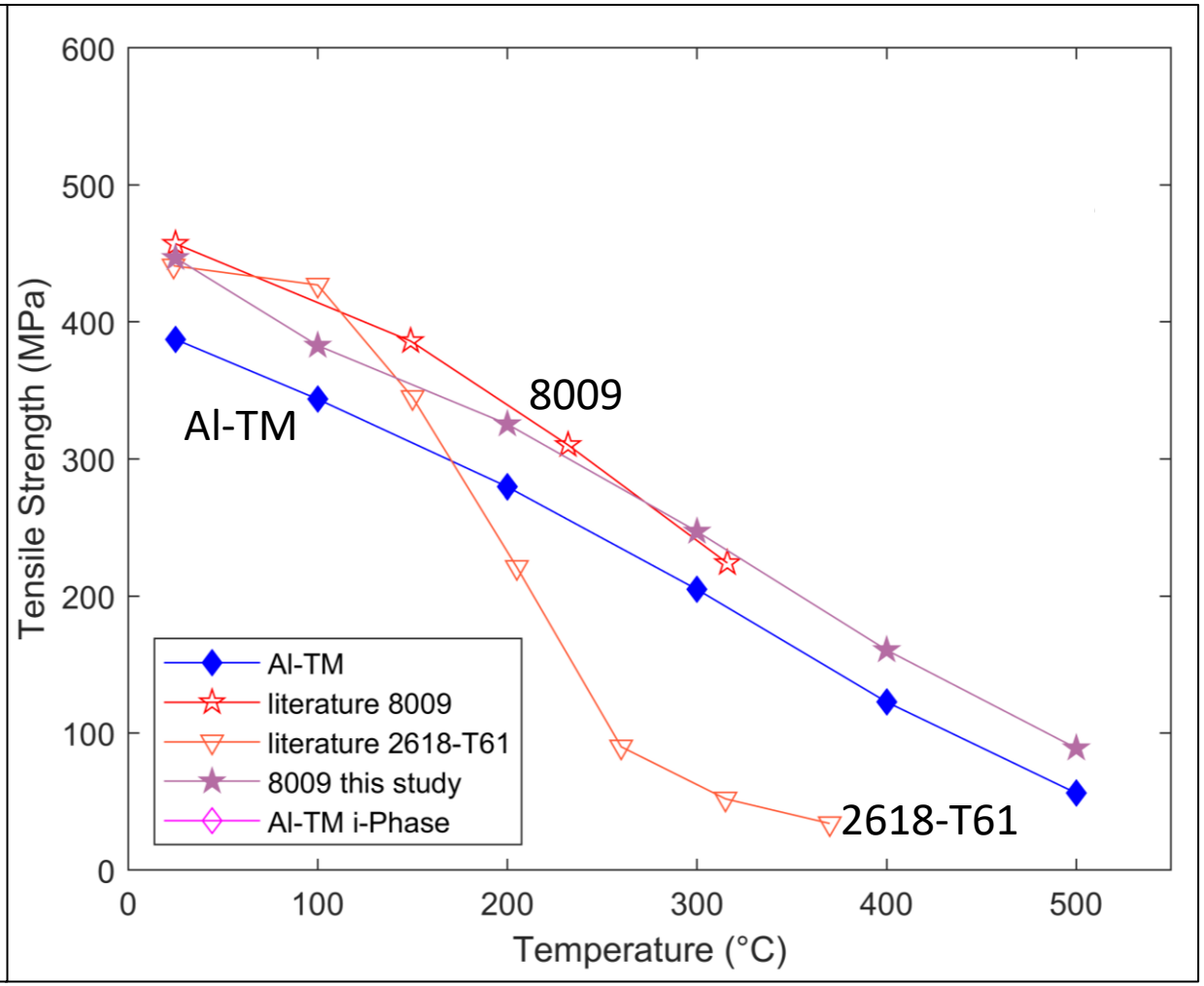
Minor Effect of Extrusion Conditions



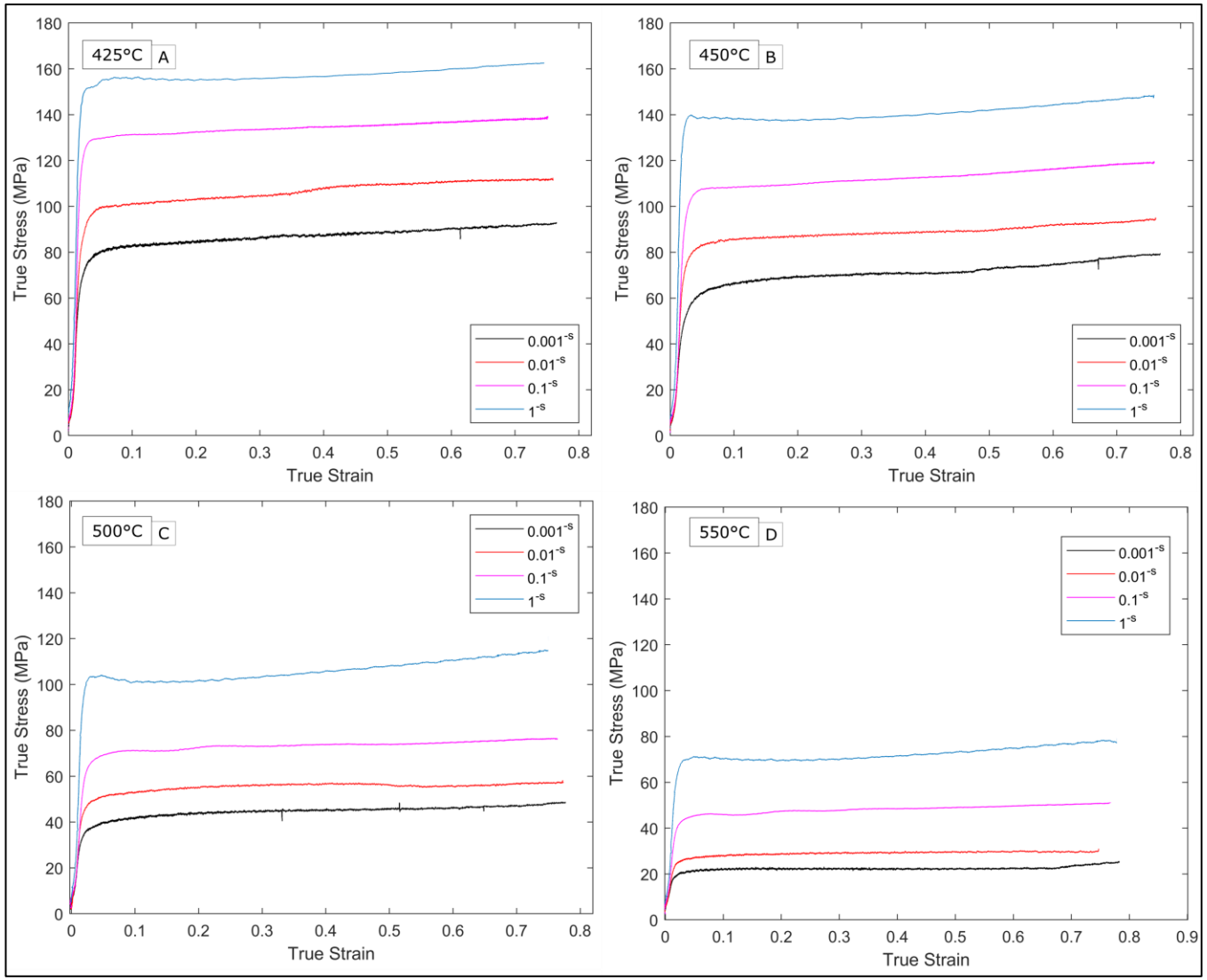
Al-TM w/icosahedral phase strain to failure 2%-7.5% [11,12]

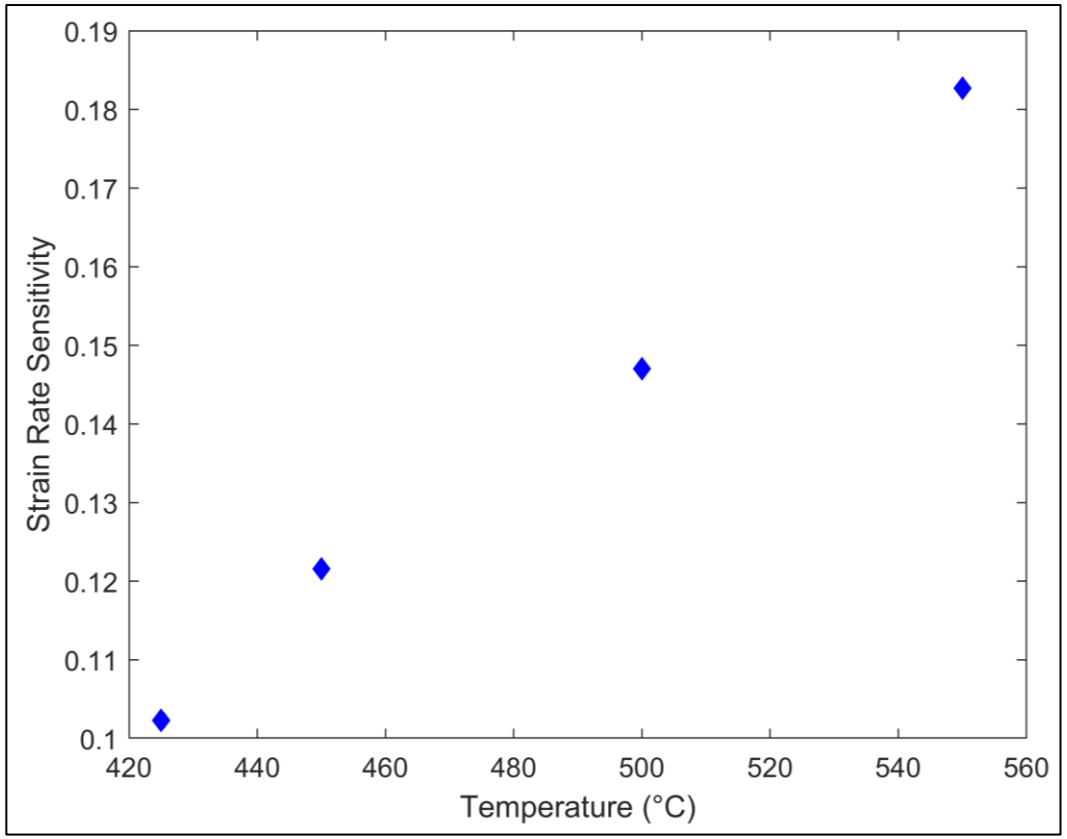
Tensile Response as a Function of Temperature





Compression Testing





Microstructure Retained and Unchanged Following Deformation

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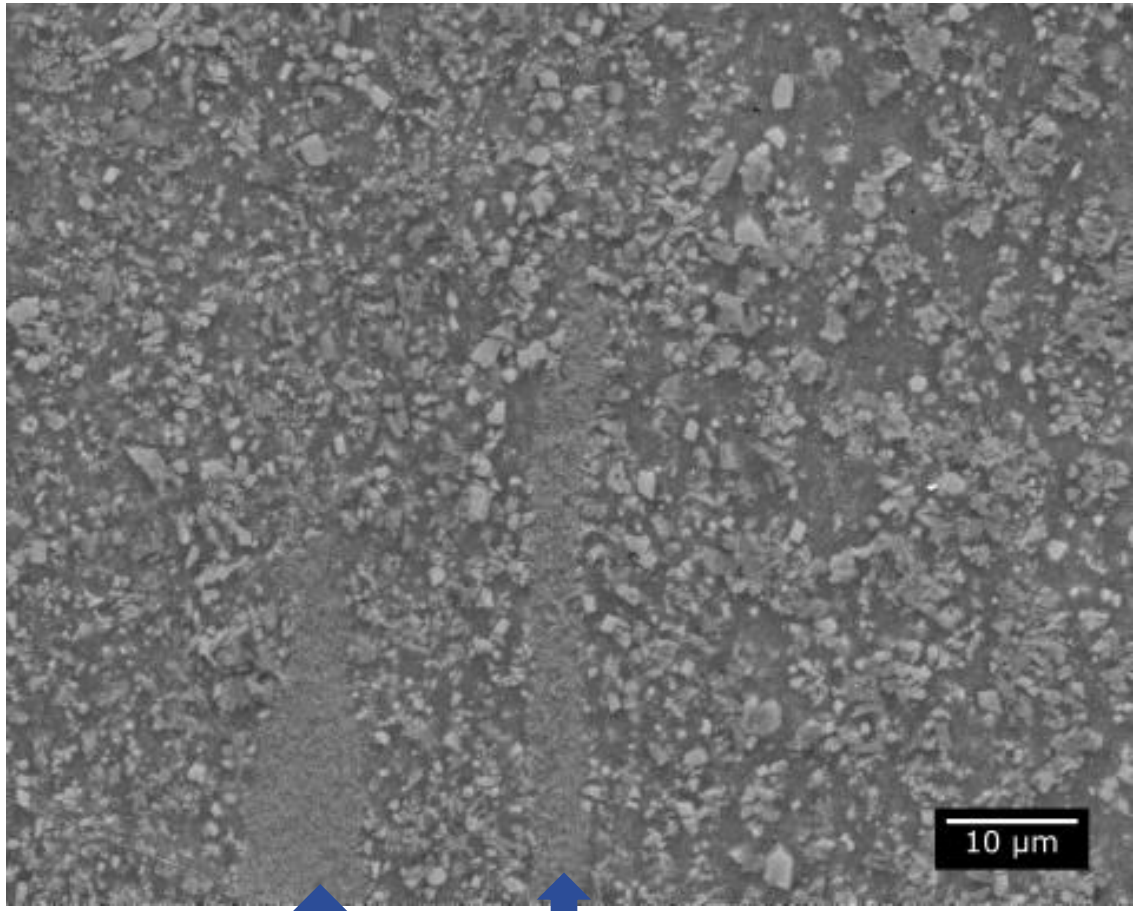
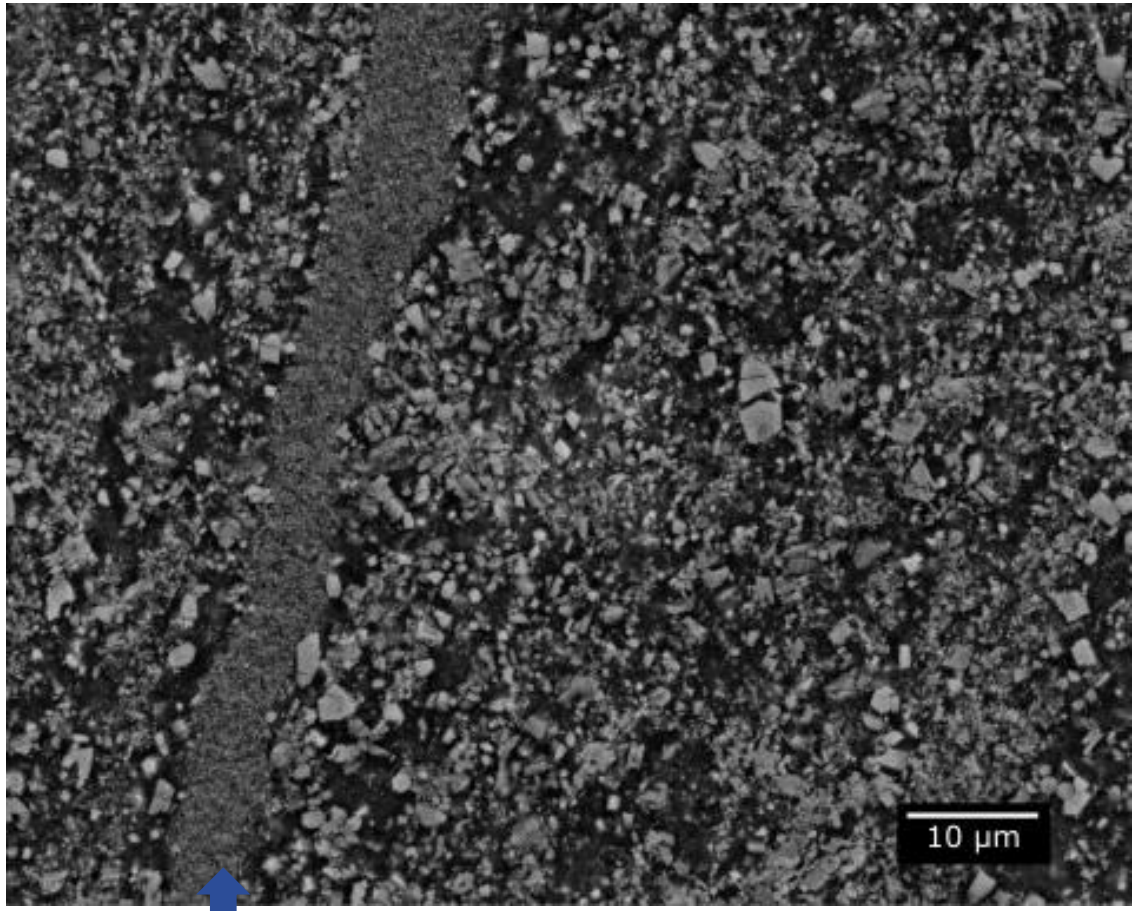
As Extruded



SEM SE

Deformed 500°C 0.1^{-s}



SEM SE

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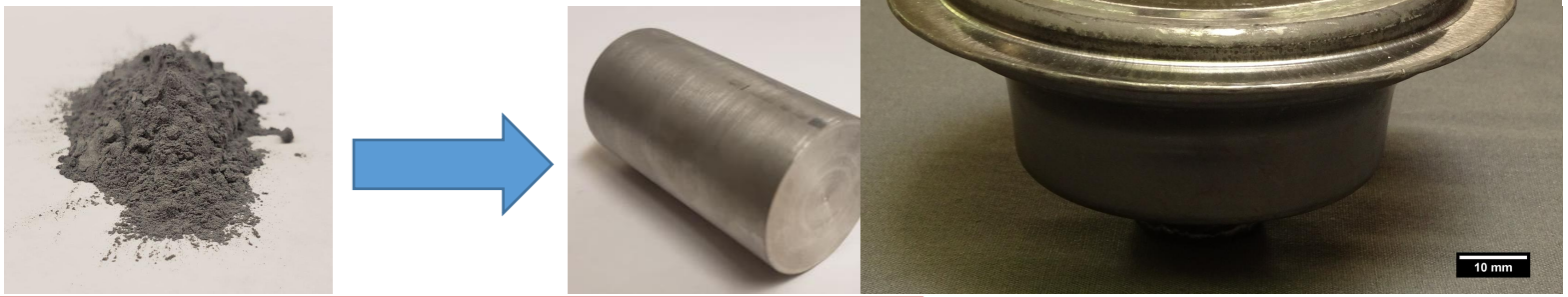
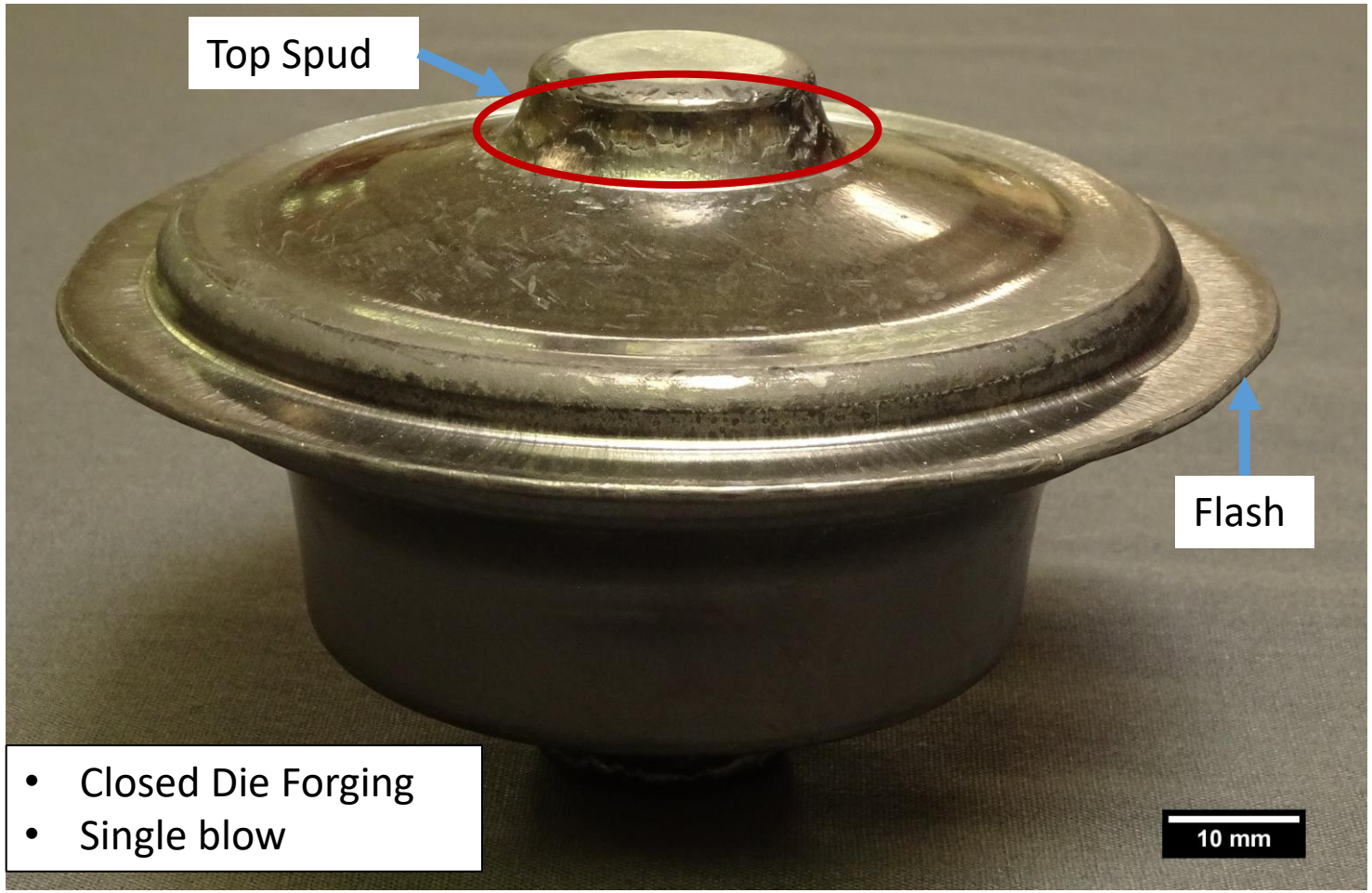


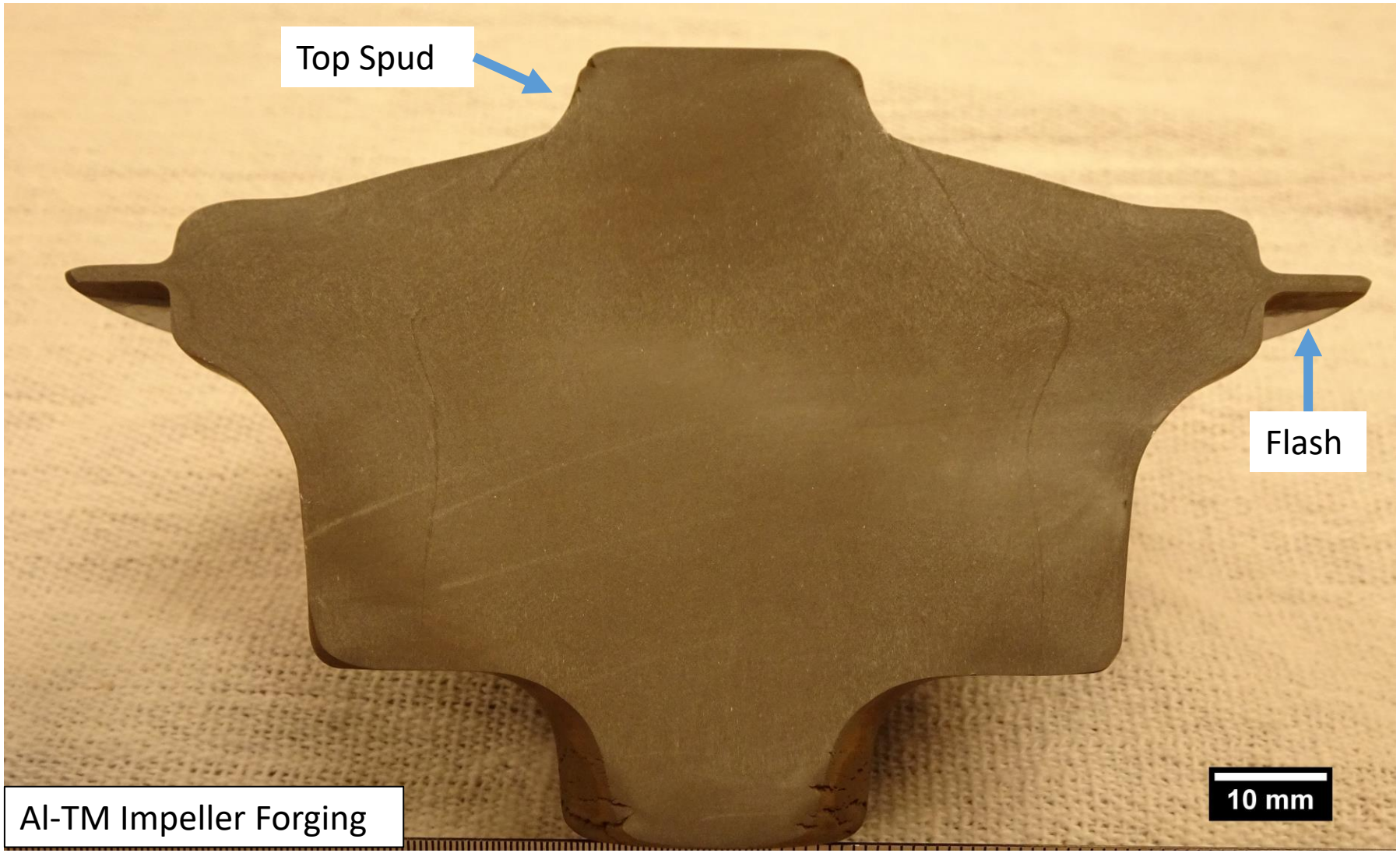
Al-TM Impeller Forging



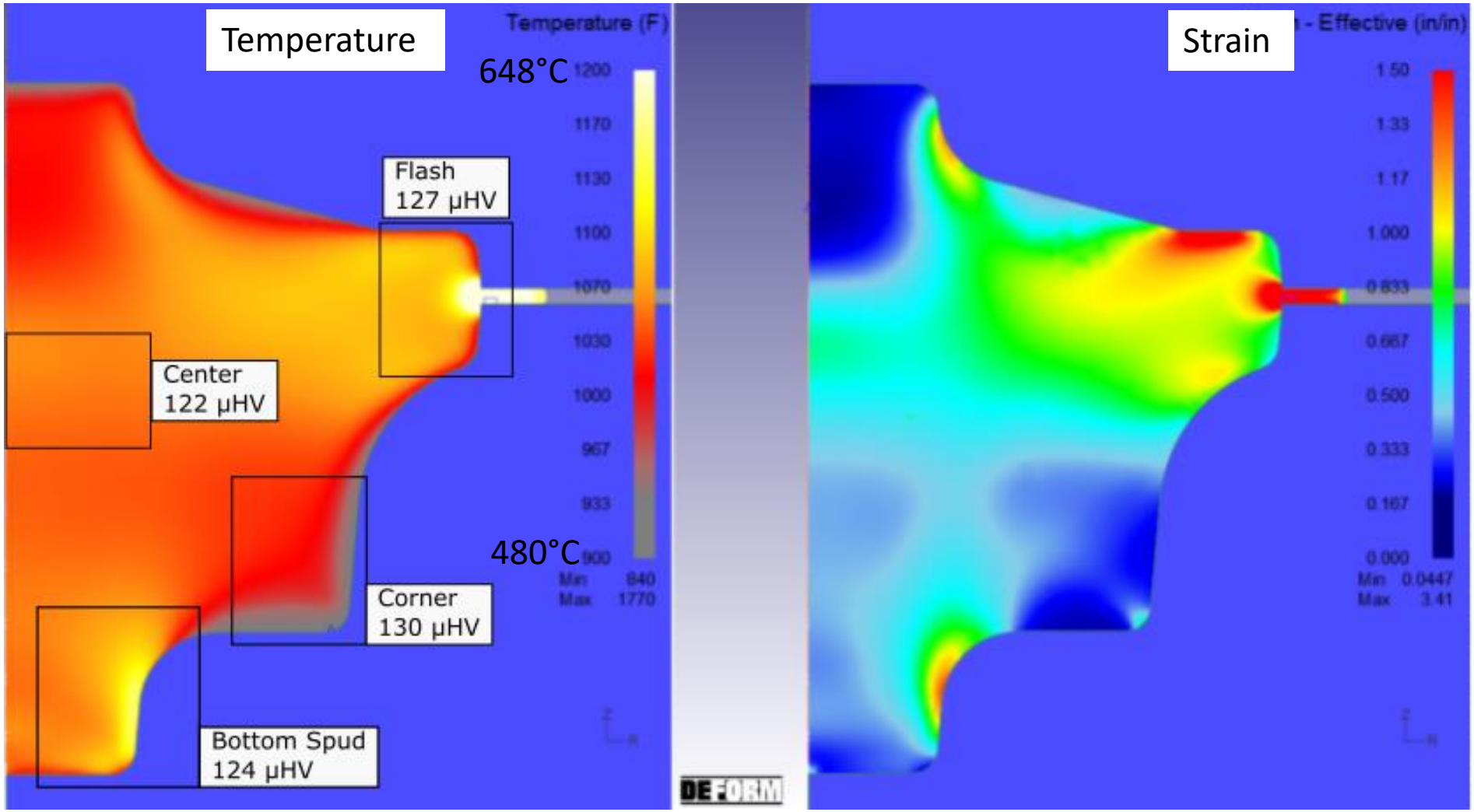
- Closed Die Forging
- Single blow

Adapted from[14]

Macro-Etch Demonstrates Good Flow



Forgings



Simulation of Al-TM forging provided by Tkach Consulting

Summary

- Extrusion
  - Wide range of consolidation temperature 350-550°C
  - Uniformity of room temperature tensile strength
  - Minor coarsening occurring in Al-TM alloy leading to a retention in hardness
  - Elevated temperature properties approach those of 8009
- Deformation
  - Increasing strain rate sensitivity with temperature
  - Stable microstructure over long time and high temperature withstands forging conditions

Acknowledgements

- Kymera International provided Al-TM extrusions and powder for this research project. Special thanks to Tom Pelletiers and Wayne Daye for technical information and project support.
- Forgings and project support provided by Rob Mayer, Queen City Forge
- Friction stir extrusion material was provided for this project by Scott Whalen, Pacific Northwest National Laboratories.
- Deform™ simulations provided by Suzanne Tkach, Tkach Metal Forming Consultants. Jim Miller & Scientific Forming Technologies for the use of Deform™.
- Michigan Technological University for the use of facilities and technical expertise
- Thank you, Dr. Kester Clarke, and Committee; Dr. Amy Clarke, and Dr. Jonah Klemm-Toole
- Thank you to the MME faculty and staff
- I could not have done this without the friendship and support of MME grad students, in particular Ben Ellyson, Chloe Johnson, Brady McBride
- Wonderful support from my mom, and roommates Tyler, and Saige

Questions?

Thank you!
Stuart Shirley
sshirley@mines.edu

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