Center for Advanced Non-Ferrous Structural Alloys

An Industry/University Cooperative Research Center

Project 31-L: Accumulative Roll Bonding of Al and Ti Sheets Toward Low Temperature Superplasticity

Fall Meeting
October 2019

- Student: Brady McBride (Mines)
- Faculty: Dr. Kester Clarke (Mines)
- Industrial Mentors: Ravi Verma (Boeing), John Carpenter (LANL)

Project 31-L: Accumulative Roll Bonding of Al and Ti Sheets Toward Low Temperature Superplasticity

CANFSA
CENTER FOR ADVANCED NON-FERROUS STRUCTURAL ALLOYS

- Student: Brady McBride (Mines)
- Advisor(s): Kester Clarke (Mines)

Project Duration
PhD: September 2017 to March 2021

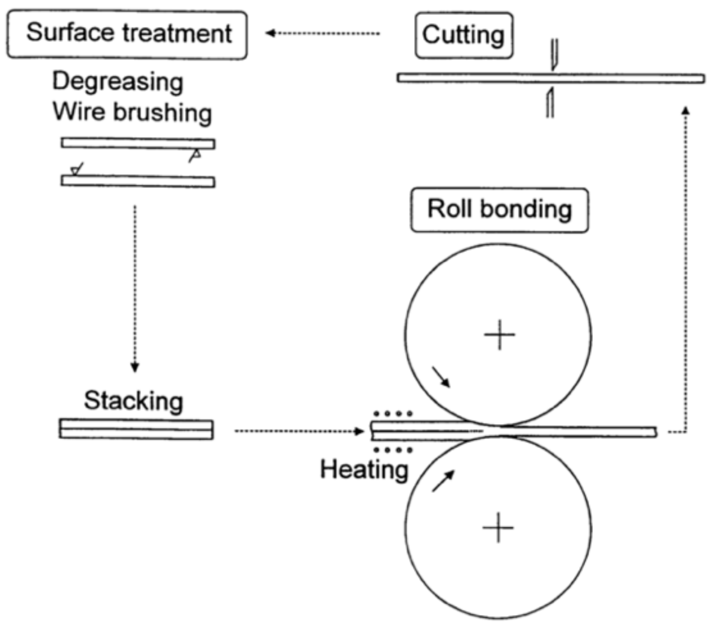
- Problem: Superplastic forming requires high temperatures and very low strain rates.
- Objective: Develop an in-depth understanding of how accumulative roll bonding affects temperature dependent strength and superplastic properties of Al and Ti alloys.
- Benefit: Low temperature superplasticity could result in reduced cost and cycle time due to reduced deformation temperatures and increased strain rates.

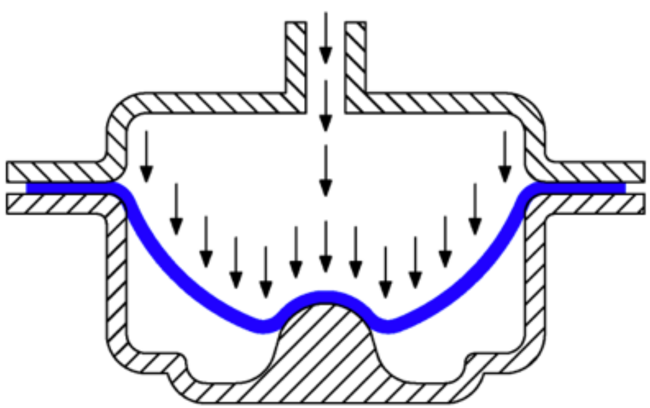
Recent Progress
- Investigation of lateral constraint to reduce edge cracking in narrow samples
- Demonstrated enhanced superplasticity of Al 5083 after 5 ARB cycles
- Trial roll-bonding wider (~3.5”) sheets of 5083 at Los Alamos National Laboratory (LANL)

Metrics

Description	% Complete	Status
1. Literature review	65%	●
2. ARB process development	100%	●
3. Tensile testing for superplasticity	5%	●
4. Microstructural characterization (grain refinement, HT microstructural evolution)	5%	●
5. Process refinement / alloy selection for optimized superplasticity	0%	●

Industrial Relevance





Enhanced properties:

- Hall-Petch strengthening
- low temperature superplasticity

Applications:

- superplastic forming
- high strength sheet components

Benefits:

- reduced cycle time
- reduced die wear
- reduced processing cost

Saito et al., *Acta Materialia*, 1999.
Cleveland et al., *Materials Science and Engineering A*, 2003.

Project Areas

Material Processing	Microstructural Evolution	Mechanical Properties
Edge Cracking	LAGB to HAGB	RT Properties
Dynamic RX	Grain Refinement	LT, MT, HT Superplasticity
Redundant Shear	Starting Microstructure	Deformation Mechanisms
Bonding Interface	Alloying Effects	Strain Rate Effects
Edge Guides & Lateral Constraint; Surface Preparation Techniques	Surface Preparation for EBSD, TEM	Tensile Setup for Superplasticity, HT

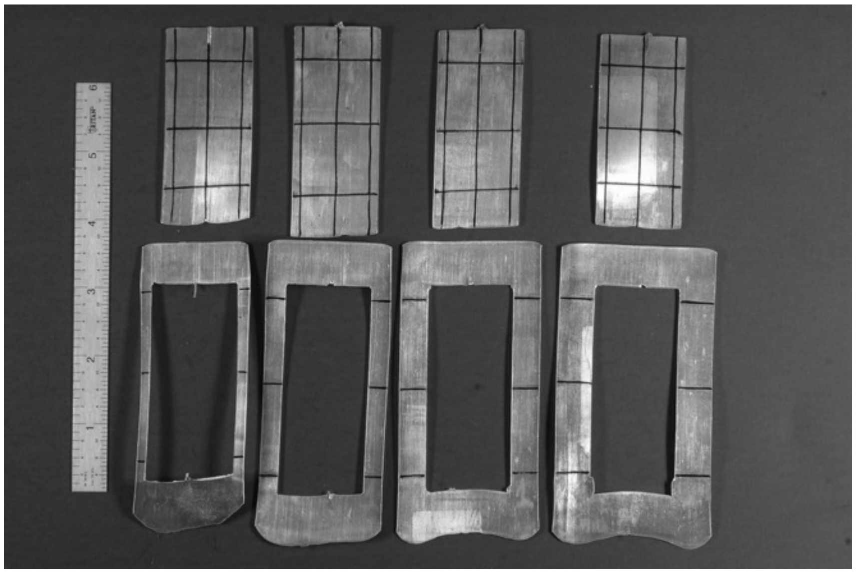
Outline

- Techniques for Edge Crack Mitigation
- Tensile Testing for Superplasticity
- Void Formation during Superplasticity
- Roll Bonding Trials at Los Alamos National Laboratory
- Future Work

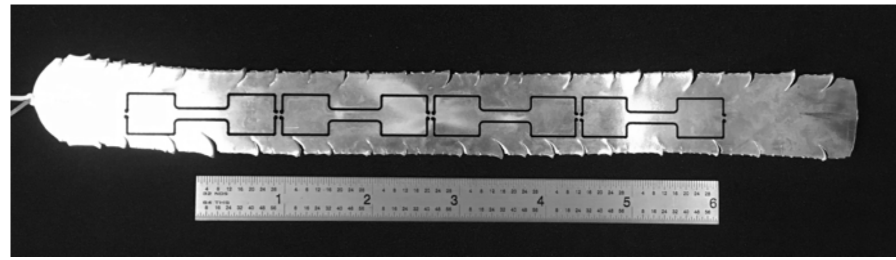
Mitigation of Edge Cracks

CANFSA
CENTER FOR ADVANCED NON-FERROUS STRUCTURAL ALLOYS

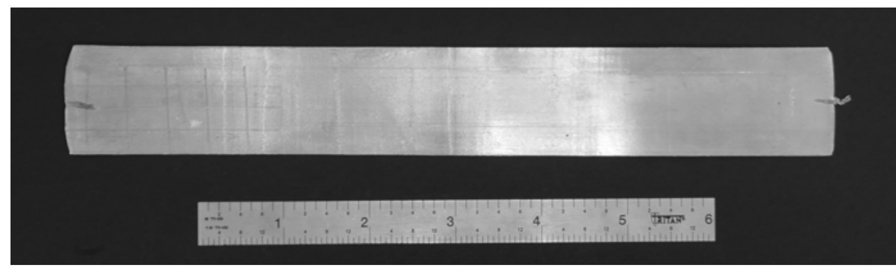
Constraint trials with 1 ARB Cycle



5083 5 ARB – No Constraint

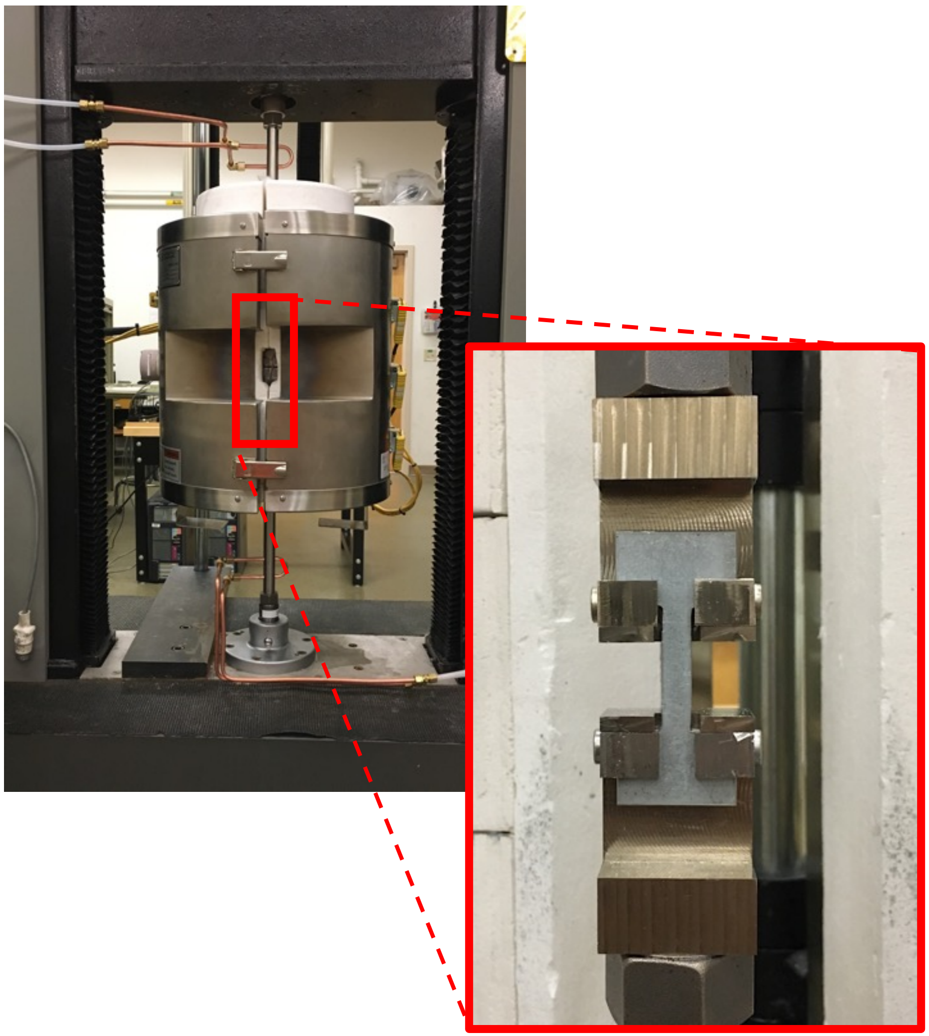


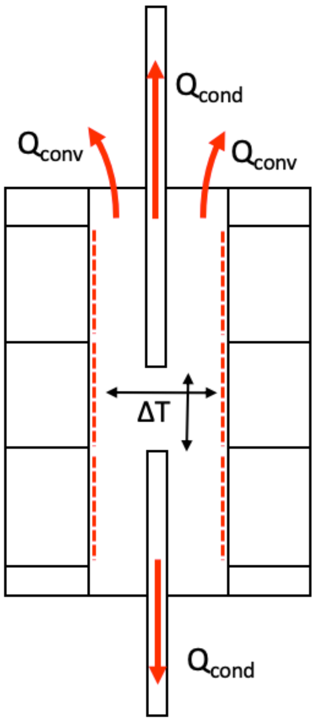
5083 5 ARB – ¼” Constraint



Constraining with sacrificial “windows” reduces edge cracking and enhances straightness

Tensile Testing for Superplasticity

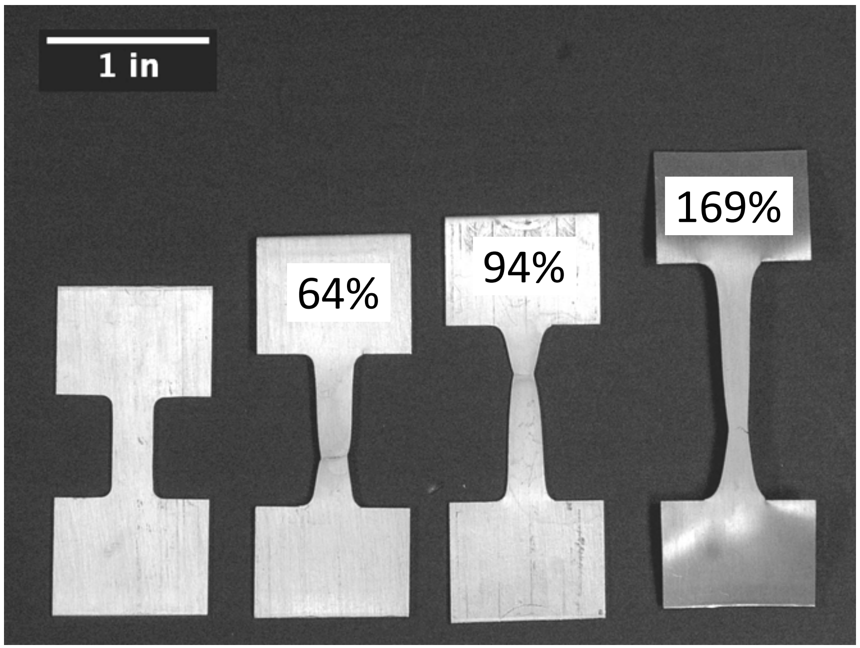




Tensile testing parameters:
- temperature 200 – 500 °C
- constant strain rate, crosshead speed
- 2-step strain rate

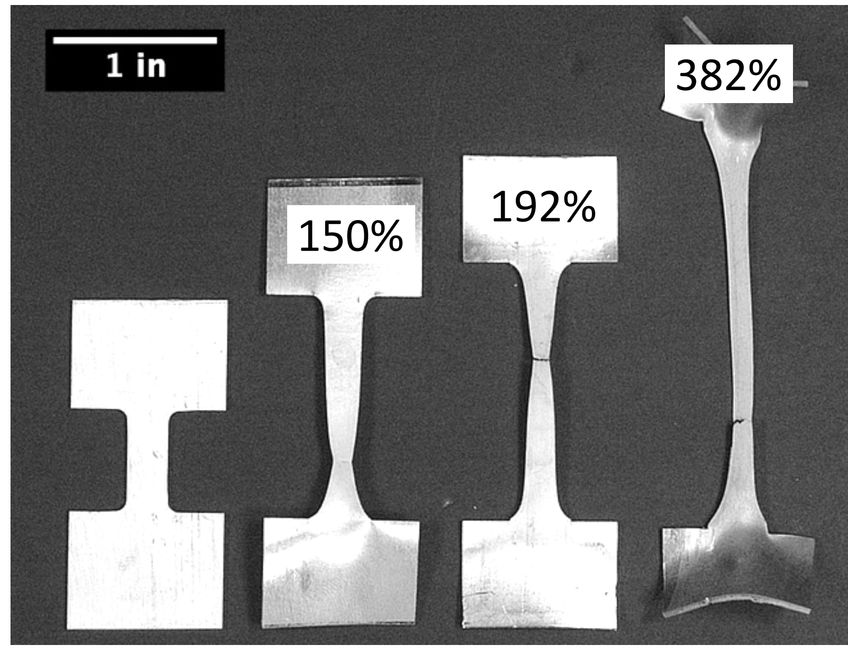
Tensile Testing for Superplasticity

Conventional Superplastic
~15 µm



As Machined 196 °C 290 °C 377 °C

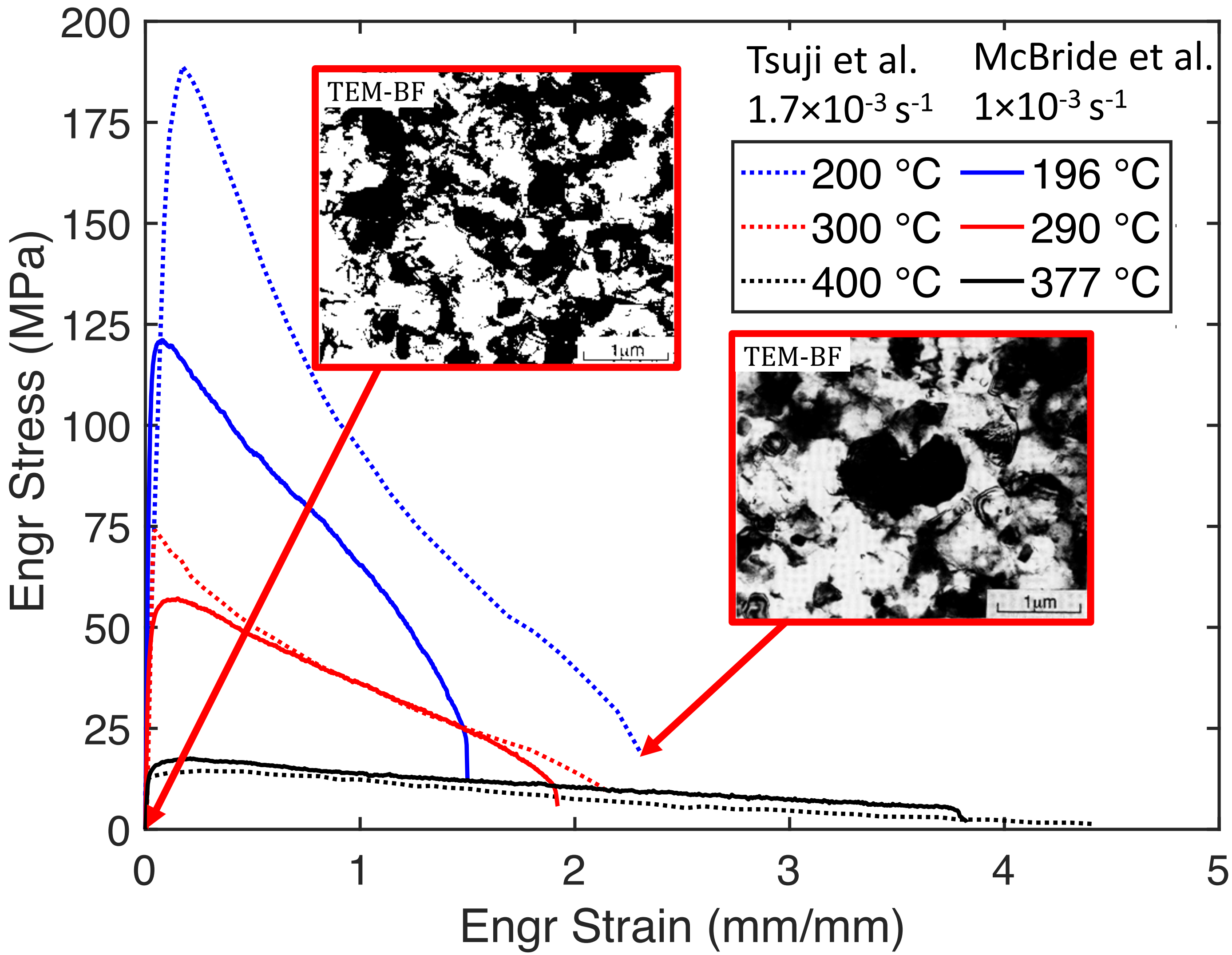
5 Cycles ARB
280 nm x 1 µm x 1 µm



As Machined 196 °C 290 °C 377 °C

Constant crosshead velocity, $\dot{\varepsilon}_0 = 10^{-3}\ s^{-1}$

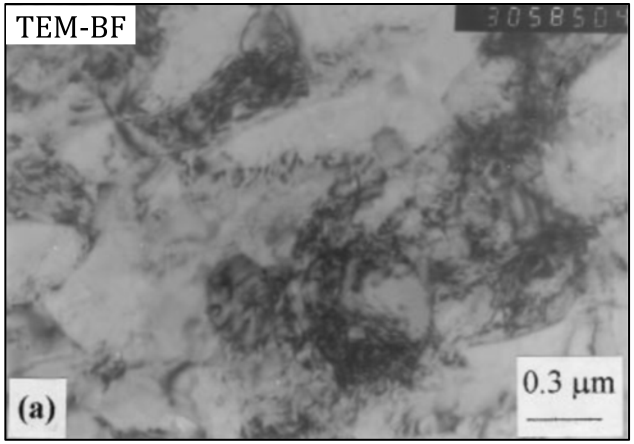
Comparison to Literature: Tsuji et al.



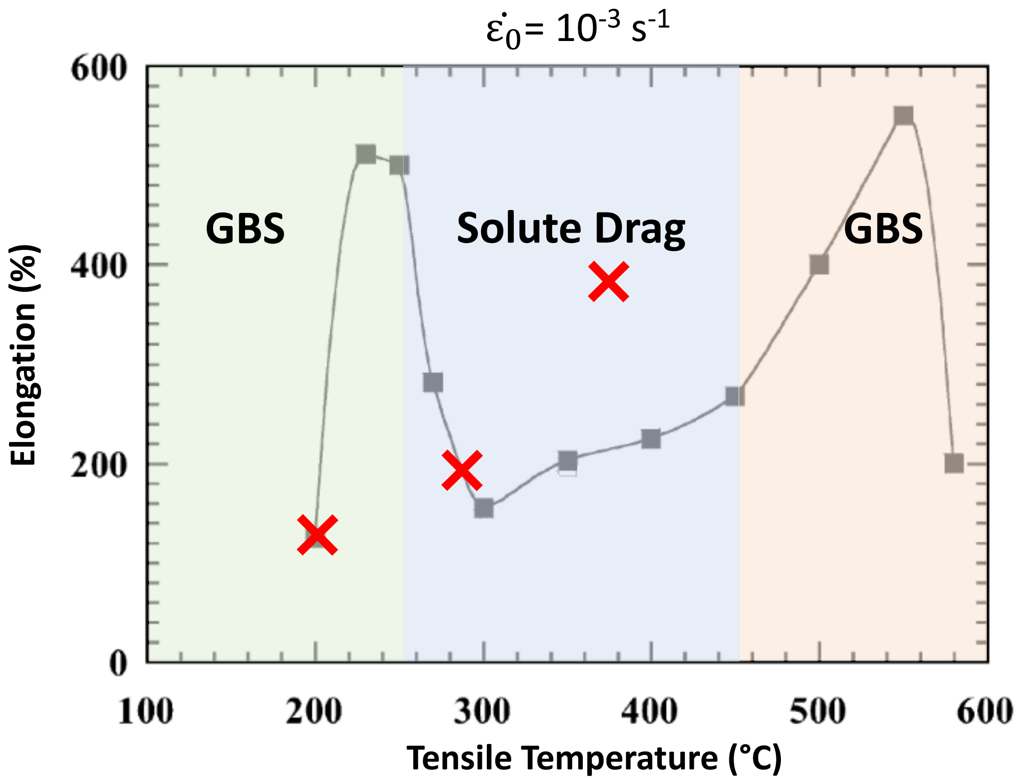
Tsuji et al., *Materials Transactions*, 1999.

Comparison to Literature: Hsiao & Huang

Conventional grain refinement with 98% warm rolling



500 nm 40% HAGB



1µm
80% HAGB

6 - 25 µm

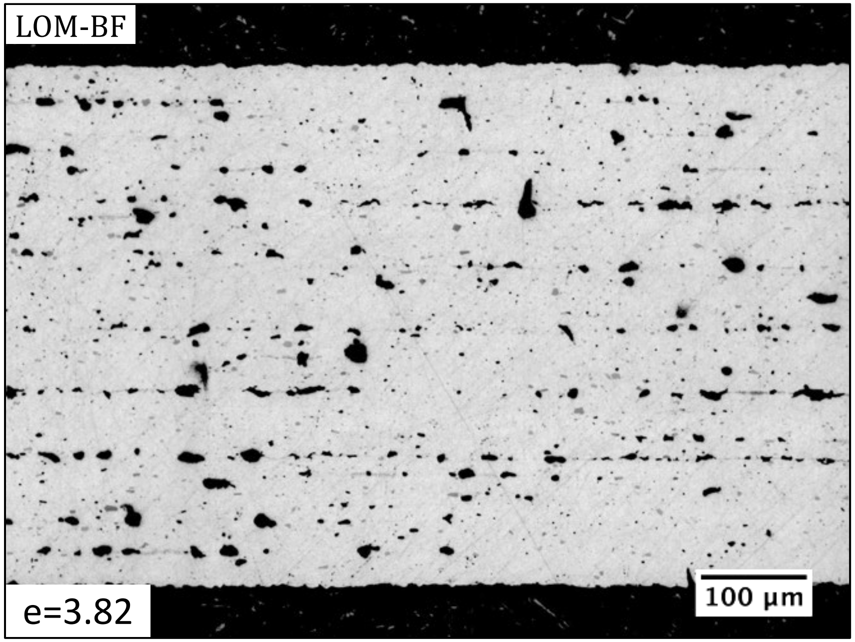
25+ µm (?)

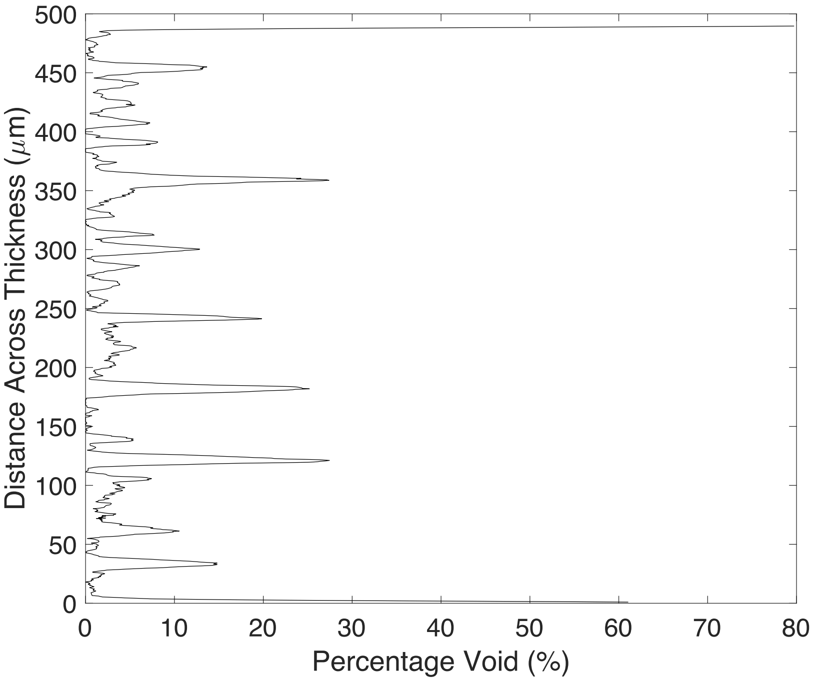
Hsiao & Huang, *Scripta Materialia,* 1999.
Hsiao & Huang, *Met. & Mat. Trans. A, 1999.*

Void Formation during Superplasticity

5083 5ARB

377 °C $\dot{\varepsilon}_0 = 10^{-3}\ s^{-1}$





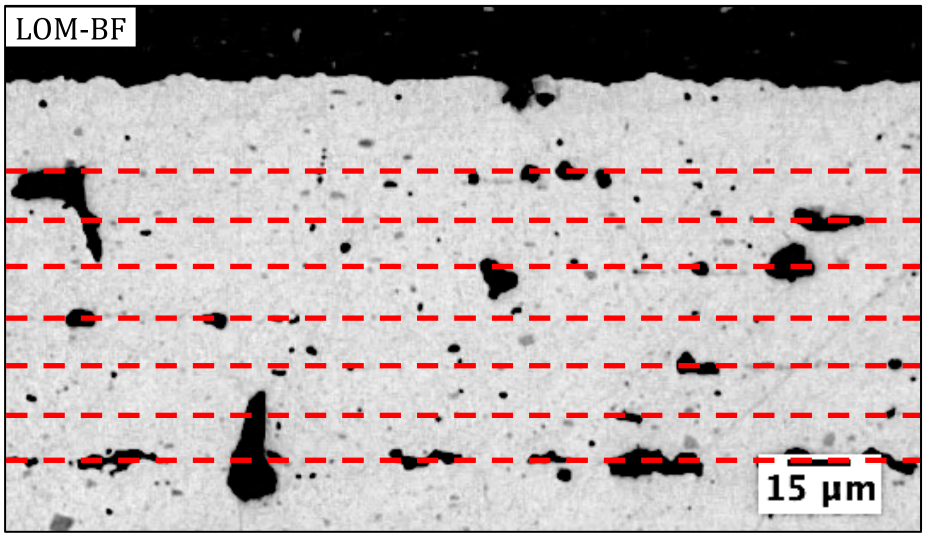
Voids form in elongated bands;

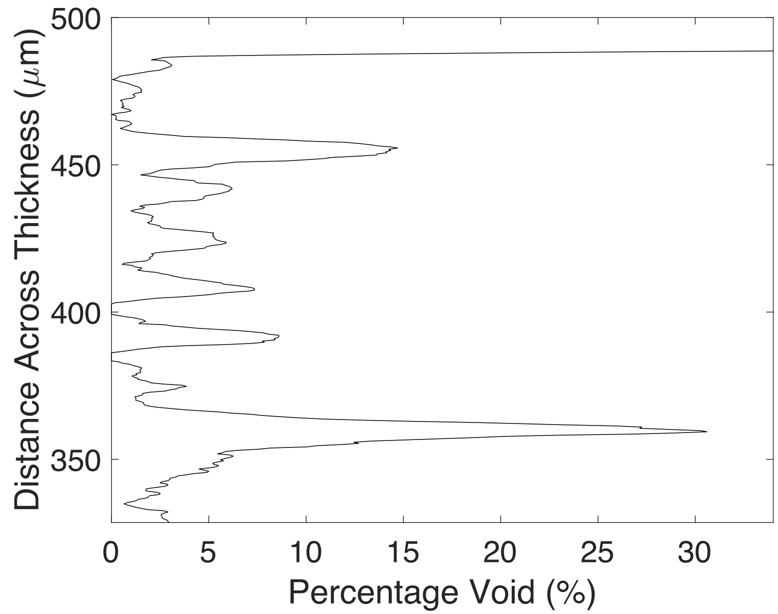
Centerline bond does not have highest void intensity

Void Formation during Superplasticity

5083 5ARB

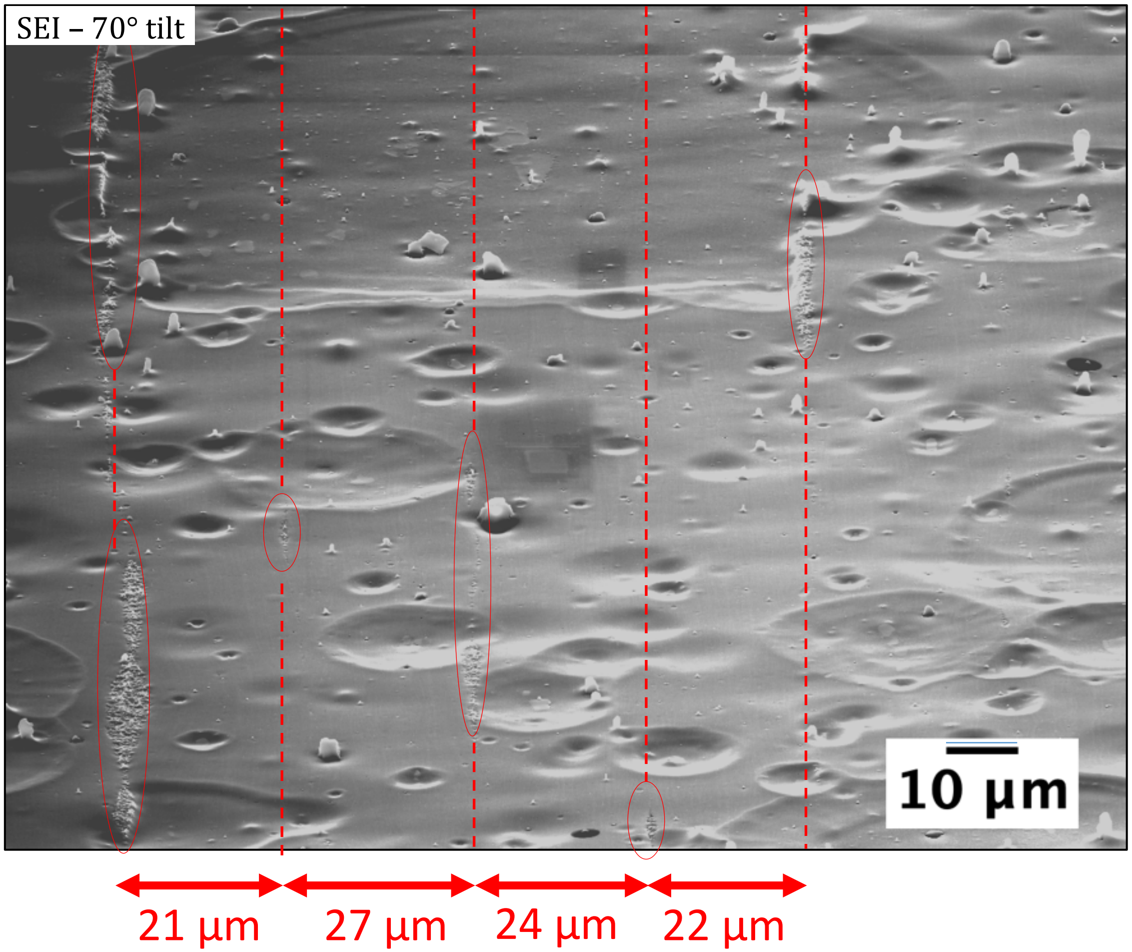
377 °C $\dot{\varepsilon}_0 = 10^{-3}\ s^{-1}$





Voids form in bands spaced 15 µm apart;
minimum layer thickness after 5 ARB cycles

Void Formation during Superplasticity

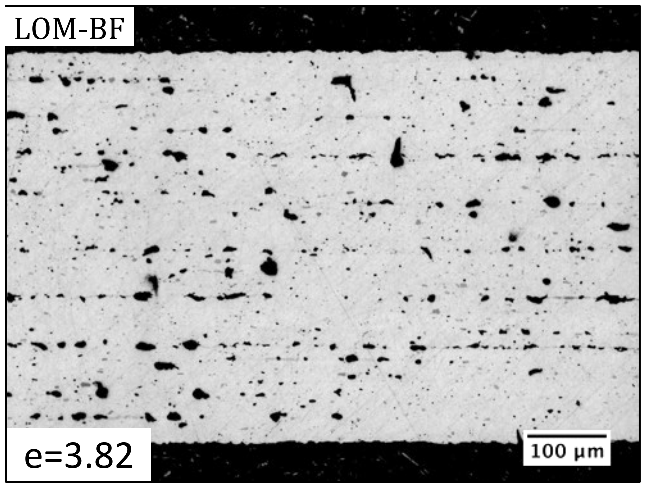


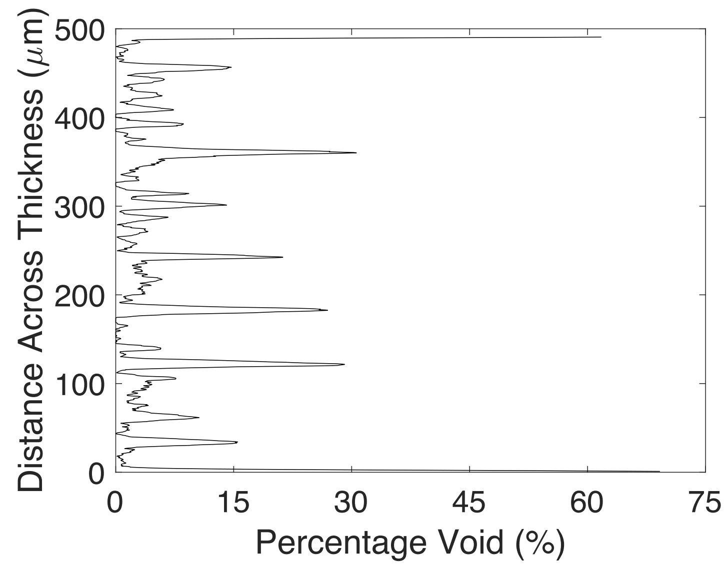
Nominal thickness of layer after 5 cycles:

$$t = \frac{t_o}{2^n} = \frac{1\text{mm}}{2^5} = 31\mu m$$

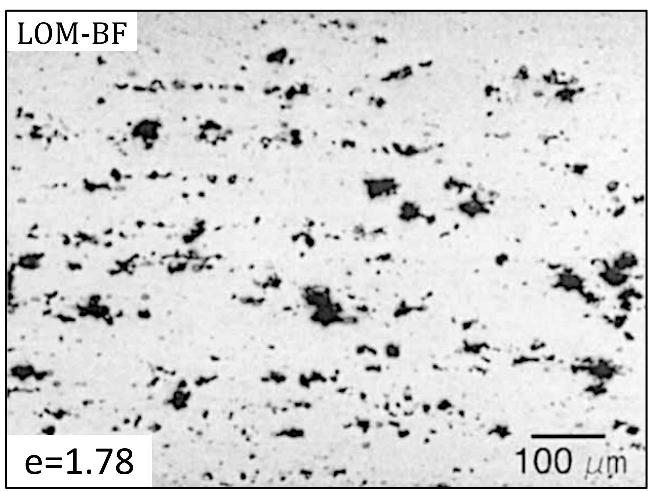
Void Formation in Literature

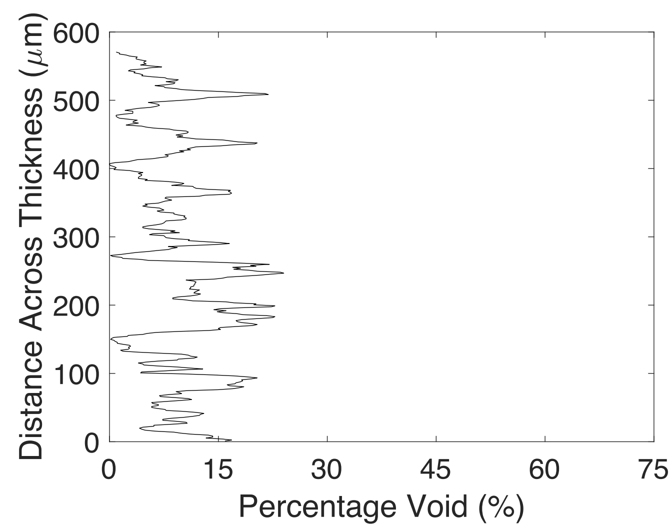
5083 5 ARB
377 °C
$\dot{\varepsilon}_0 = 10^{-3}\ s^{-1}$





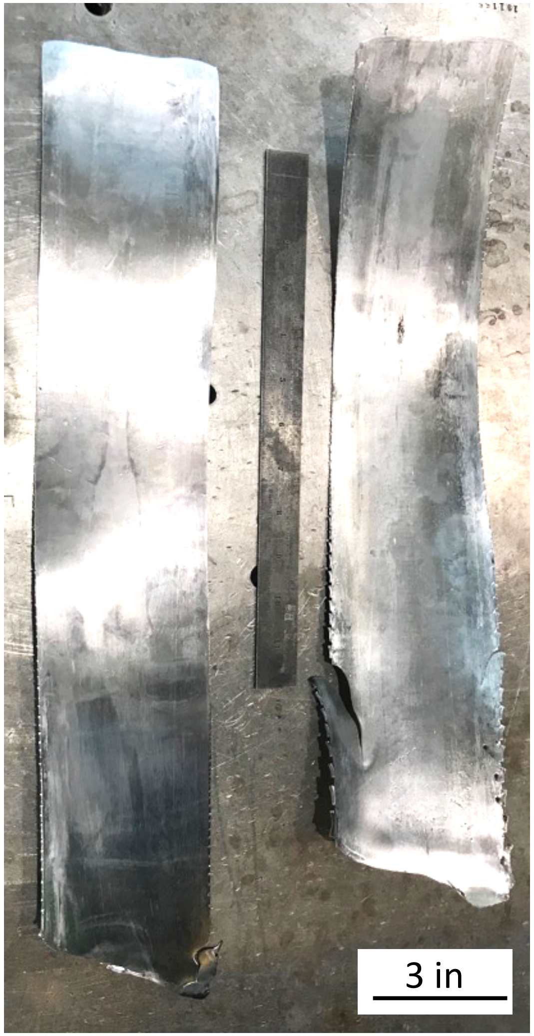
RX 5.6 µm
500 °C
$\dot{\varepsilon}_0 = 10^{-3}\ s^{-1}$





Cleveland et al., *Materials Science and Engineering A*, 2003.

ARB trials at Los Alamos National Laboratory

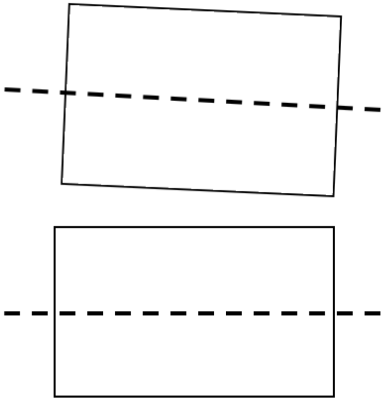


Higher load capacity:

- wider sheets for less edge cracking
- greater sample yield
- roll bond harder materials (Ti)

Larger work rolls:

- more redundant shear



Slight misalignment in rolls leads to significant distortion

Future Work

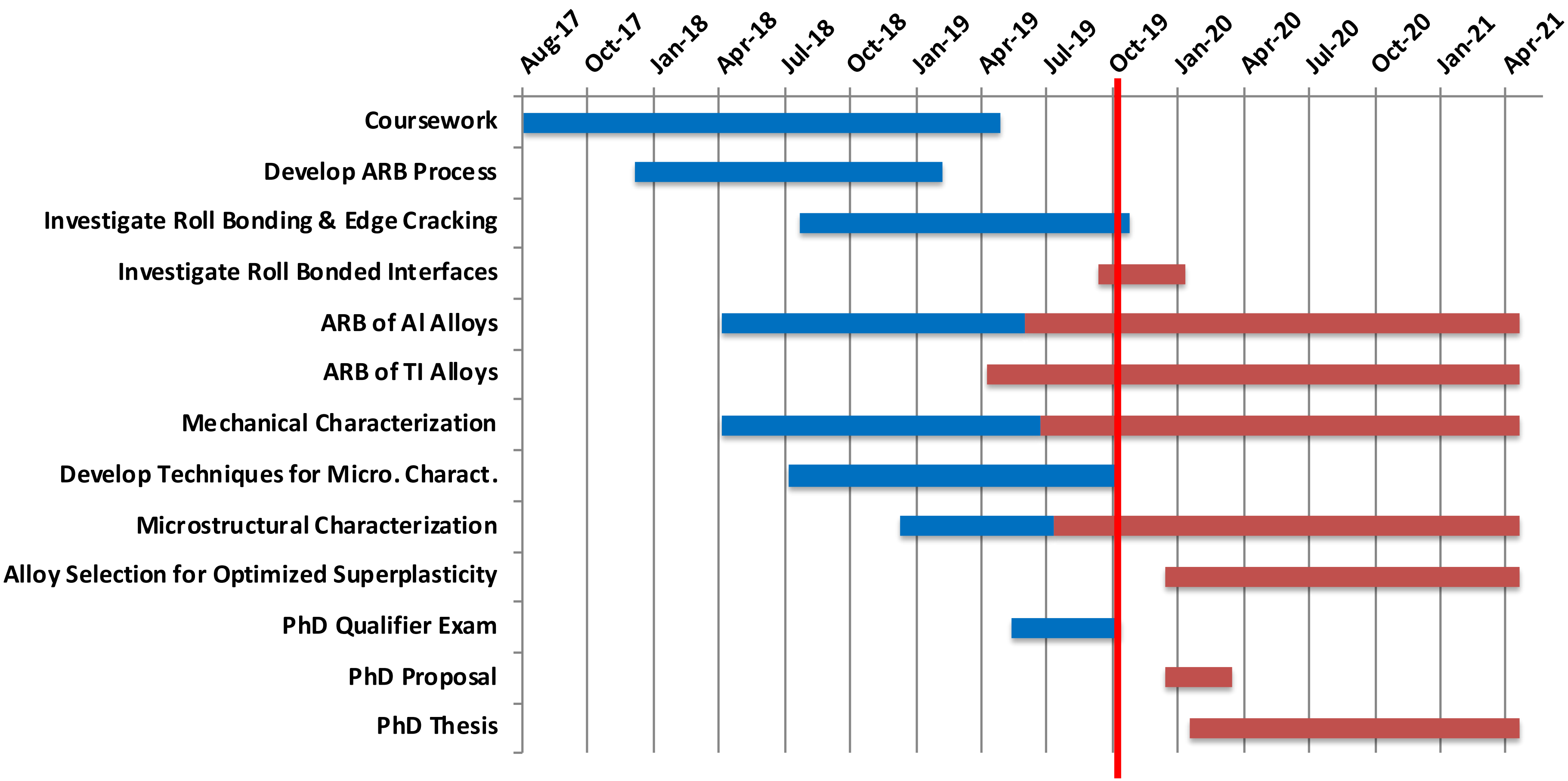
- Microstructural analysis on tensile tested material

- Consider other Al alloys and compositions
  - size and distribution of dispersoids, 2^{nd} phase particles

- Investigate bonding interface development
  - Use FIB lift-outs to characterize bond interface development

- Develop process for larger rolling mill at LANL
  - Wider sheets of Al alloys and Ti alloys

Progress



Aug-17
Oct-17
Jan-18
Apr-18
Jul-18
Oct-18
Jan-19
Apr-19
Jul-19
Oct-19
Jan-20
Apr-20
Jul-20
Oct-20
Jan-21
Apr-21
Coursework
Develop ARB Process
Investigate Roll Bonding & Edge Cracking
Investigate Roll Bonded Interfaces
ARB of Al Alloys
ARB of TI Alloys
Mechanical Characterization
Develop Techniques for Micro. Charact.
Microstructural Characterization
Alloy Selection for Optimized Superplasticity
PhD Qualifier Exam
PhD Proposal
PhD Thesis

Challenges & Opportunities

- Chemical surface preparation of Al, Ti alloys
  - Remove surface oxidation and annealing stains
  - Usually requires dilute Hf solutions in large volumes (wider sheets)
- Access to high capacity rolling mill
  - Adapt existing process for mill at LANL
- Comparison of bonding mechanisms: HIP vs roll bonding
  - Concurrent study with PNNL looking at HIP bonded Al 6061

Thank you!

Brady McBride
bmcbride@mines.edu

References

[1] Y. Saito, H. Utsunomiya, N. Tsuji, and T. Sakai, "Novel ultra-high straining process for bulk materials—development of the accumulative roll-bonding (ARB) process," *Acta Materialia*, vol. 47, no. 2, pp. 579–583, 1999.

[2] R. M. Cleveland, A. K. Ghosh, and J. R. Bradley, "Comparison of superplastic behavior in two 5083 aluminum alloys," *Materials Science and Engineering A*, vol. 351, no. 1-2, pp. 228–236, 2003.

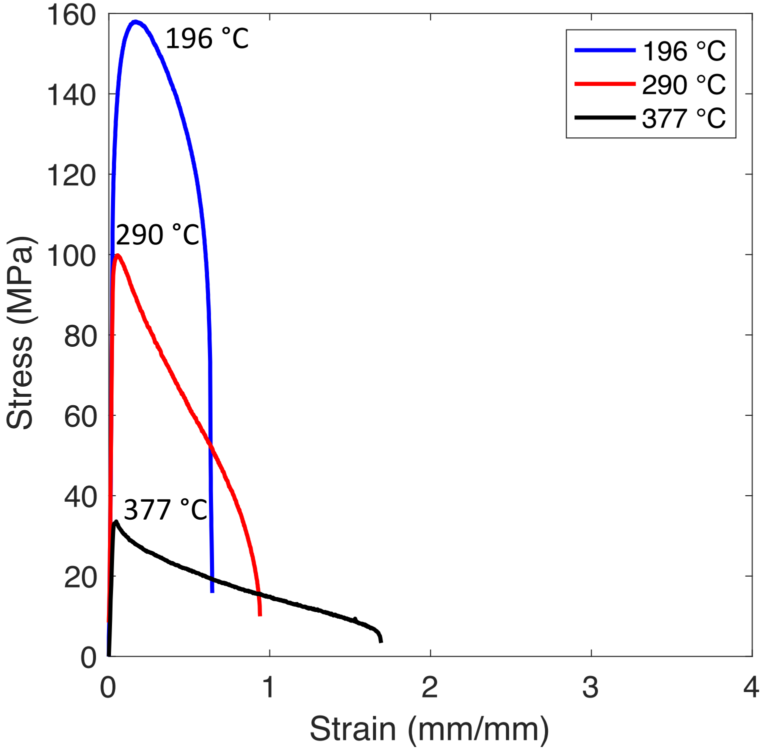
[3] N. Tsuji, K. Shiotsuki, and Y. Saito, "Superplasticity of ultra-fine grained Al-Mg Alloy by ARB," *Materials Transactions*, vol. 40, no. 8, pp. 765–771, 1999.

[4] Hsiao, I. C., and J. C. Huang. "Development of low temperature superplasticity in commercial 5083 Al-Mg alloys." *Scripta Materialia,* vol. 40, no. 6, pp. 697-703, 1999.

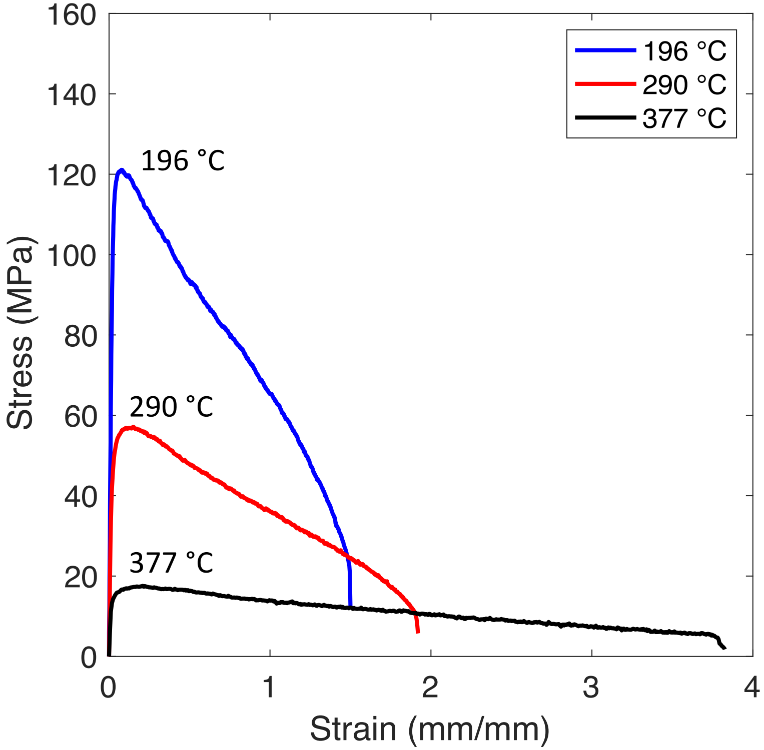
[5] Hsiao, I. C., and J. C. Huang. "Deformation mechanisms during low-and high-temperature superplasticity in 5083 Al-Mg alloy." *Metallurgical and Materials Transactions A*, vol. 33, no .5, pp. 1373-1384, 2002.

Superplastic Deformation

Conventional Superplastic
~15 µm

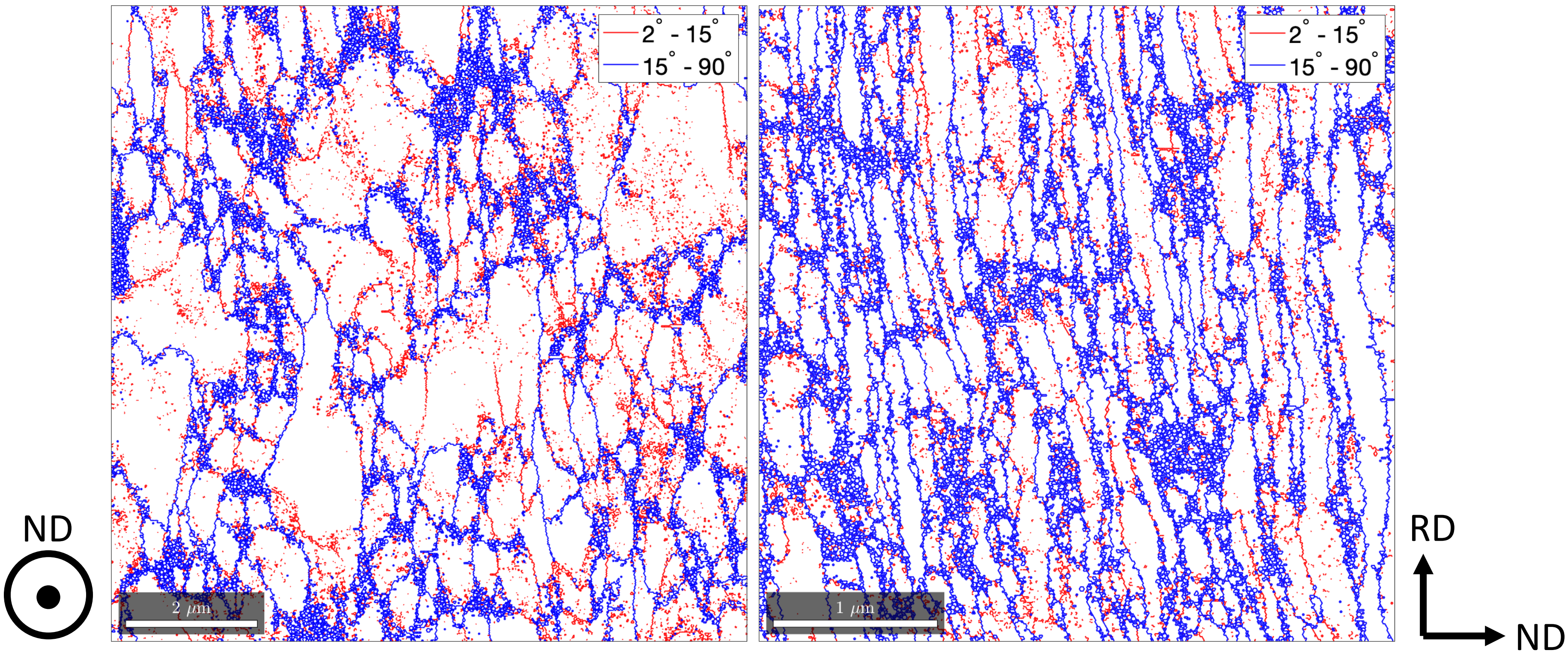


5 Cycles ARB
280 nm x 1 µm x 1 µm



Constant crosshead displacement, $\dot{\varepsilon}_0 = 10^{-3}\ s^{-1}$

Al 5083 5 ARB Grain Structure



68 % HAGB

80 % HAGB

Apparent grain size:

250 nm x 1 µm x 1 µm