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

Fall 2018 Semi-Annual Meeting
Colorado School of Mines, Golden, CO
October 2-4, 2018

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
- Rolling mill upgrades: edge guides and load cell data acquisition system
- Eight successful roll bonding cycles of Al 1100
- Room temperature tensile tests of roll bonded Al 1100 alloys subject to different heat treatments

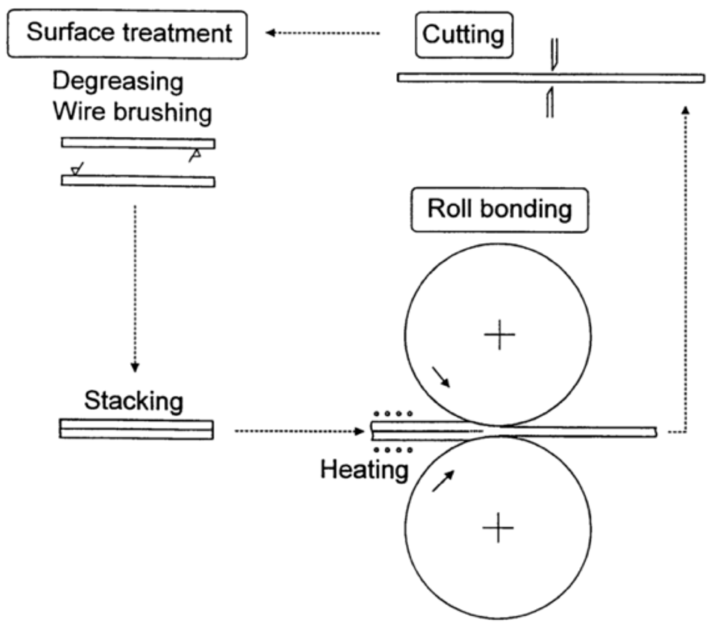
Metrics

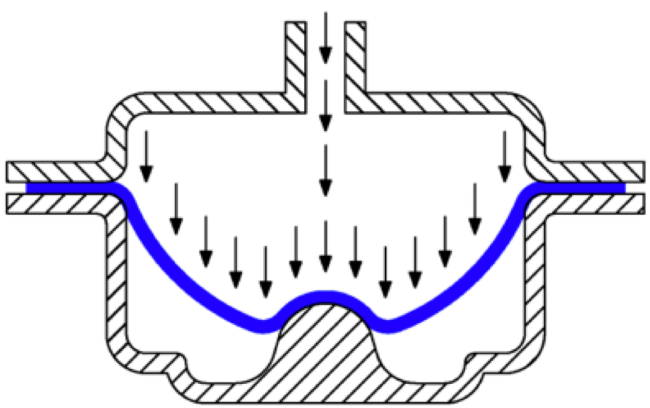
Description	% Complete	Status
1. Literature review	30%	●
2. ARB process development	75%	●
3. Investigate roll bonding process parameters	20%	●
4. Mechanical & microstructural characterization	5%	●
5. Process refinement / alloy selection for optimized superplasticity	0%	●

Overview

- Project introduction
- Development of ARB Process
  - Available equipment
  - Tooling and process development
- Mechanical Properties of ARBed Material
  - Room temperature
  - Post-process heat treatments
- Bonding Development
  - Theory of bonding
  - Fracture character
- Next Steps

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.

Fenn Rolling Mill at CSM

CANFSA
Center for ADVANCED NON-FERROUS STRUCTURAL ALLOYS

Load capacity:	100,000 lbs
Roll diameter:	5.25”
Roll width:	8”
Roll speed:	37 RPM
Roll surface speed:	50 SFPM

Tooling Development

CANFSA
Center for ADVANCED NON-FERROUS STRUCTURAL ALLOYS

Adjustable edge guides

2 degrees of freedom
Sheet Width: 0.85” – 3.0”
Sheet Height: 0 – 0.25”

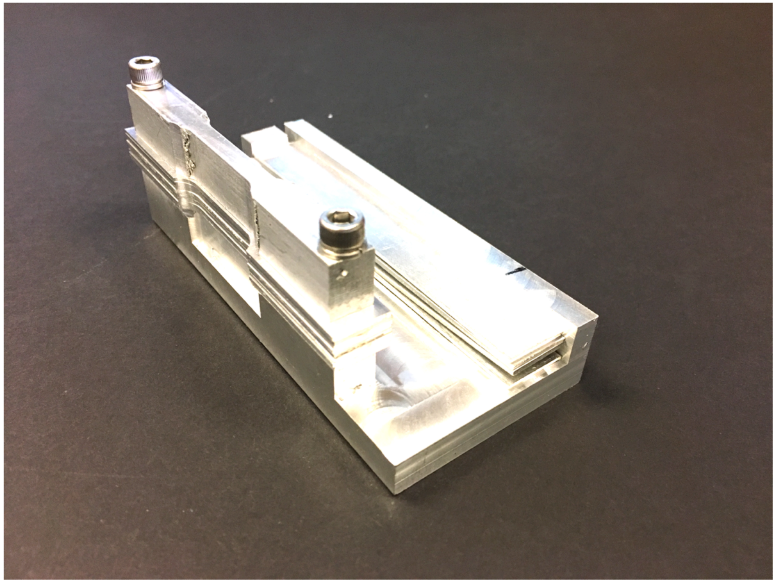
Load cell data acquisition system

2X 50,000 lb load cells
Resolution +/-175 lbs
Automatic load detection

Tooling Development

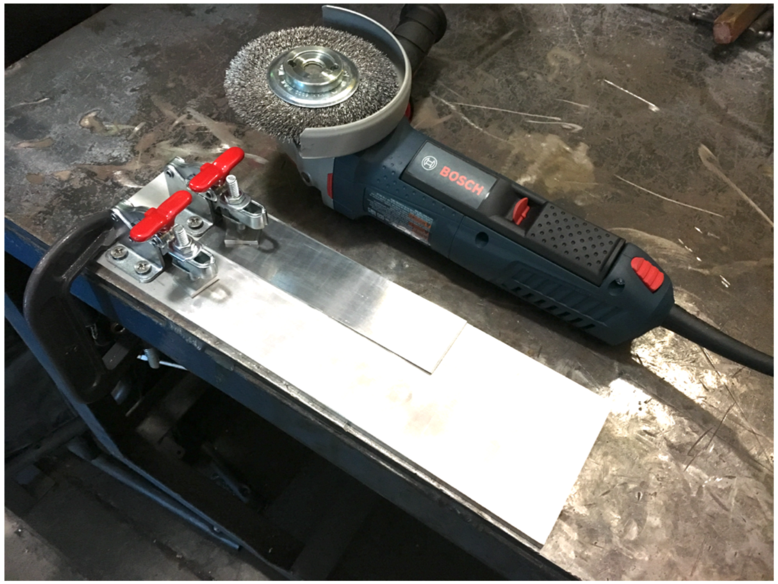
CANFSA
Center for ADVANCED NON-FERROUS STRUCTURAL ALLOYS

CNC Tensile Fixture



Machine up to 8 samples simultaneously

Wire Brushing Clamp-Down Fixture



Non-contaminating aluminum surface

Al 1100 Macroscopic Samples

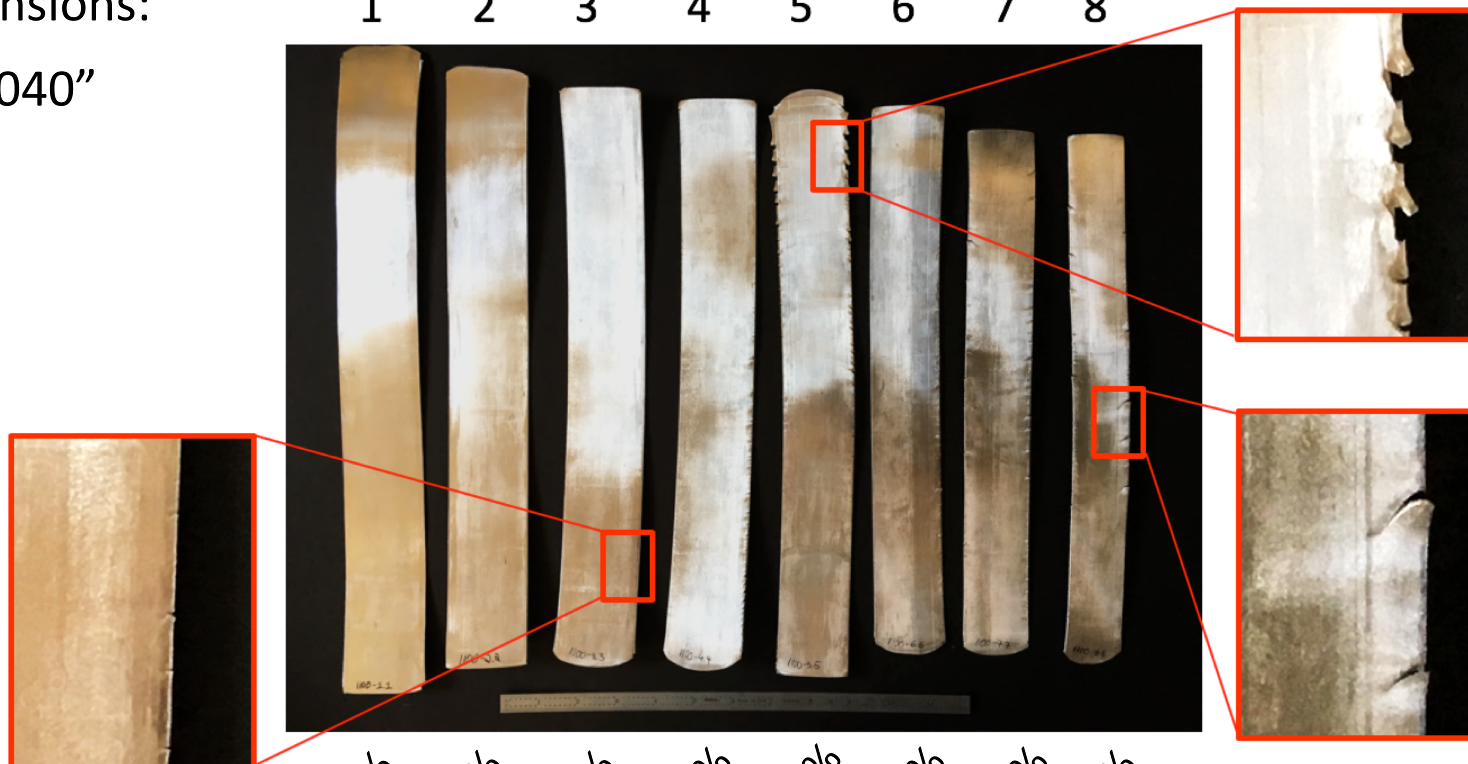
CANFSA
Center for ADVANCED NON-FERROUS STRUCTURAL ALLOYS

Original dimensions:

2” x 8” x 0.040”

Number of Cycles

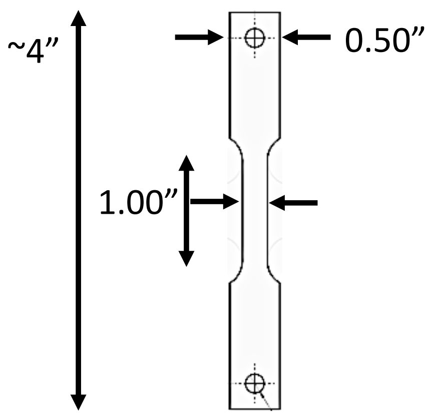
1 2 3 4 5 6 7 8



50% 75% 87.5% 93.8% 96.9% 98.4% 99.2% 99.6%

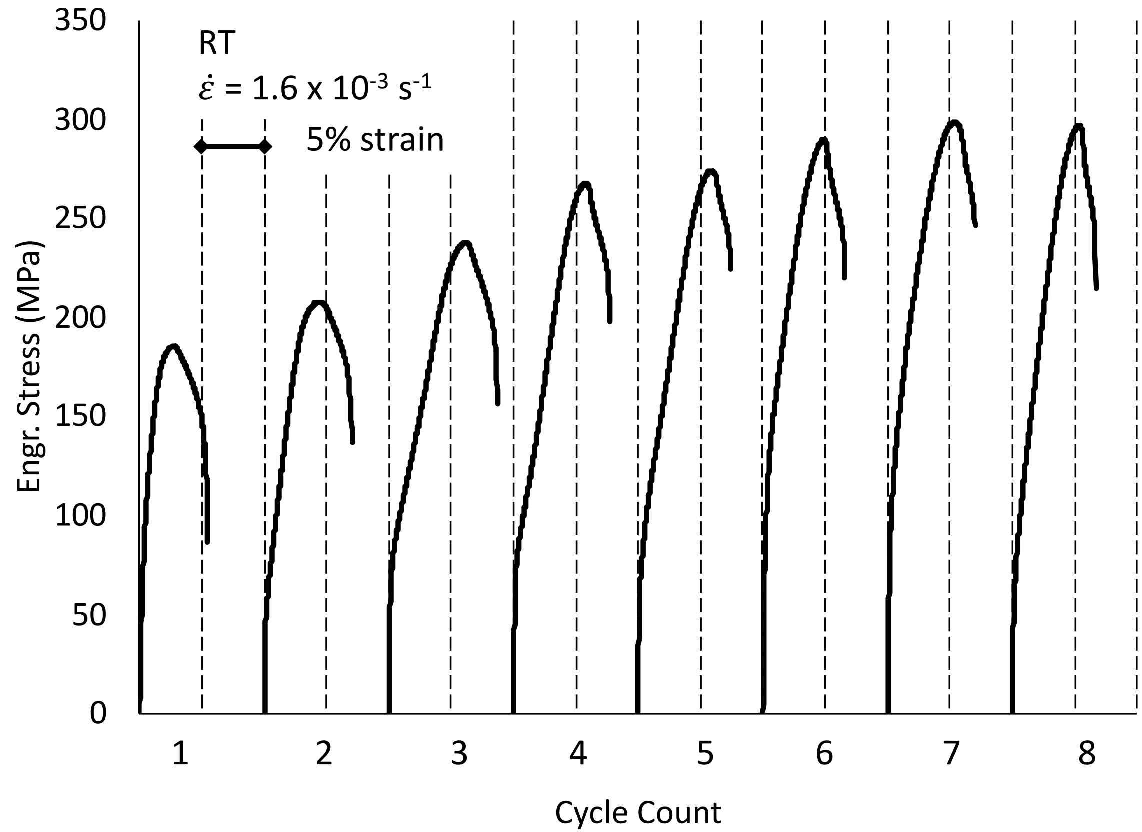
Equivalent Reduction (%)

Al 1100 RT Tensile Tests



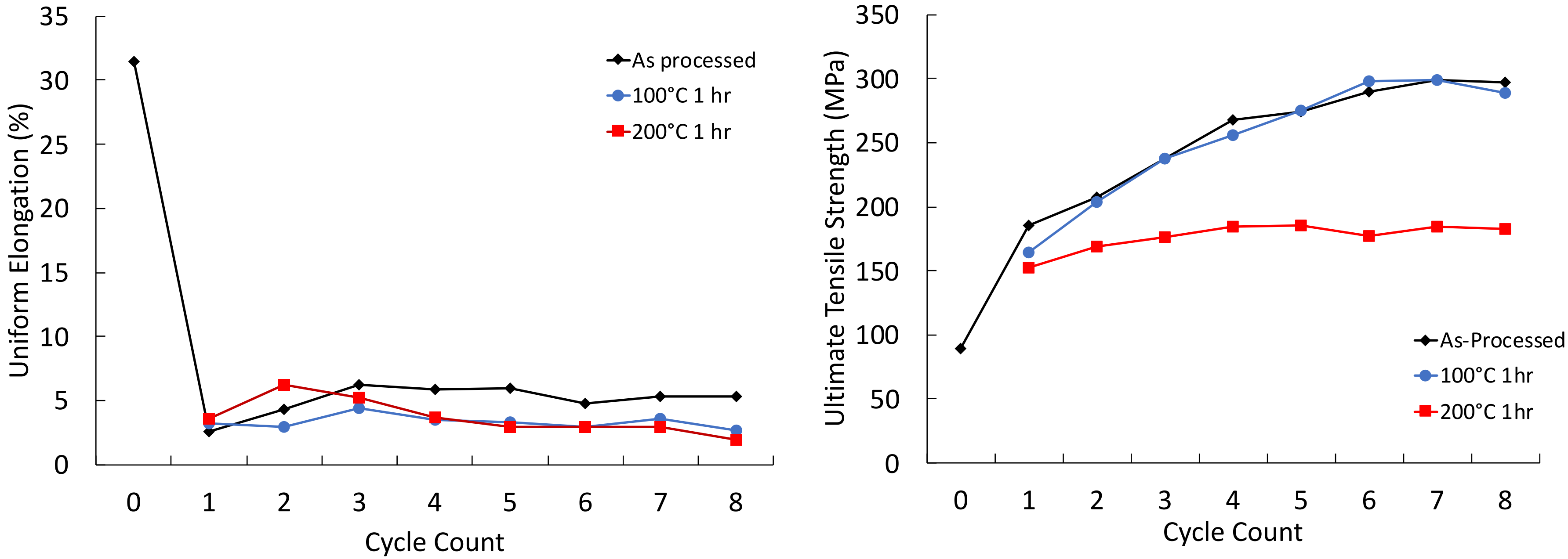
Fully annealed

Ultimate tensile:	89 MPa
Uniform elongation:	30 %



Post ARB Heat Treatments

100°C
200°C
for 1 hour

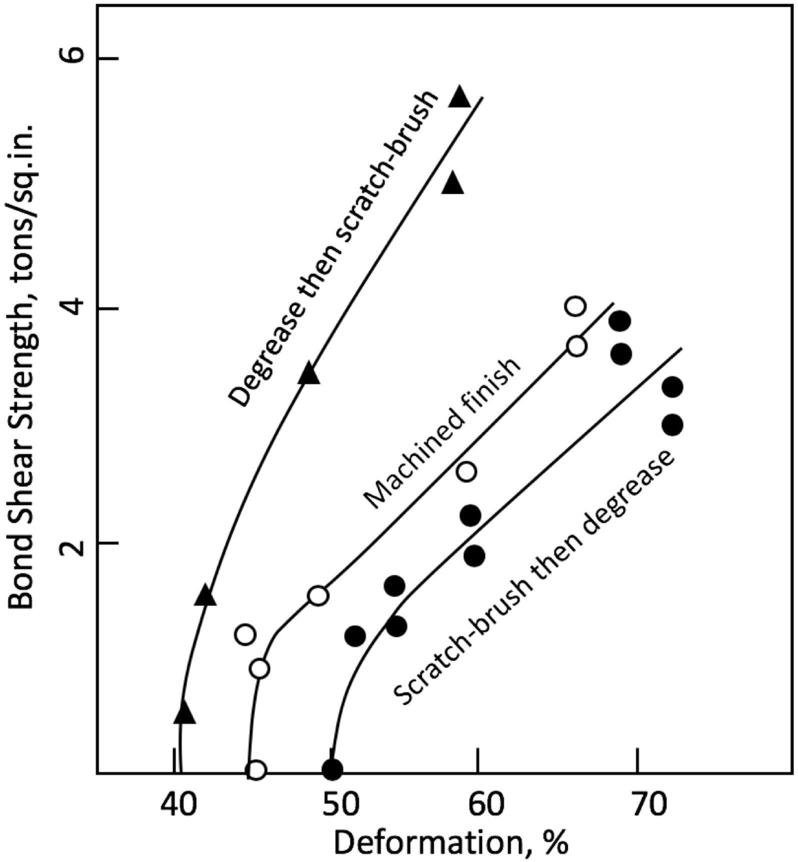


Post-process heat treatment in excess of 200°C significantly alters mechanical properties.

Bonding Interfaces

Acetone degrease → Wire brush → 50% Reduction Roll bond

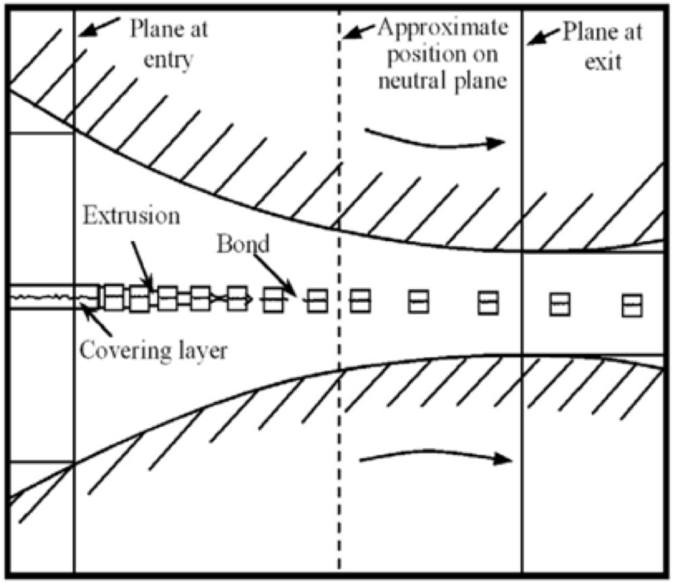
(Preheat)



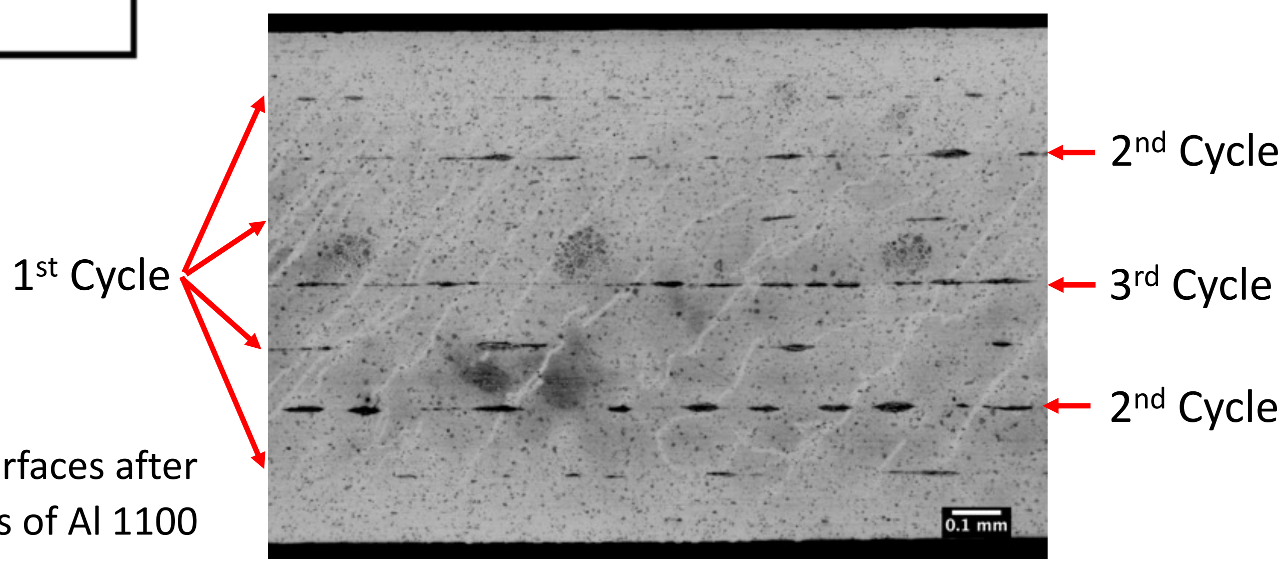
Effects of surface condition on roll bonding of aluminum.

Vaidyanath & Milner, *British Welding Journal*, 1960.

Bonding Interfaces



Fraction and extrusion of oxide surface

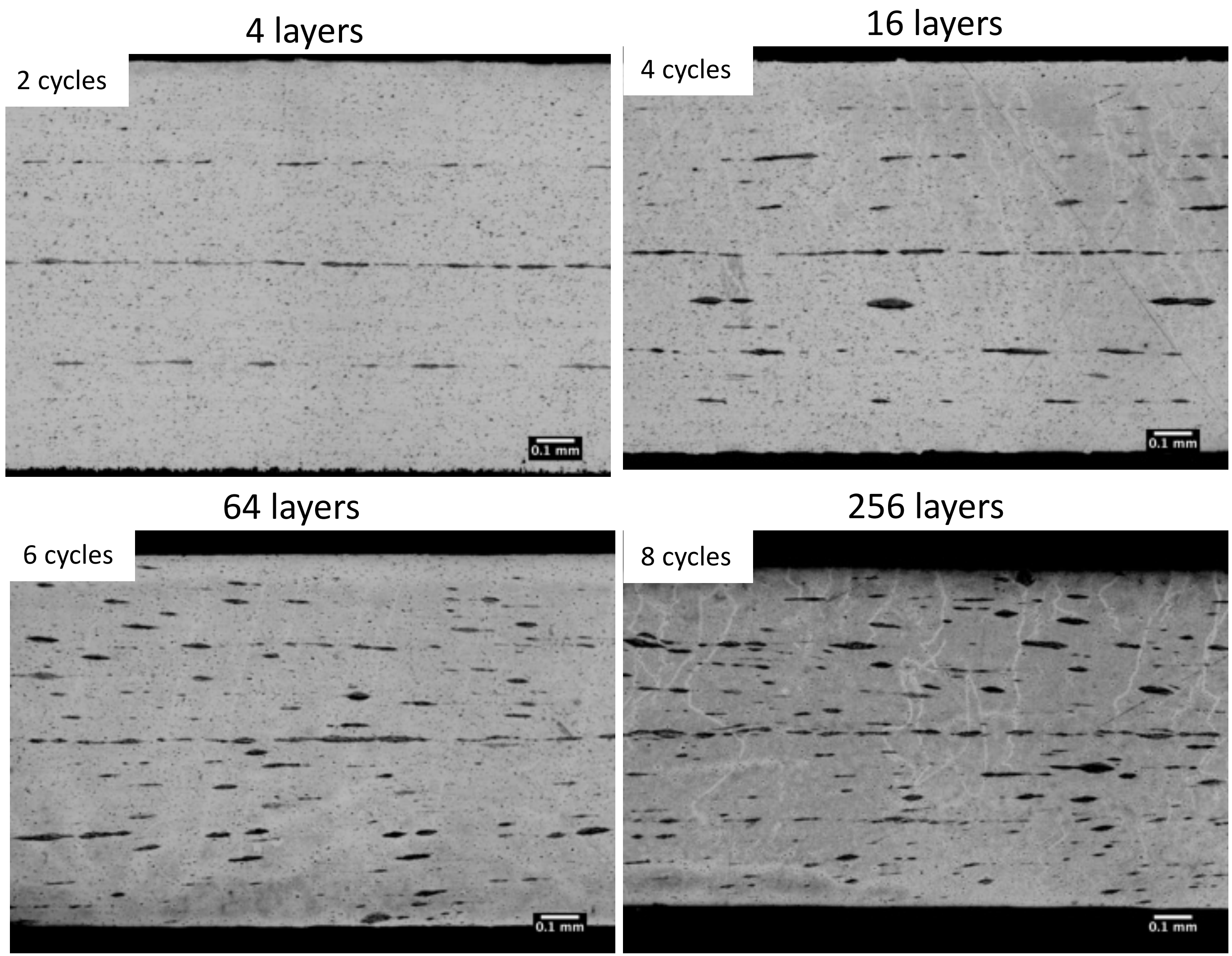


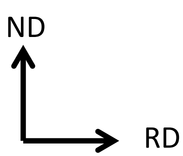
Bond interfaces after 3 cycles of Al 1100

Li, Nagai & Yin, *Science and Technology of Advanced Materials*, 2008.

Bonding Interfaces

Individual layers indistinguishable after 4th cycle





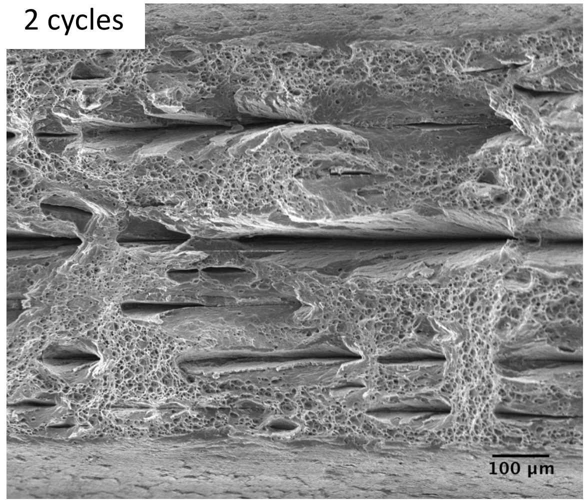
Tensile Fracture Surfaces: As Processed

CANFSA
Center for ADVANCED NON-FERROUS STRUCTURAL ALLOYS

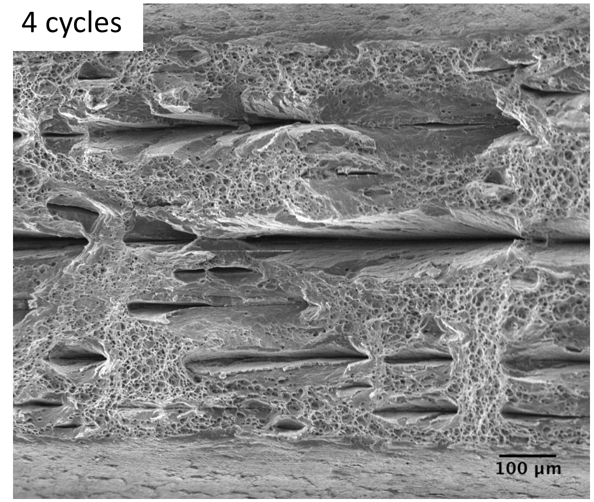
Extreme centerline, quarterline delamination

Layers delaminate <u>individually</u>

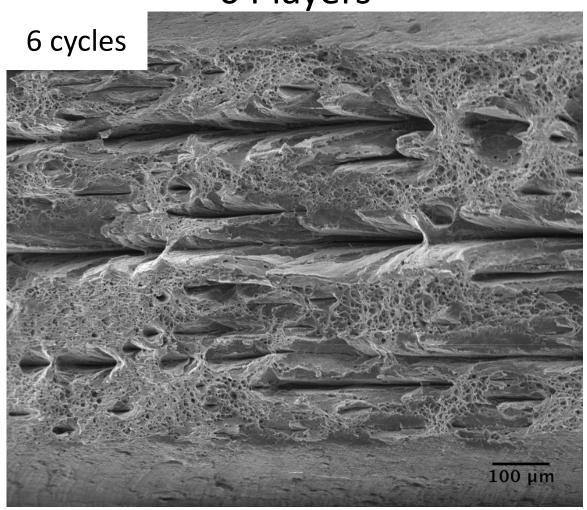
4 layers



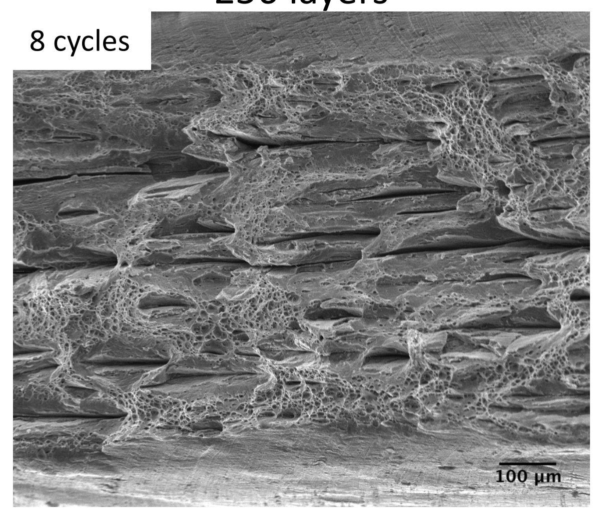
16 layers

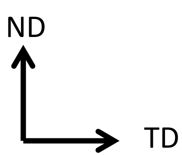


64 layers



256 layers



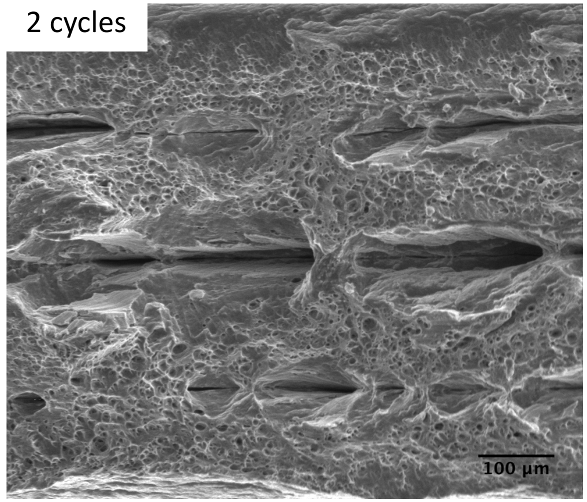


Tensile Fracture Surfaces: 100°C for 1 hour

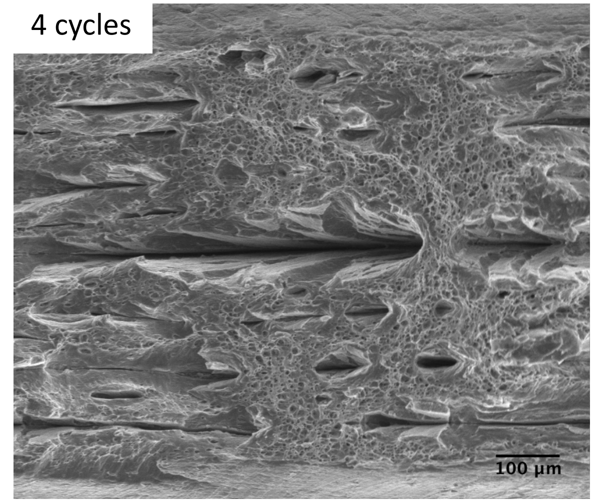
Extreme centerline delamination

Layers delaminate in <u>groups</u>

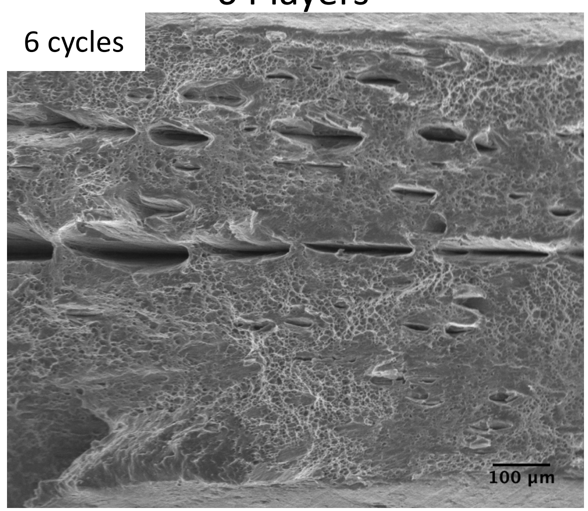
4 layers



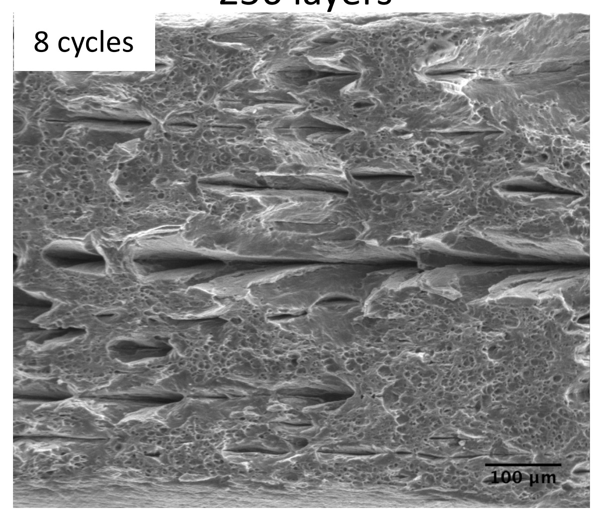
16 layers

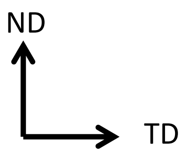


64 layers



256 layers



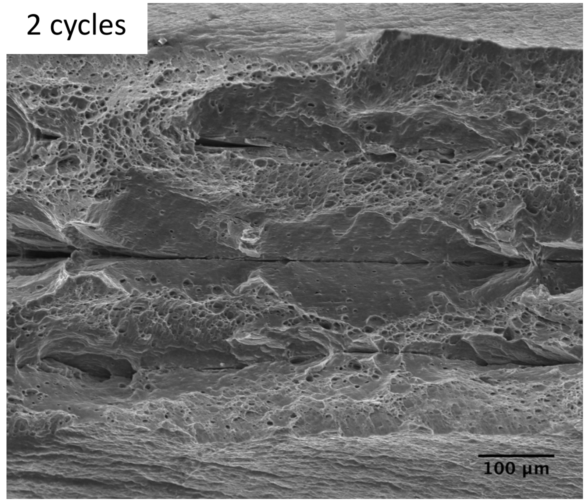


Tensile Fracture Surfaces: 200°C for 1 hour

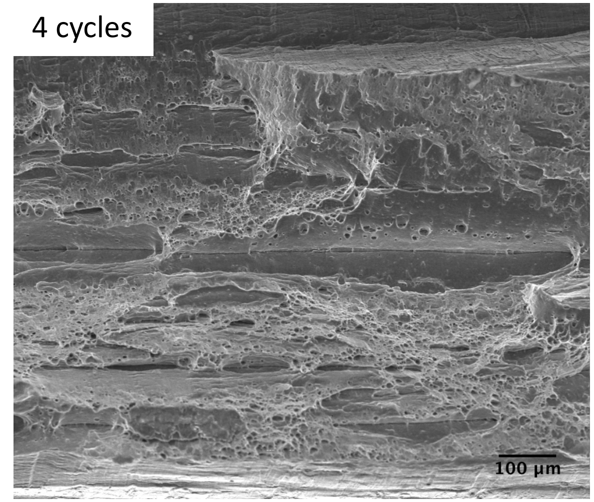
No centerline delamination

Homogenous deformation

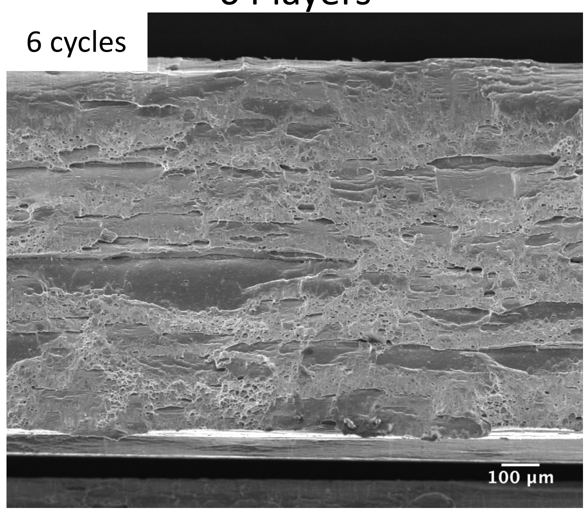
4 layers



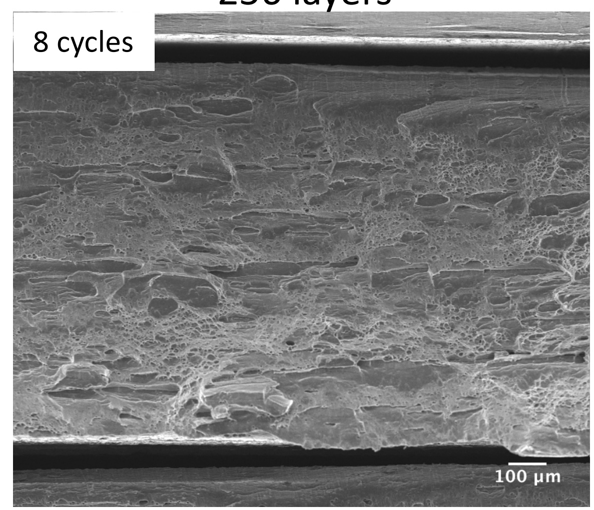
16 layers

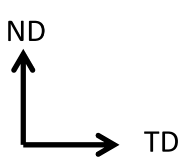


64 layers



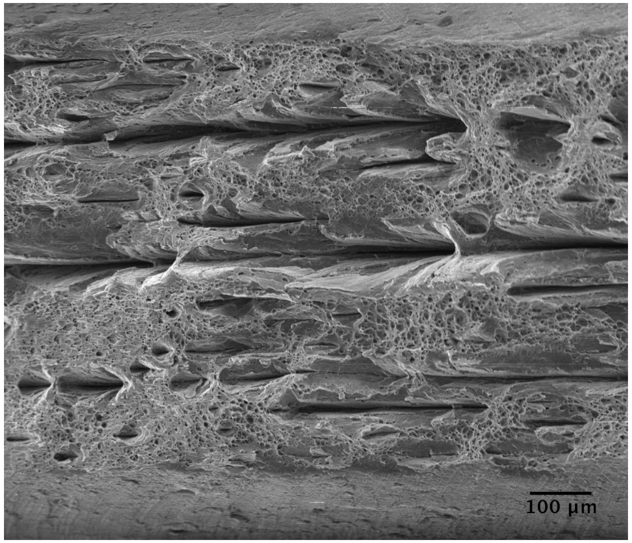
256 layers





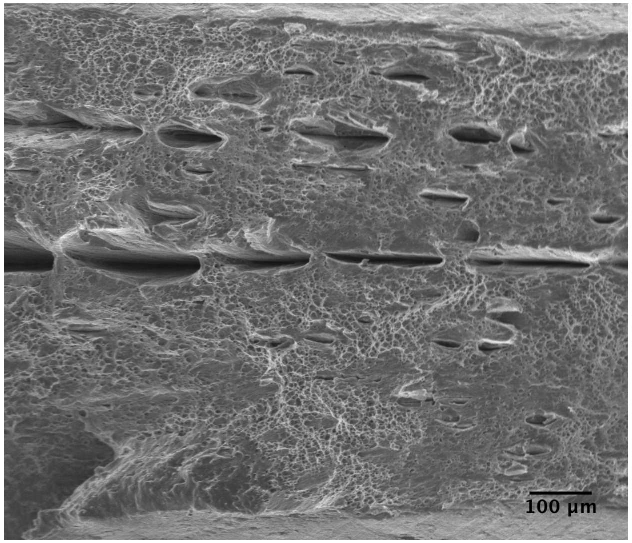
Tensile Fracture Evolution

As Processed



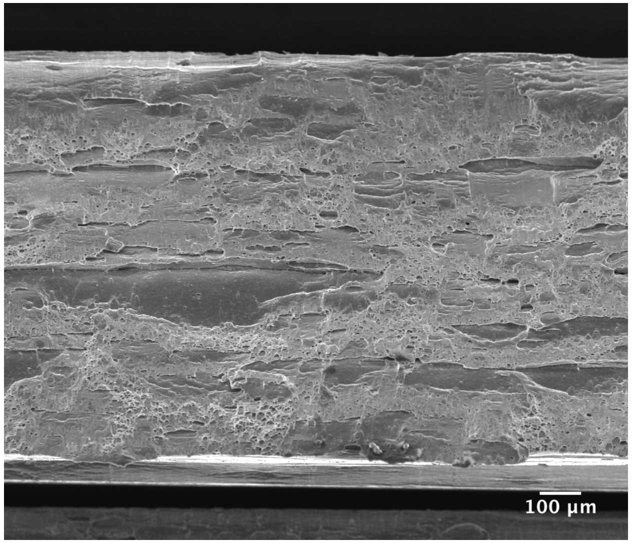
Delamination of
multiple bonds

100°C for 1 hour



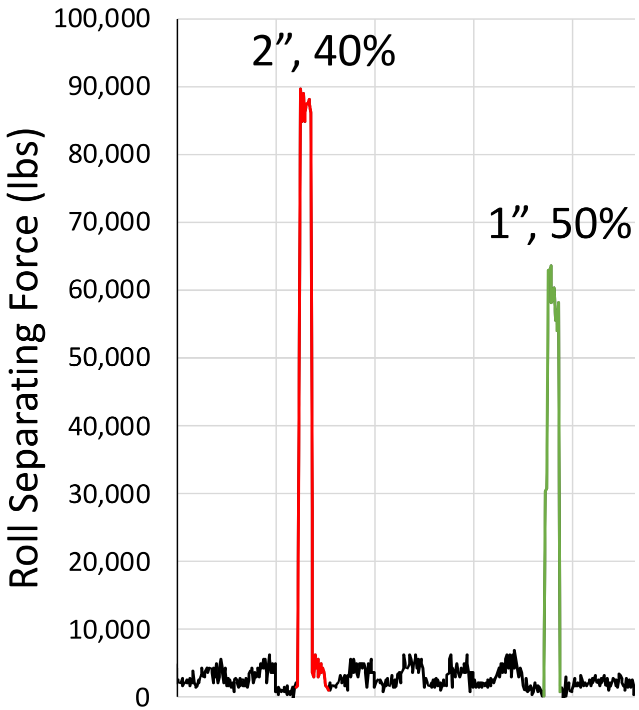
Delamination of
most recent bonds

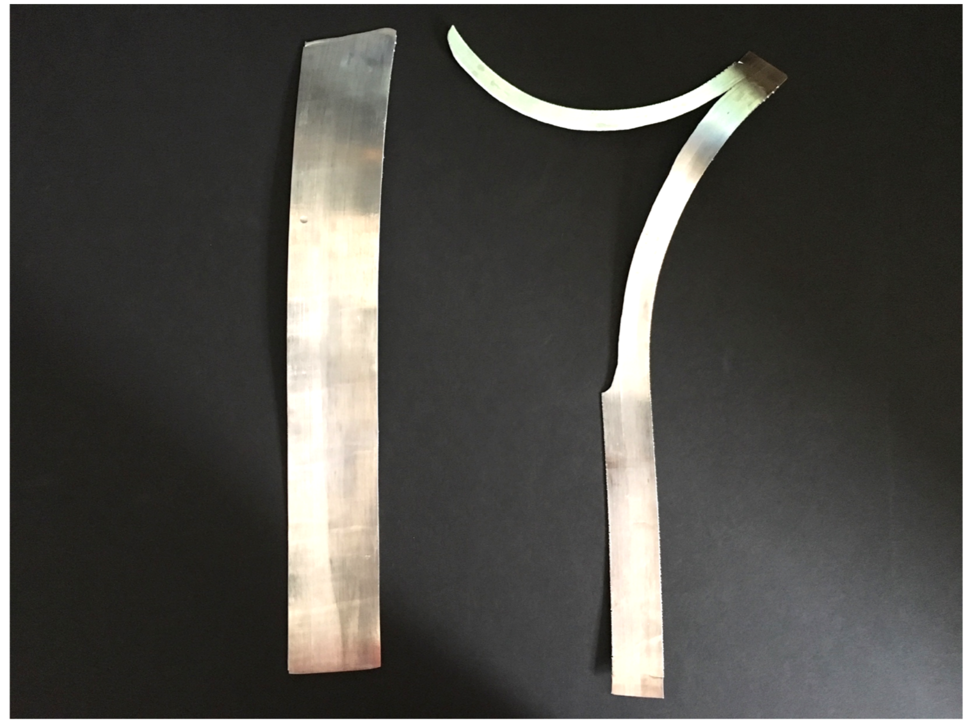
200°C for 1 hour



Homogeneous
deformation

ARB Rolling Loads in 5182





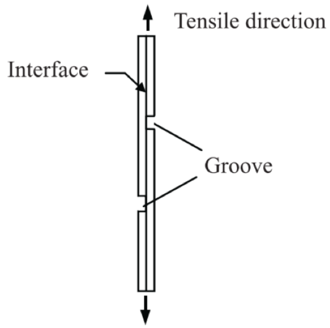
2” 1”

Mitigation Strategies:

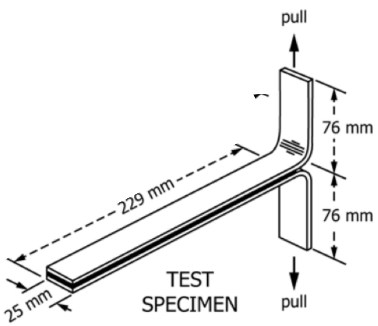
- wider samples with high capacity mill (>50 tons)
- preheat before rolling

Moving Forward

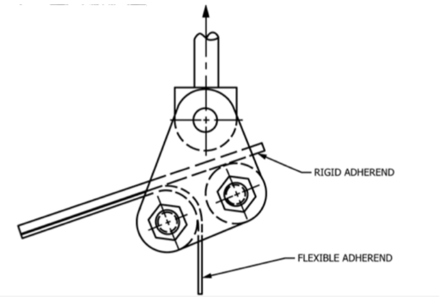
- Mechanical and microstructural characterization
  - Gleeble, load frame furnace
  - EBSD, TEM
- Bonding mechanisms
  - Preheating and post-deformation heat treatments



Shear Lap Test



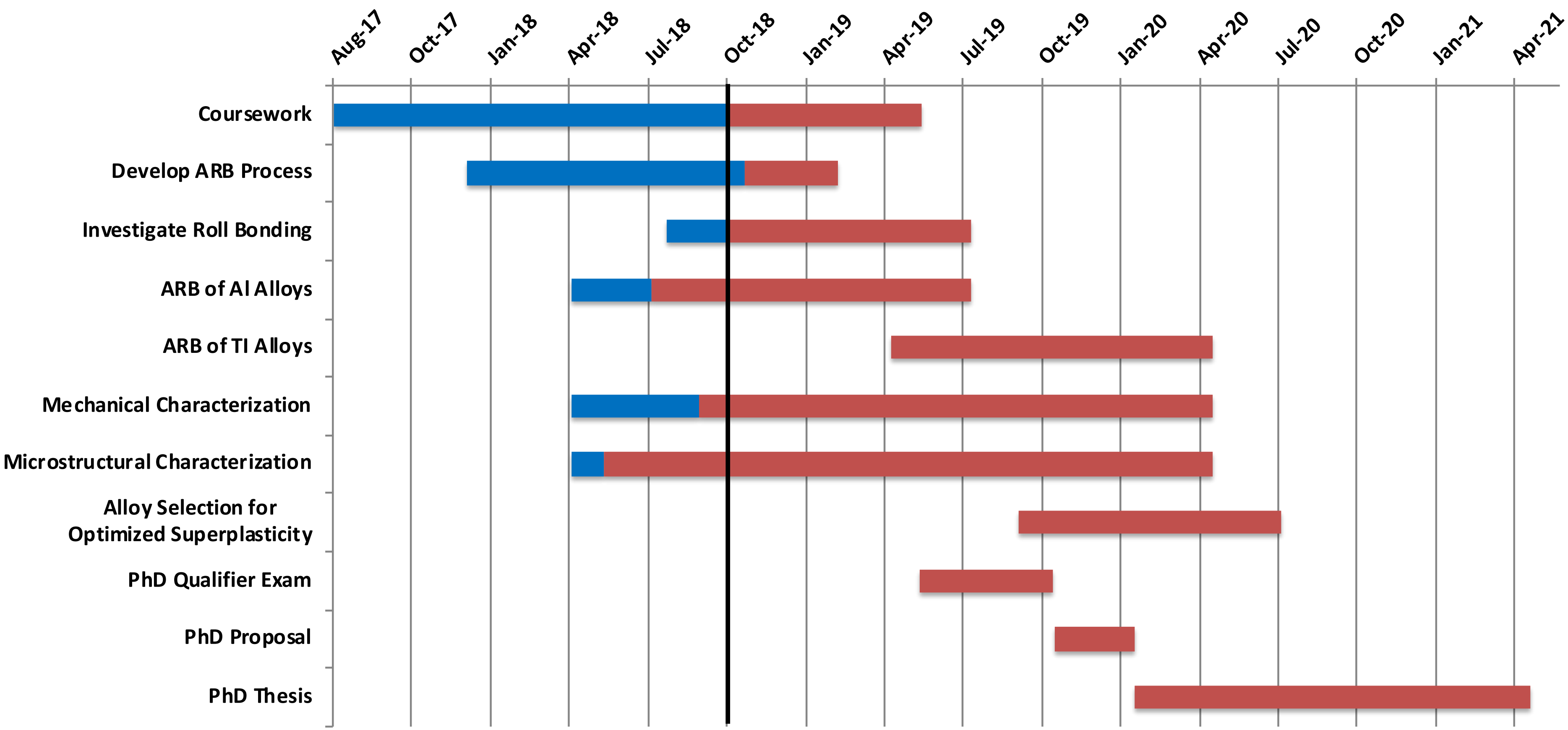
ASTM D1876



ASTM D3167

- Other alloys
  - 5182, 5754 (Al-Mg)

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
ARB of Al Alloys
ARB of TI Alloys
Mechanical Characterization
Microstructural Characterization
Alloy Selection for Optimized Superplasticity
PhD Qualifier Exam
PhD Proposal
PhD Thesis

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, 1999.

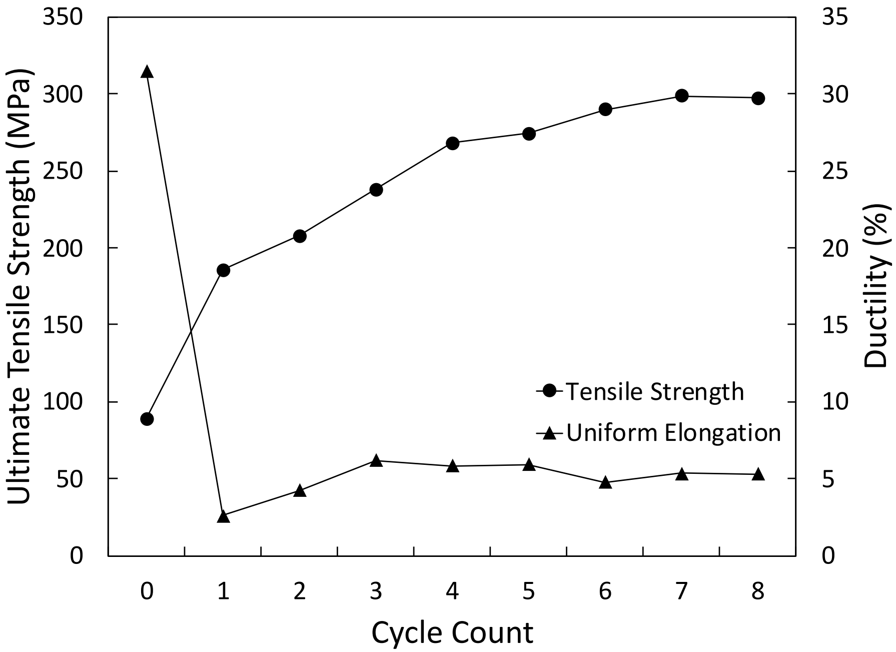
[2] R. M. Cleveland, A. K. Ghosh, and J. R. Bradley, “Comparison of superplastic behavior in two 5083 aluminum alloys,” Materials Science and Engineering A, vol. 351, no. 1-2, pp. 228–236, 2003.

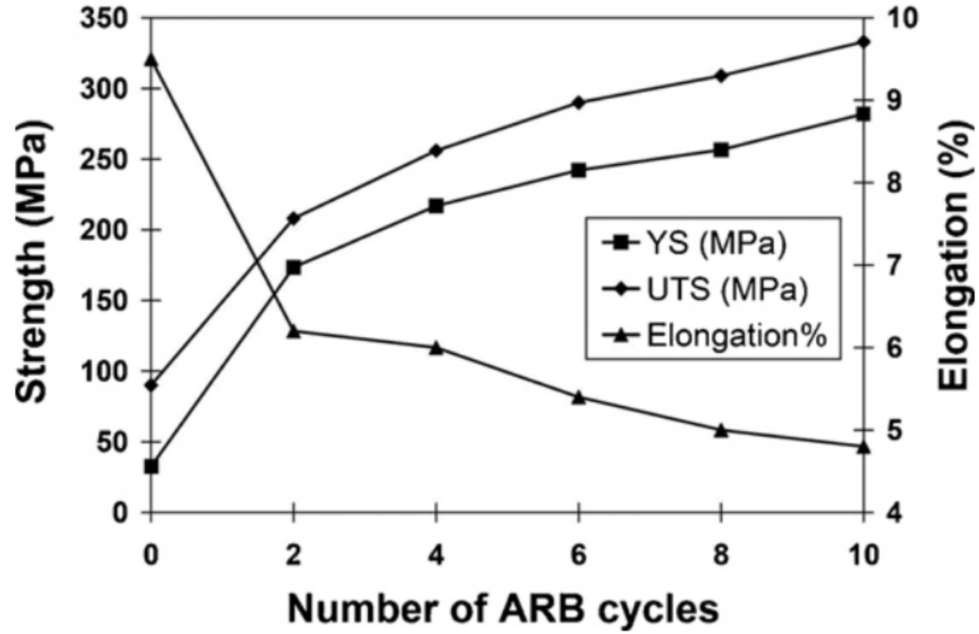
[3] L. Vaidyanath and D. Milner, “Significant of Surface Preparation in Roll Bonding,” British Welding Journal, vol. 7, no. 1, pp. 1–6, 1960.

[4] L. Li, K. Nagai, and F. Yin, “Progress in cold roll bonding of metals,” Science and Technology of Advanced Materials, vol. 9, no. 2, 2008.

Al 1100 RT Tensile Tests

CANFSA
Center for ADVANCED NON-FERROUS STRUCTURAL ALLOYS



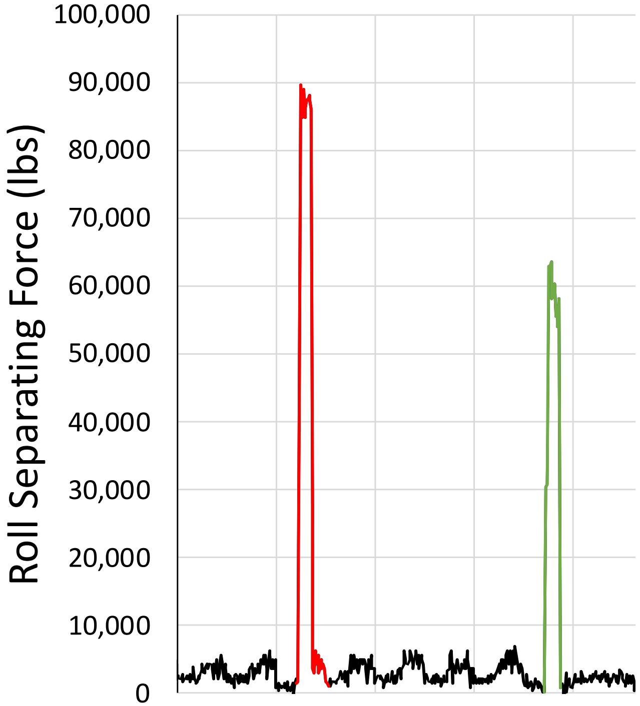


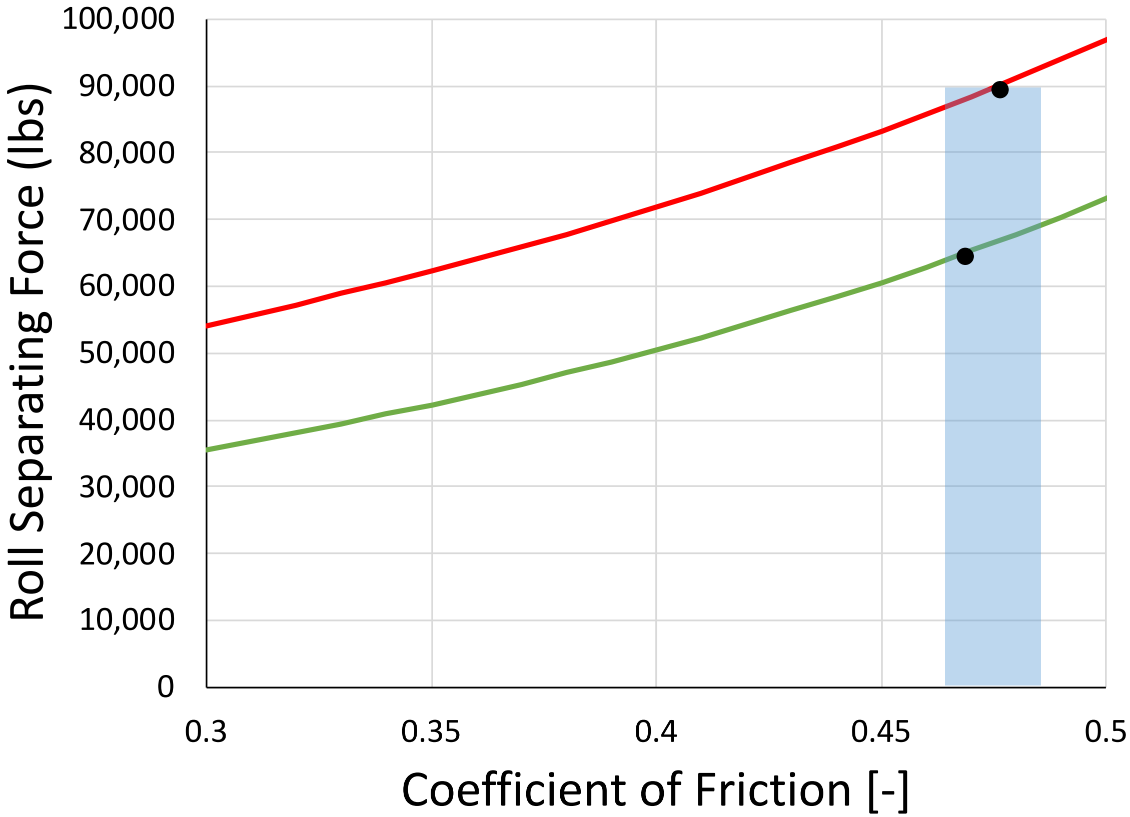
Similar results to published study by *Pirgazi et al., 2008.*

Pirgazi et al., 2008.

ARB Rolling Loads

CANFSA
Center for ADVANCED NON-FERROUS STRUCTURAL ALLOYS





2”, 40% reduction
1”, 50% reduction

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

Student: *Brady McBride*

Faculty: *Kester Clarke*

Industrial Partners: *Boeing (Ravi Verma), LANL (John Carpenter)*

Project Duration: *August 2017 – May 2021*

Achievement

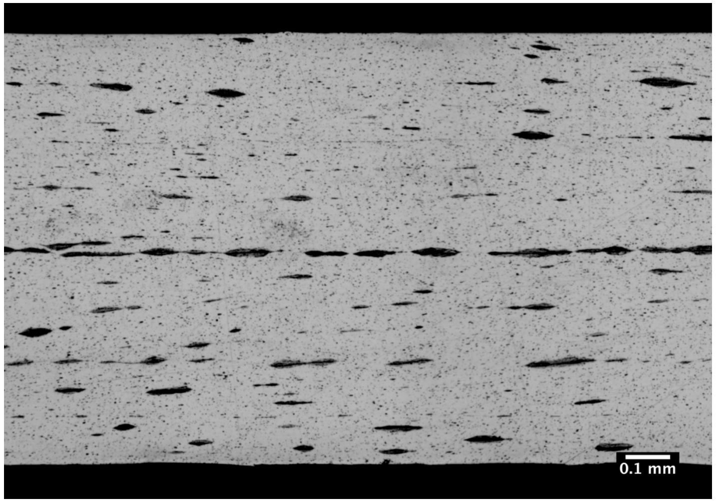
- Development of a process capable of producing ultra-fine grained microstructures in Al and Ti alloys that exhibit superplasticity at lower temperatures than conventional processing methods.

Significance and Impact

- Low temperature superplasticity would enhance superplastic forming operations by reducing cycle time as well as reducing costs related to heating and die wear.

Research Details

- Development of a specific rolling process and tooling as with microstructural and mechanical characterization to quantify superplastic responses of processed material.



Cross-section of roll bonded Al 1100 showing interfaces between 128 individual layers of material.

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

Student: *Brady McBride*

Faculty: *Kester Clarke*

Industrial Partners: *Boeing (Ravi Verma), LANL (John Carpenter)*

Project Duration: *August 2017 – May 2021*

Achievement

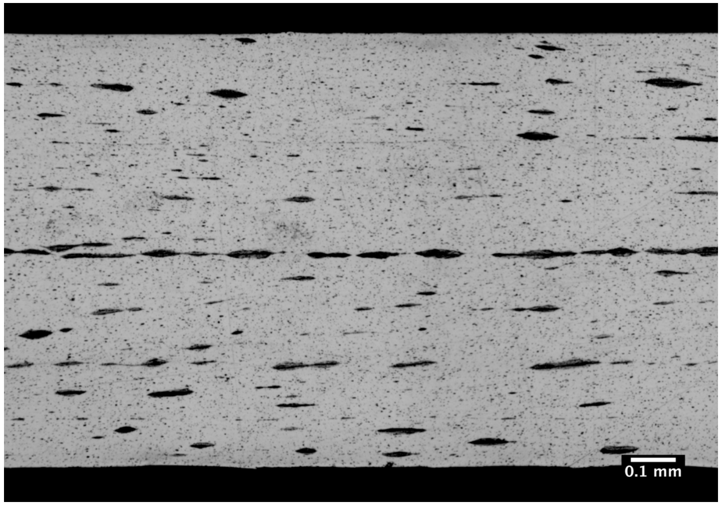
- Development of a process capable of producing ultra-fine grained microstructures in Al and Ti alloys that exhibit superplasticity at lower temperatures than conventional processing methods.

Significance and Impact

- Low temperature superplasticity would enhance superplastic forming operations by reducing cycle time as well as reducing costs related to heating and die wear.

Research Details

- Improved superplastic formability by means of reduced temperature and increased forming strain rates will reduce operating costs and prolong die life.



Cross-section of roll bonded Al 1100 showing interfaces between 128 individual layers of material.

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

Student: *Brady McBride*

Faculty: *Kester Clarke*

Industrial Partners: *Boeing (Ravi Verma), LANL (John Carpenter)*

Project Duration: *August 2017 – May 2021*

Program Goal

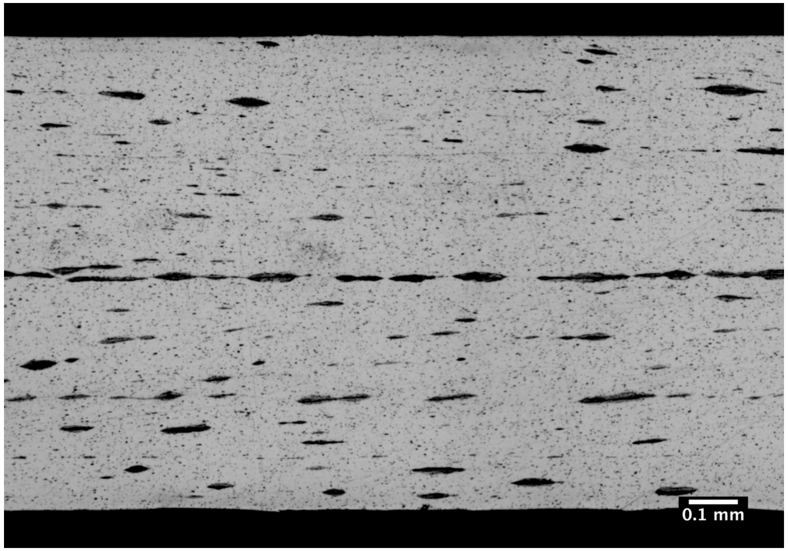
- Investigate enhanced superplasticity of ultra fine grained materials produced by accumulative roll bonding

Approach

- Develop a process for accumulative roll bonding and determine microstructural mechanisms related to superplasticity

Benefits

- Improved superplastic formability by means of reduced temperature and increased forming strain rates will reduce operating costs and prolong die life



Cross-section of roll bonded Al 1100 showing interfaces between 128 individual layers of material.