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

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

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

Project Duration

PhD: September 2017 to May 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

- Literature review of ARB processes pertaining to aluminum alloys
- Development of ARB surface preparation procedures
- Two successful roll bonding cycles of Al 6061 with adequate bonding

Metrics

Description	% Complete	Status
1. Literature review	15	●
2. ARB process development	50	●
3. ARB of select alloys (Al 2024, Al 5083)	0	●
4. Mechanical & microstructural characterization	0	●
5. Process refinement / alloy selection for optimized superplasticity	0	●

Accumulative Roll Bonding (ARB)

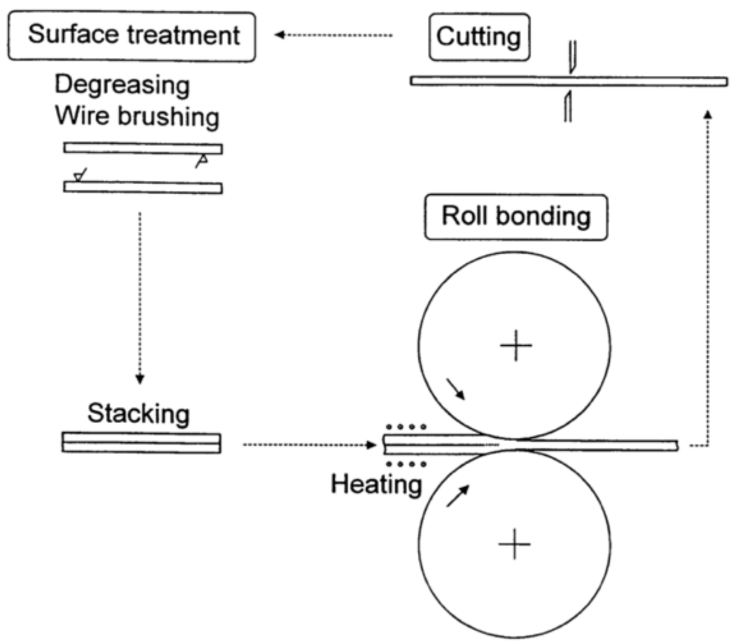


Fig. 1. Typical accumulative roll bonding procedures [1].

ARB Cycles (n)	# of Layers (N)	Layer Thickness (µm)
1	2	500
2	4	250
3	8	125
4	16	62.5
5	32	31.2
6	64	15.6

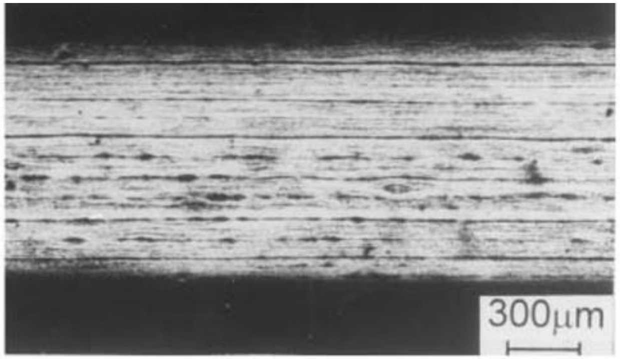


Fig. 2. Individual layers present in IF steel after 5 ARB cycles Typical accumulative roll bonding procedures [2].

Industrial Relevance

Enhanced properties:

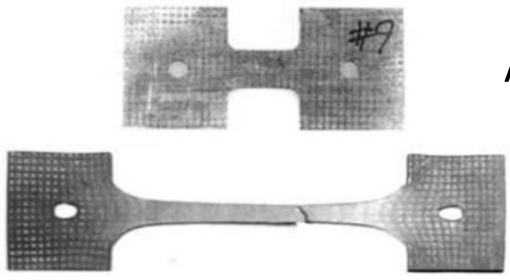
- low temperature superplasticity
- Hall-Petch strengthening

Applications:

- superplastic forming
- high strength sheet components

Benefits:

- reduced cycle time
- reduced die wear



As machined

T = 550 °C

$\dot{\varepsilon}$ = 10^{-3} s^{-1}

%El = 310 %

Fig. 3. Observed superplasticity in Al 5083 [3].

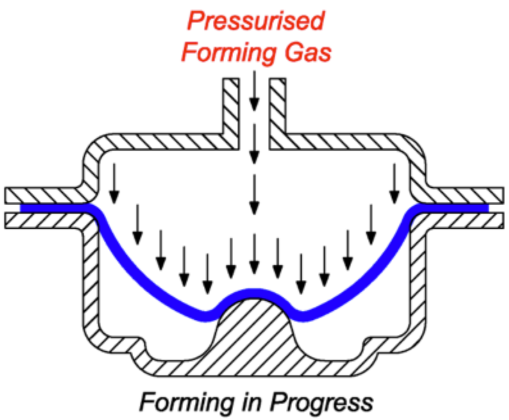


Fig. 4. Superplastic forming process [4].

Superplastic Effects

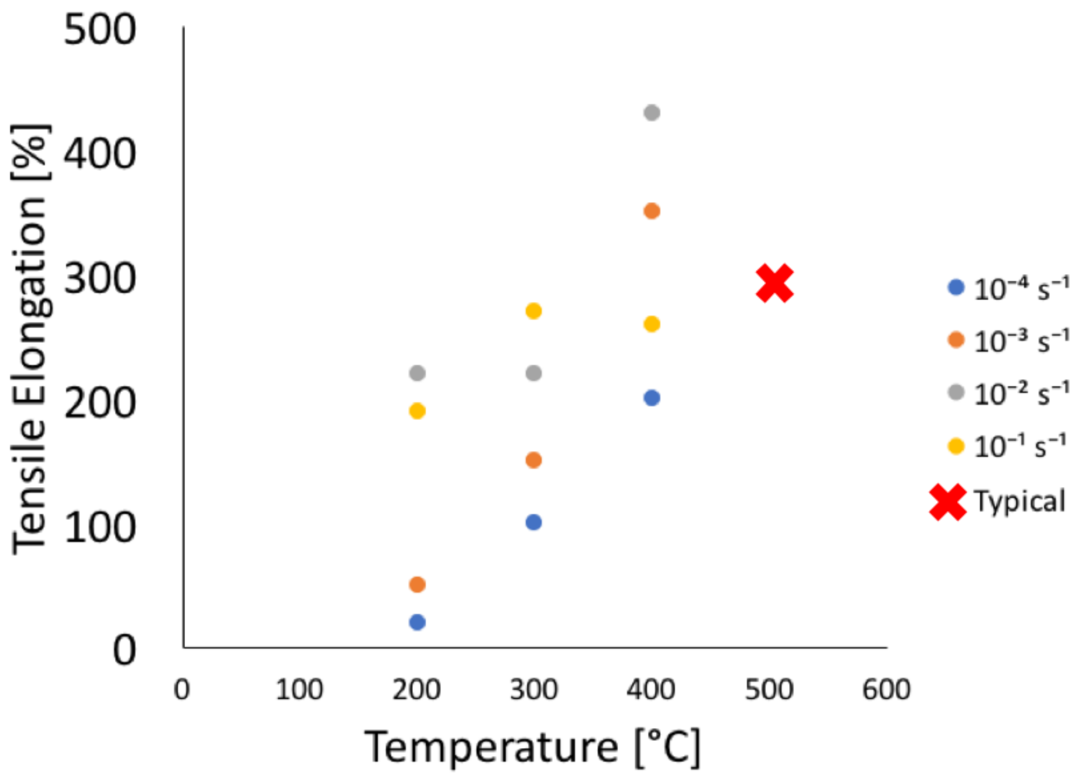


Fig. 5. Elevated temperature superplasticity results of ARBed 5083 obtained from recent studies [1,2,5,6,7].

Typical Conditions:

T = 500 °C

$\dot{\varepsilon}$ = 10^{-3} s^{-1}

%El = 200 - 300 %

Potential Materials

Aluminum Alloys

- Al 2024
- Al 5083

Titanium Alloys

- CP Ti
- Ti-6Al-4V

Fig. 6. 100,000 lb Fenn 2-high rolling mill at CSM.

1 ARB Cycle

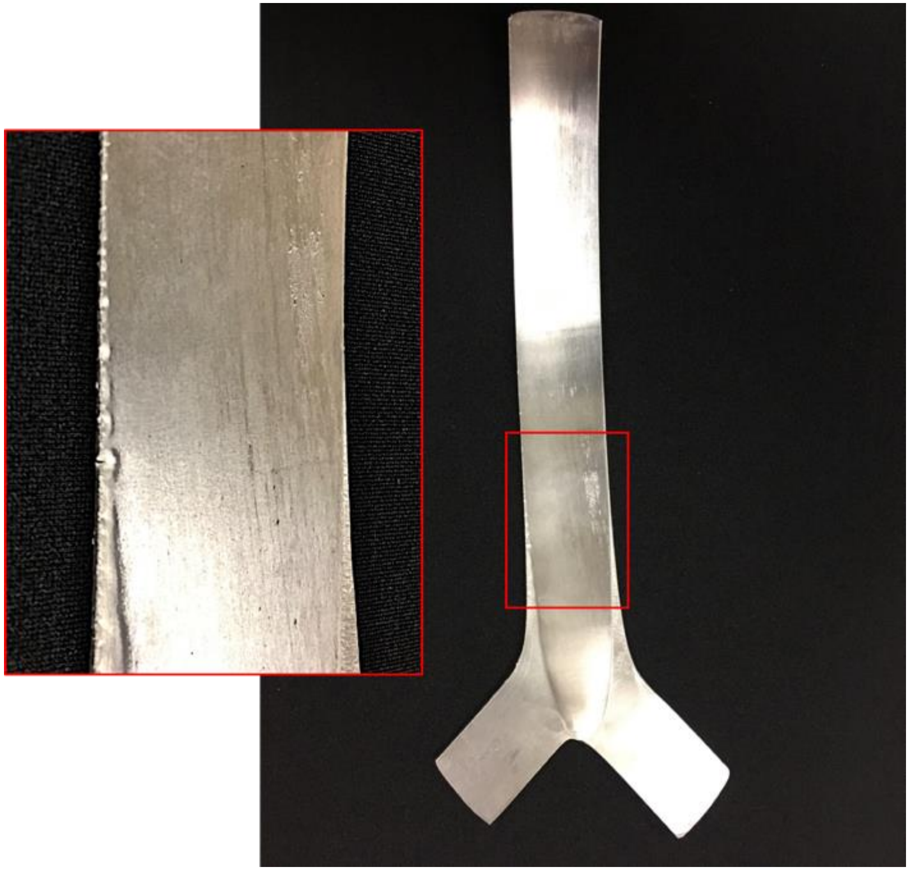


Fig. 7. Al 6061 sample subject to 1 ARB cycle.

Initial Dimensions:

(2x) 0.063 in x 1 in

Final Dimensions:

(1x) 0.068 in x 1 in

46 % 1-pass reduction

1 ARB Cycle

Fig. 7. Al 6061 sample subject to 1 ARB cycle.

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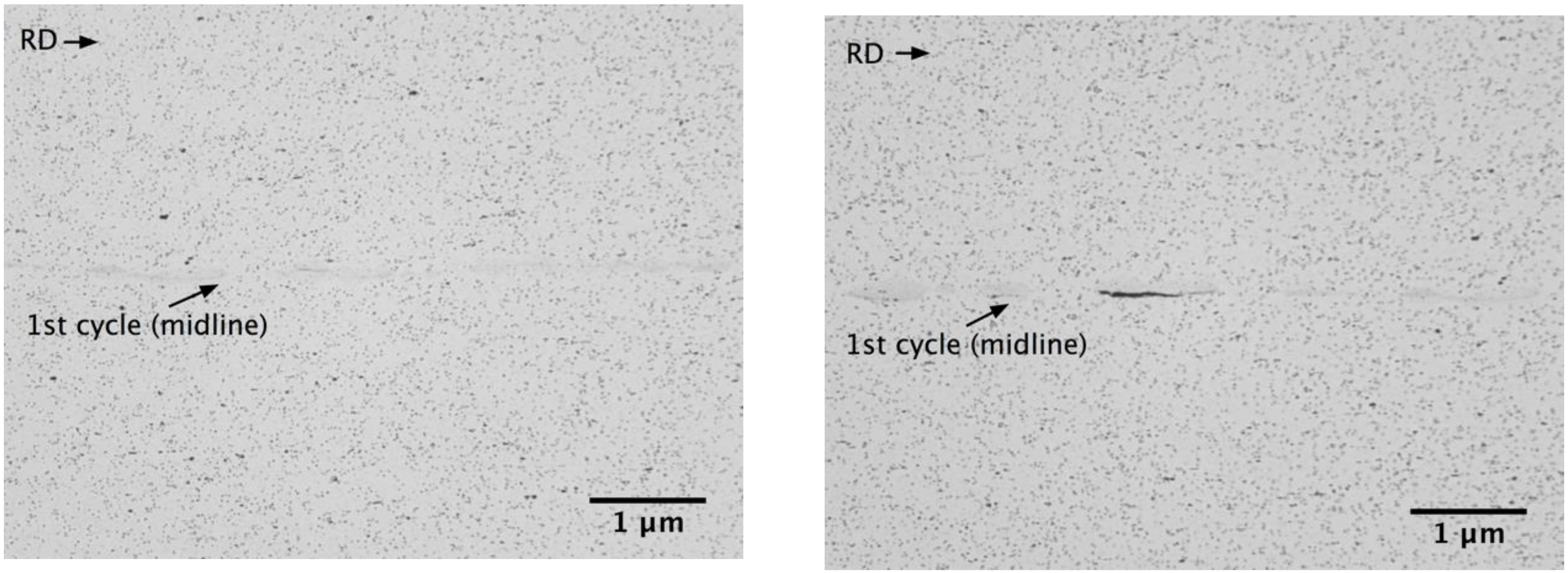
1 ARB Cycle

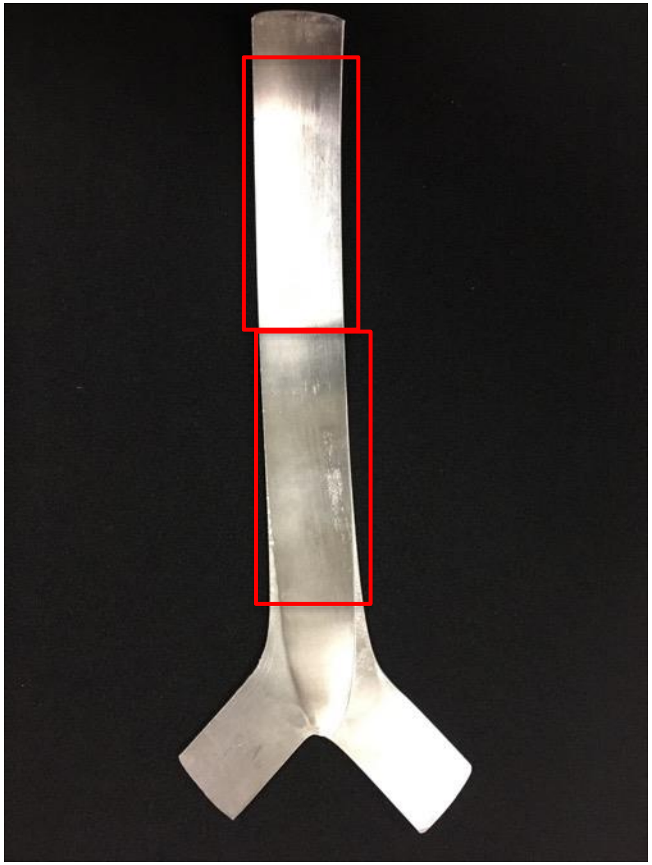


(a) (b)

Fig. 8. (a,b) Optical micrographs of longitudinal cross section Al 6061 subject to 1 ARB cycle showing degree of bonding. (b) shows lack of bonding or inclusion along interface.

Adequate bonding; limited inclusions

1 ARB Cycle



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2 ARB Cycles

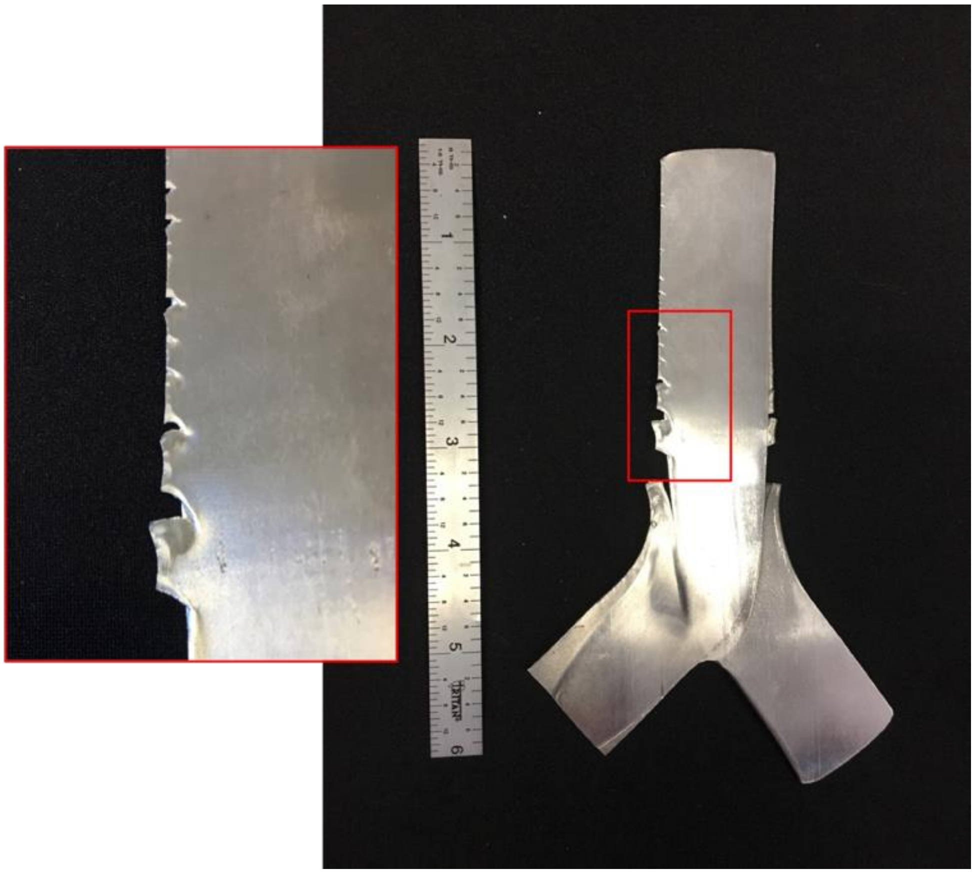


Fig. 9. Al 6061 sample subject to 2 ARB cycles.

Initial Dimensions:

(2x) 0.068 in x 1 in

Final Dimensions:

(1x) 0.069 in x 1 in

49 % 1-pass reduction

2 ARB Cycles

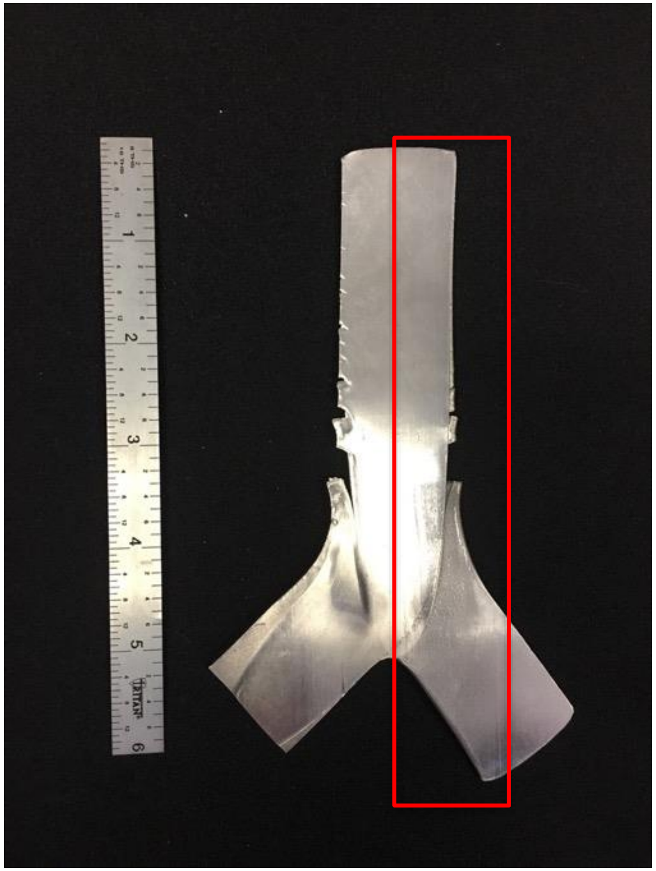


Fig. 9. Al 6061 sample subject to 2 ARB cycles.

Initial Dimensions:

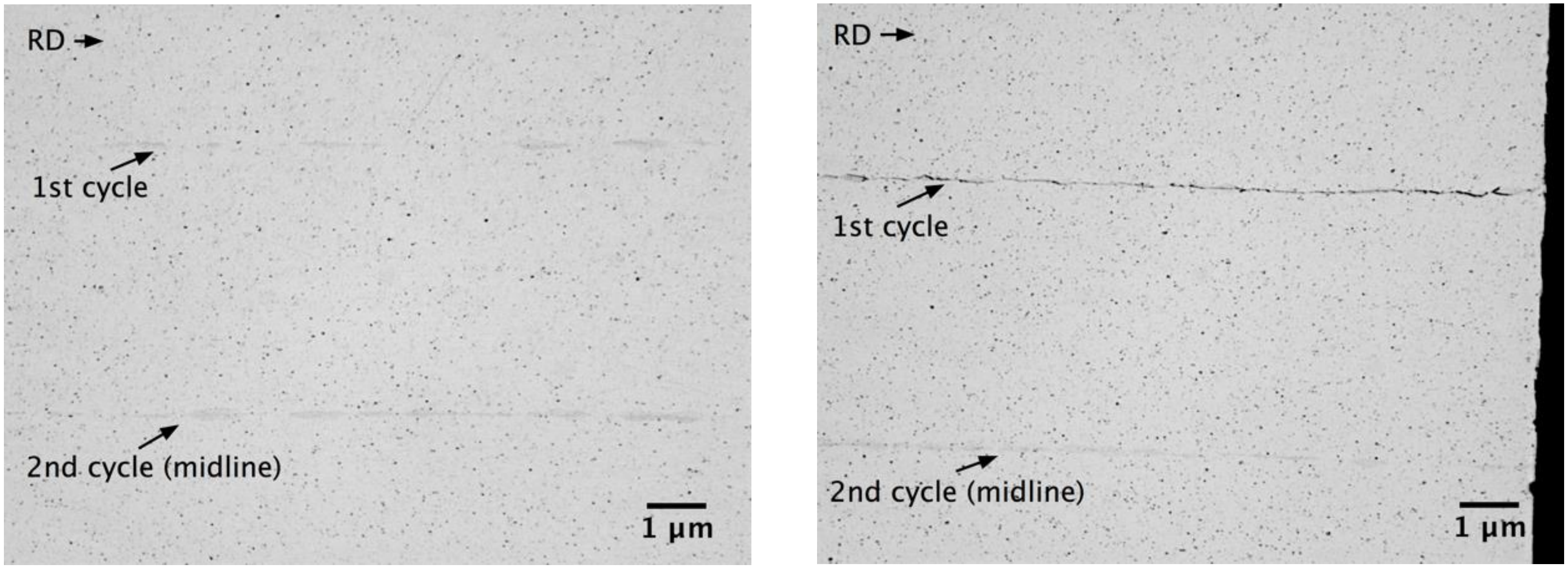
(2x) 0.068 in x 1 in

Final Dimensions:

(1x) 0.069 in x 1 in

49 % 1-pass reduction

2 ARB Cycles



(a) (b)

Fig. 10. (a,b) Optical micrographs of longitudinal cross section Al 6061 subject to 2 ARB cycles showing degree of bonding. (b) shows lack of bonding near trailing edge from first bonding cycle.

Change of interface character near trailing edge

Current Issues in Research

Lateral Spreading

- spot welds
- wire binding
- edge guides

Edge Cracks

- wider samples
- “warm” rolling

Fig. 11. Wire-binding preparation before ARB [8].

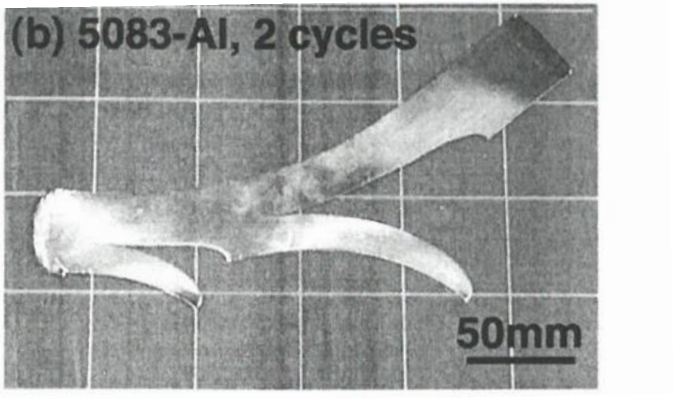


Fig. 12. Severe splitting of Al 5083 after 2 ARB cycles [9].

Processing Limitations

8” wide rolls

5.25” roll diameter

Fixed 50 SPM speed

100,000 lb capacity

No edge control

Fig. 13. 100,000 lb Fenn 2-high rolling mill at CSM.

Edge Guides

Fig. 14. Current infeed table of Fenn 2-high rolling mill at CSM.

Fig. 15. Edge guides used on rolling mill for ARB studies at Osaka University [8].

Accomplishments

Progress to Date

Development of surface preparation methods

- acetone degrease
- 2,500 RPM wire brushing

Adequate bonding in two successful ARB cycles

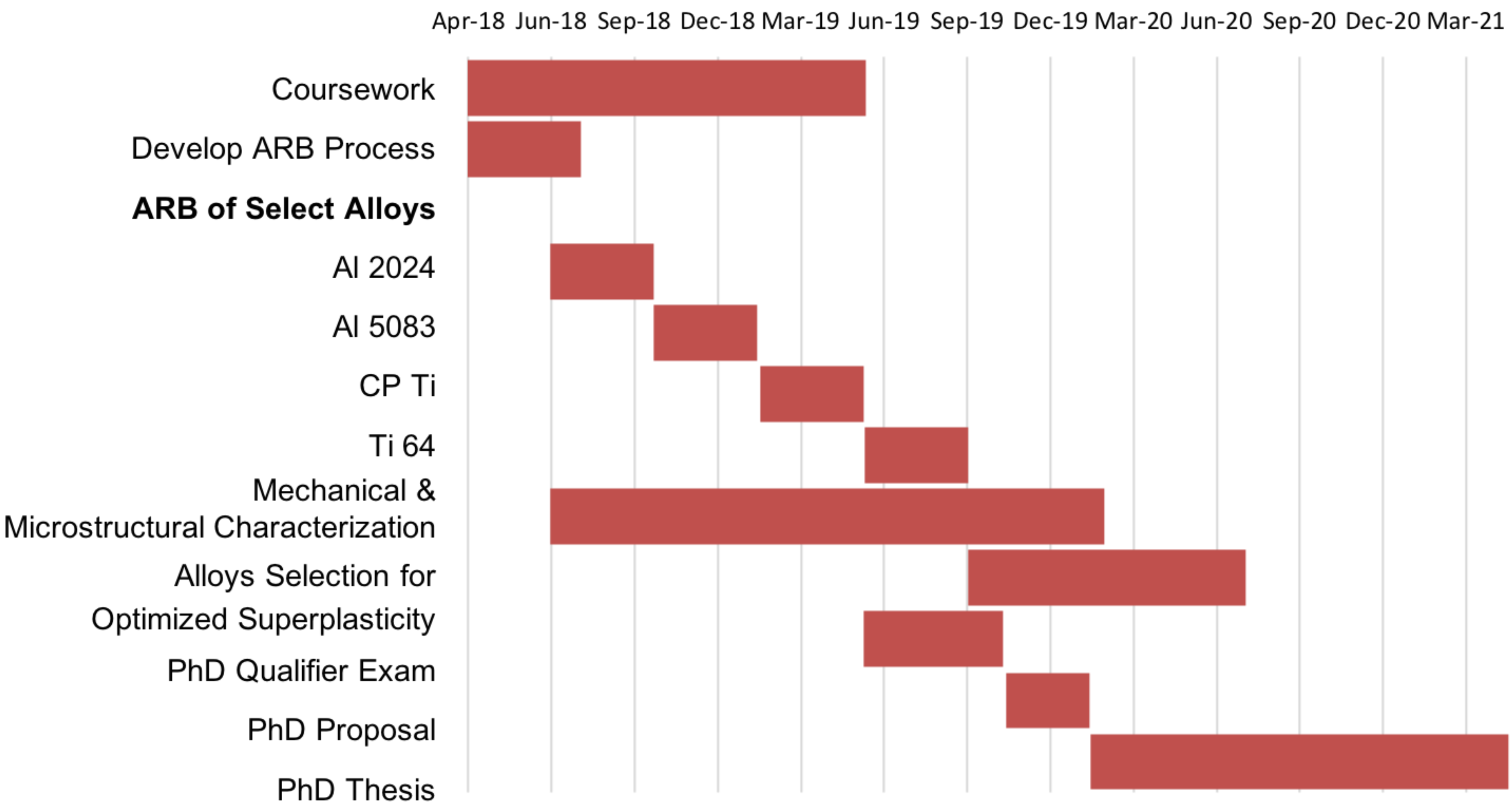
Next Steps

Characterize bonding interface

Examine microstructural development

Characterize resulting tensile properties

Gantt Chart


Apr-18 Jun-18 Sep-18 Dec-18 Mar-19 Jun-19 Sep-19 Dec-19 Mar-20 Jun-20 Sep-20 Dec-20 Mar-21
Coursework
Develop ARB Process
ARB of Select Alloys
Al 2024
Al 5083
CP Ti
Ti 64
Mechanical & Microstructural Characterization
Alloys Selection for Optimized Superplasticity
PhD Qualifier Exam
PhD Proposal
PhD Thesis

Thank you!

Brady McBride
bmcbride@mines.edu

References

[1] 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.

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Strengthening Effects

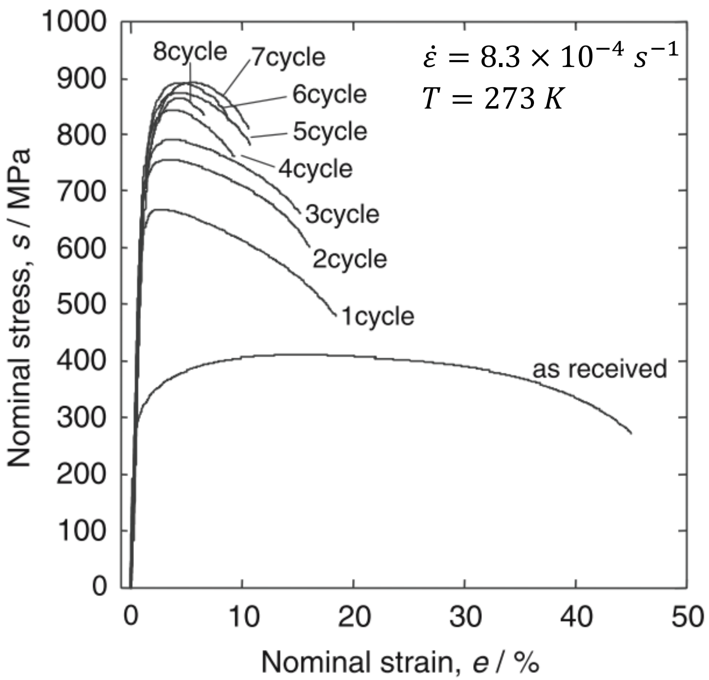

Fig. 16. Stress-strain curves of ARBed CP Ti from tensile tests conducted at room temperature [10].

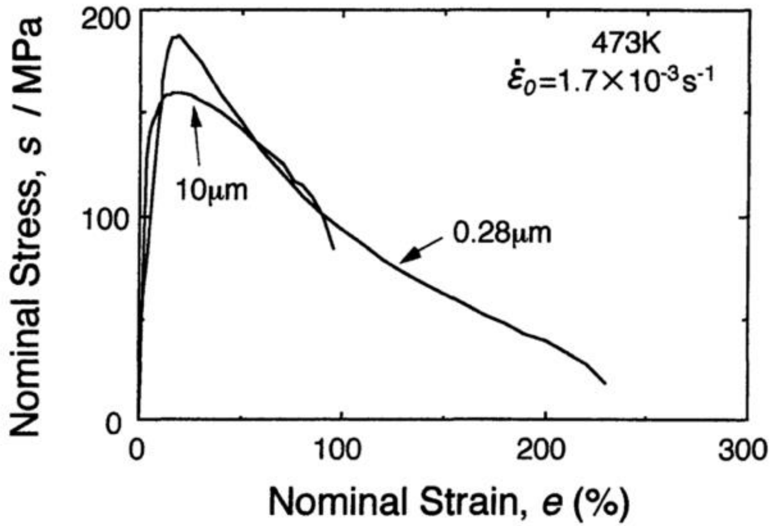

Fig. 17. Stress-strain curves of ultrafine grained (0.28μm) 5083 processed by ARB compared to coarse grain (10μm) 5083 [1].

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Program Goal

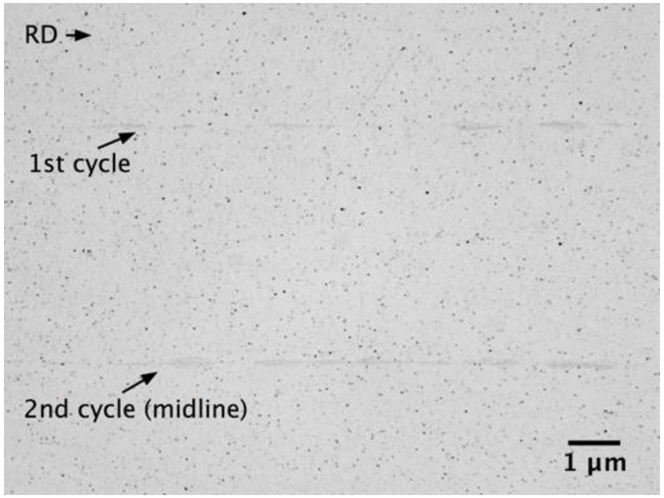
Investigate enhanced superplasticity of ultra fine grained materials produced by accumulative roll bonding

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 with reduce operating costs and prolong die life



Bonding interfaces developed in Al 6061 after 2 roll bonding cycles

Project Duration

August 2017 to May 2021