Project 48: Grain Boundary Fracture Analysis in Aluminum

Semi-annual Fall Meeting

October 2021

- Student: Scott Blazanin (ISU)
- Faculty: Dr. Peter Collins (ISU)
- Industrial Mentors: Dr. Matt Krug (AFRL)

Project 48: Grain Boundary Fracture Analysis in Aluminum

- Student: Scott Blazanin
- Advisor(s): Professor Peter Collins

Project Duration
Master's: November 2020 – May 2022

- Problem: Atypical cracking behavior is observed in forged aluminum 7085 plates after fatigue testing. The mechanisms of crack propagation and branching events in this alloy are understudied.
- Objective: Conduct comprehensive metallographic characterization for the analysis of delamination cracking and surrounding microstructure.
- Benefit: Understanding crack behavior in Al 7085 during cyclic loading will allow for a wider application of this alloy.

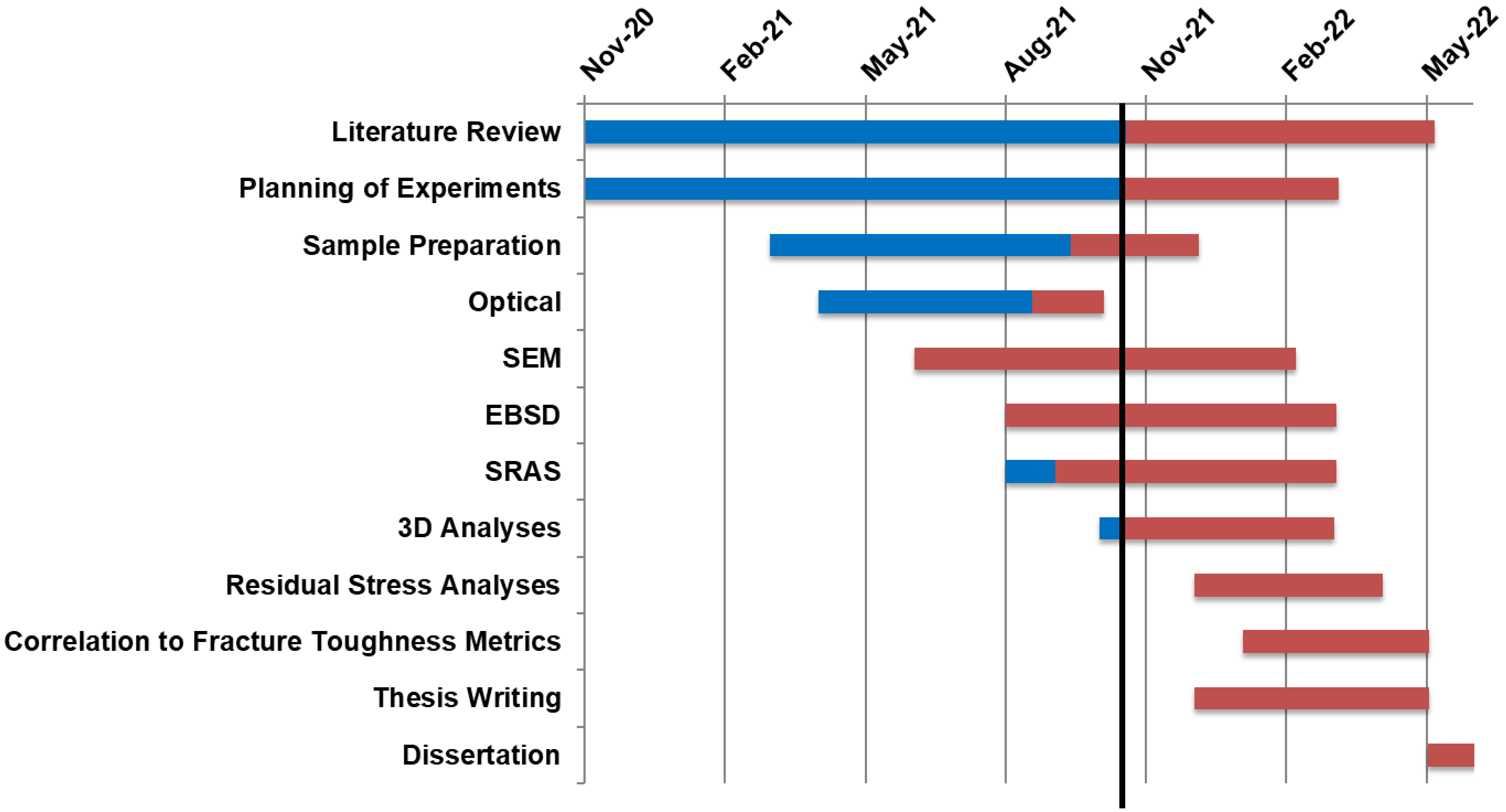
Recent Progress

- Sample preparation recipe developed with AFRL. Recipe optimized for fracture edge EBSD analysis.
- All Neely plate samples received following EDM.
- LS-01 sample sectioned, mounted, and prepped.
- Optical microscopy initiated, SEM to follow this week.

Metrics

Description	% Complete	Status
1. Literature review	70%	
2. Sample preparation for optical and SEM-BSE imaging and EBSD analysis	30%	
3. Imaging (optical, SEM-BSE) and texture analysis (EBSD, SRAS)	15%	
4. Microstructural characterization (grain size via MIPAR, EBSD micro-texture analysis)	5%	
5. Relate microstructural features to fatigue crack growth metrics	0%	

Gantt Chart


Nov-20
Feb-21
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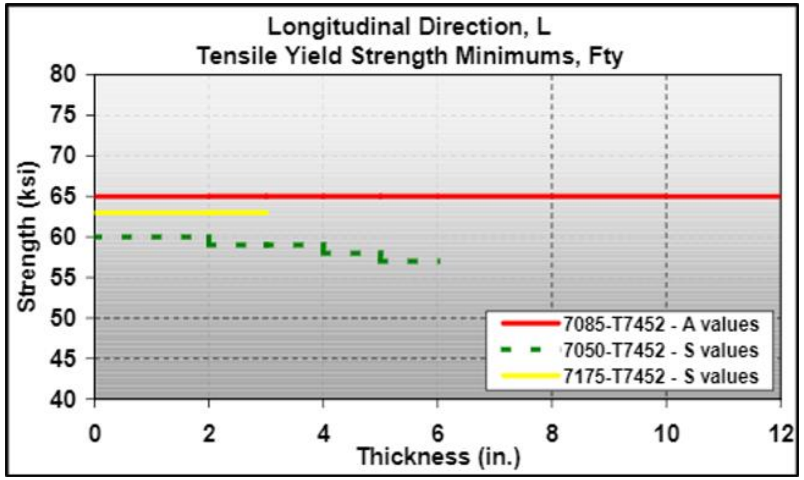
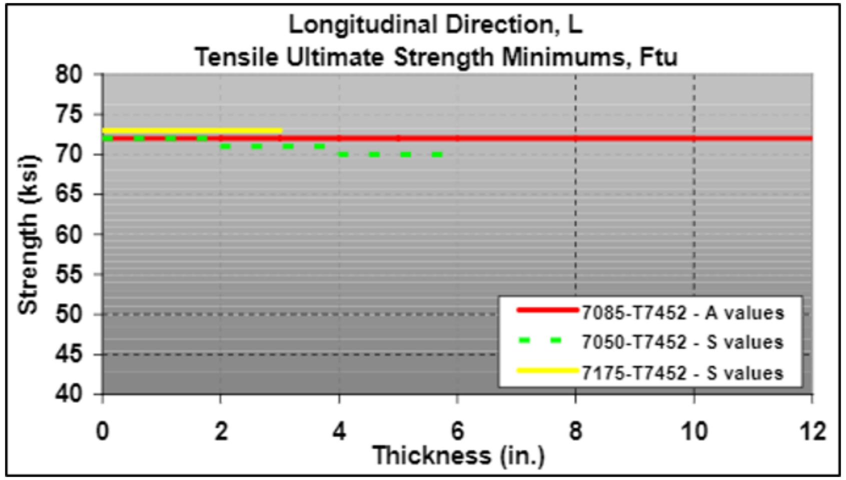
Literature Review
Planning of Experiments
Sample Preparation
Optical
SEM
EBSD
SRAS
3D Analyses
Residual Stress Analyses
Correlation to Fracture Toughness Metrics
Thesis Writing
Dissertation

Relevance of This Work to Industry

- Material-geometry combinations for structural aircraft components have changed
  - Manufacture of unitized components for structural support shows improved performance and reduced weight
- AA7085 (Al 7085)
  - 7-8 Zn, 1.2-1.8 Mg, 1.3-2.0 Cu, 0.08-0.15 Zr, 0.08 Fe, 0.06 Si, balance Al (wt%)
  - Advantageous to other 7xxx series Al alloys
    - Constant YS and UTS (thickness from 0 to 12")
    - Improved fracture toughness and fatigue properties

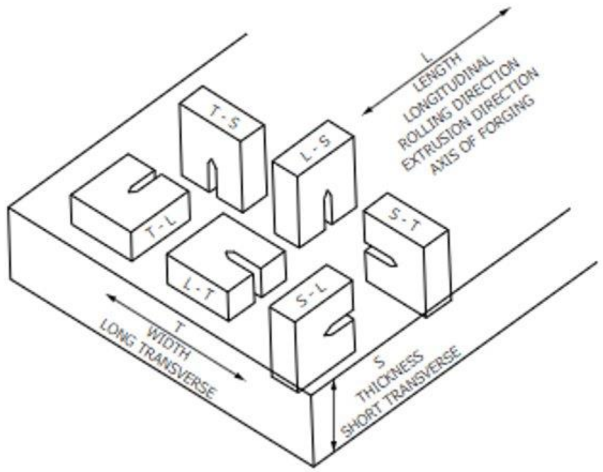


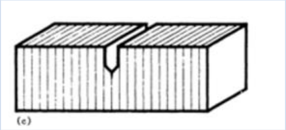
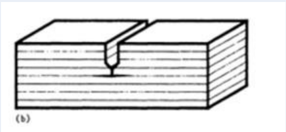
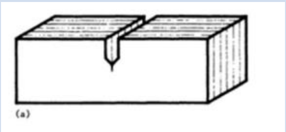


Burns et al., *International Journal of Fatigue*, 2015. (p 253)
Mueller et al., *ALCOA 7085 Forgings: 7th Generation Structural Solutions*, 2006. (p 12-13)

Prior Work on Al 7085

- Jared Neely studied fatigue crack growth behavior in Al 7085
  - Critical fracture toughness, K_{IC}, is orientation dependent
  - Concluded that "microstructure is what drives the size, direction, and quantity of macroscopic branching cracks"
- Neely's work investigated macroscale mechanics of atypical cracking in this alloy
  - Useful observations and K_{IC} data, but critically lacks microstructural analysis
- Current work aims to connect microstructure to cracking



Condition	Orientation	Diagram
Crack splitting delamination	S-L, S-T	
Crack arrester delamination	T-S, L-S	
Crack divider delamination	L-T, T-L	

Neely, *Thesis*, 2015.
Rao et al., *Materials Science and Technology*, 1989.
ASTM E399-20a, 2021.

Project Background

Problem

- Delamination cracking intrinsic to the fracture process in Al 7085 presents design and life prediction challenges
  - Current testing and assessment procedures (ASTM E647) do not account for the effects of delamination cracking on toughness and strength, nor do they account for the orientation dependence of secondary cracking in AA7085

Objectives

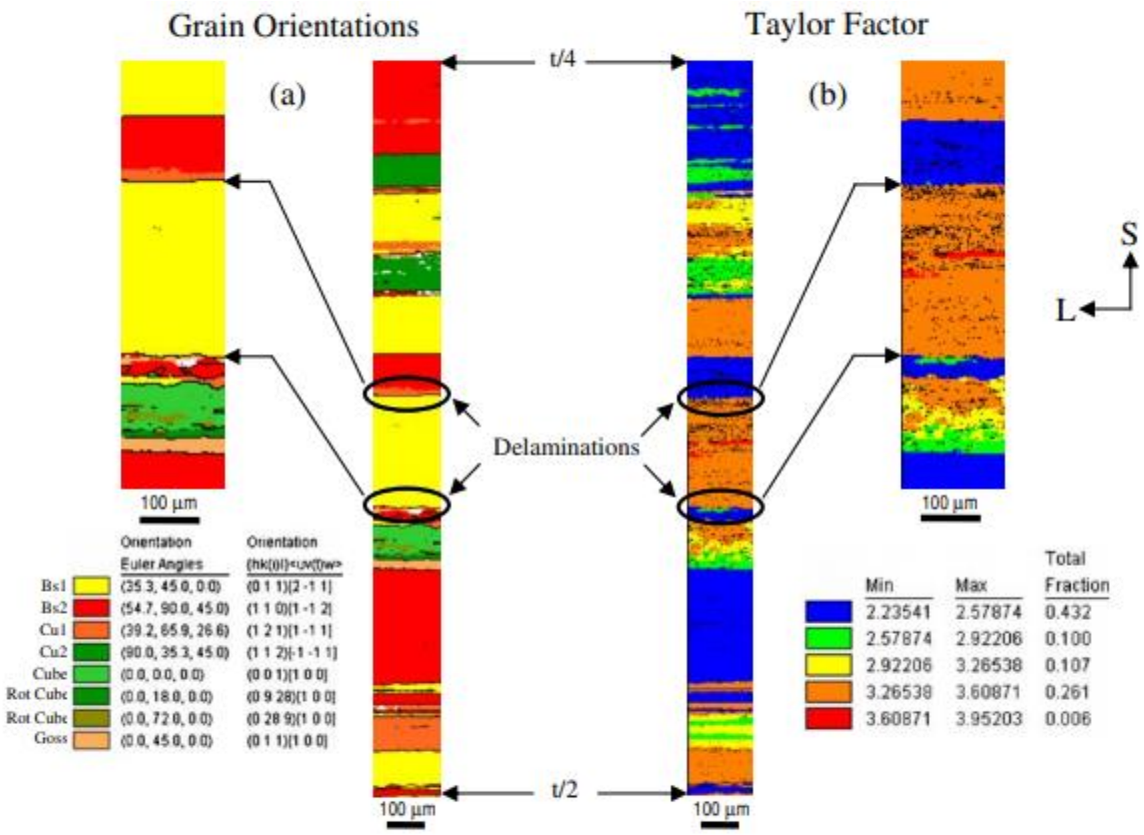
- Develop methods to comprehensively analyze grain effects on crack behavior
  - Understand influence of local crystallographic orientation on crack tip energy
  - Relate loading conditions and crack growth
  - Determine microstructural conditions that promote secondary cracking
- Understand crack branching and grain boundary delamination behavior in Al 7085
  - Provide information for better design decisions and qualification of components using this alloy within the aerospace industry
  - Refine predictions on part life
  - Enable processing modifications for the reduction or elimination of unwanted crack behavior

ASTM E399-20a, 2021.
ASTM E1820-20, 2021.

Groundwork from Literature

According to foundational work on delamination cracking in aluminum alloys:

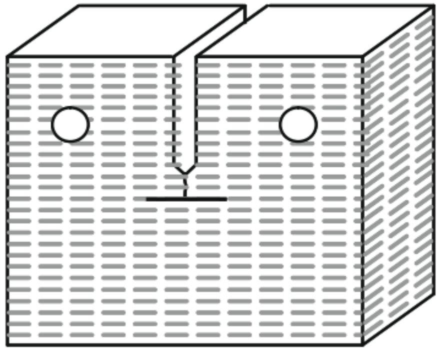
- Grain anisotropy affects fracture initiation processes in Al-Li plates, with elongated grain boundaries showing increased delamination cracking (Sohn et al.)
- Small-scale-yielding, crystal plasticity simulations show elevated mean stress on grain boundaries in Al-Li alloys. This favors conditions for void growth, triggering delamination cracking (Messner, Beaudoin et al.)
- Delamination in Al-Li alloys typically initiates between soft and stiff grain pairs and may be characterized by a difference in Taylor factors (Messner et al., Tayon et al.)
- Delamination cracking often increases apparent fracture toughness via deflection and shielding of the primary crack (Rao and Ritchie)

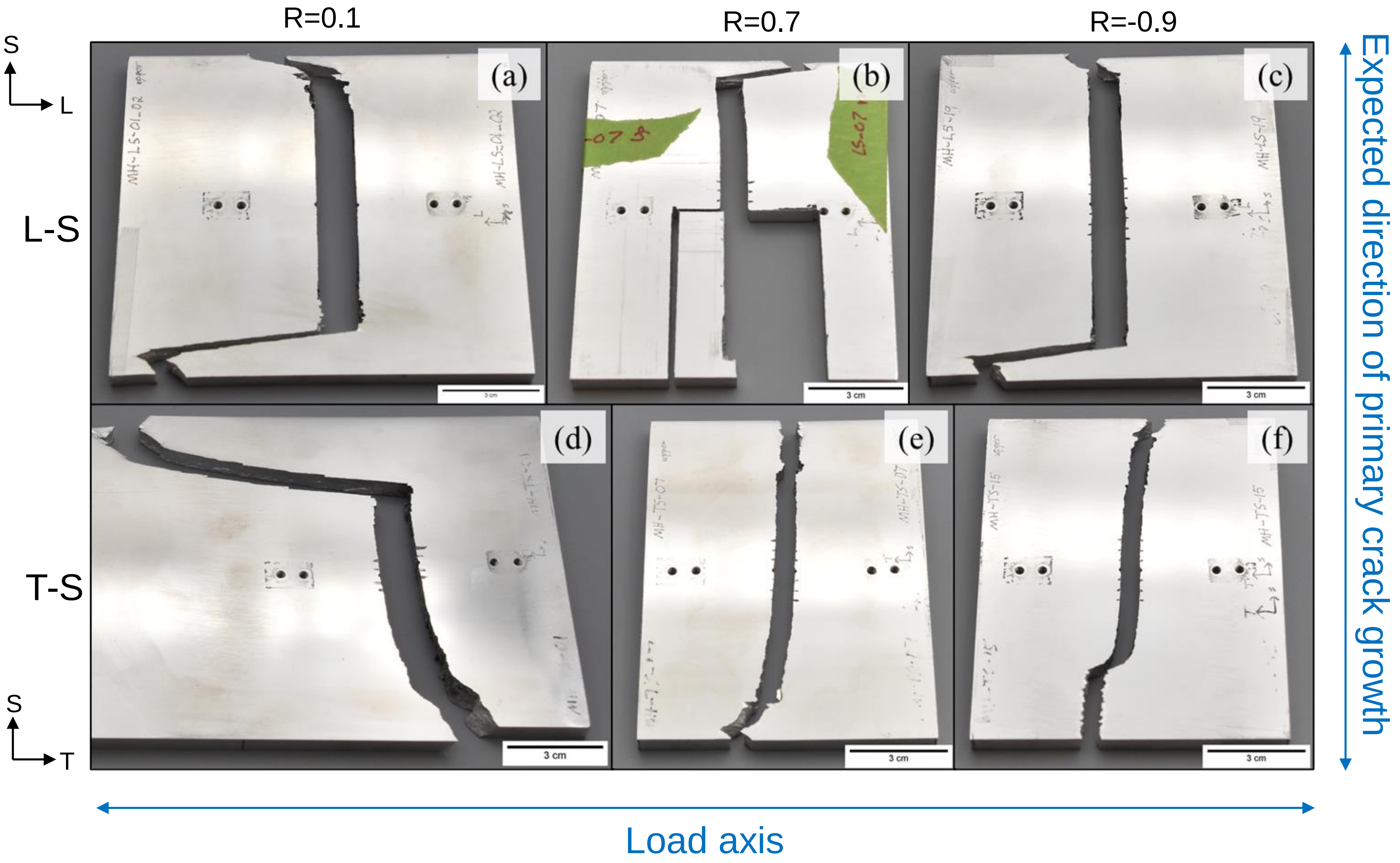


Tayon et al., *Experimental Mechanics*, 2008.

Sample Set Overview

Crack arrester delamination
(L-S, T-S)

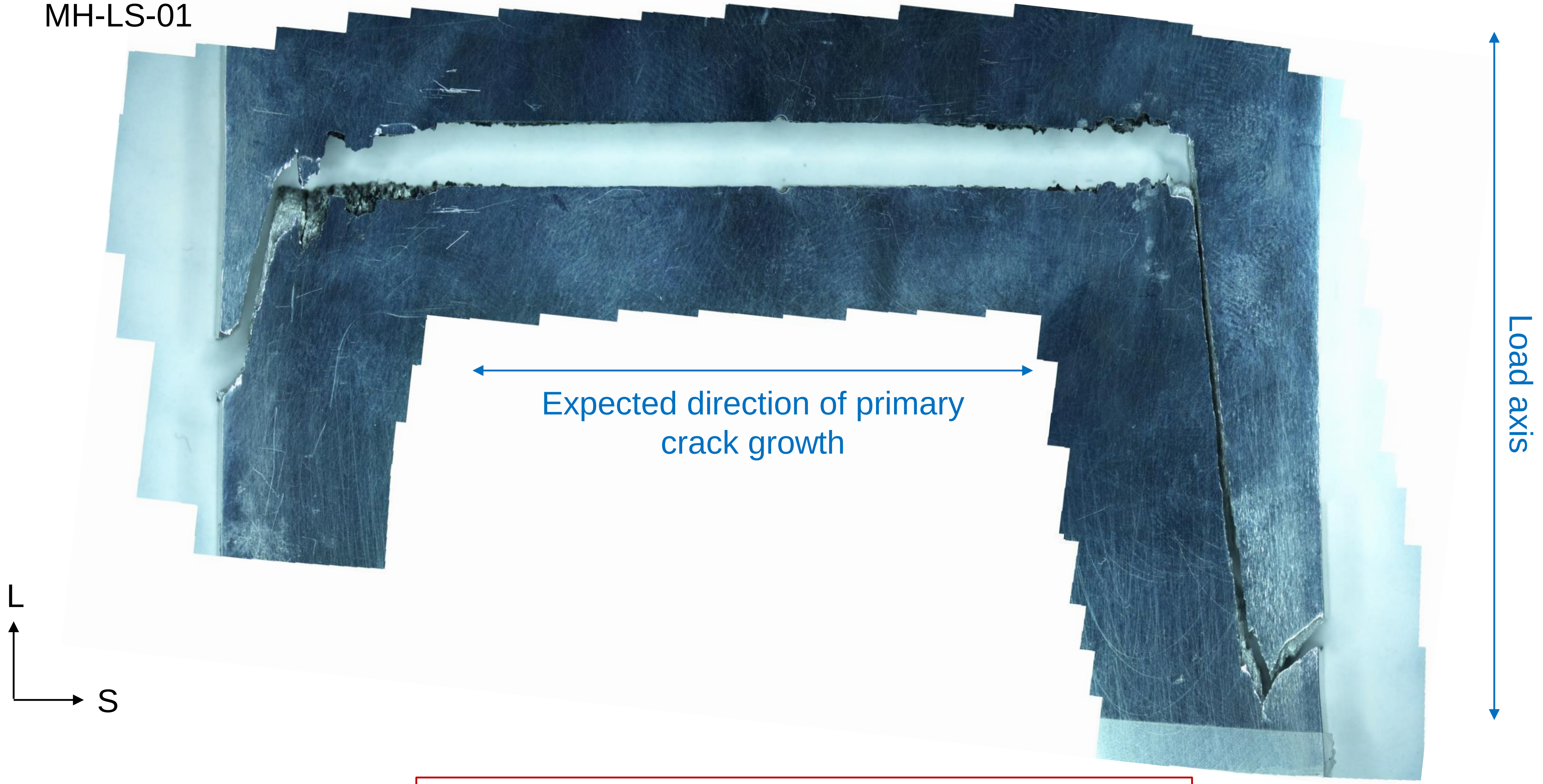




Kalyanam et al., *Engineering Fracture Mechanics*, 2009.

Fracture Edge Mosaics

MH-LS-01



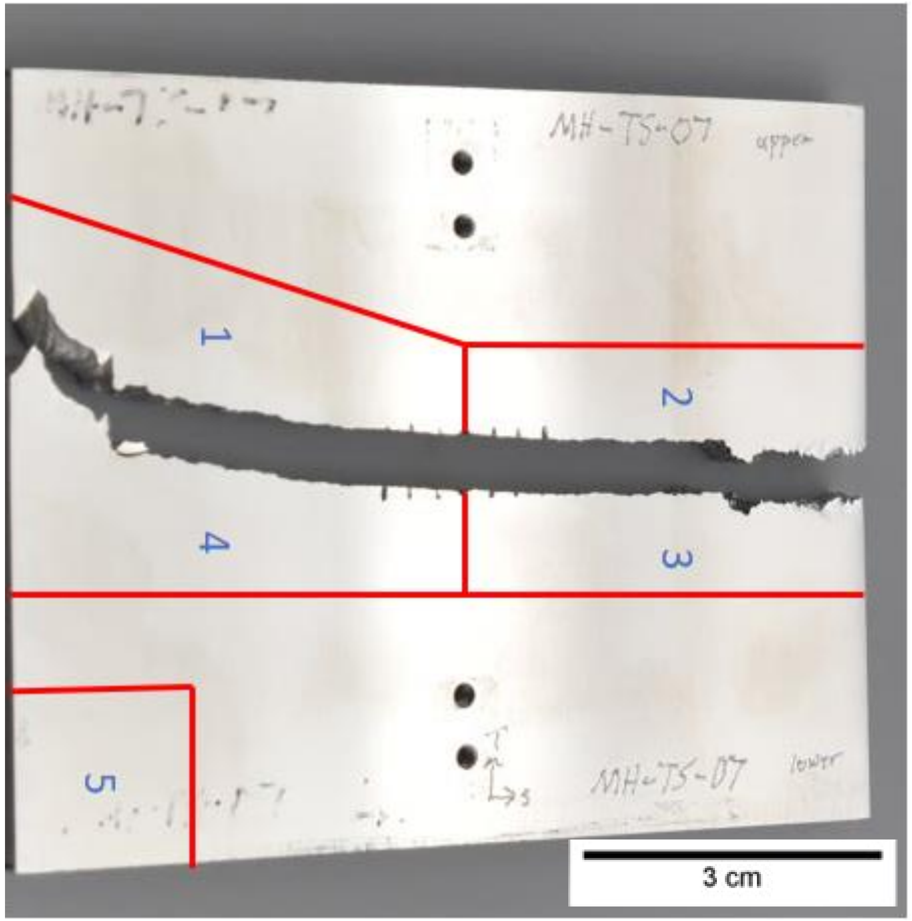
EDM Sectioning

Electrical discharge machining used to section each of the 6 L-S and T-S Neely plate specimens

- 4 fracture edge specimens per plate
- 1 section of base material per plate

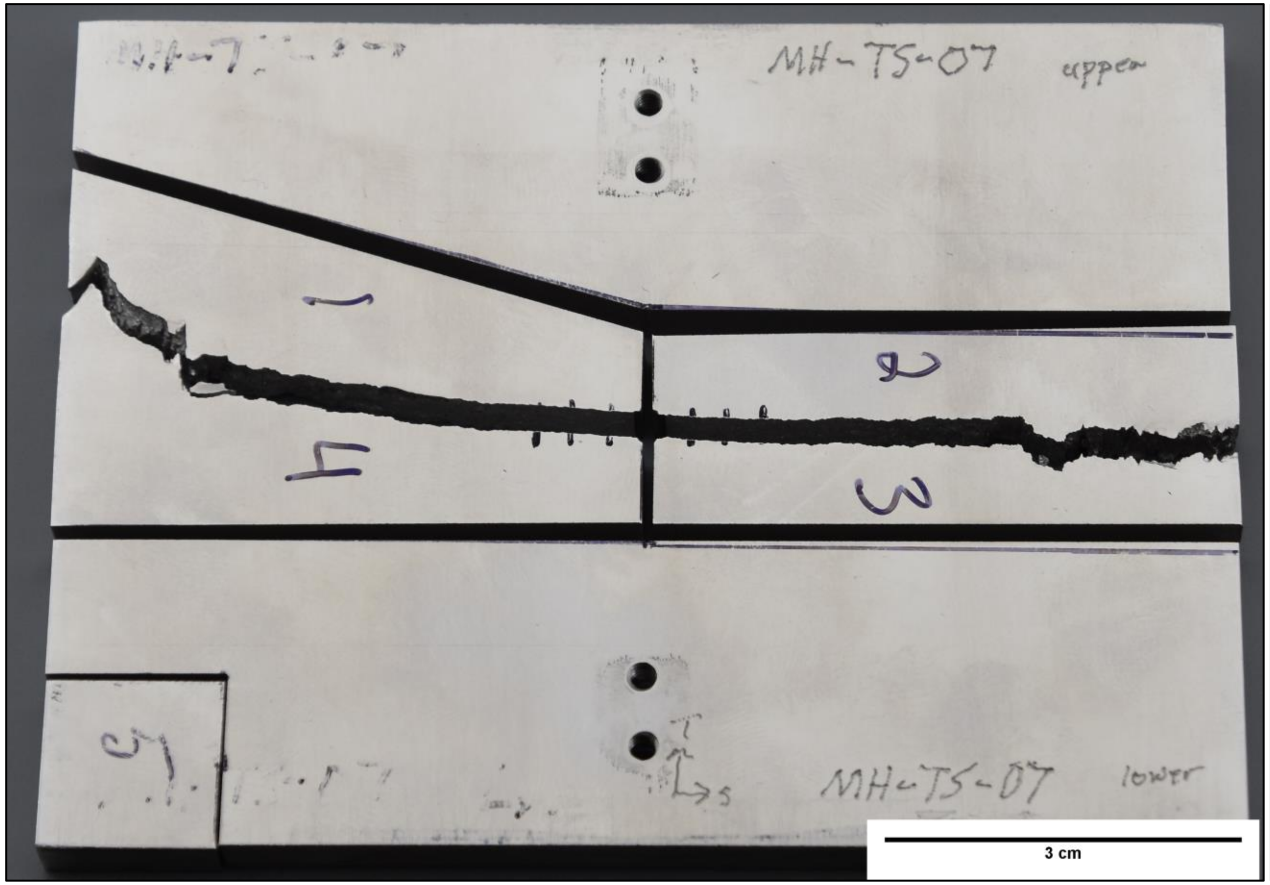
Numbering system used to document fracture edge quadrants

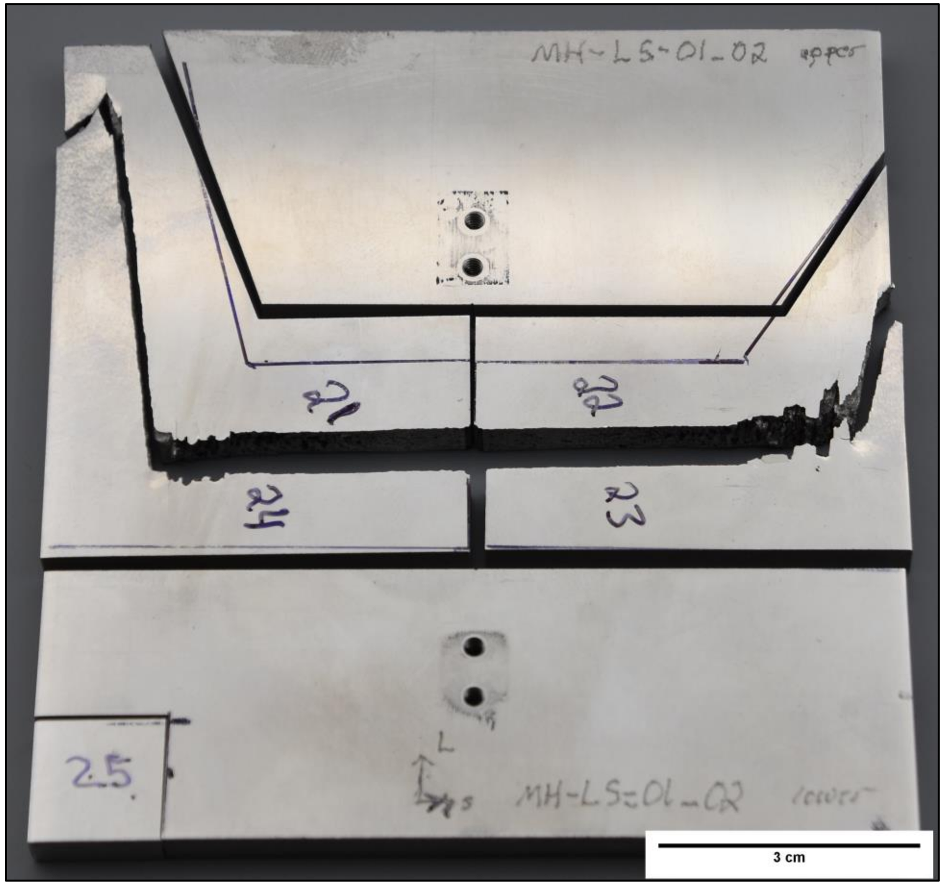
- Left vs. right
- Upper vs. lower



Recent Progress - EDM Sectioning

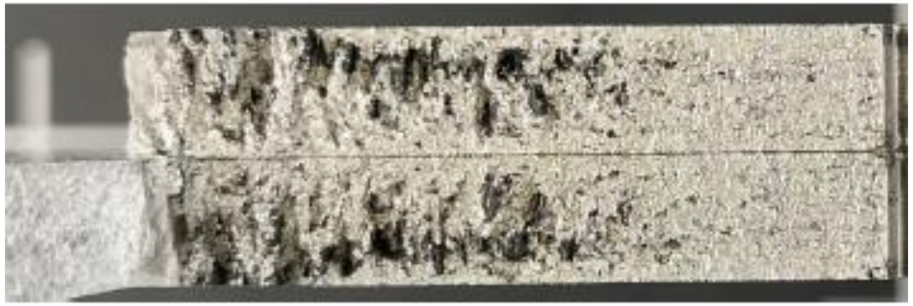
- All samples recently received from off-site machining facility

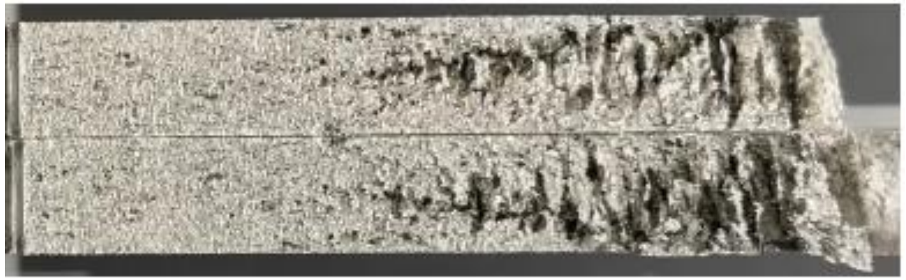


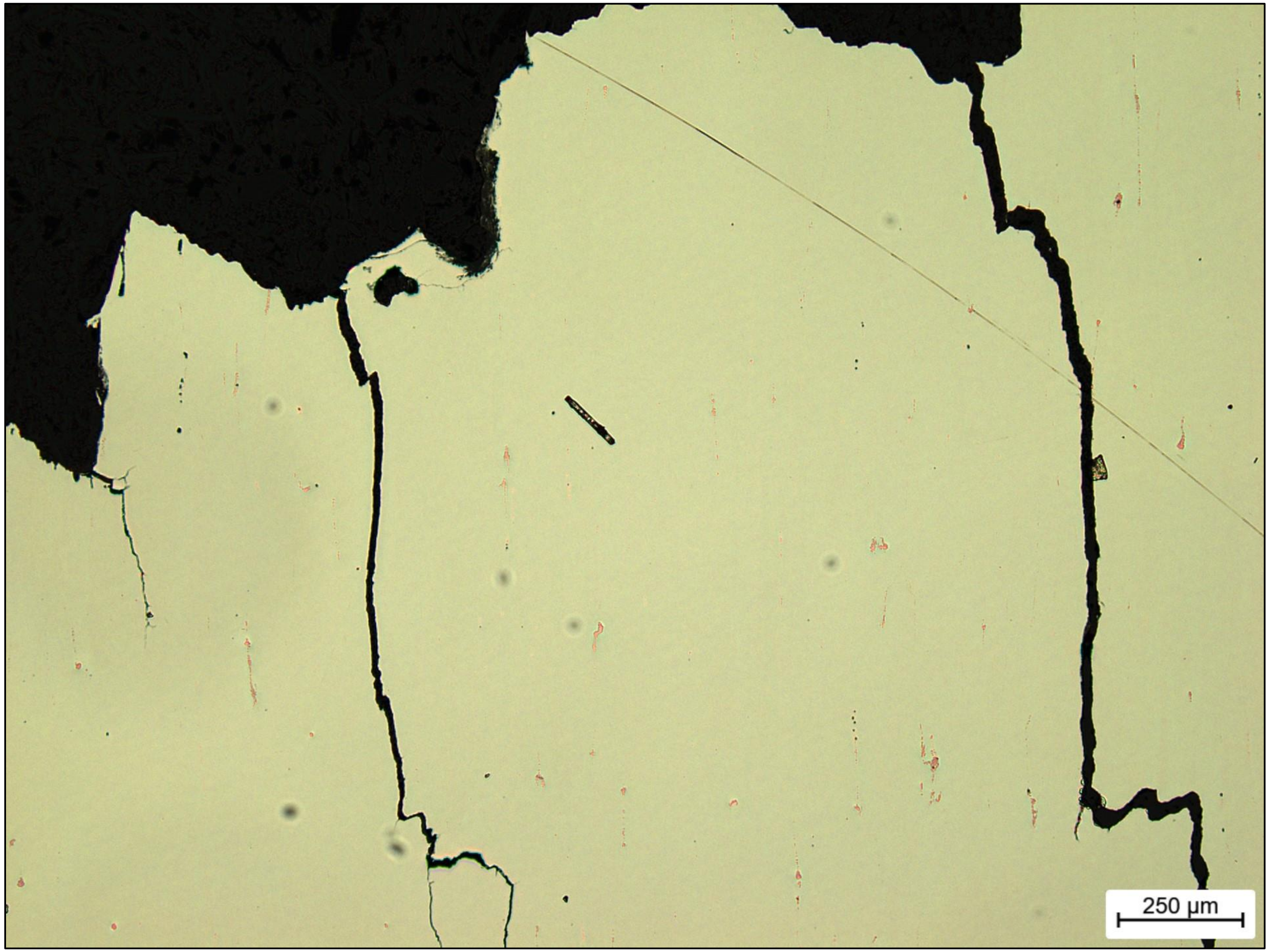


Optical Microscopy

- “Moving window” analysis along primary fracture edge
  - Total secondary crack length in window vs distance along primary crack
  - Analysis at centerline thickness for all plate samples

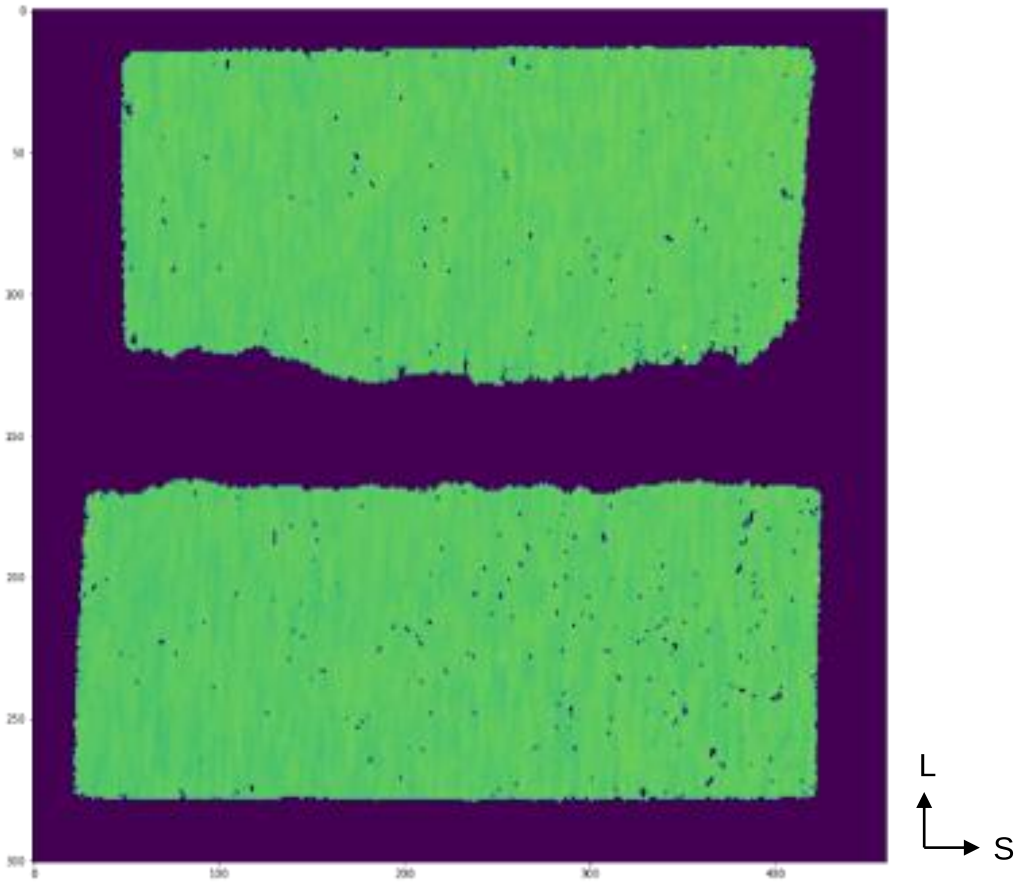


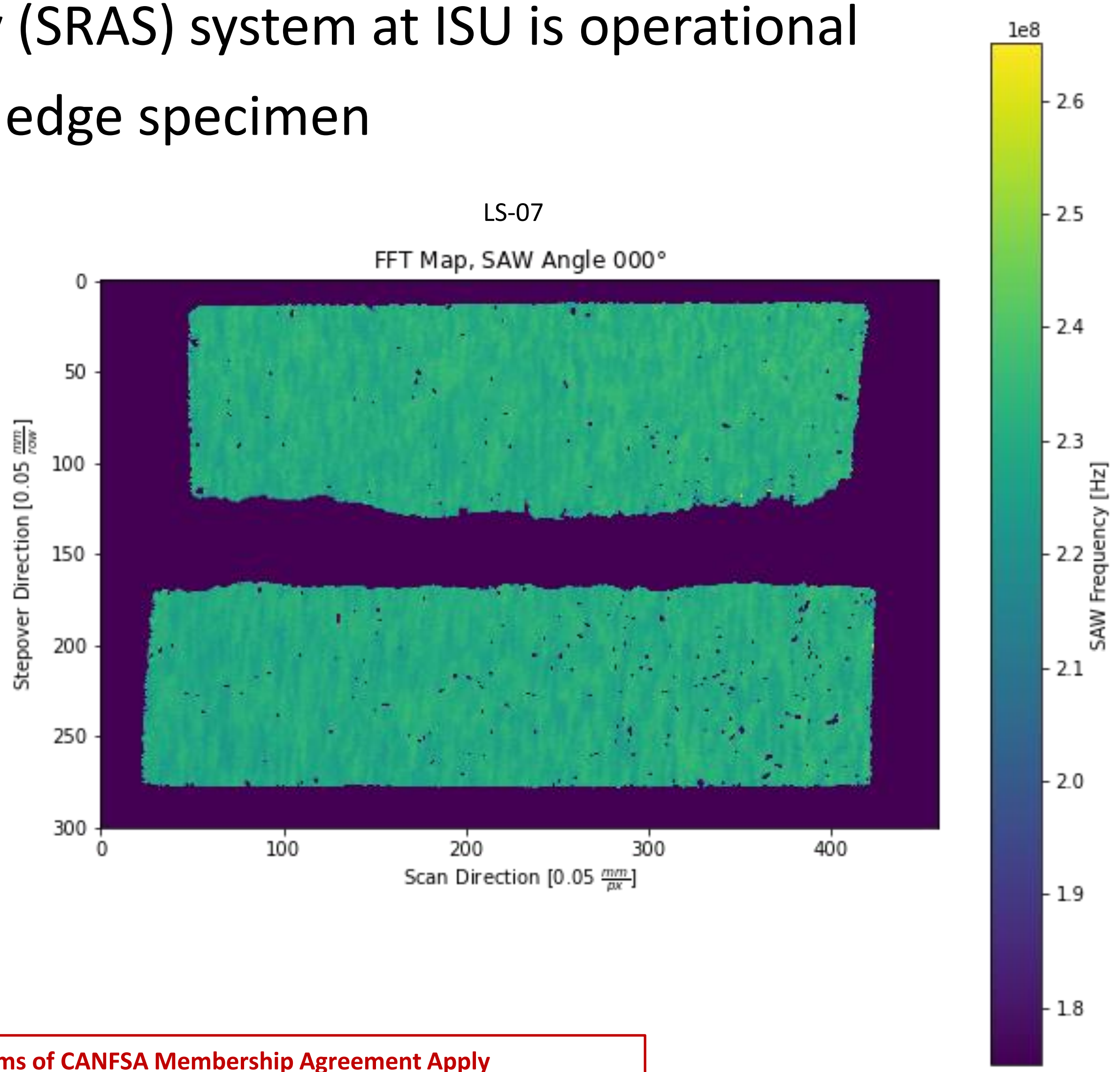




SRAS

- Spatially resolved acoustic spectroscopy (SRAS) system at ISU is operational
- Initial scan conducted on LS-07 fracture edge specimen





Future Experiments

1. Optical
   - Secondary crack length quantification
2. SEM
   - Qualitative survey of microstructure and secondary cracking
3. EBSD
   - Influence of local grain orientation on secondary cracking
   - Analysis of grain misorientation along delamination cracks and crack bifurcations
   - Useful data on crack propagation conditions (TF, texture component)
4. Spatially resolved acoustic spectroscopy (SRAS)
   - Large area of analysis
   - Secondary cracks able to be resolved
5. Relate crack-microstructure relationship to stress intensity changes along primary crack
   - Variation in Neely data may correlate with crack-microstructure relationships observed
6. 3D crack network analyses
   - X-ray computed tomography; X-ray computed laminography
7. Residual stress analyses
   - Mean stress plays an important role in fatigue crack growth
   - Non-destructive methods (XRD)
8. Plastic zone size analyses via nanoindentation
   - Along primary cracks, bifurcations, and crack termination

Challenges & Opportunities

- Recovering from unpredictable project delays
- Large population for microstructure and crack analysis
  - Balance statistical significance with efficiency of work and results
- Many causal relationships affect crack behavior
  - Processing history
  - Test conditions
  - Global and local microstructure
  - Mechanical properties of the alloy
  - Alloy composition

Thank you!

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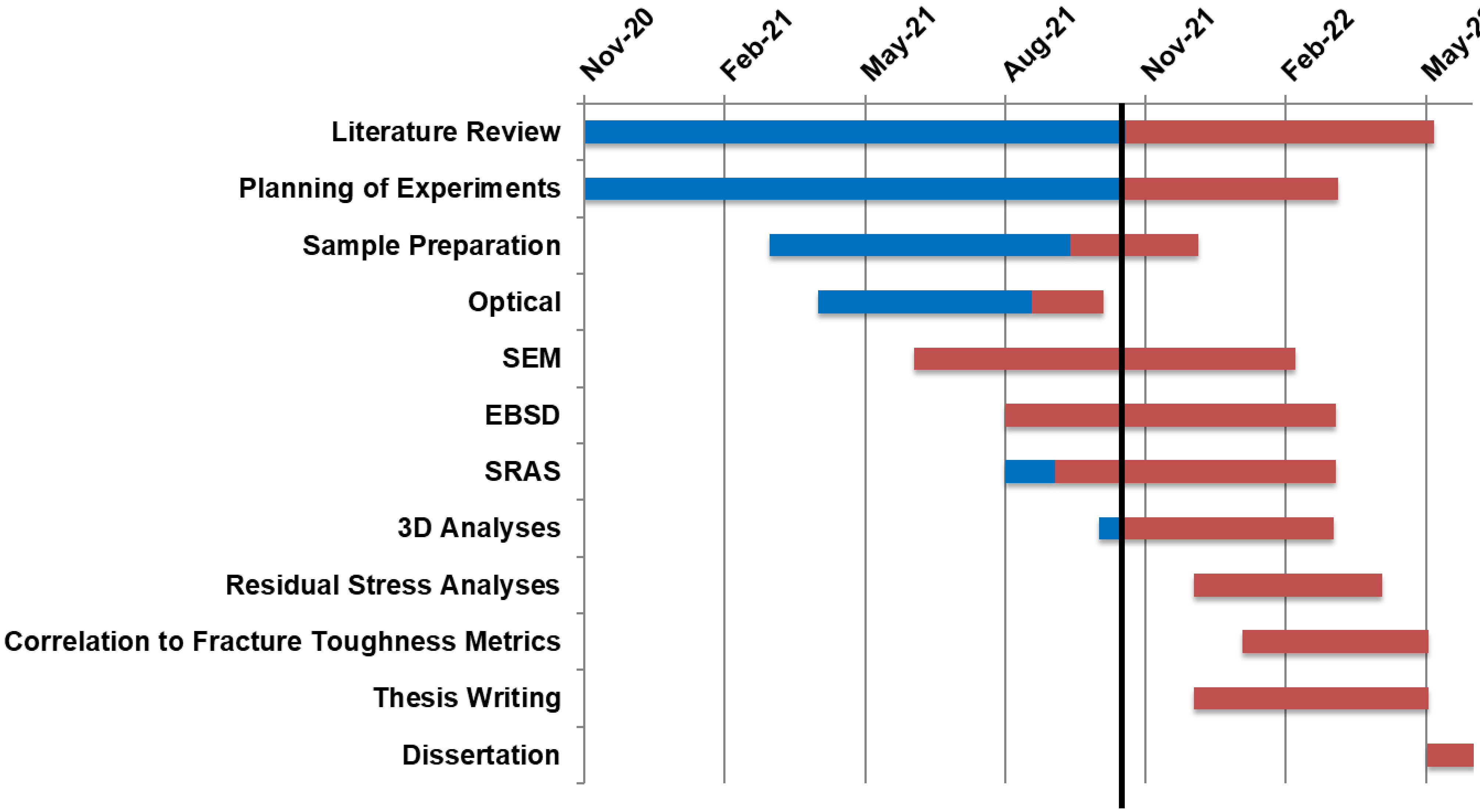
Gantt Chart



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