Project 40-L: Evaluation of Processing Path Effects on Microstructure and Properties of Powder-Based Al-TM alloy

Fall 2021

Student: Stuart Shirley (Mines)

Faculty: Kester Clarke (Mines)

Industrial Mentors: Rob Mayer (Queen City Forge)

Project 40-L: Evaluation of Processing Path Effects on Microstructure and Properties of Powder Al-TM alloy

CANFSA
CENTER FOR ADVANCED NON-FERROUS STRUCTURAL ALLOYS

- Student: Stuart Shirley (Mines)
- Advisor(s): Kester Clarke (Mines)

Project Duration

Masters: August 2019 to December 2021

- Problem: Al-TM alloys have excellent performance, but can be challenging to process via conventional processing pathways.
- Objective: Evaluate the effect of processing path on the microstructure and mechanical properties of Al-TM alloy.
- Benefit: Improved understanding of processing path effects on microstructure and properties Al-TM powders.

Recent Progress

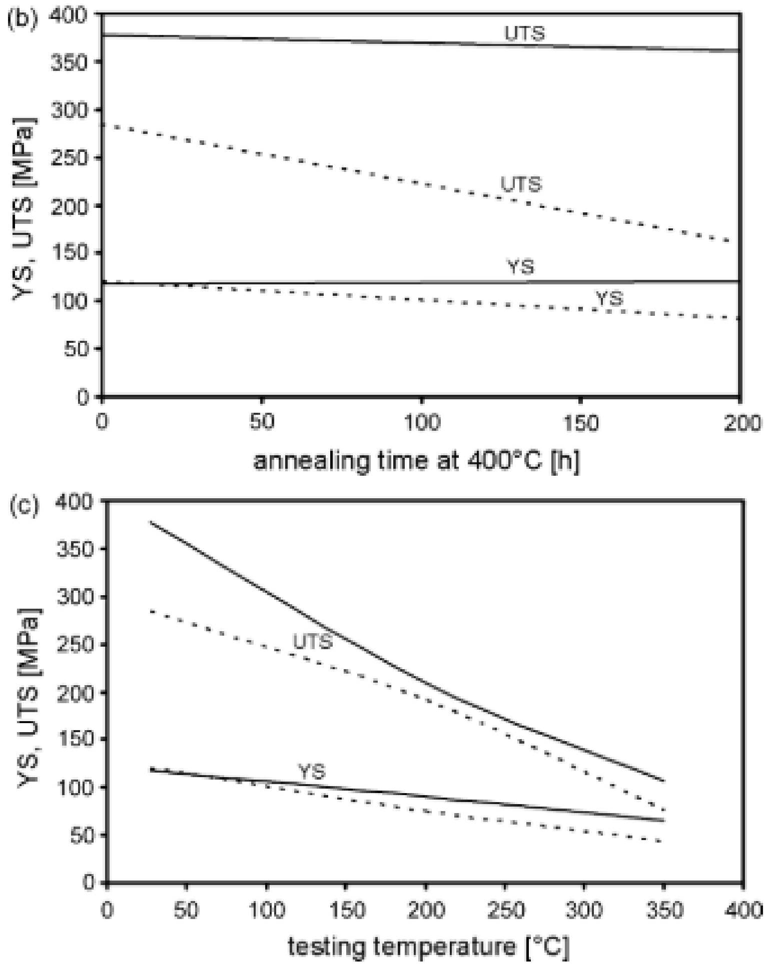
- Low Temperature Extrusions
- Hot Hardness Testing
- Powder Characterization
- Completion of Thermal Stability Testing
- Microstructural Characterization
- Start of Thermomechanical Testing

Metrics

Description	% Complete	Status
1. Literature review	75	●
2. Microstructure Characterization of Al-TM	20	●
4. Microstructure Characterization of ShAPE Al-TM alloy	40	●
5. Thermal Stability Testing	100	●

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 [2]
- High temperature thermal stability
  - Annealing and room temperature hardness
  - Hot hardness testing
- Ductility
  - 15% elongation via ShAPE processing [3]
  - 4-9% elongation via extrusion [4]

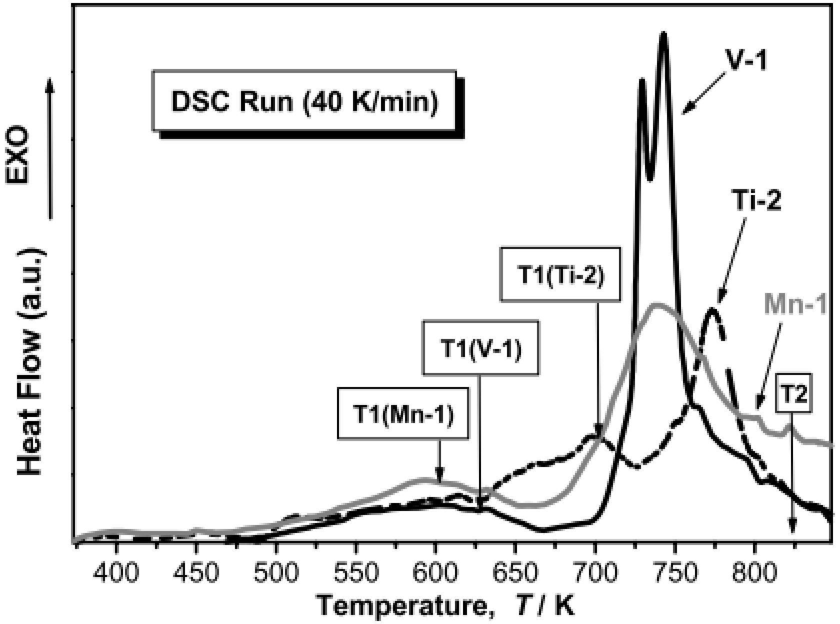


Solid line: PM extrusion consolidated Al-Cr-Fe-Ti
Dashed line: Al–12Si–1Ni–1Cu–1Mg casting alloy
Sourced: Adapted from [1]

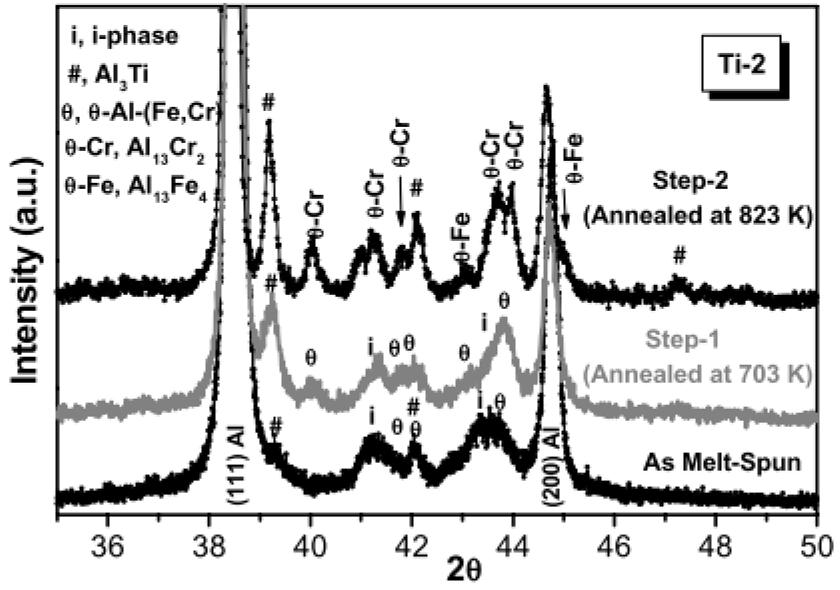
Al-TM Phase Evolution

Strengthening Precipitates

- Quasi-crystalline particles 50-80 nm [5]
- Coarsening at ~427°C (800°F) and transformation at ~500°C (932°F) [5,6]



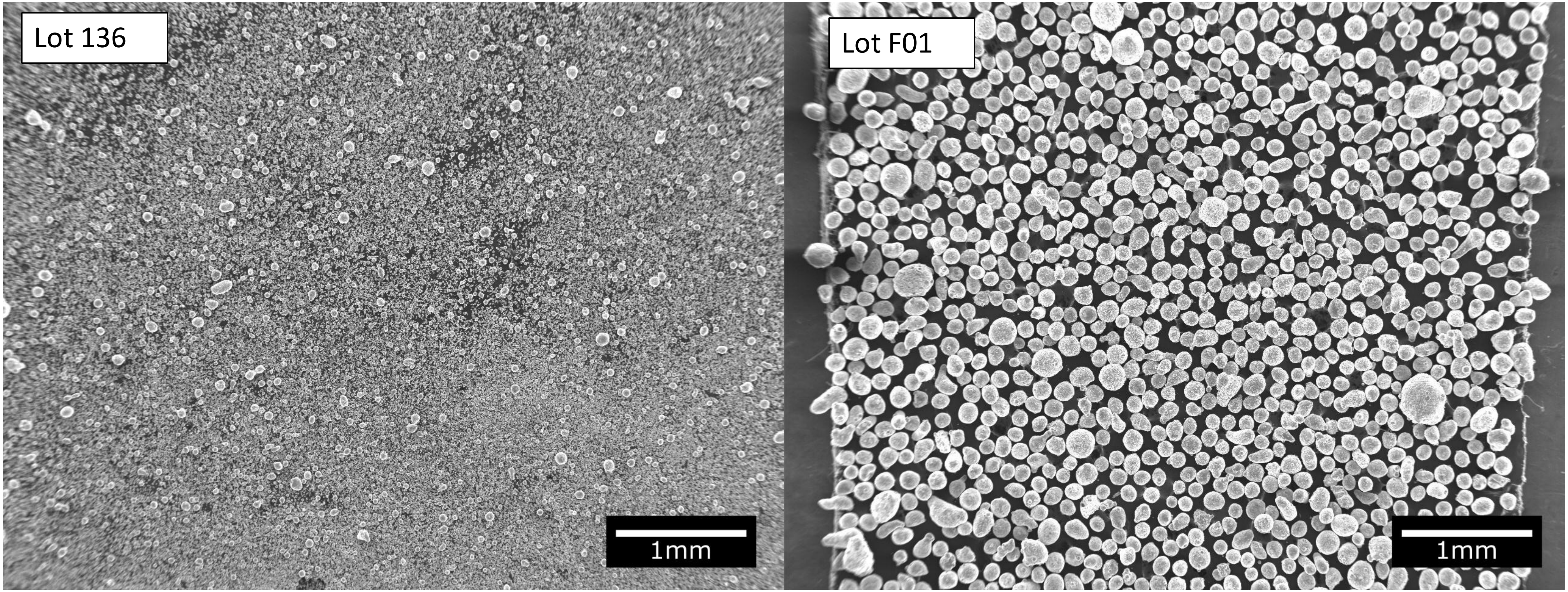
Adapted from [5]



Motivation

Extrusion
ShAPE

The case of two powder lots

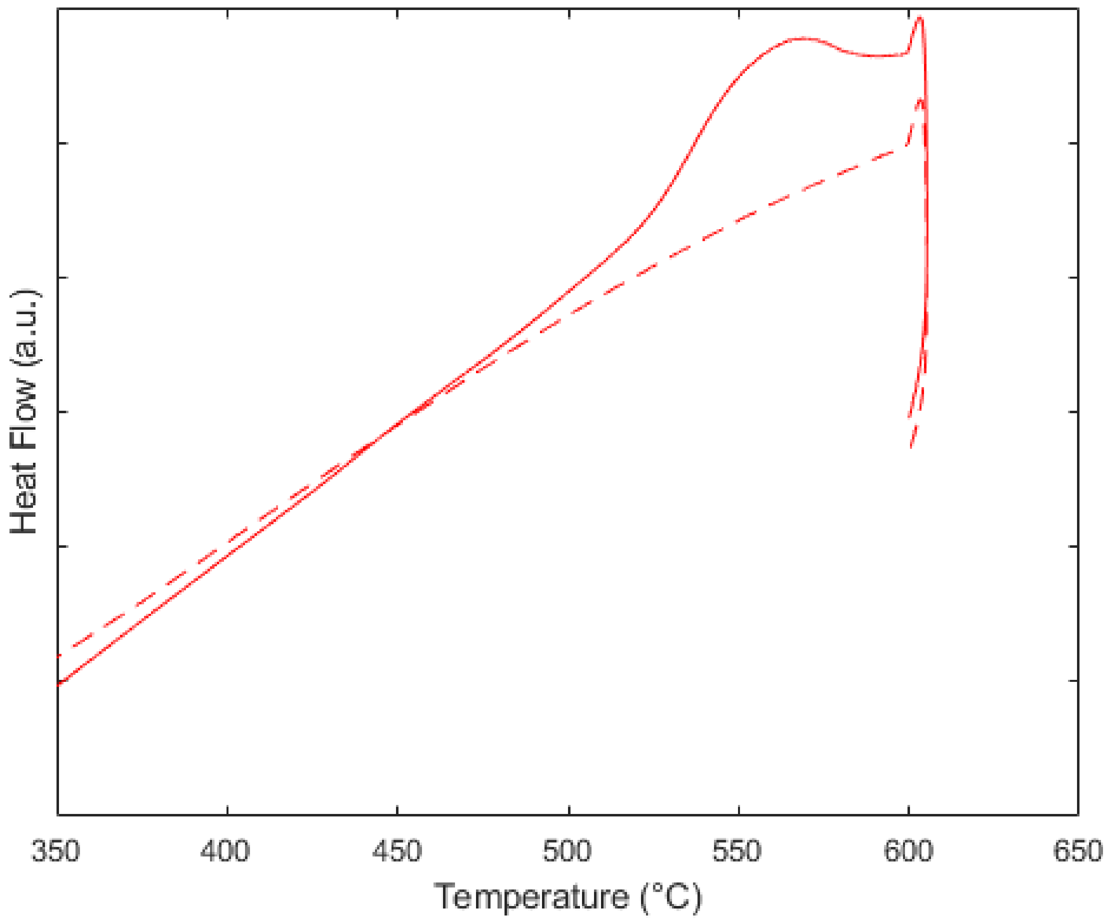


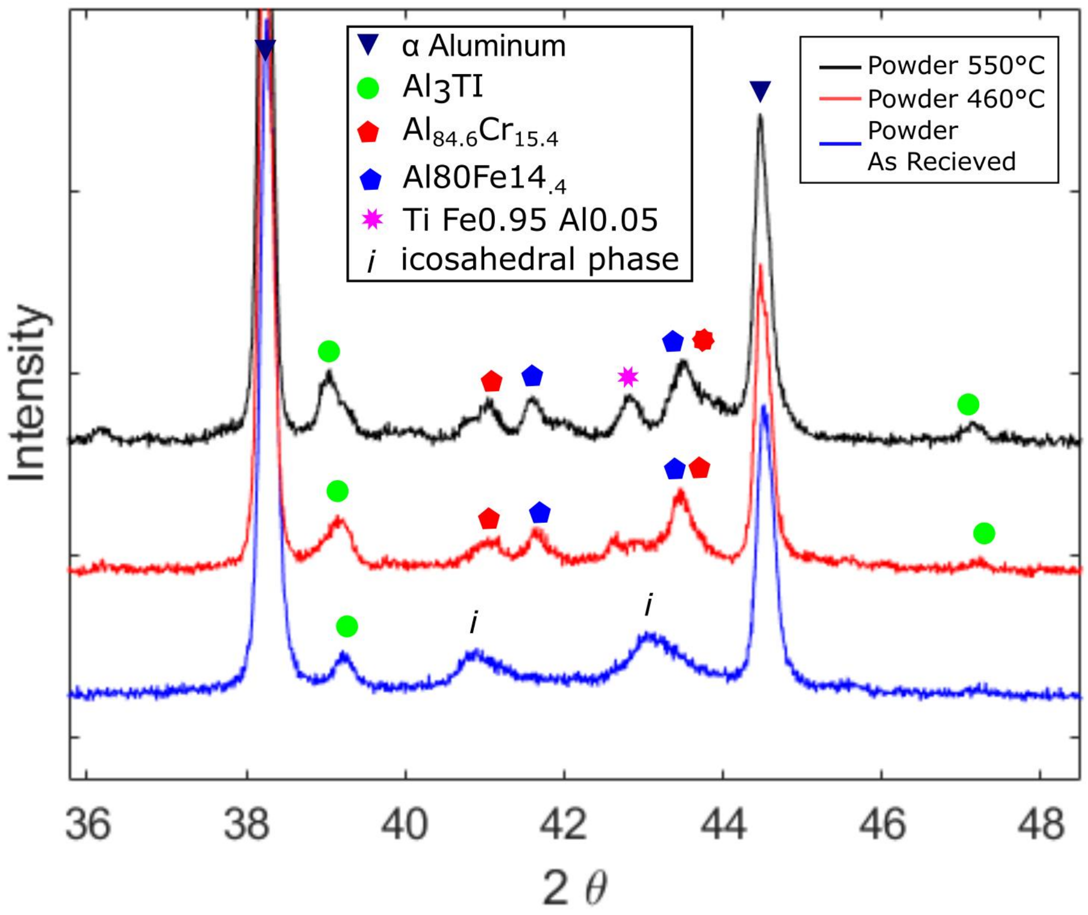
20 µm powder

150 µm powder

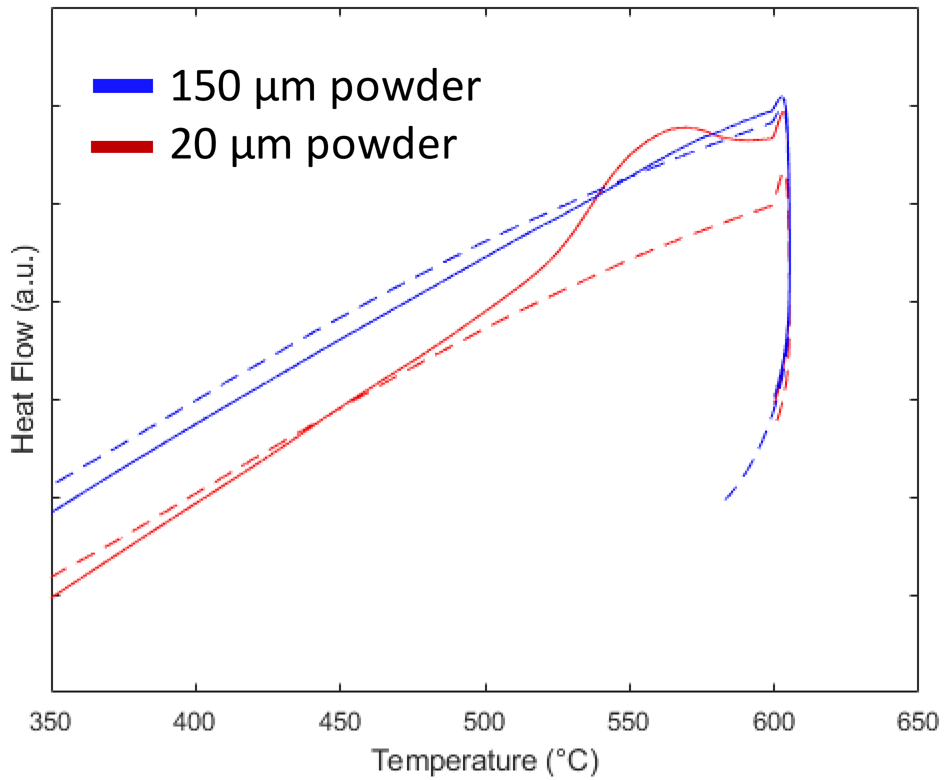
Phase Evolution in this Study

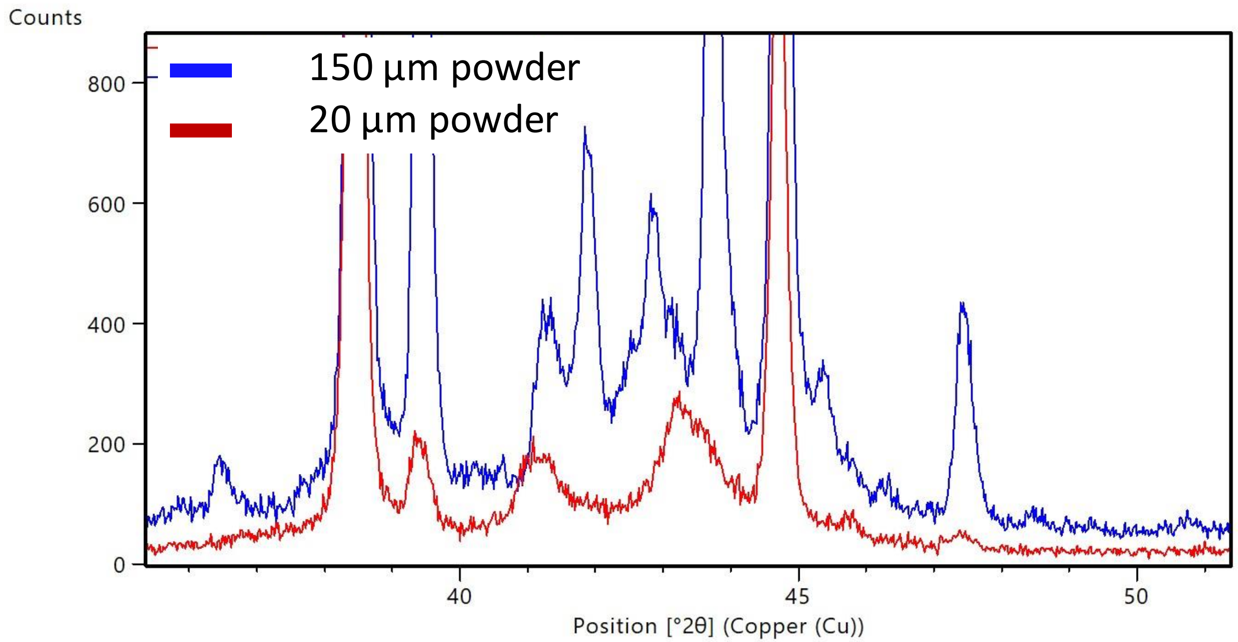
Lot 136



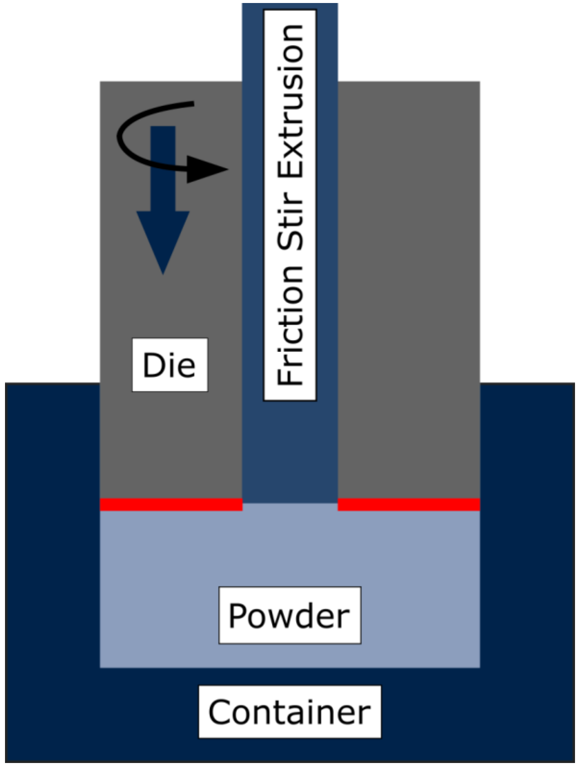


Icosahedral Phase Powder Size Dependent

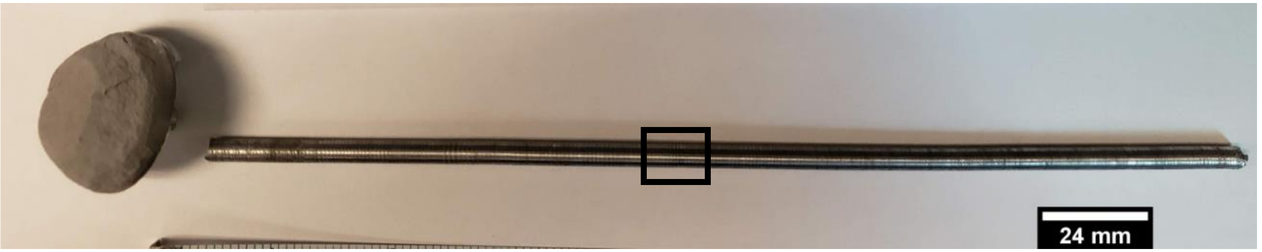




Friction Stir Extrusion

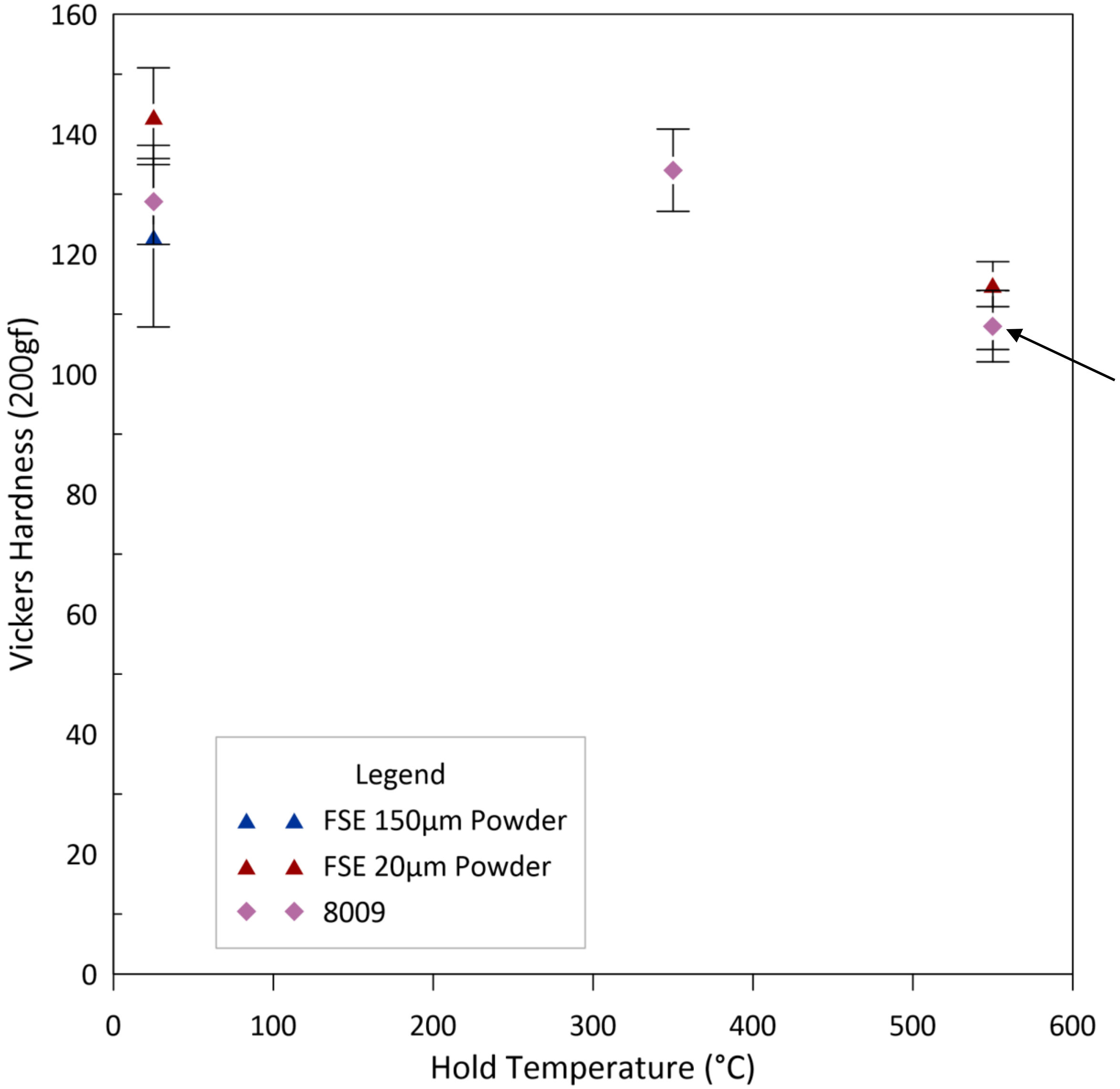


- Powder loaded open to atmosphere
- Aluminum, Copper, Magnesium [7-9]
- ShAPE™



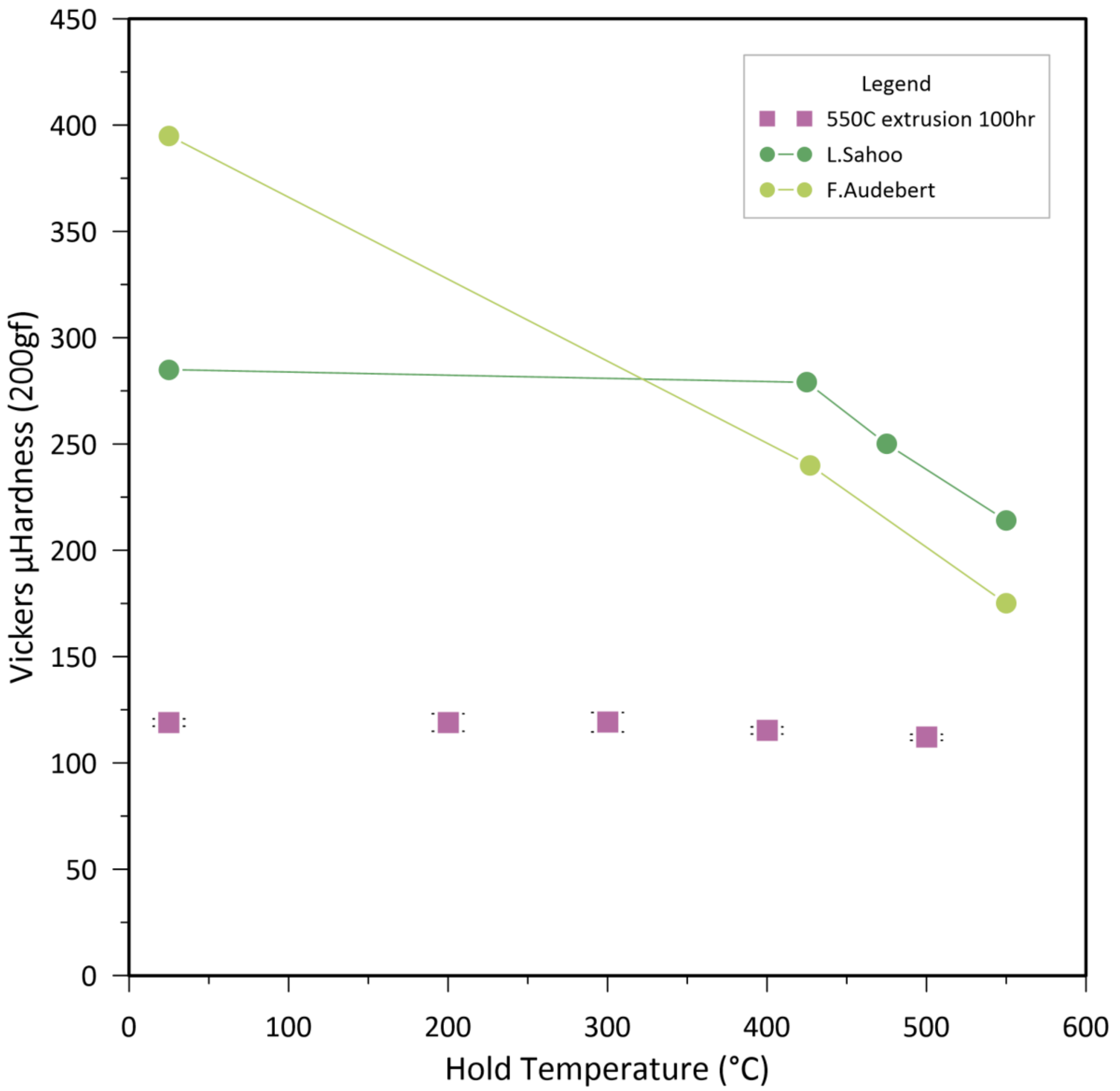
FSE graciously provided by Scott Whalen of PNNL

FSE Shows Equivalent Hardness to 8009

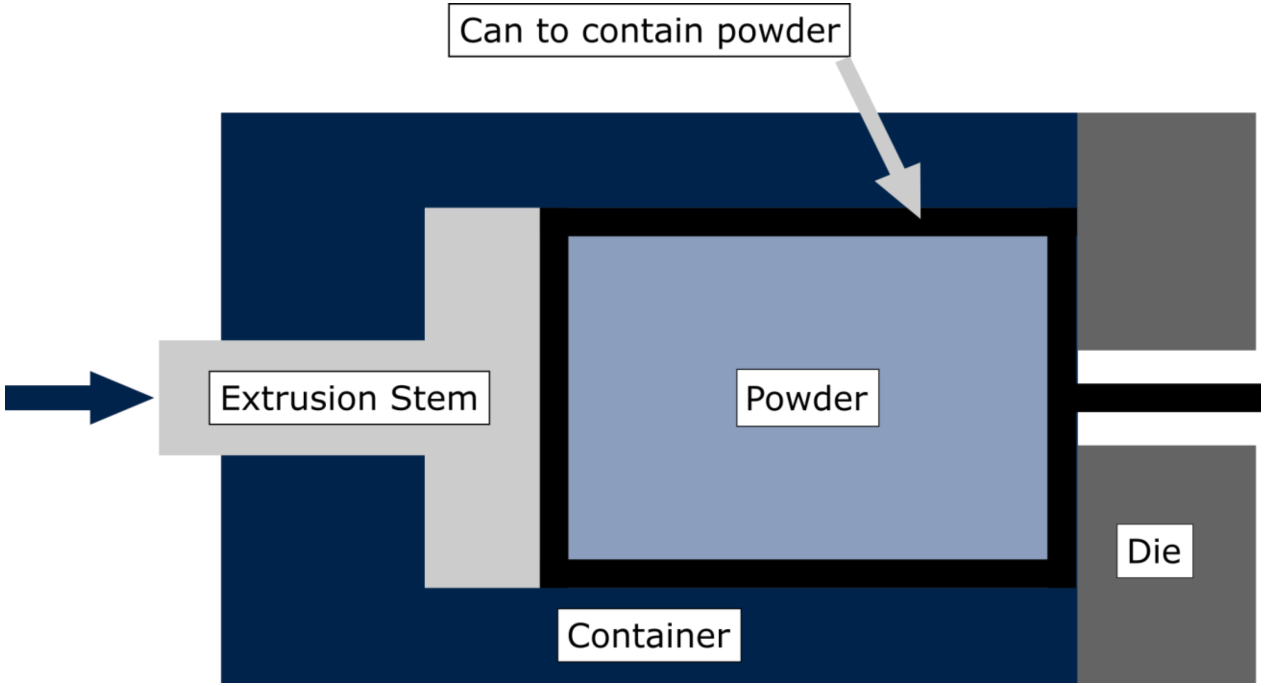


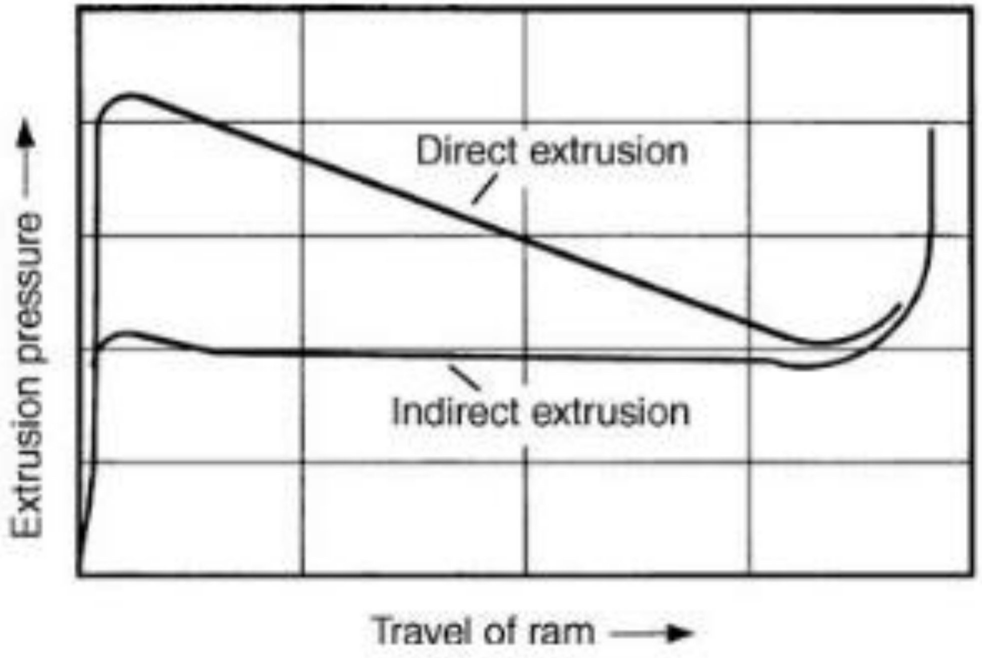
8009 and FSE 150 µm powder overlap

Thermal Stability

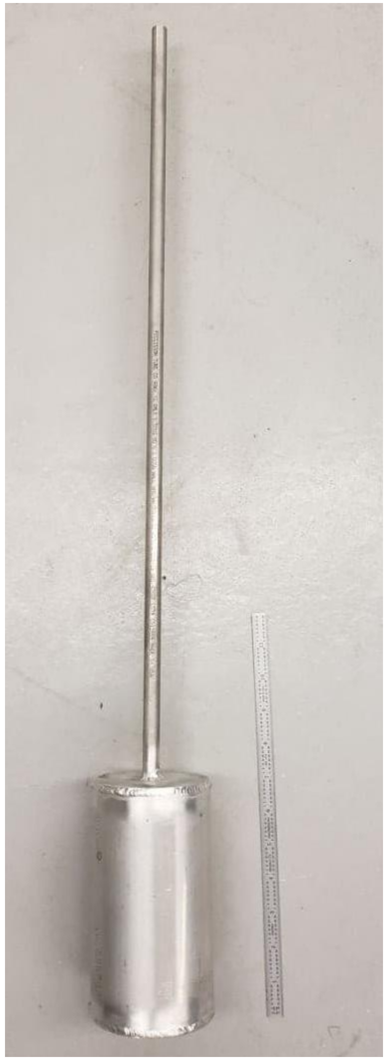


Direct Extrusion

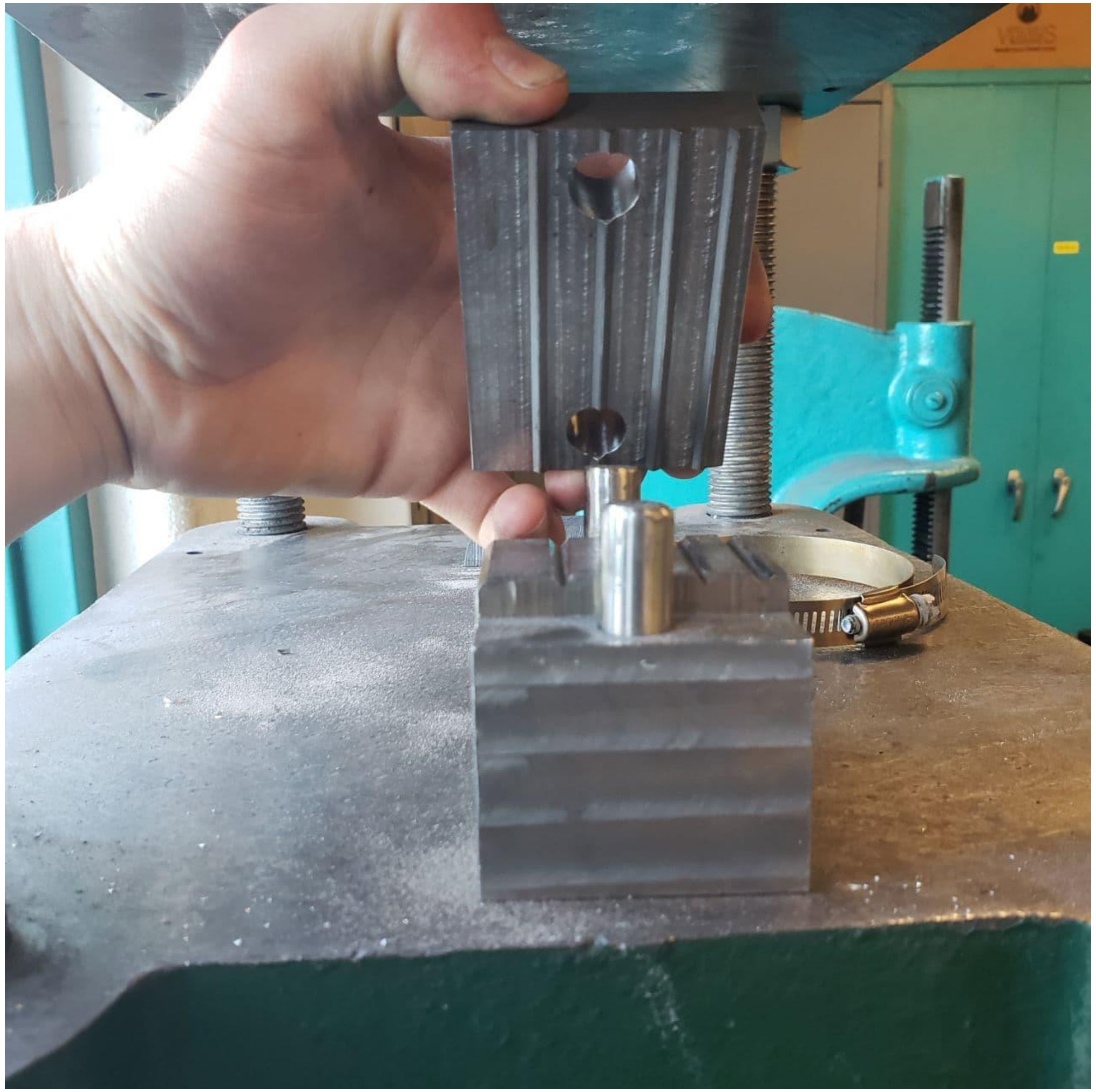


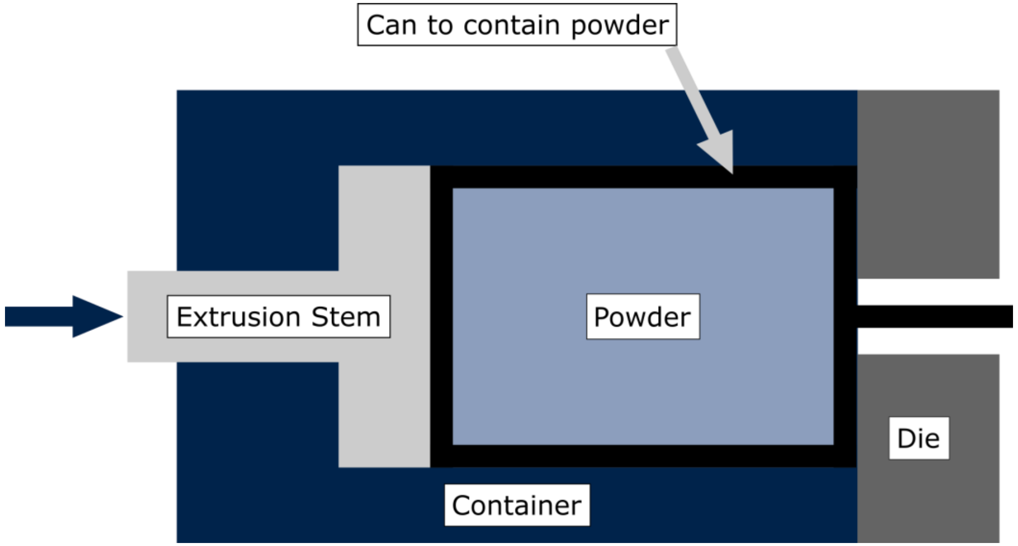


Direct Extrusion



Direct Extrusion





550 Ton Press

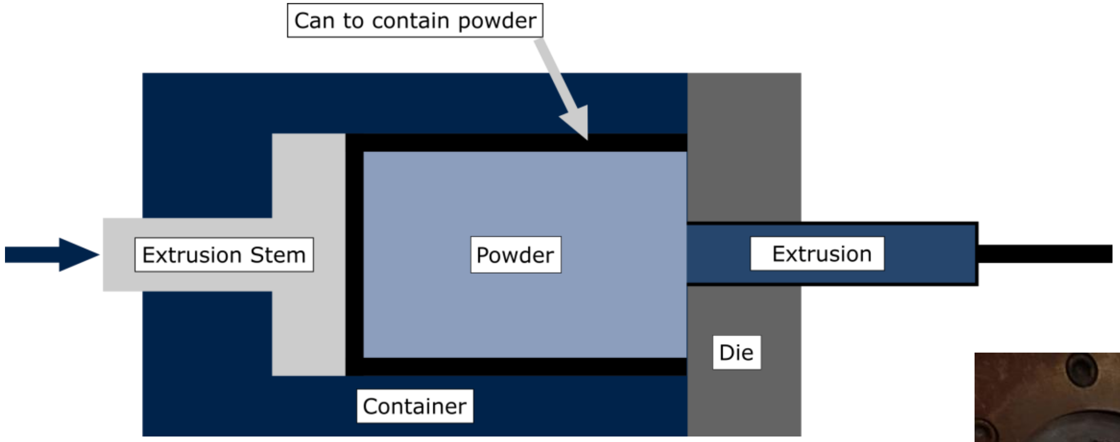
Center Proprietary – Terms of CANFSA Membership Agreement Apply

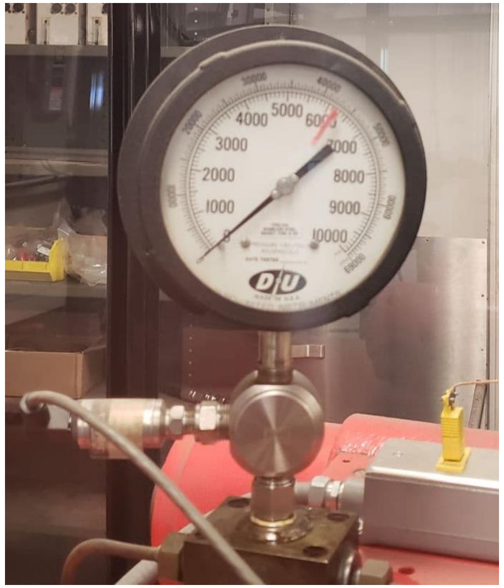
Direct Extrusion Conditions

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*

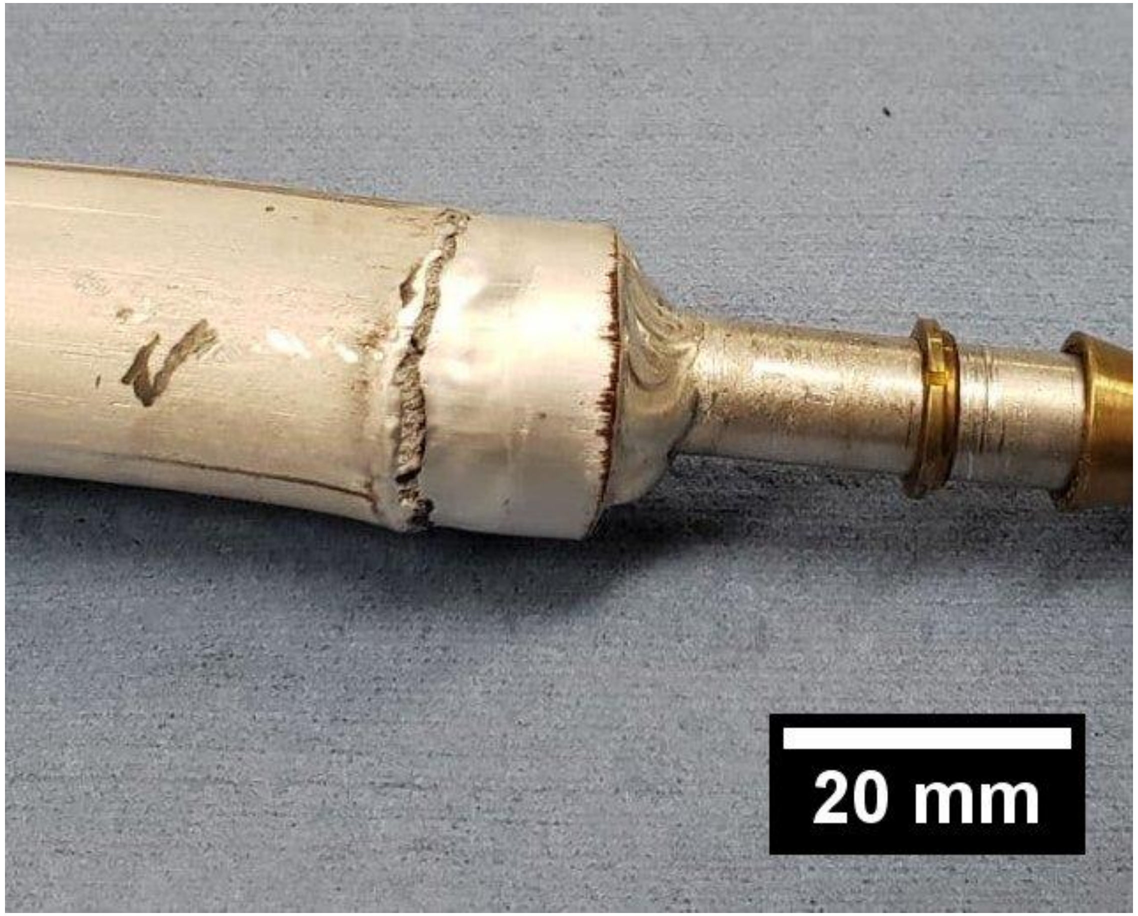
*Difficulties loading can into extrusion chamber, external thermocouple dropped 50C before loading

Direct Extrusion

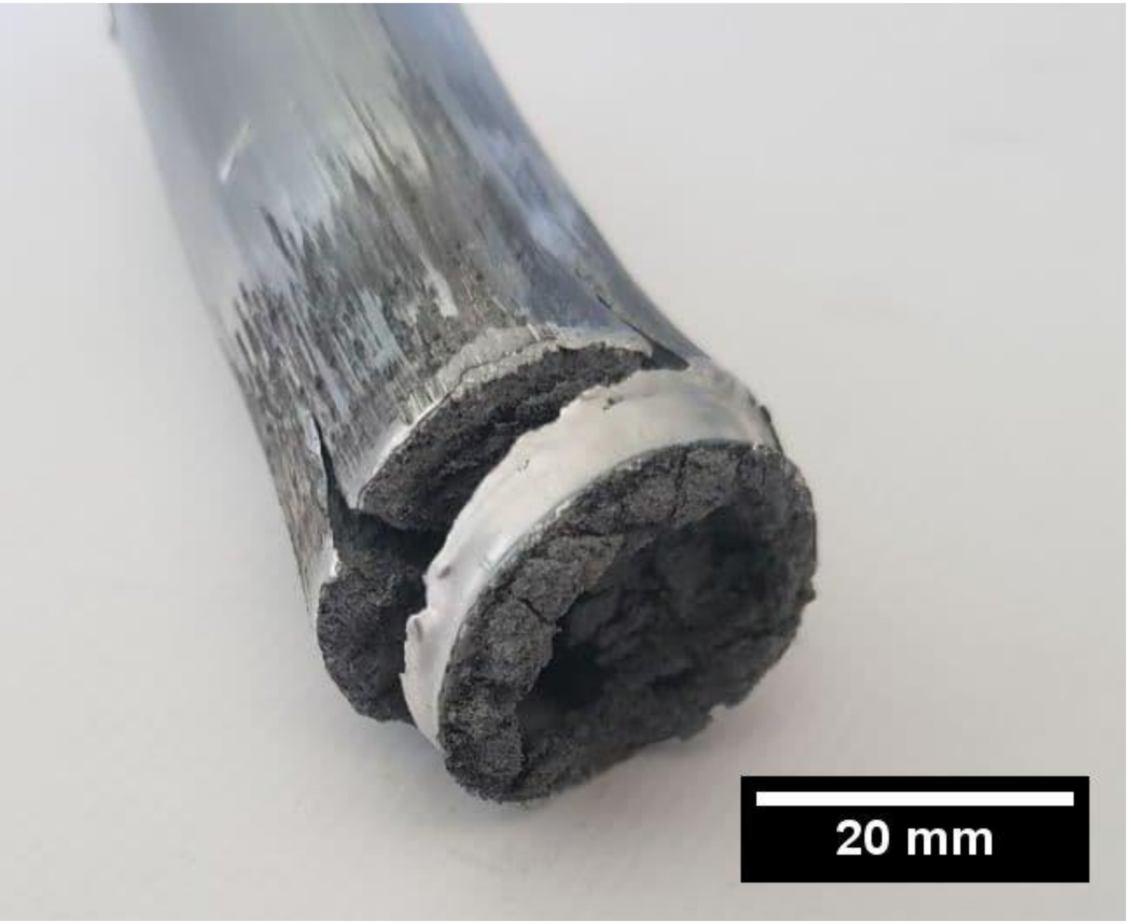




Extrusion Start

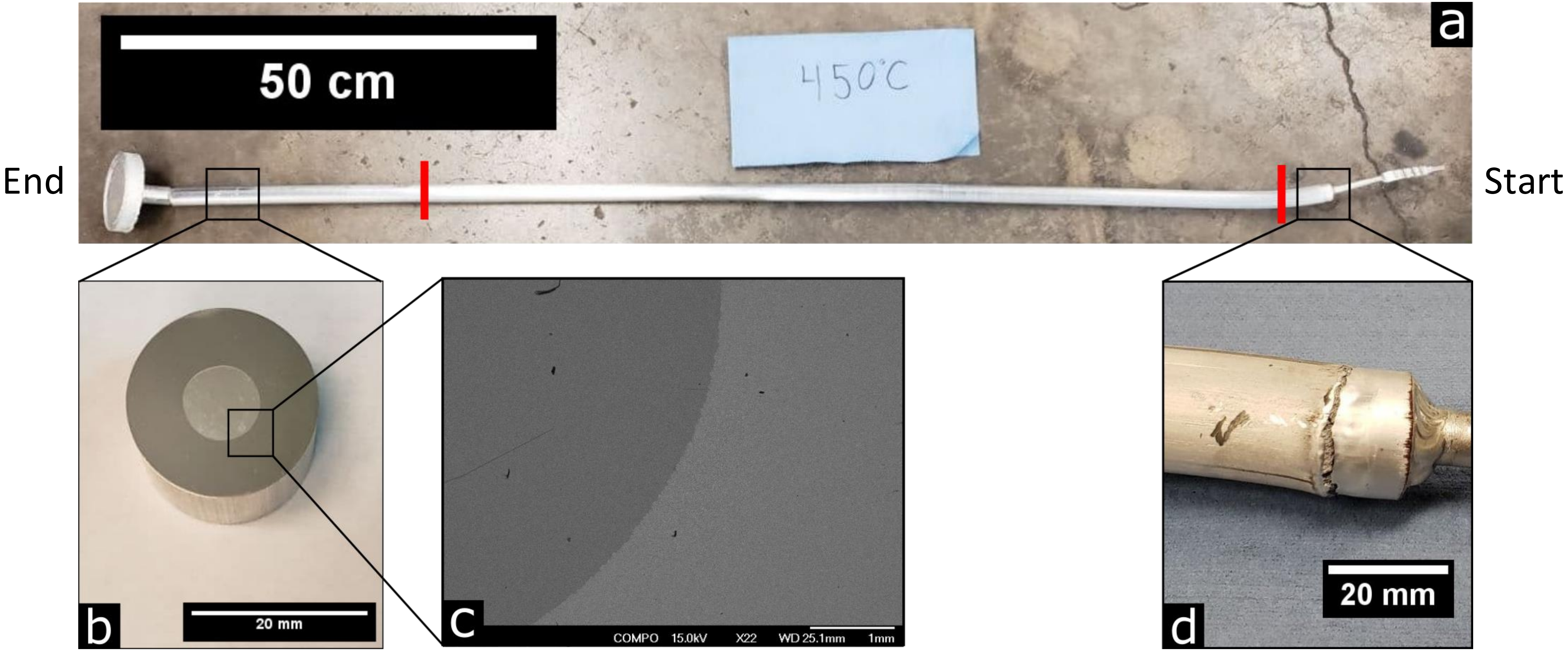


425°C extrusion temperature 16:1 ER

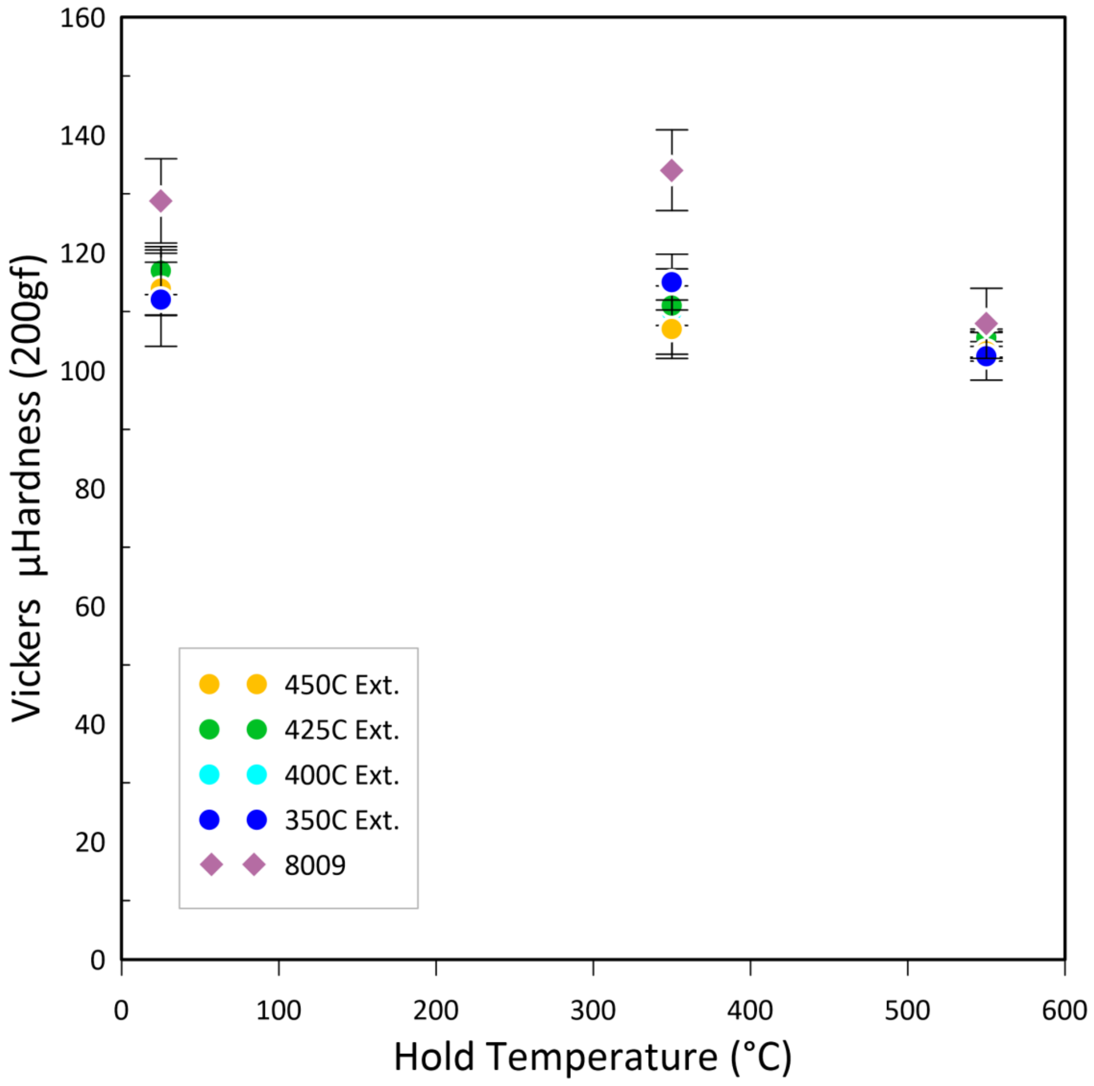


350°C extrusion temperature 10:1 ER

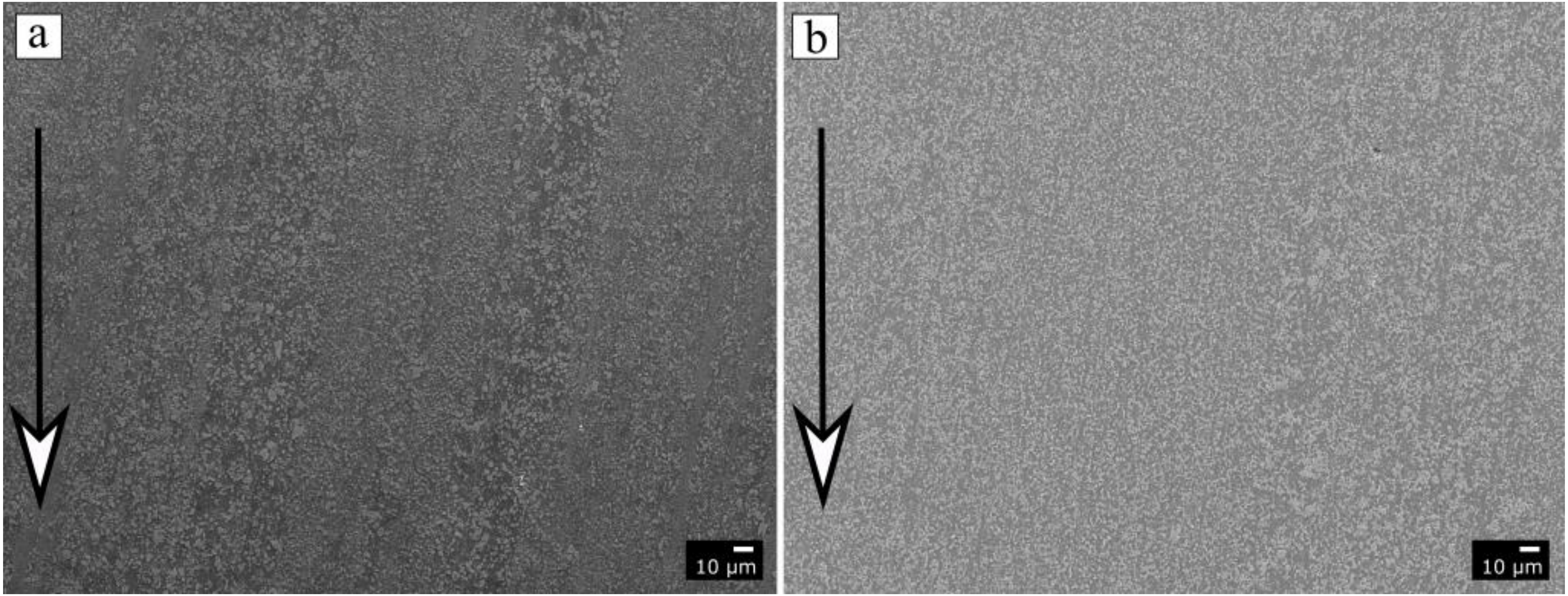
Sound Extrusions



Al-TM Alloys Maintain Hardness After Annealing at 550C



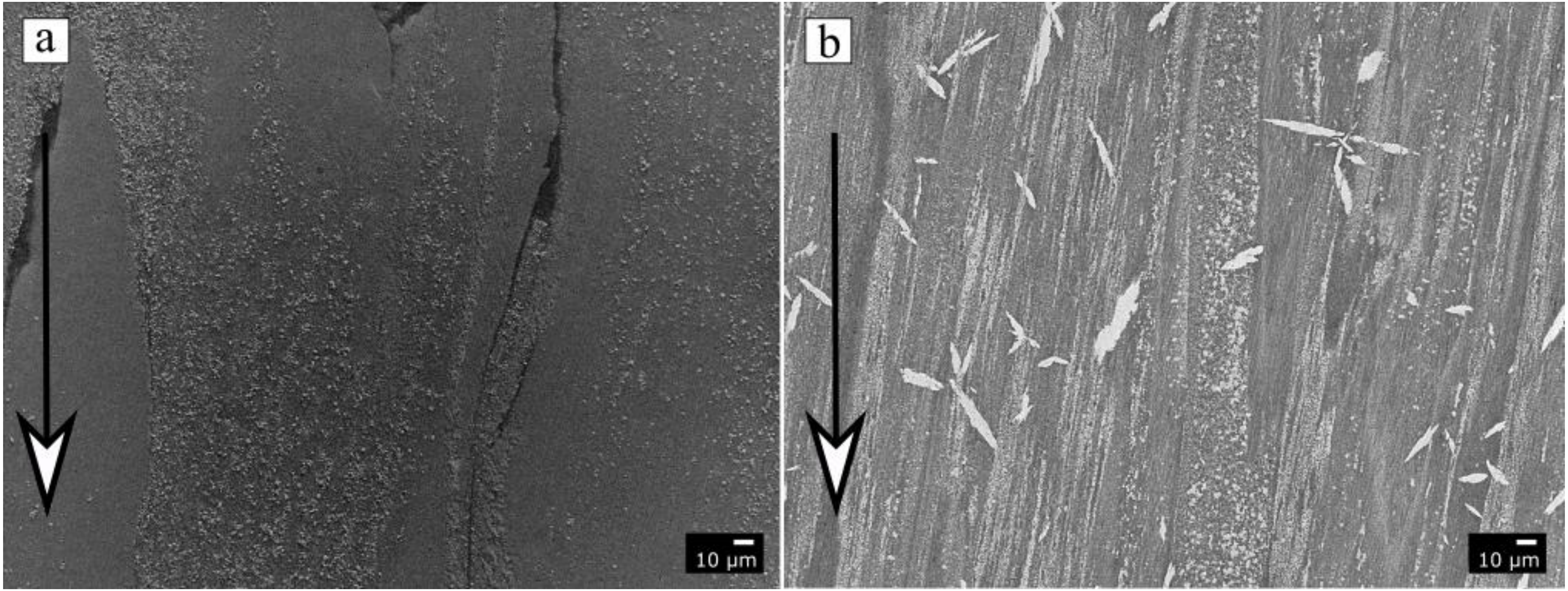
Al-TM



As Extruded

550°C hold 100 hours

8009 Secondary Phases Significantly Coarsen



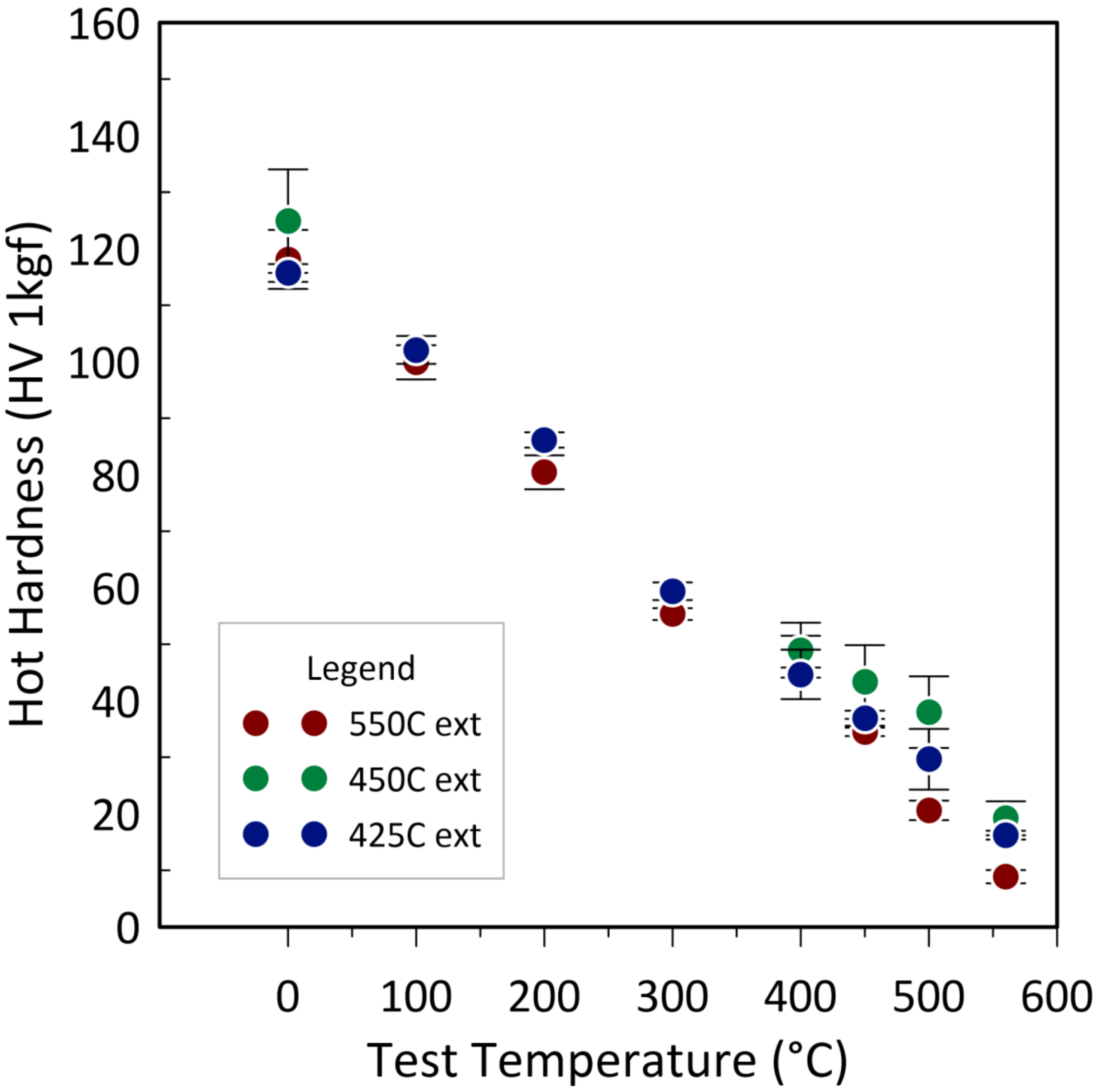
As Extruded

550°C hold 100 hours

Vickers Hot Hardness

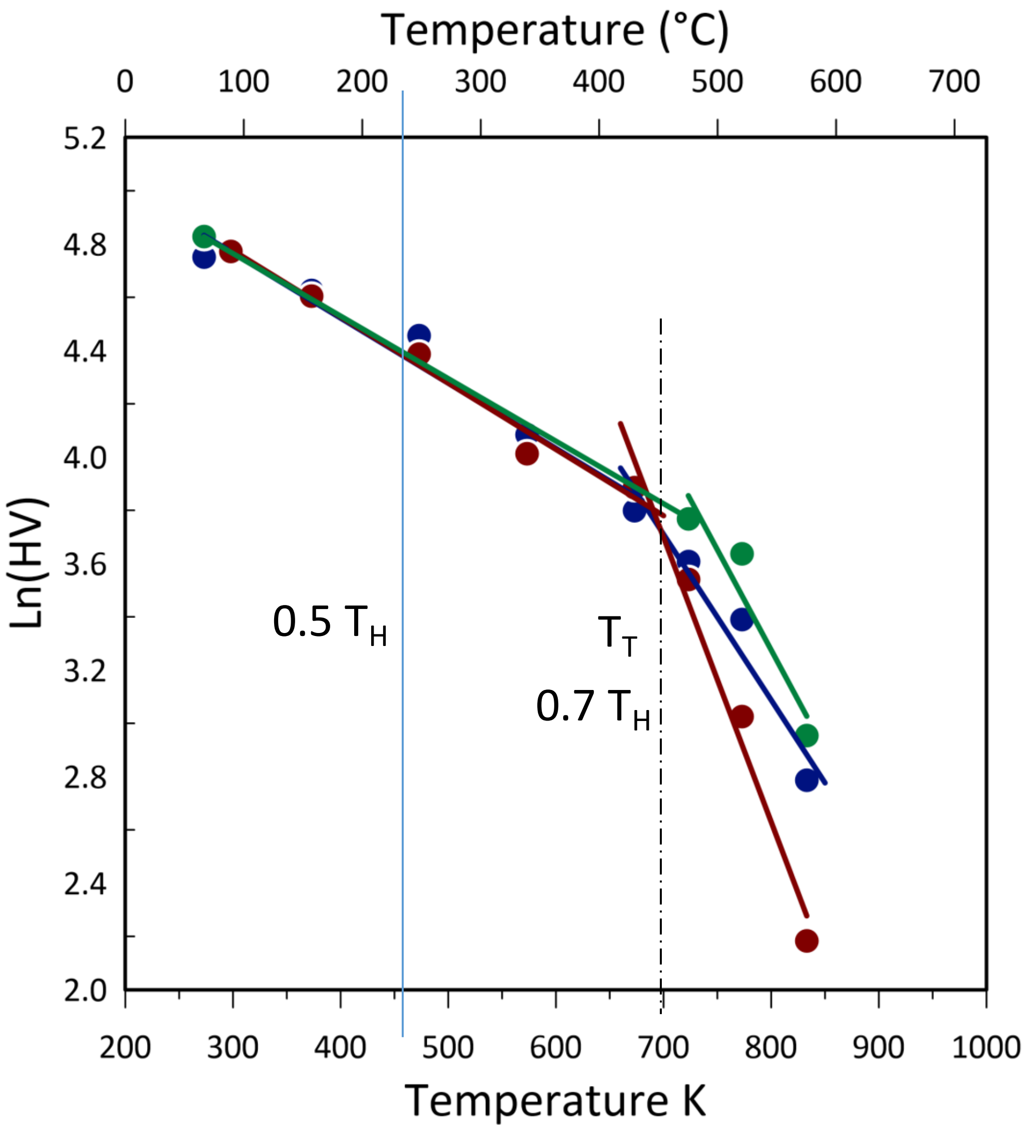
- 25°C to 600°C open atmosphere
- K-type Thermocouple attached to sample
- Sample held for 10 minutes at temperature
- Minimum of 3x indent diameter between indents and edge of sample

Hot Hardness



- Average of 10 indents
- One standard deviation

Al-TM Delays Transition to Dislocation Climb

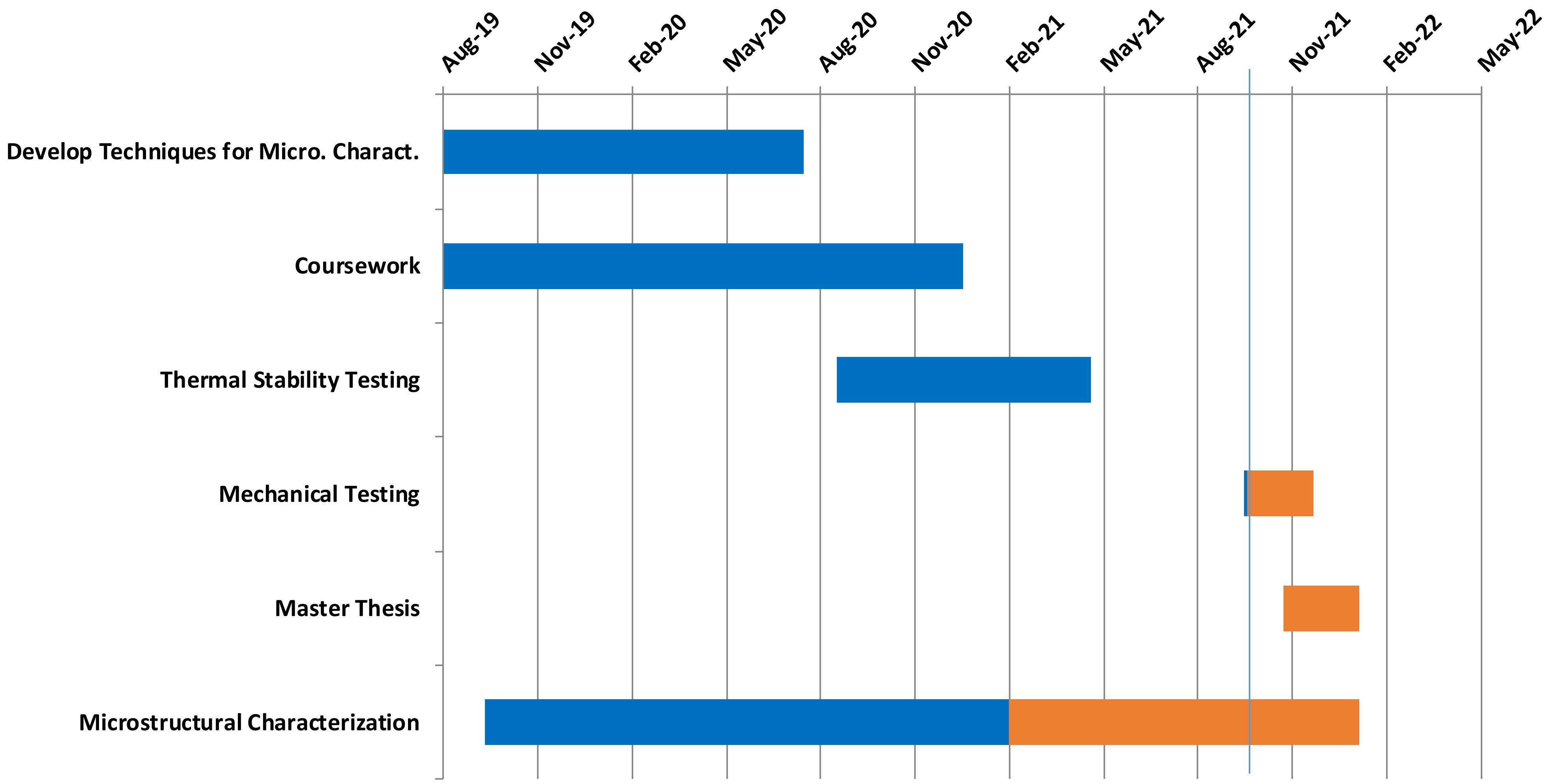


Melting temperature for Al-TM determined via DSC

Challenges & Opportunities

- Elevated temperature Tensile and Compression testing
- Thesis writing

Gantt Chart



Aug-19
Nov-19
Feb-20
May-20
Aug-20
Nov-20
Feb-21
May-21
Aug-21
Nov-21
Feb-22
May-22
Develop Techniques for Micro. Charact.
Coursework
Thermal Stability Testing
Mechanical Testing
Master Thesis
Microstructural Characterization

Summary

- Extrusion
  - Successful extrusion from 350-450°C
  - Minor coarsening occurring in Al-TM alloy leading to a retention in hardness
- Hot Hardness indicates good tensile and creep properties

Acknowledgements

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- 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.
- Michigan Technological University for extrusion and hot hardness testing
- Friction stir extrusion material was provided for this project by Scott Whalen, Pacific Northwest National Laboratories.
- Forgings and project support provided by Rob Mayer, Queen City Forge.
- Deform™ simulations provided by Suzanne Tkach, Tkach Metal Forming Consultants. Jim Miller & Scientific Forming Technologies for the use of Deform™.

Questions?

Thank you!

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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.
- AFSD billets are to be produced by research groups at Virginia Tech under Dr. Hang Yu and University of Alabama under Dr. Paul Allison.
- Friction stir extrusion material was provided for this project by Scott Whalen, Pacific Northwest National Laboratories.
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- 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

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Thermal Stability

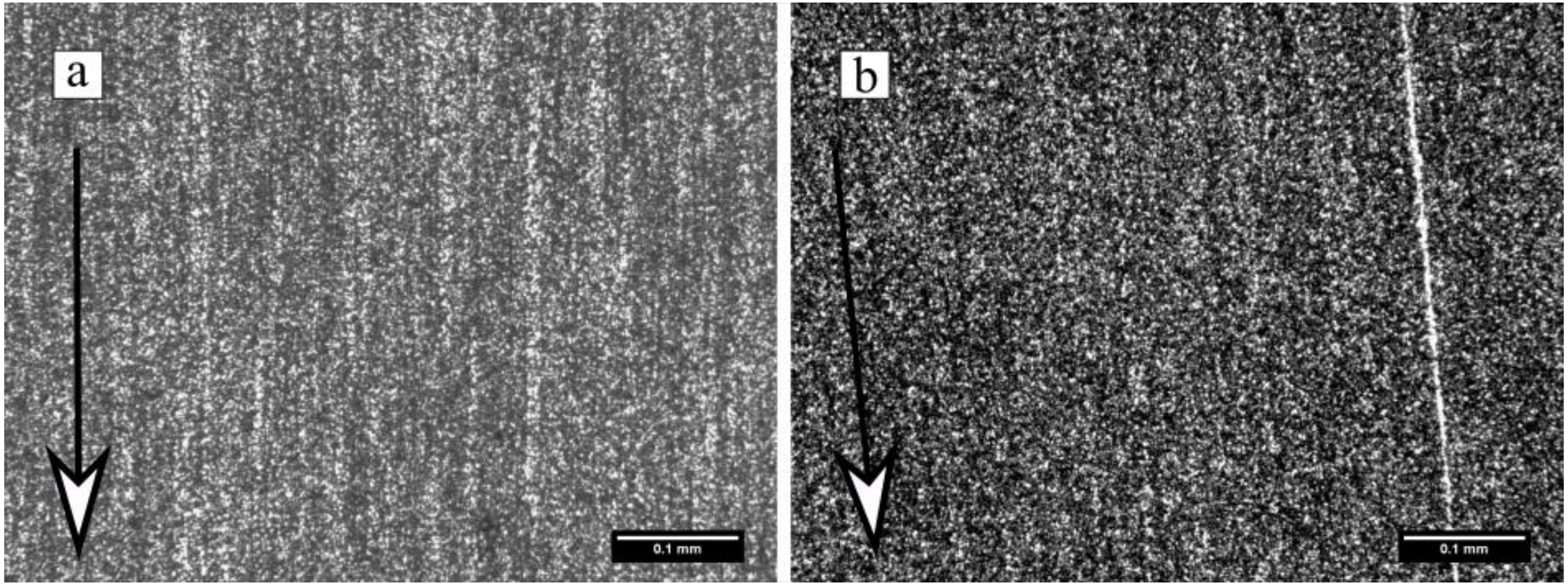
- 1 hour thermal stability test

TEMP FOR 1HR (°C)	200	300	350	400	450	500	550
EXTRUDED							

- 100 hour long time treatment

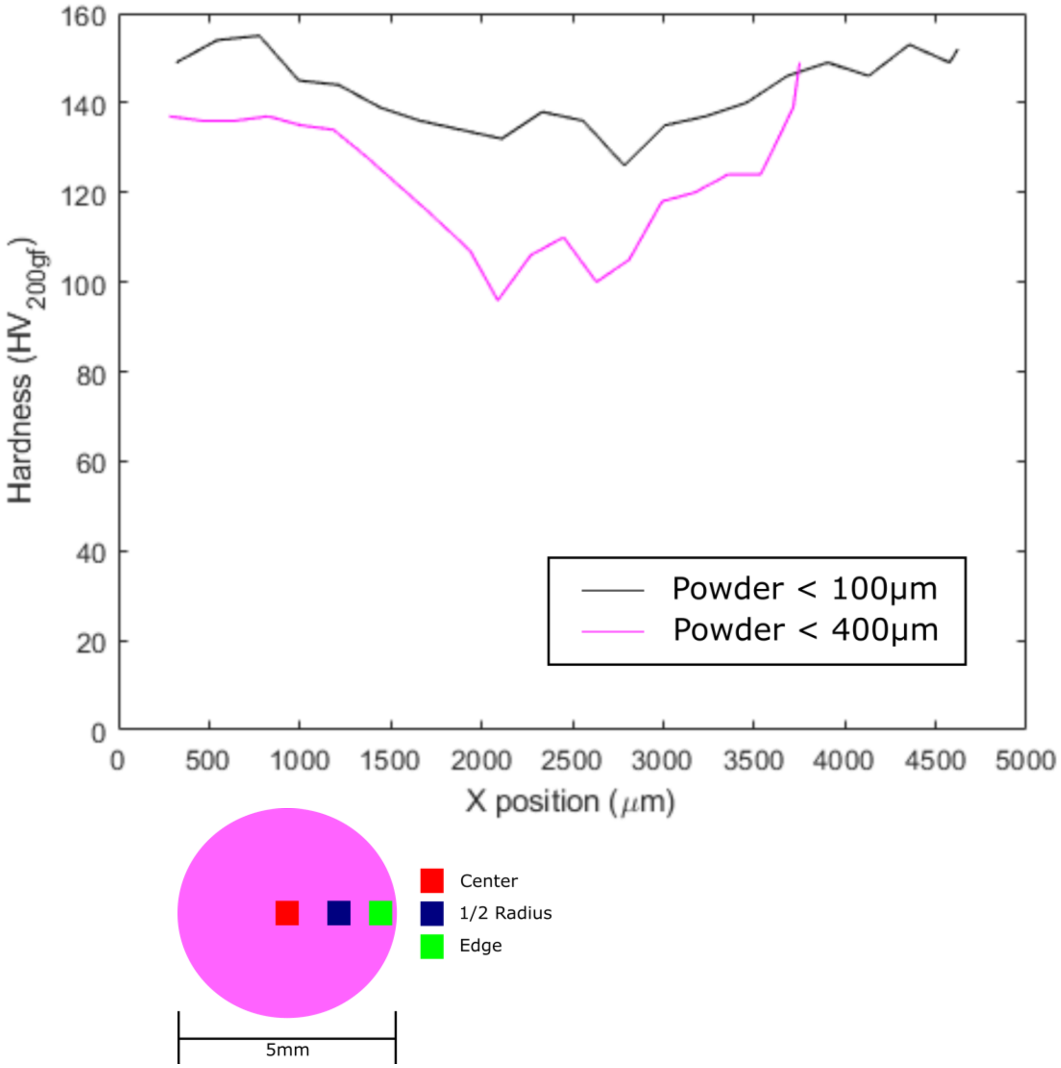
TEMP FOR 100HR (°C)	200	300	400	500
EXTRUDED				

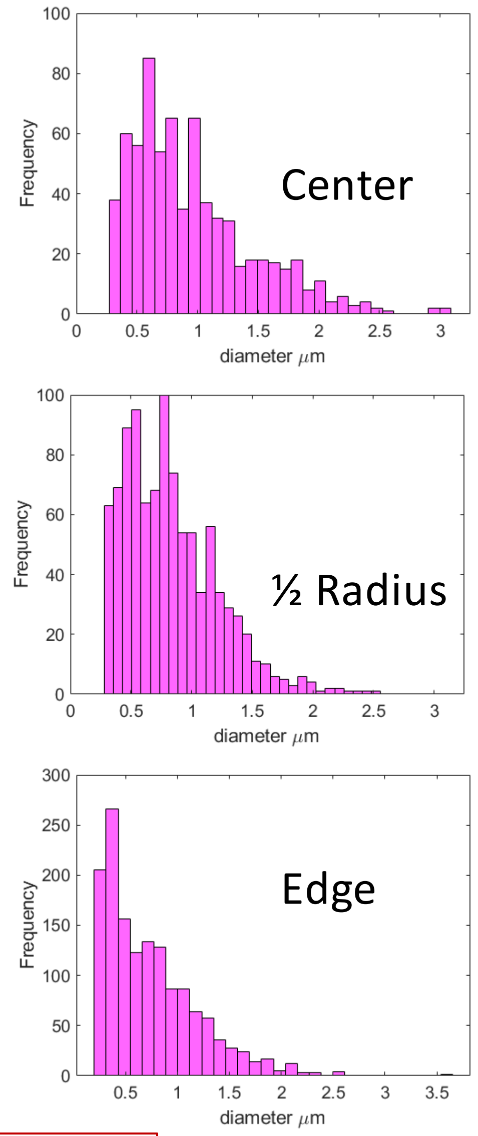
Thermal Stability Microstructure



Light optical microscope image of 17:1 extrusion etched with Keller's reagent; extrusion direction indicated with arrow. A) Microstructure of the extrusion in the as received condition. B) Microstructure of the extrusion after 100 hours at 500°C showing little change in grain size or morphology. Scale bar 0.1mm

FSE hardness





Direct Extrusion Conditions

Temperature (°C)	Extrusion Ratio	Tension (quasi-static)	Compression
350	10:1	25C,300C	ε̇:0.01,0.1,1,10 Temp: 400°C-550°C
400	16:1		ε̇:0.01,0.1,1,10 Temp: 400°C-550°C
400, 350 pre compact	16:1	Temp:25°C*not enough material	Could make a few compression
425	16:1	Temp:25°C,200°C,300°C,400°C,500°C	
450	16:1	Temp:25°C,350°C,450°C	
550	25:1	Temp:25°C,200°C,300°C,400°C,500°C	ε̇:0.01,0.1,1,10 Temp: 400°C-550°C