UNIVERSITY of WASHINGTON BOEING SEKISUI SEKISUI AEROSPACE SOLVAY

Experimental and Computational Investigation into the Use of Discontinuous Fiber Composites to Manufacture a Bracket

5/22/2024

Marco Salviato (UW)

JAMS meeting 2024

Research Team

University of Washington

PIs: Marco Salviato (AA)

Graduate students: Collins Davis
(Total of 12: 1 PhD and 2 master)

Undergraduate students: Yusuf Rasyid, Alexander Javor, Luke Kuklenski…
(50+ students)

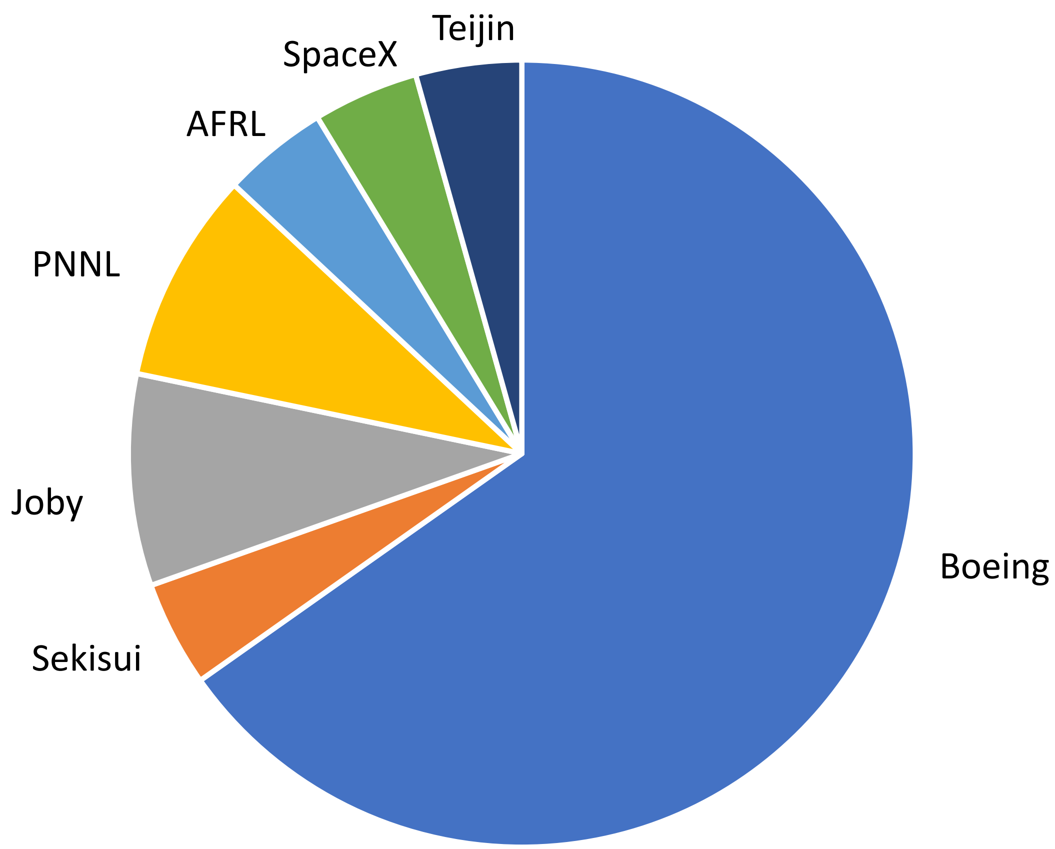
FAA: Dave Stanley (Technical monitor)
Larry Ilcewicz
Amhet Oztekin
Cindy Ashforth

Industry Mentors: William Avery (UW)
Michael Larson (Boeing)
Matthew Soja (Boeing)
Scott James (Sekisui Aerospace)

Sponsors

The Joint Center for Aerospace Technology Innovation

Career Opportunities



Introduction

Carbon Fiber Reinforced Composites Market

Primary Structures

Aviationweek.com

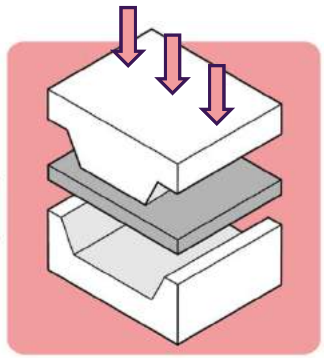
TheGuardian

Secondary Structures

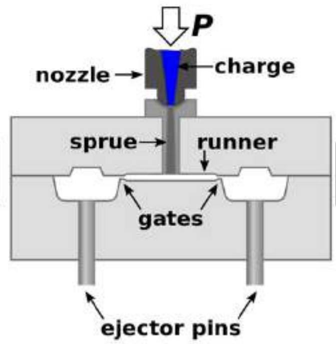
Aviationweek.com

Discontinuous Fiber Composites (DFCs)

Platelet (Chip) based, discontinuous fiber form



Compression molding



Injection molding

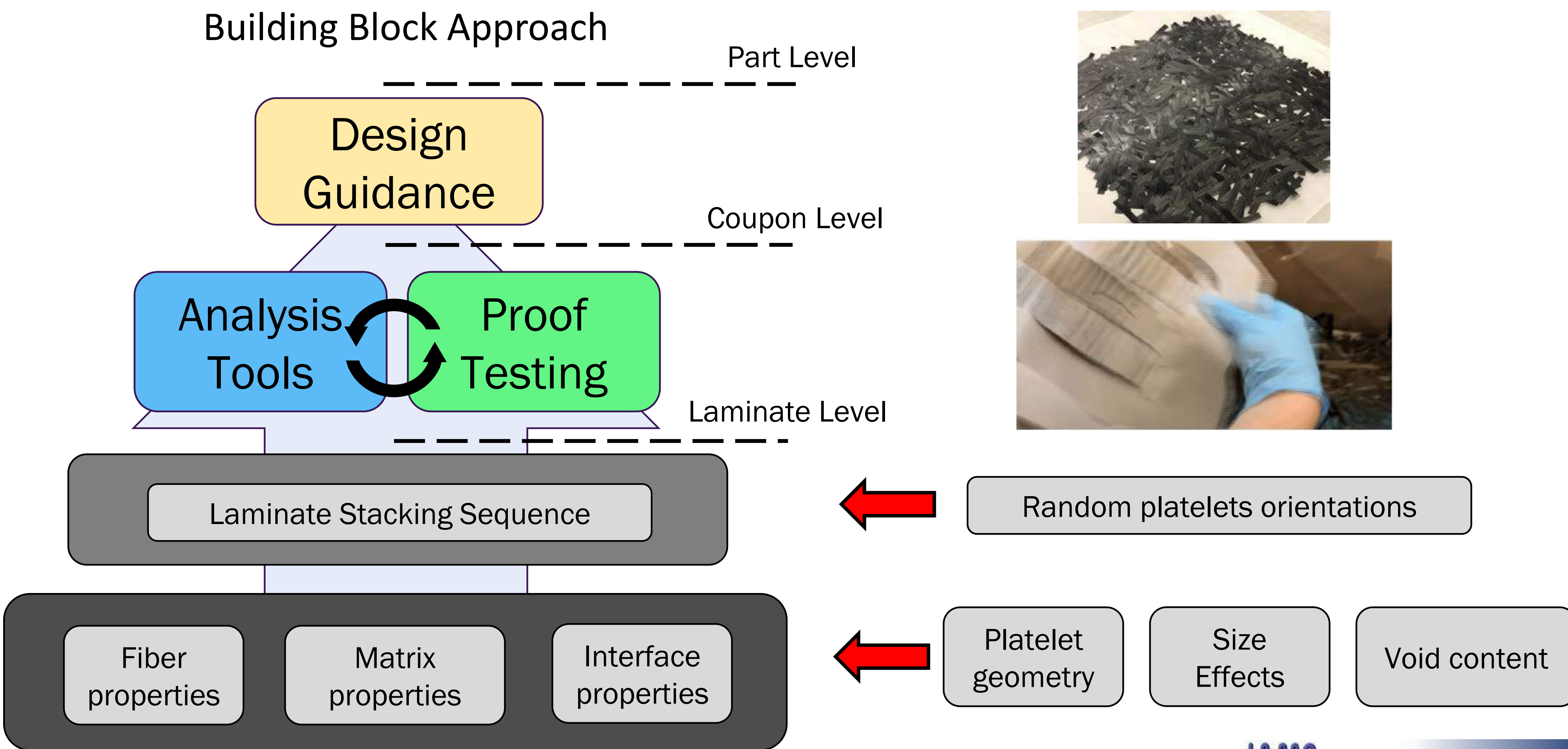
- Achieve complex contours
- Minimum material waste
- Short curing period (within 2 minutes – Hexcel's HexMC)
- Suitable for automation
- Cost saving

Mitsubishi and Toyota

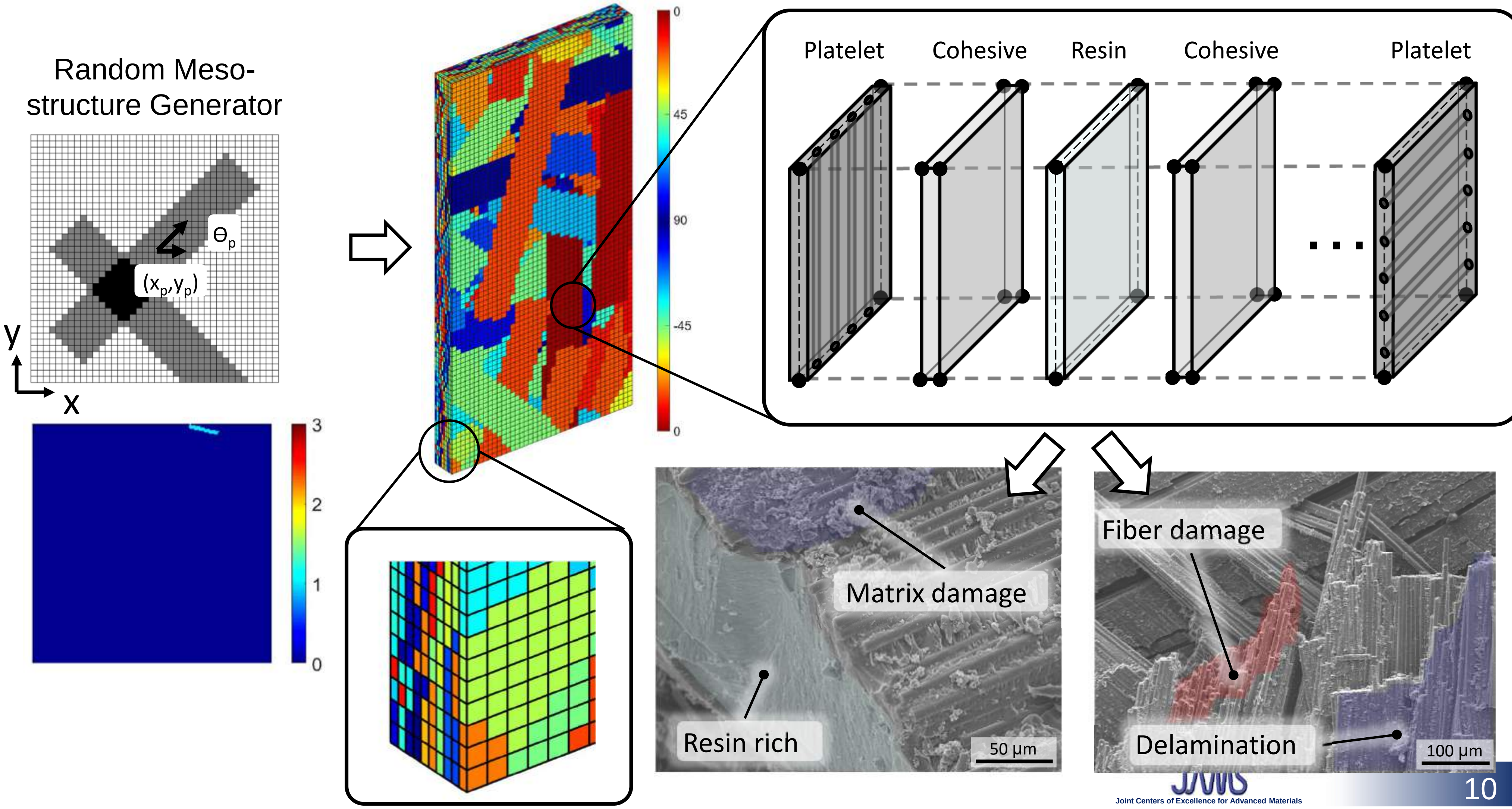
Boeing

Project Overview

Challenges for DFCs – Design Guidance



Finite Element Framework



Project Plan

Experiment: UNIVERSITY of WASHINGTON NIAR

Flat tensile coupons
3D Structures

Experiment: UNIVERSITY of WASHINGTON

Flat tensile coupons

2024

Year 3

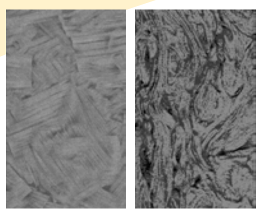
Experiment: BOEING

Flat tensile coupons

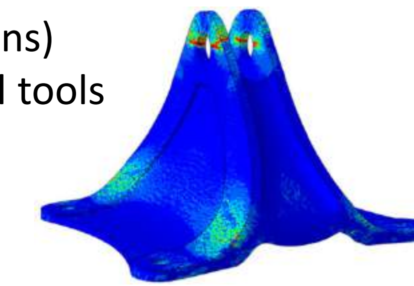
Year 2

- Analyze flow effects
- Extend finding of flat coupons to 3D structures

Year 1



- Execute experiment plan (flat tensile coupons)
- Analyze the results using the computational tools
- Expand CT-measured platelet orientations



2021

- Utilize existing data from Boeing / Purdue U. (flat tensile coupons)
- Develop computational tools
- Design 2021 experiment plan

Project Plan

2021

Year 1

Experiment: BOEING

Flat tensile coupons

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Year 2

Experiment: UNIVERSITY of WASHINGTON

Flat tensile coupons

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Flat tensile coupons
3D Structures

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Project Plan

2021

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Project Plan

Experiment: UNIVERSITY of WASHINGTON NIAR

Flat tensile coupons
3D Structures

Experiment: UNIVERSITY of WASHINGTON

Flat tensile coupons

2024

Year 3

Experiment: BOEING

Flat tensile coupons

Year 2

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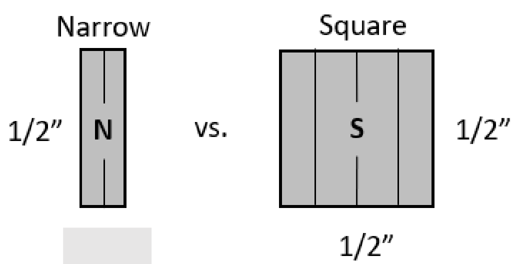
Year 1

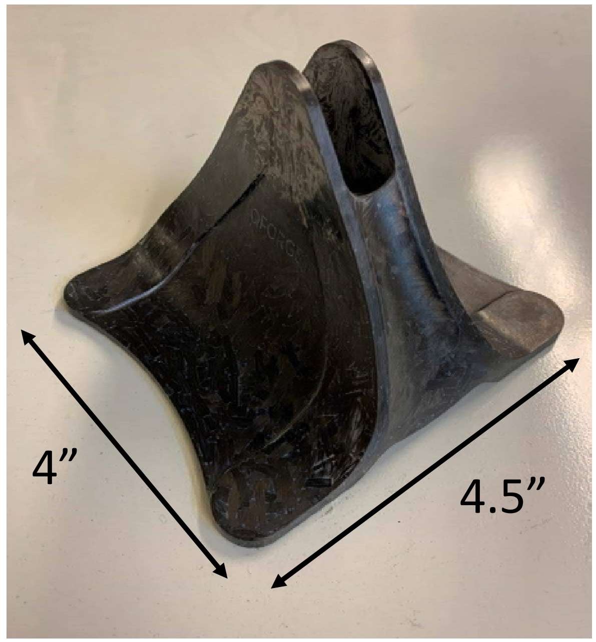
2021

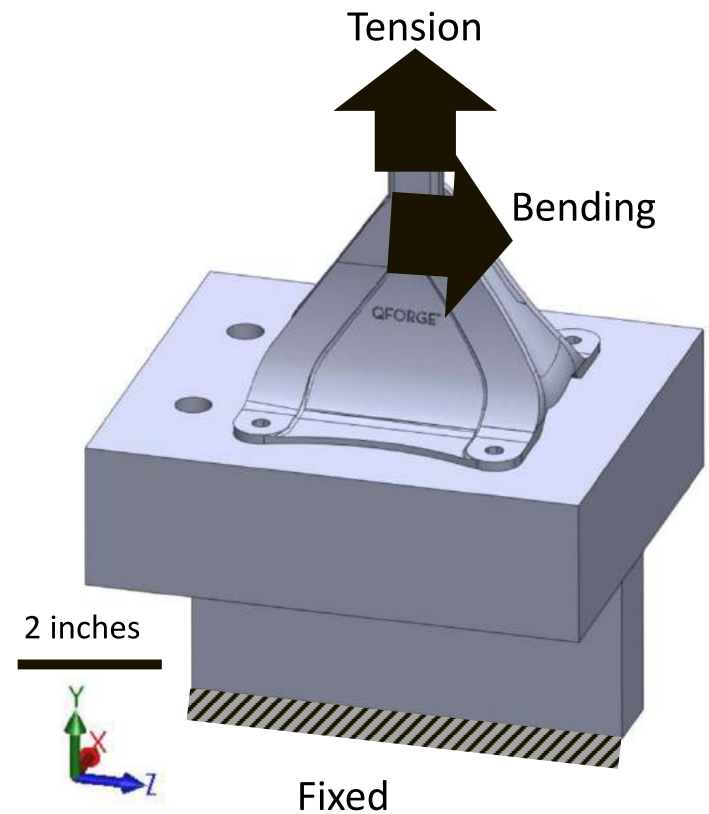
- Utilize existing data from Boeing / Purdue U. (flat tensile coupons)
- Develop computational tools
- Design 2021 experiment plan

Year 3 (2023-24) Summary

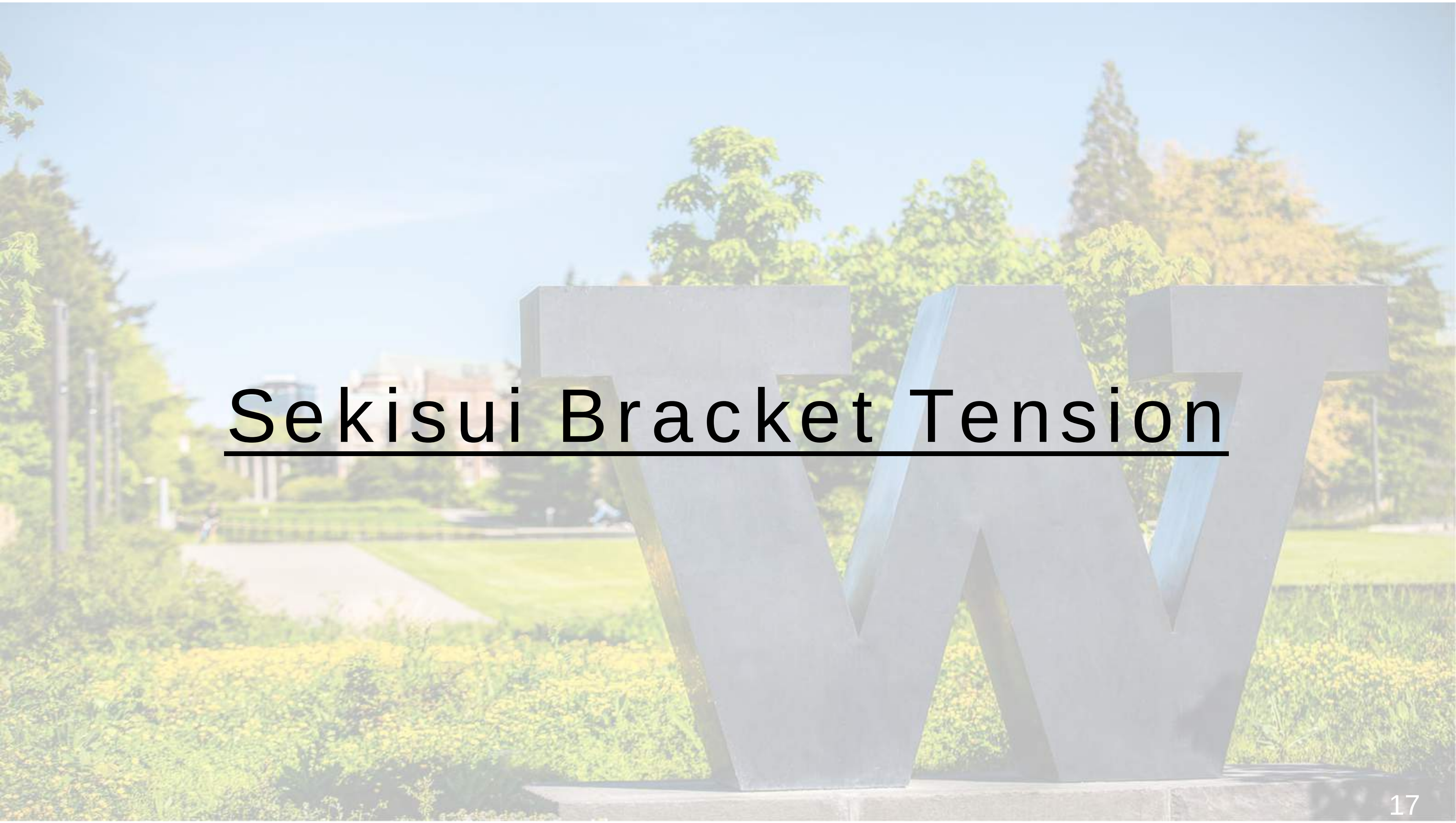
Sekisui Bracket Test Configuration





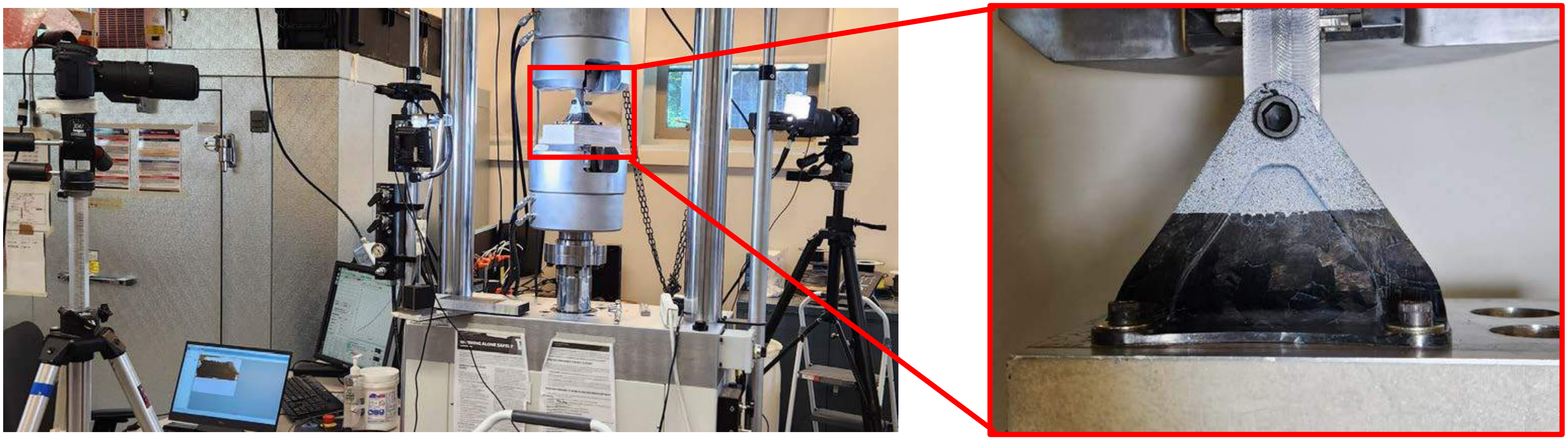


- Testing 2 configurations of the Sekisui QForge Bracket
  1. Square Platelet (14 brackets, 7 x-ray CT)
  2. Narrow Platelet (14 brackets, 7 x-ray CT)
- DIC at the top load pin where we think failure will occur



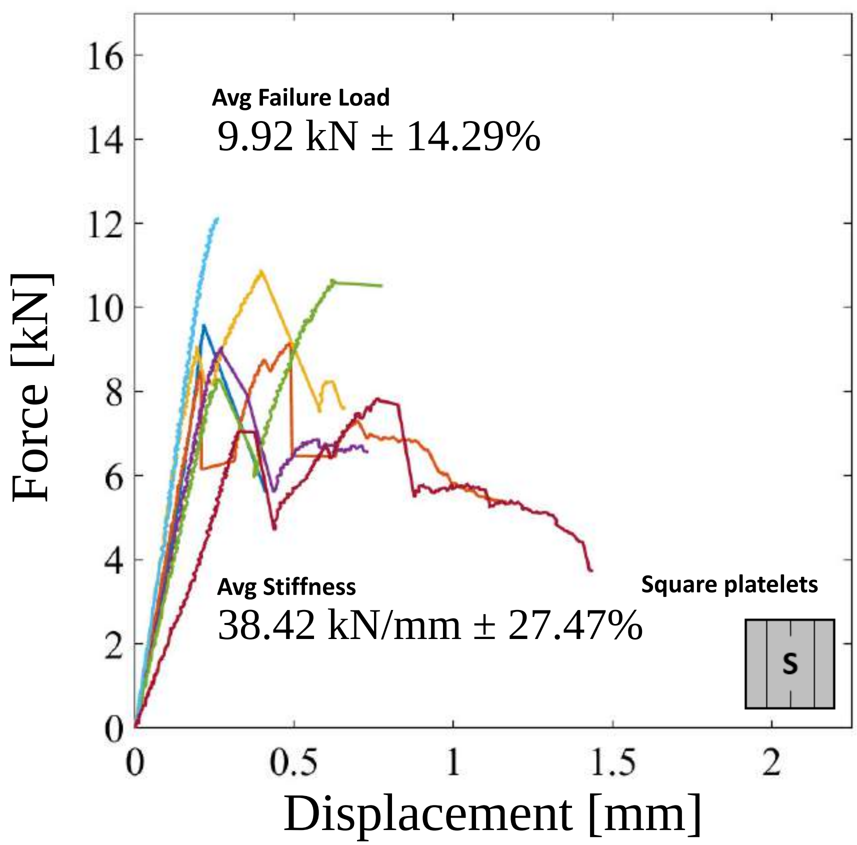
Sekisui Bracket Tension

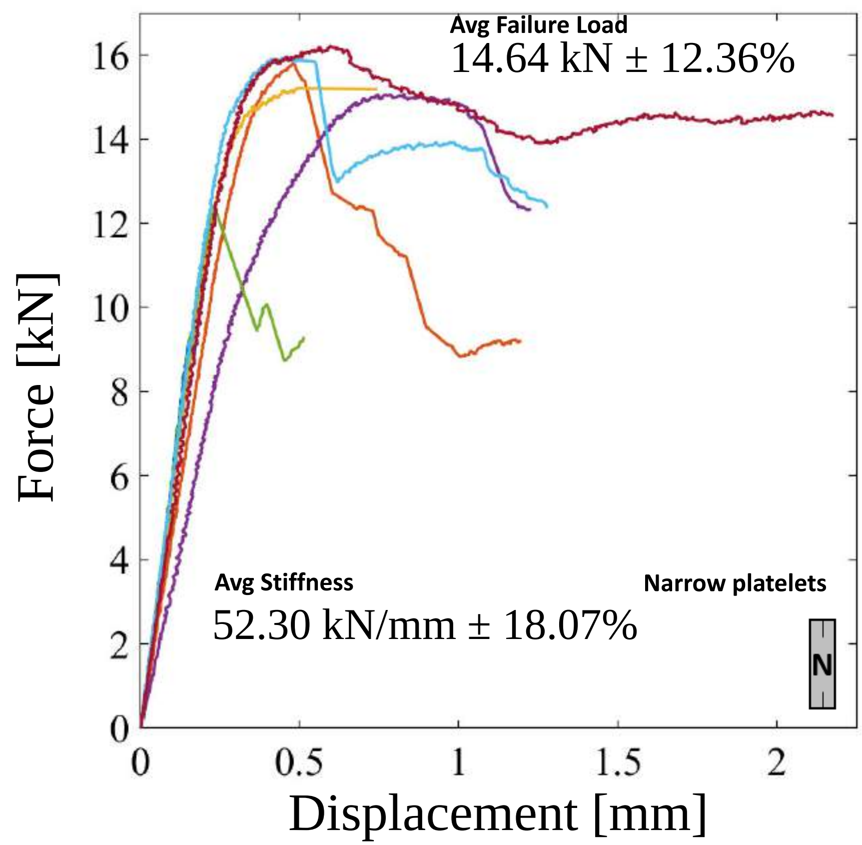
Tension Test Setup



- Rate: 0.3 mm/min
- 2 camera setup for DIC
- 1 camera at capturing the base to see if the bracket lifts off the fixture
- Base bolts torqued to 10 lb-ft

Load Displacement Curves

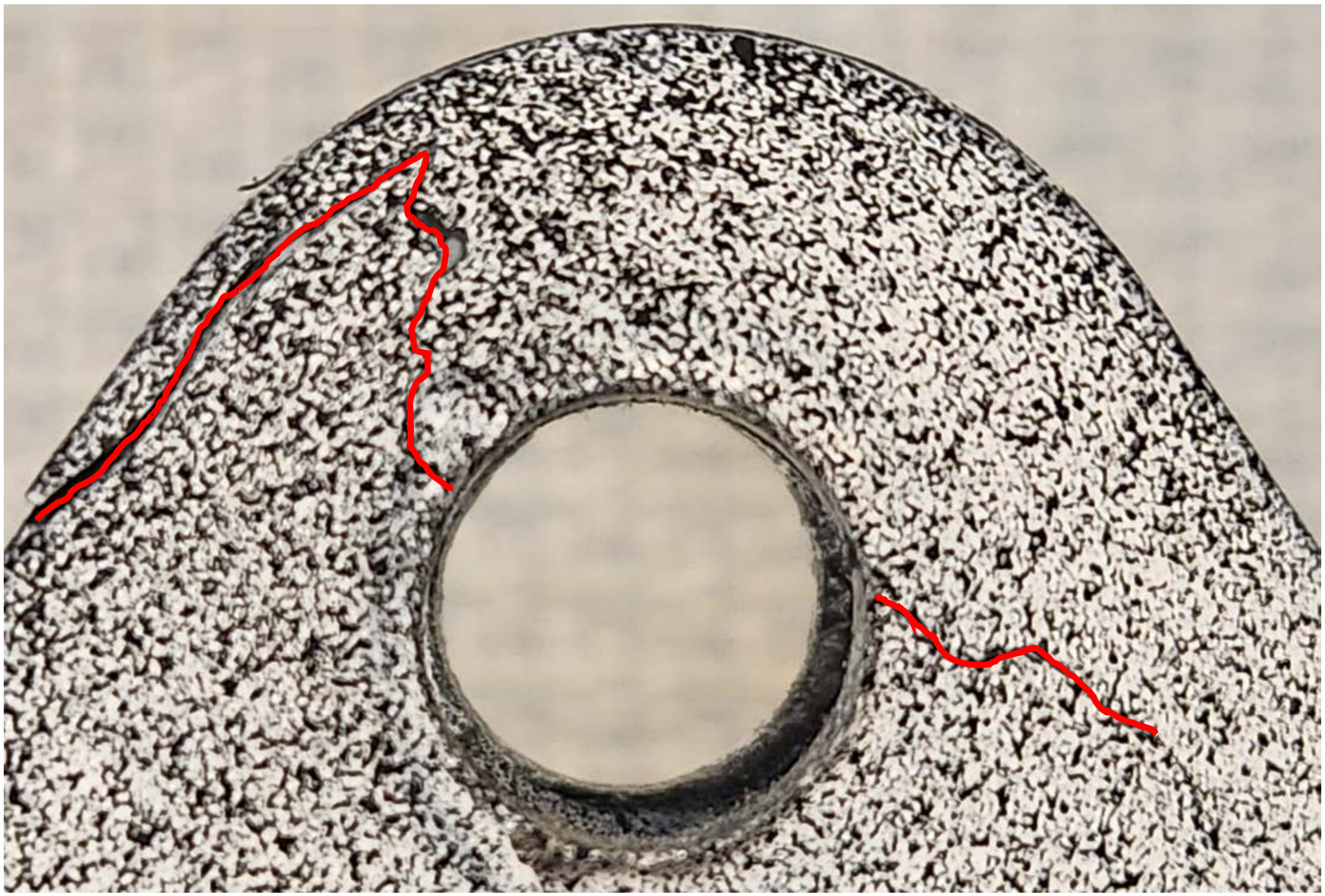




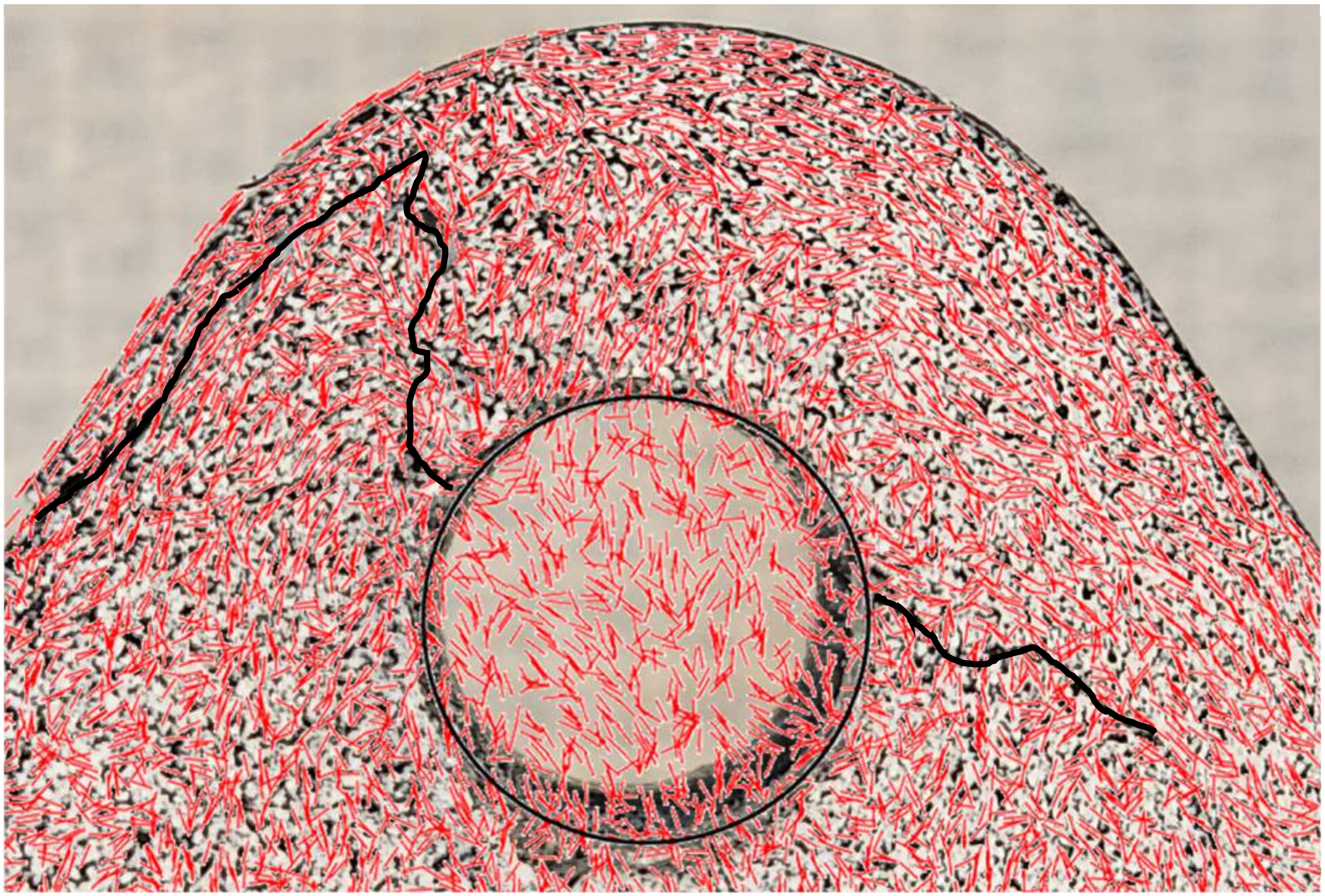
Similarly to the UNT, the narrow platelets outperform the square.
The stiffness and strength have a percent difference of 30.61% and 38.46% respectively.

N

Narrow Platelet Sekisui Failure 1

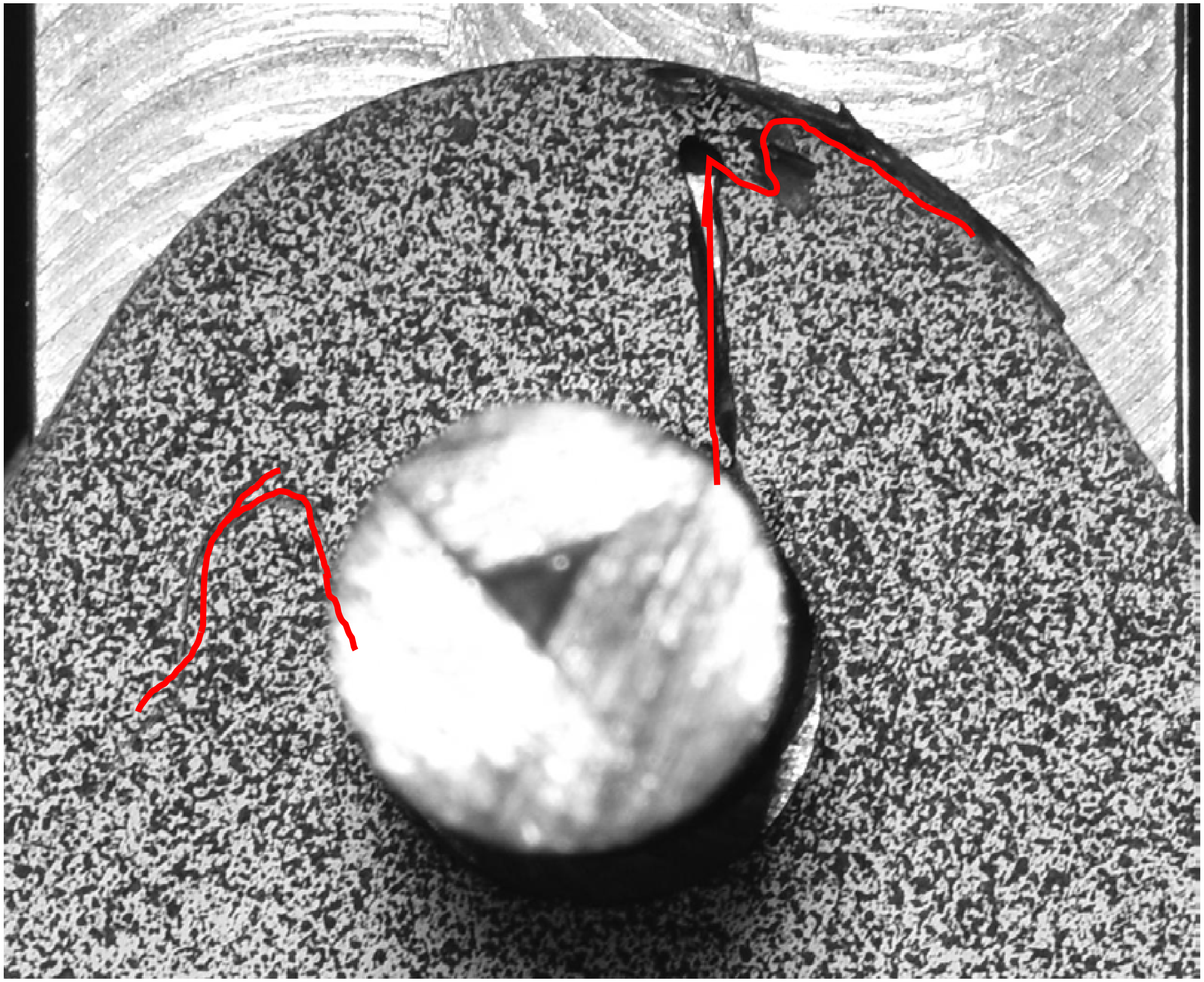


Narrow Platelet Sekisui Failure 1



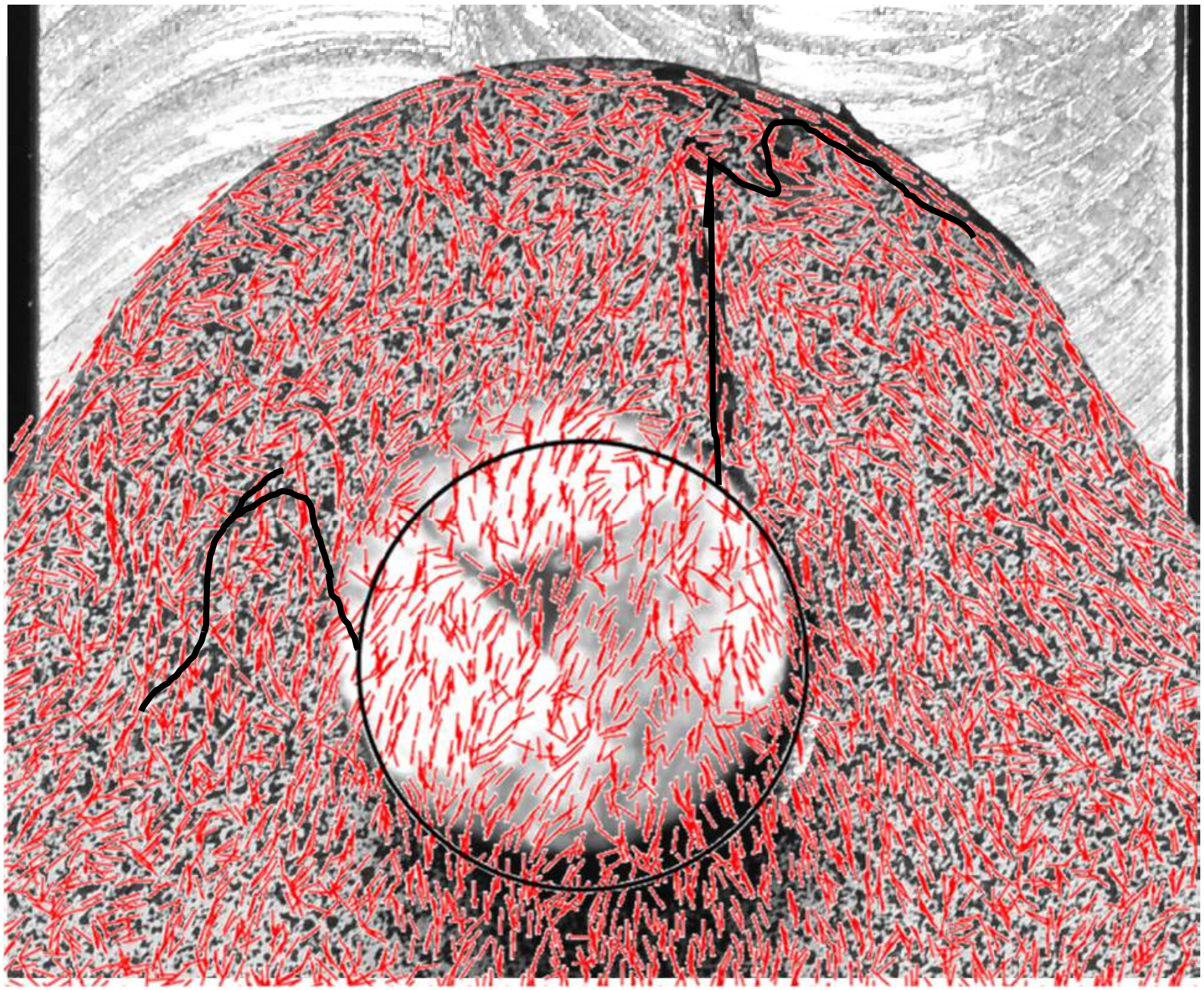
N

Narrow Platelet Sekisui Failure 1

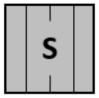


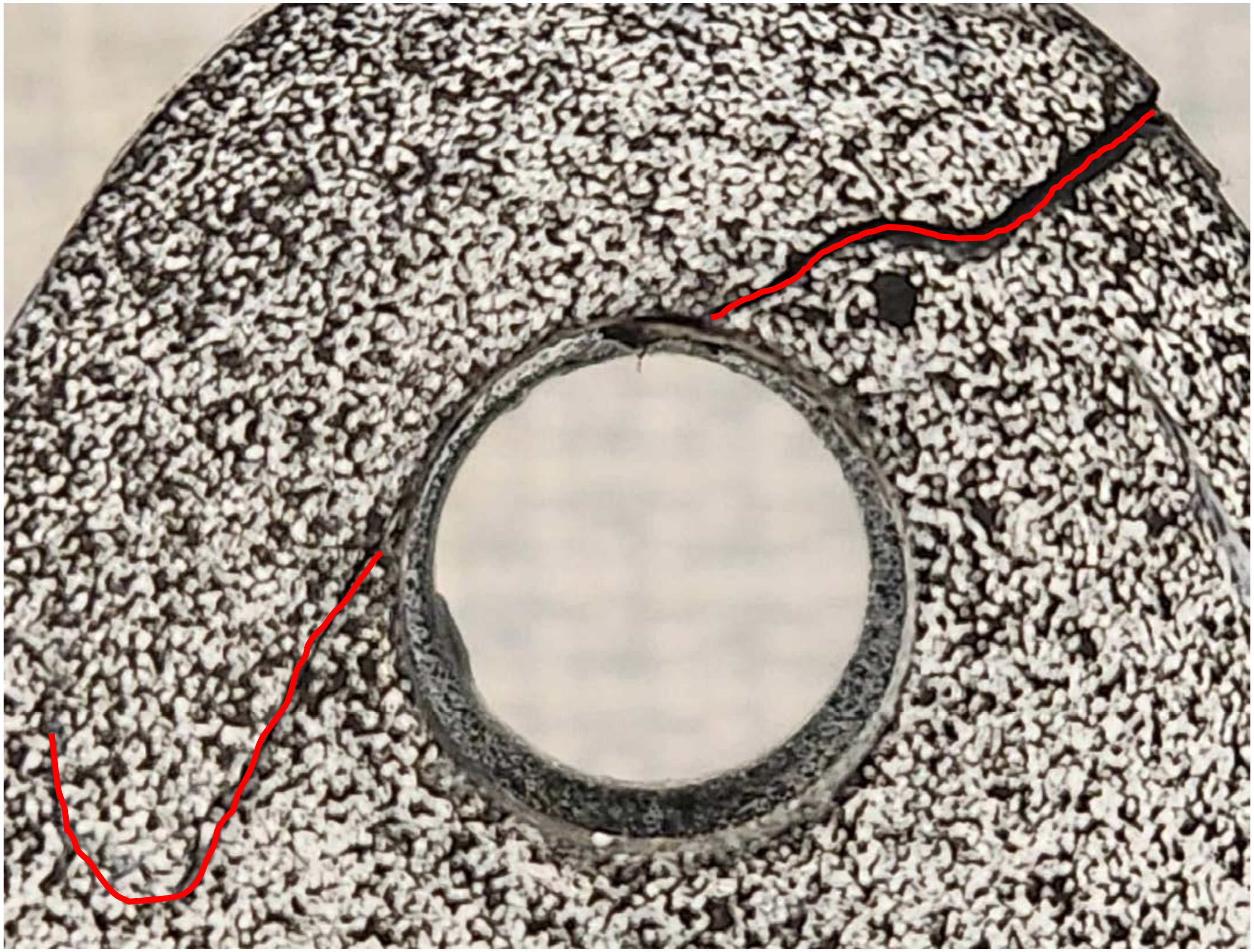
N

Narrow Platelet Sekisui Failure 1



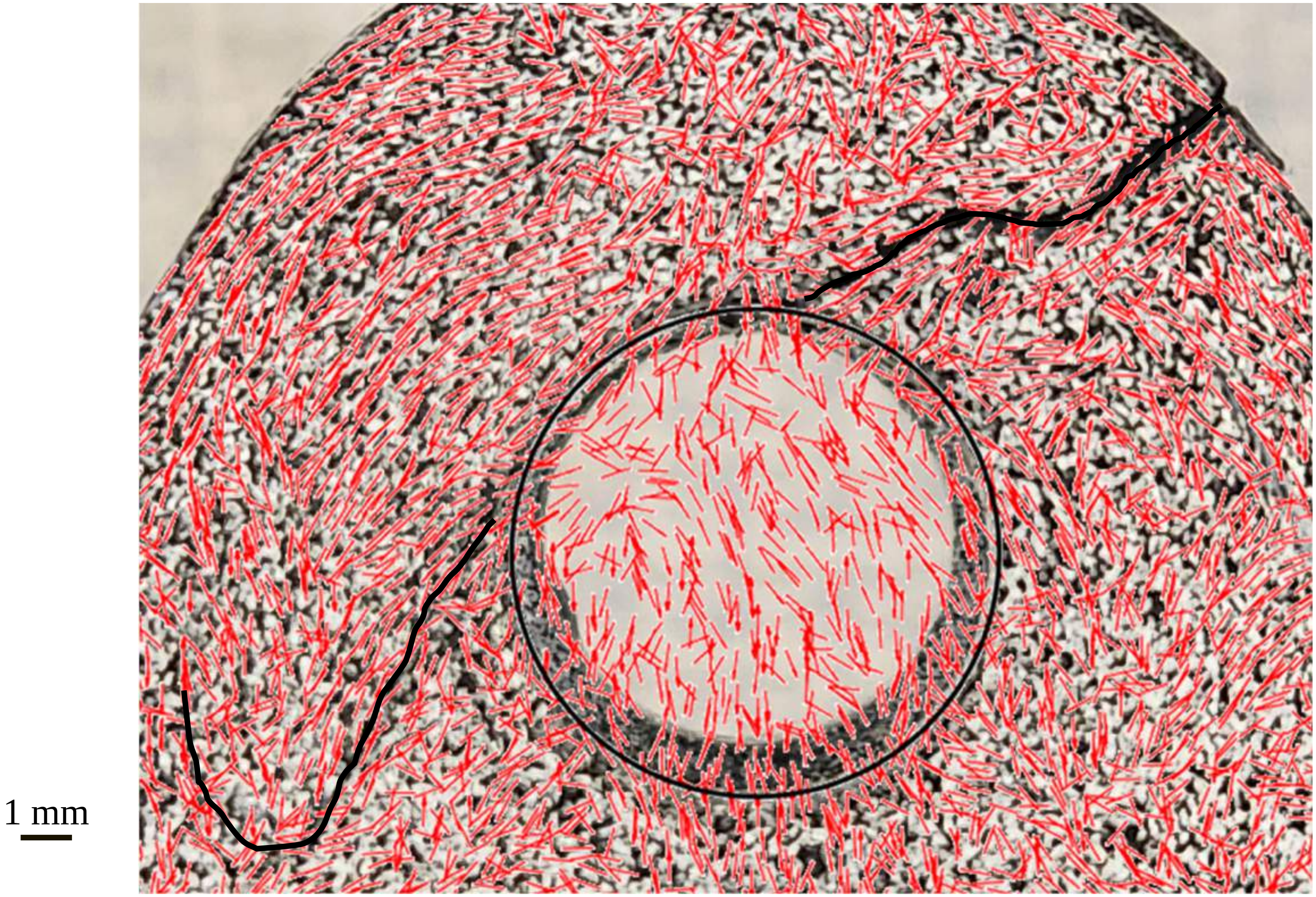
Square Platelet Sekisui Failure 1

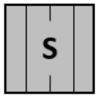




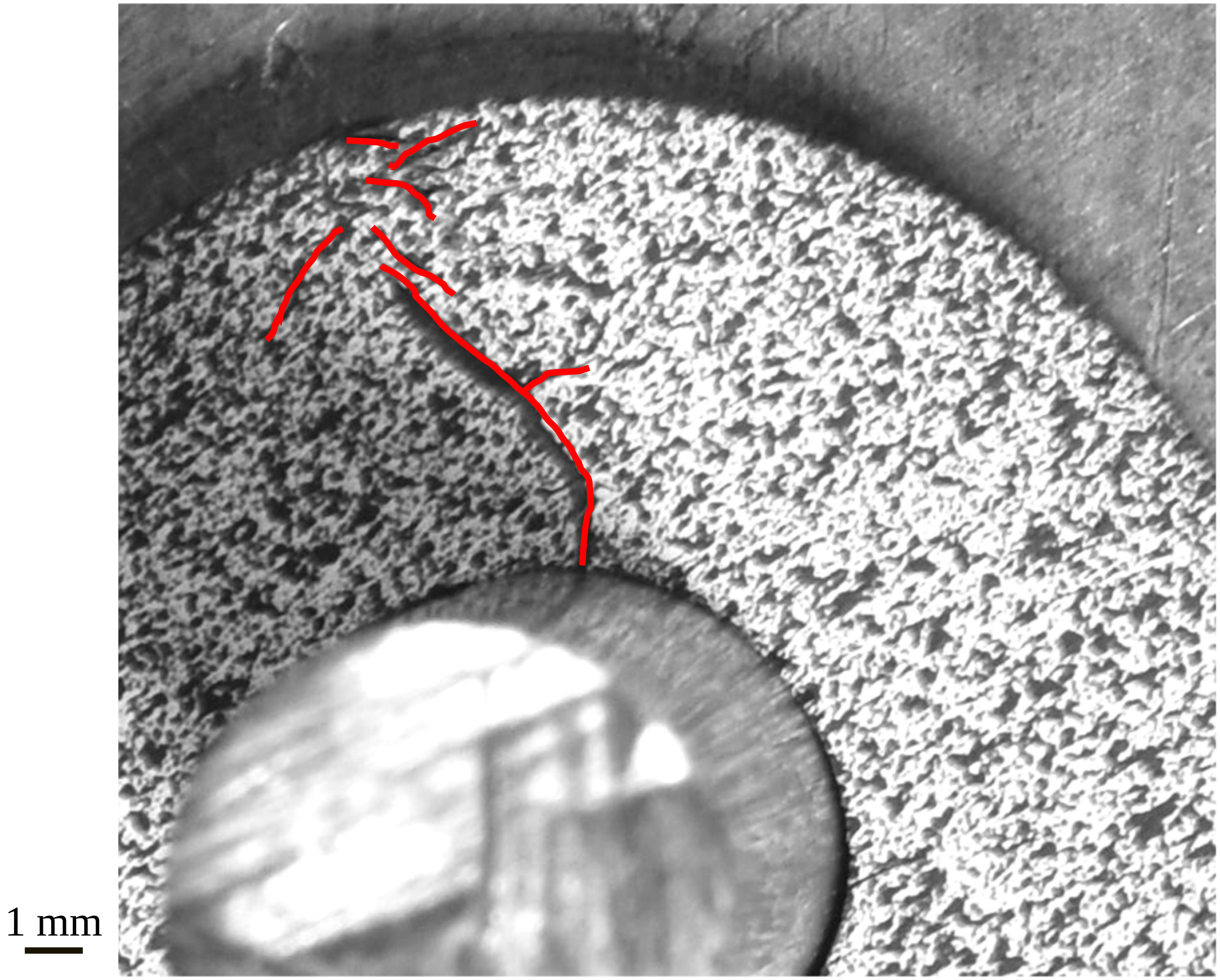
1 mm

Square Platelet Sekisui Failure 1

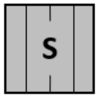


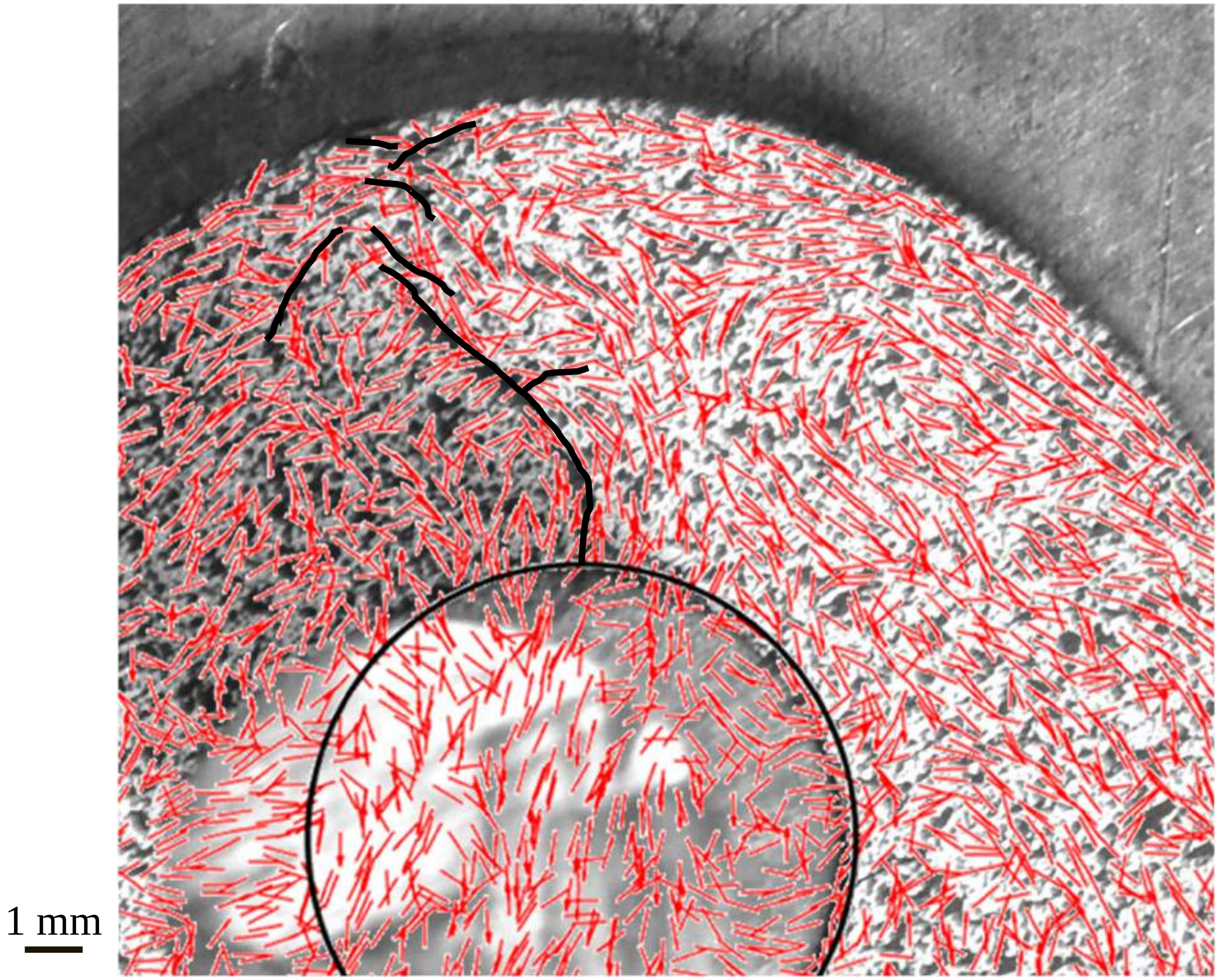


Square Platelet Sekisui Failure 1

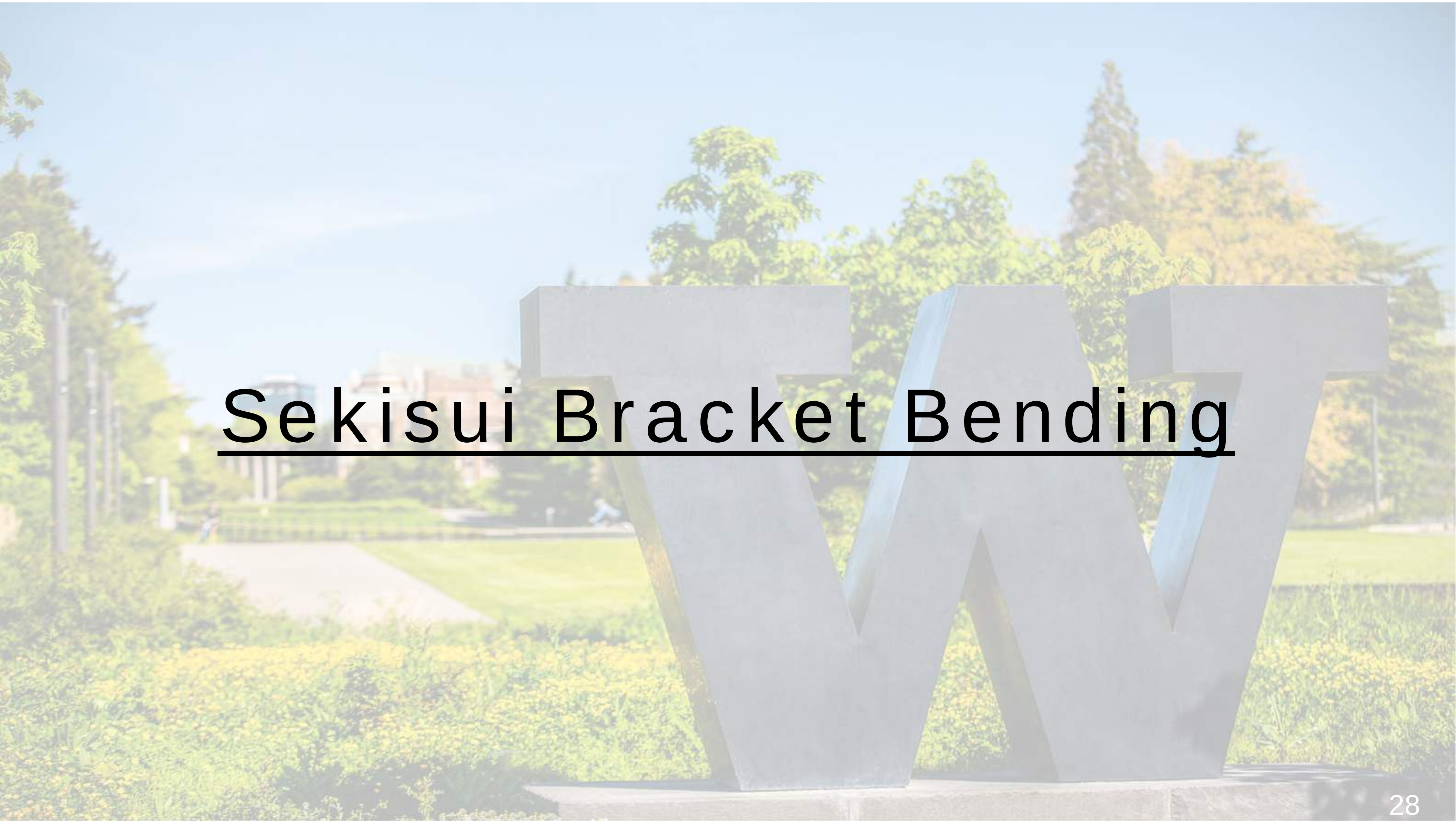


Square Platelet Sekisui Failure 1

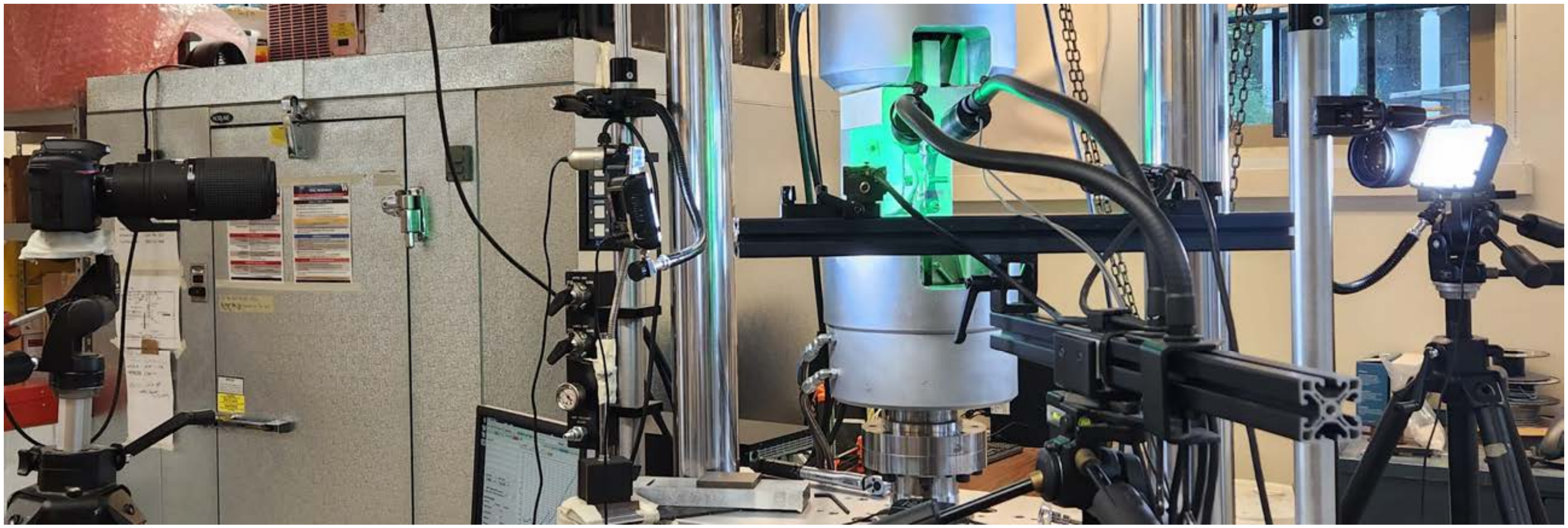




Sekisui Bracket Bending

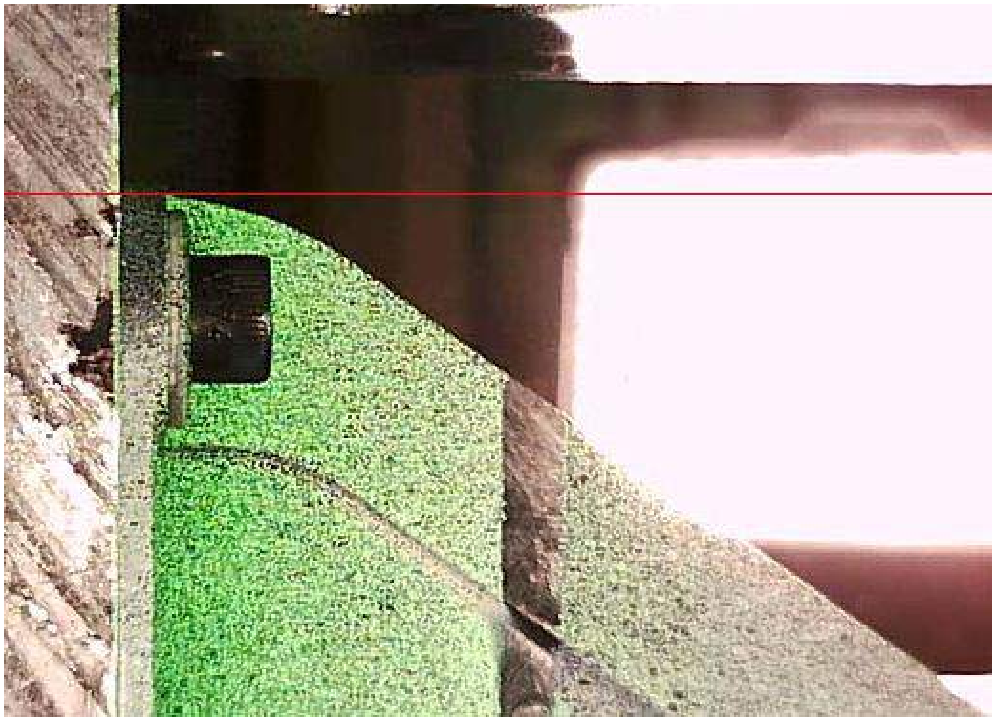


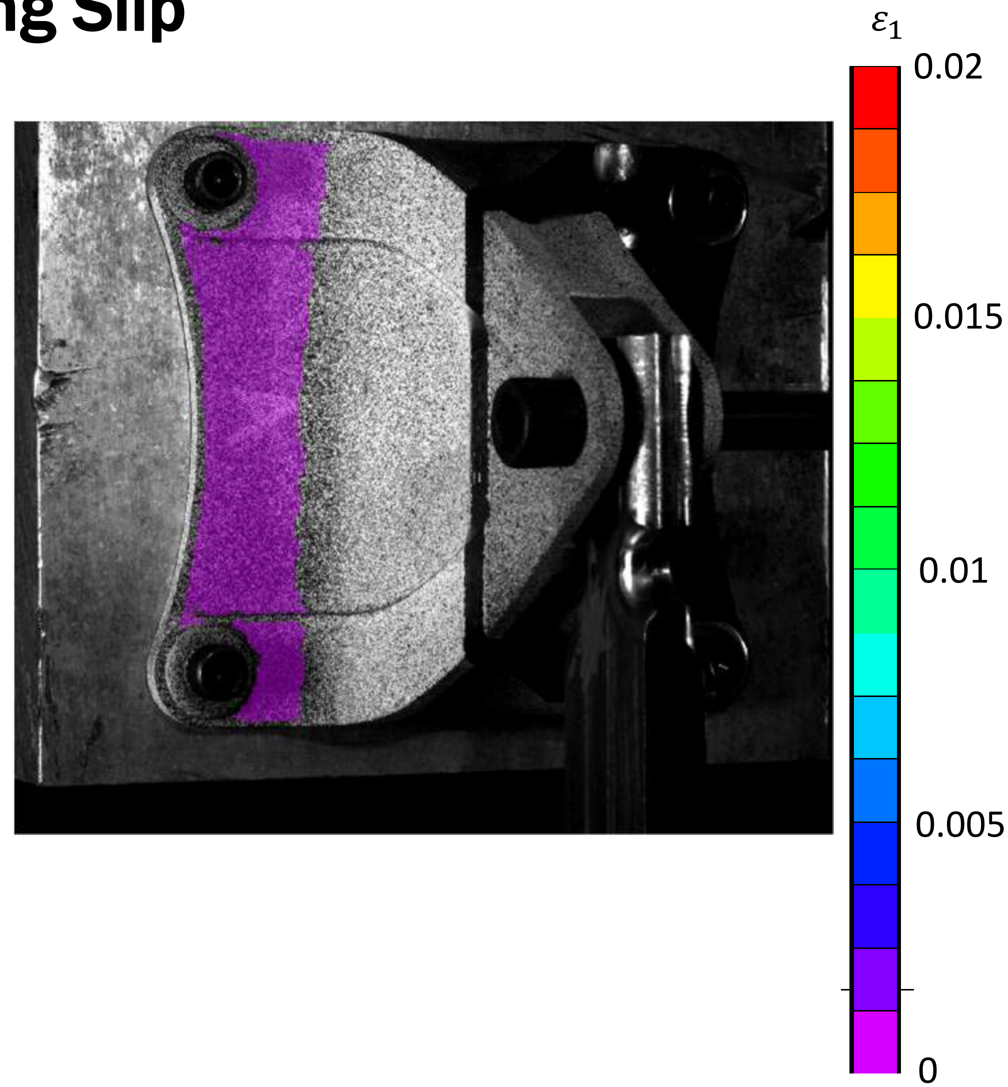
Bending Test Setup



- Rate: 0.6 mm/min
- 2 camera setup for 2D DIC at the load pin
- 2 camera setup for 3D DIC of the base of the bracket
- 1 camera at capturing the base to see if the bracket lifts off the fixture
- Base bolts torqued to 10 lb-ft

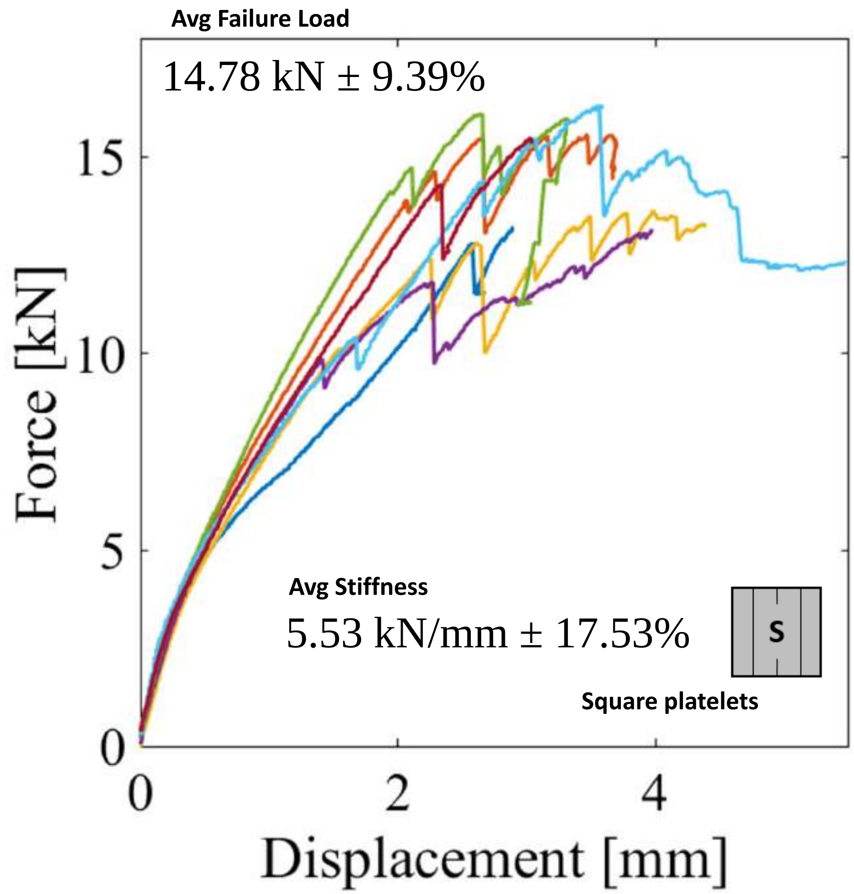
Bending Slip

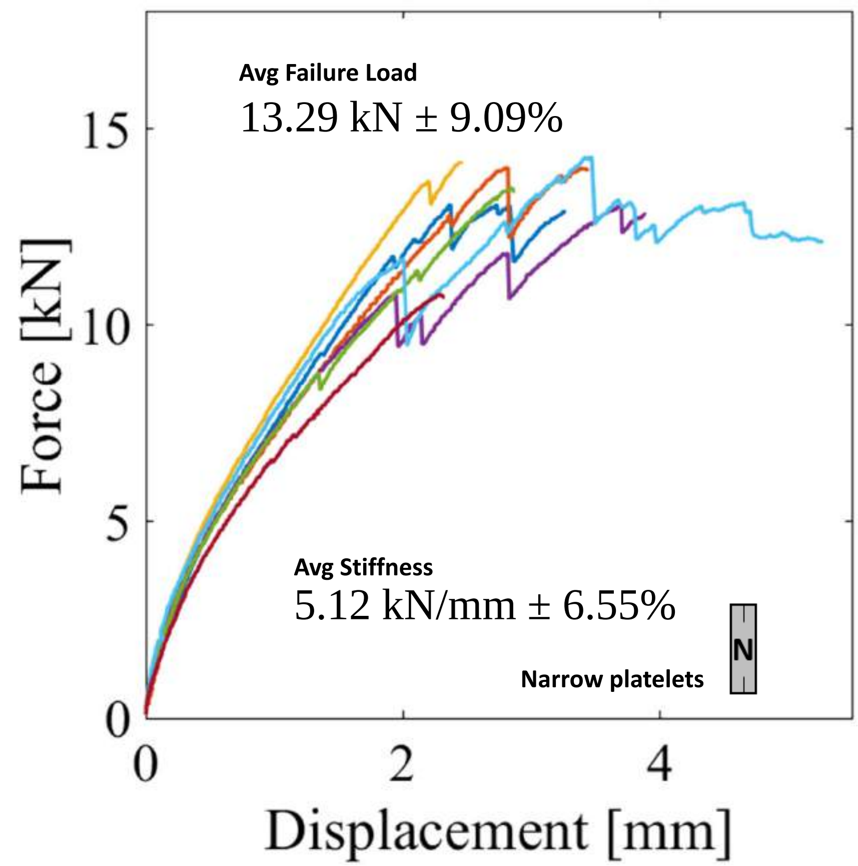




- Bracket does not slip

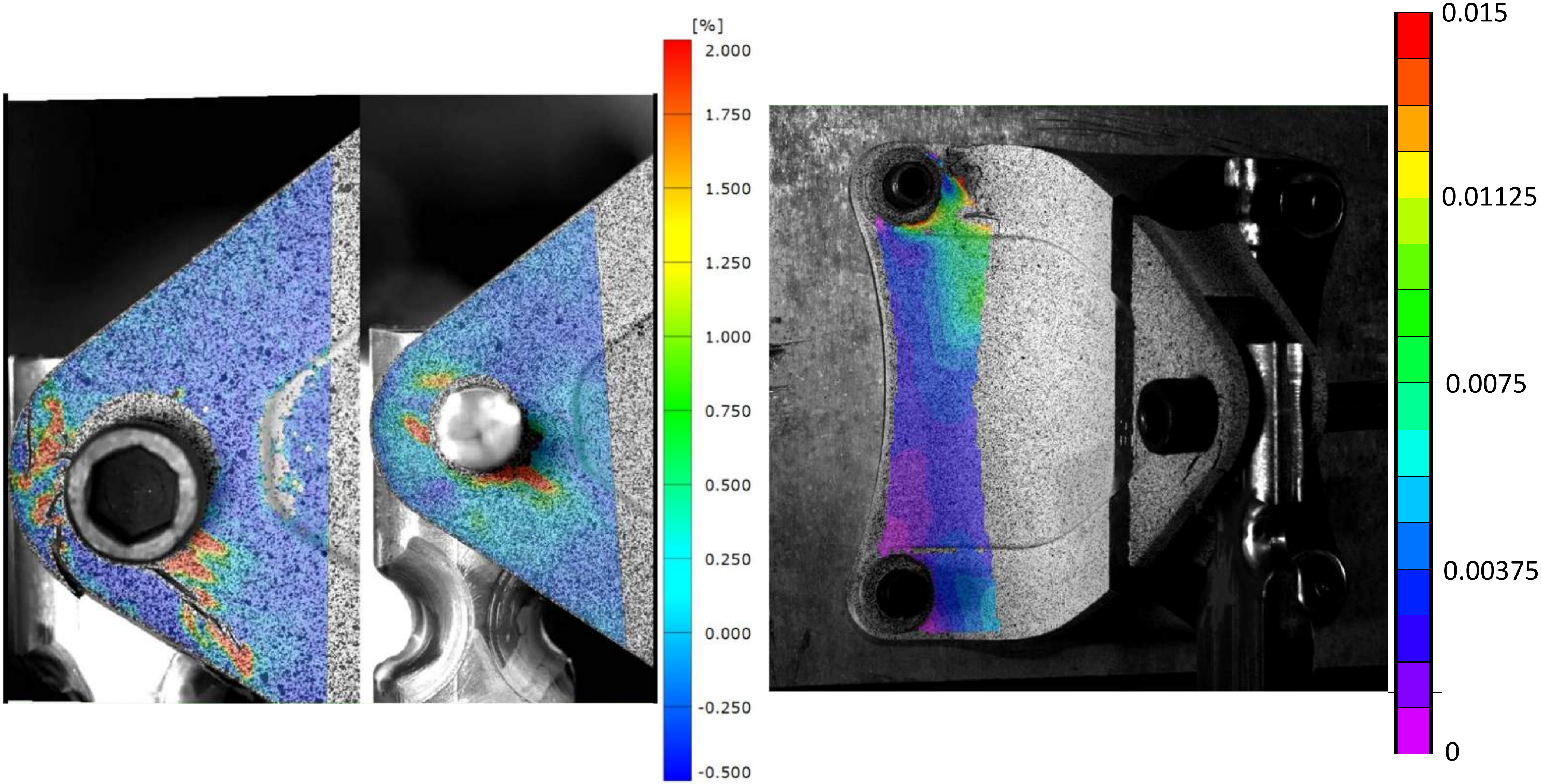
Load Displacement Curves





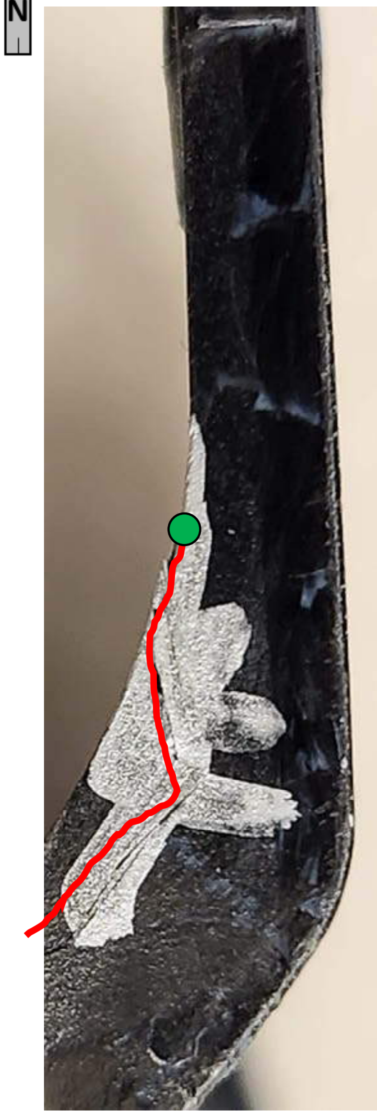
Similar to the UNT, the narrow platelets outperform the square.
The stiffness and strength have a percent difference of 10.66% and 9.27% respectively.

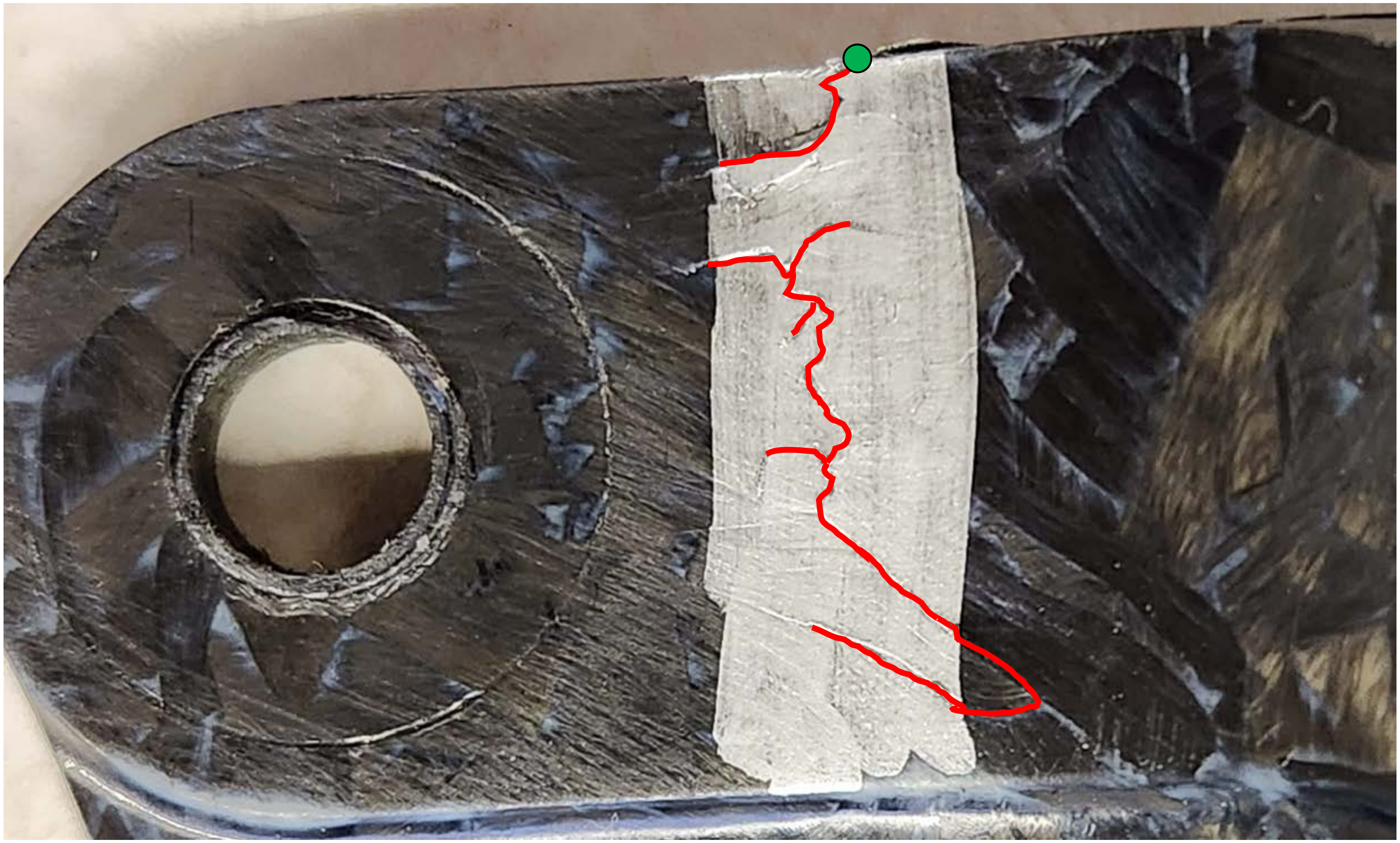
a) NP Loading Hole Failure – Max Principal Strain



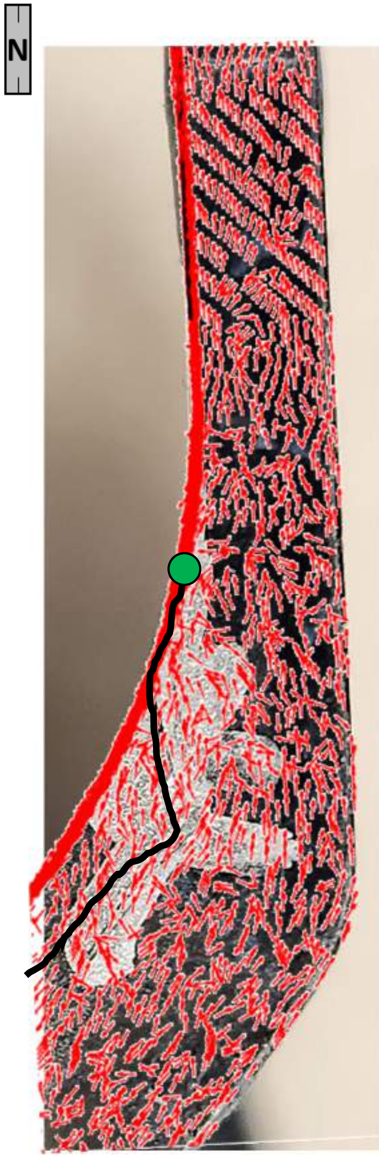
Narrow Platelet Sekisui Failure 1

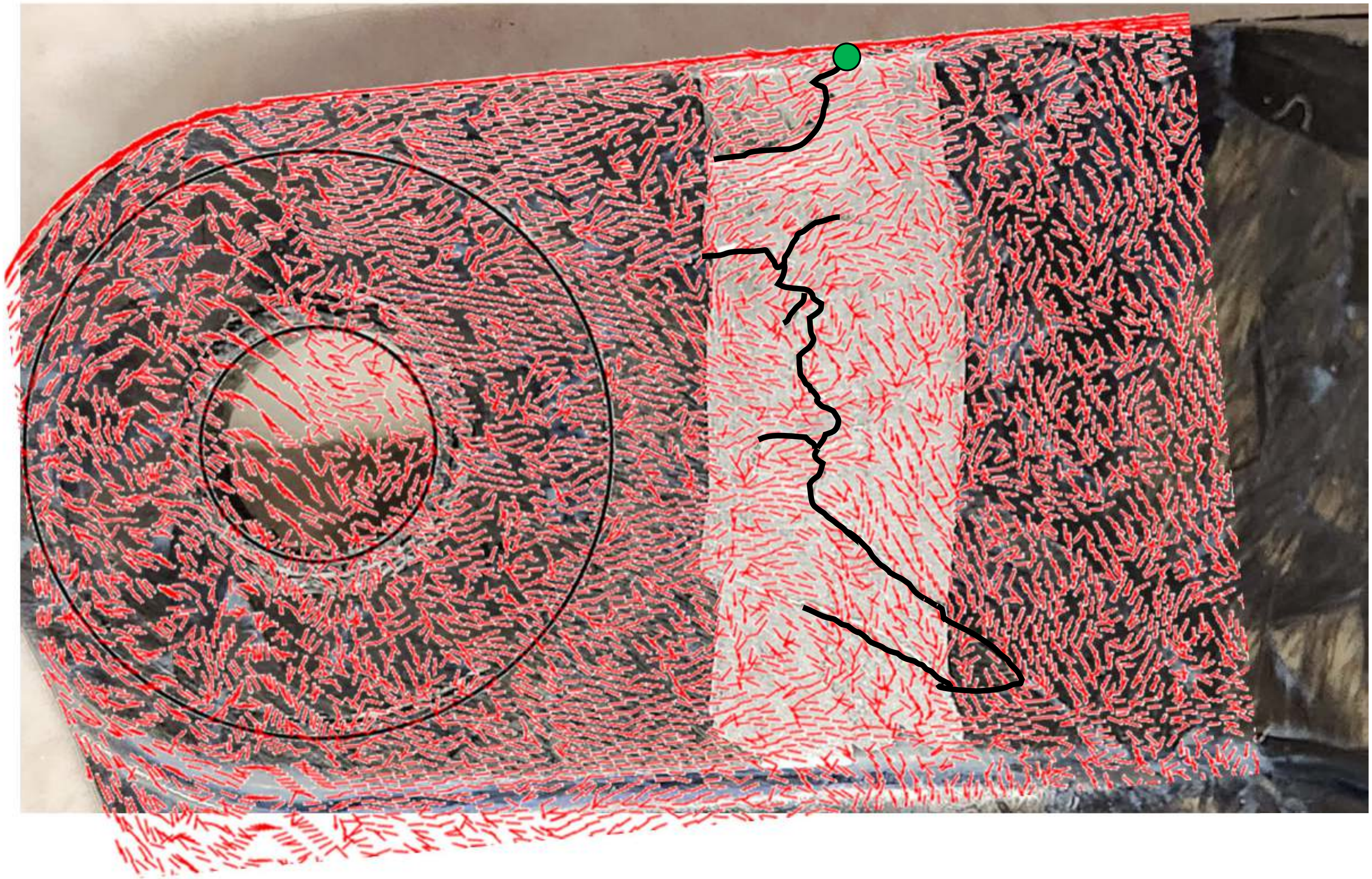
N





Narrow Platelet Sekisui Failure 1





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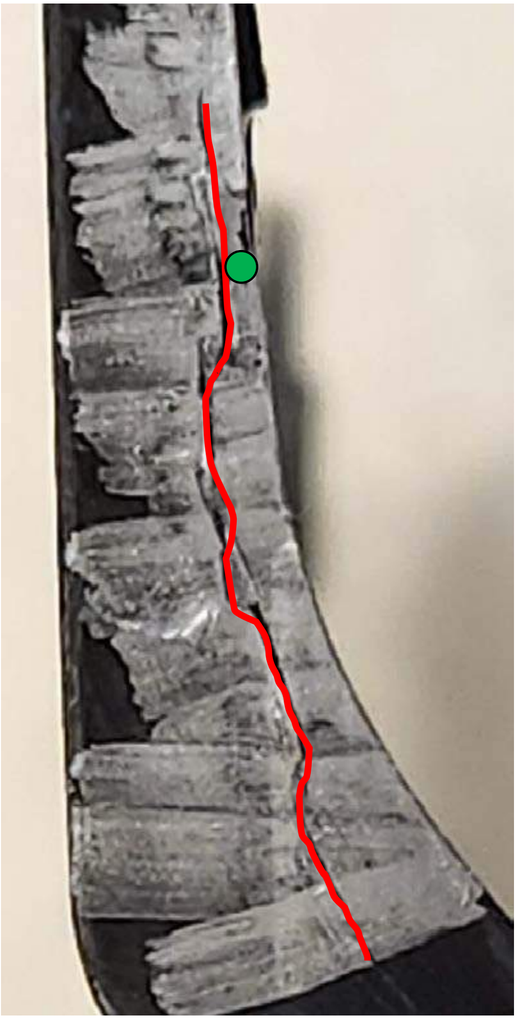
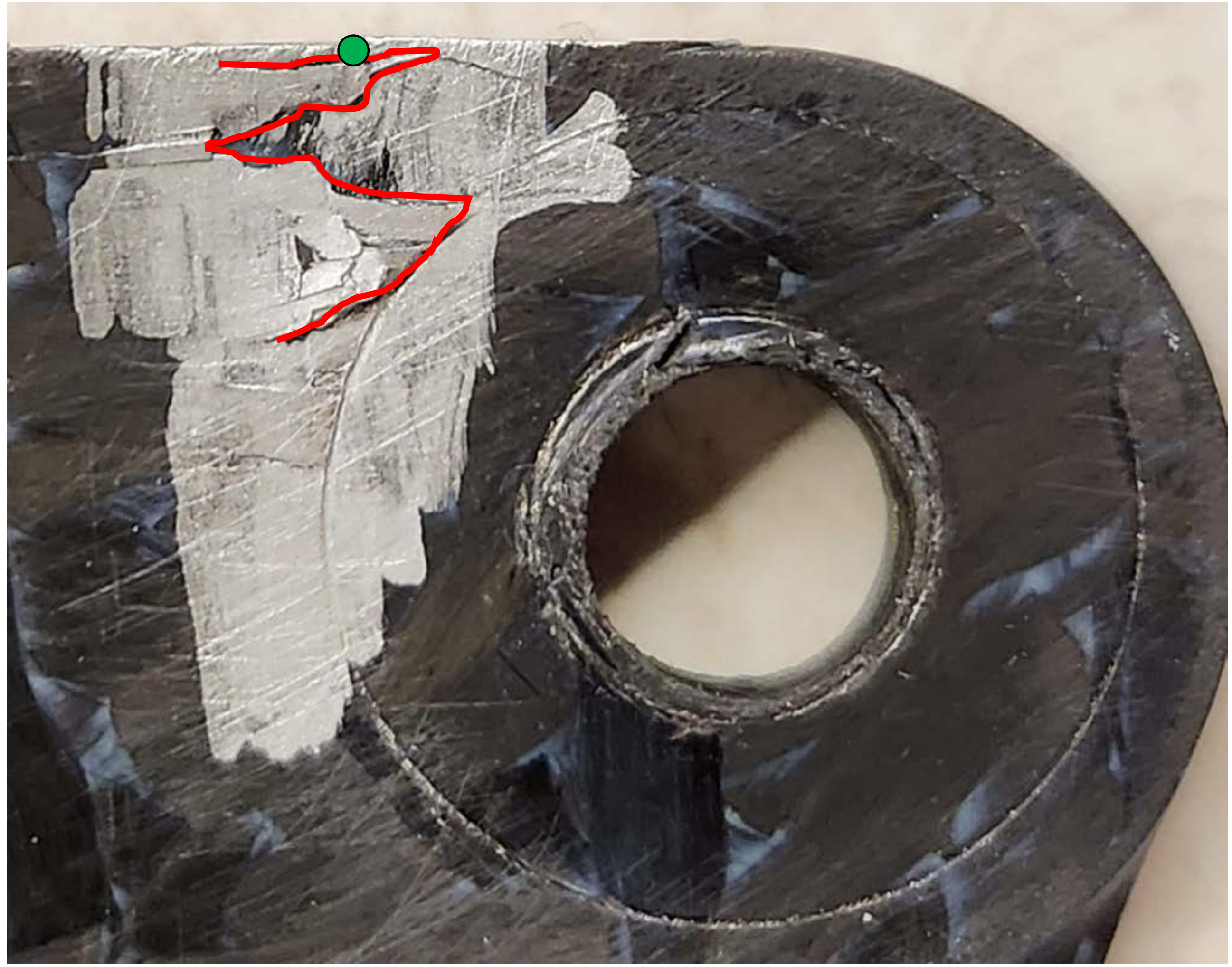
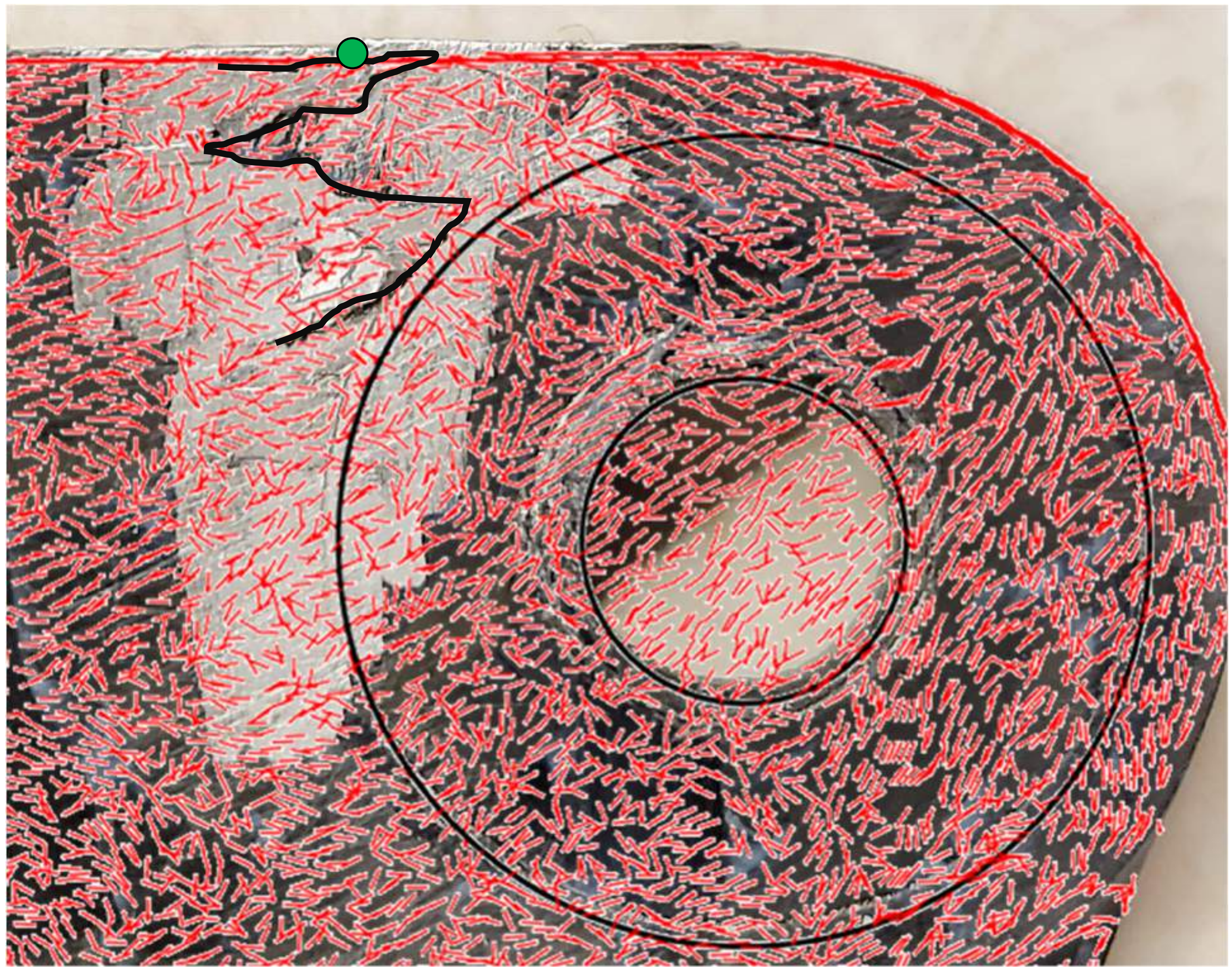
Narrow Platelet Sekisui Failure 1

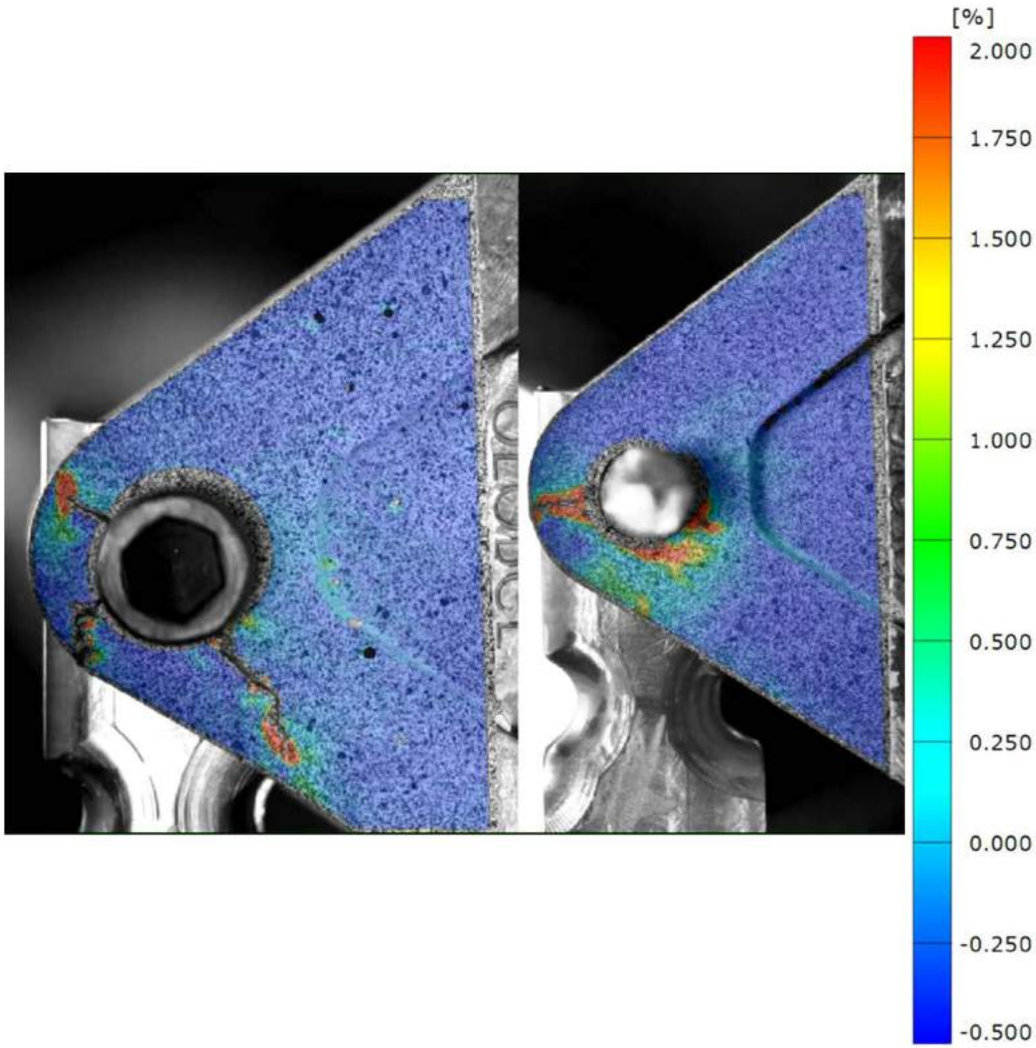


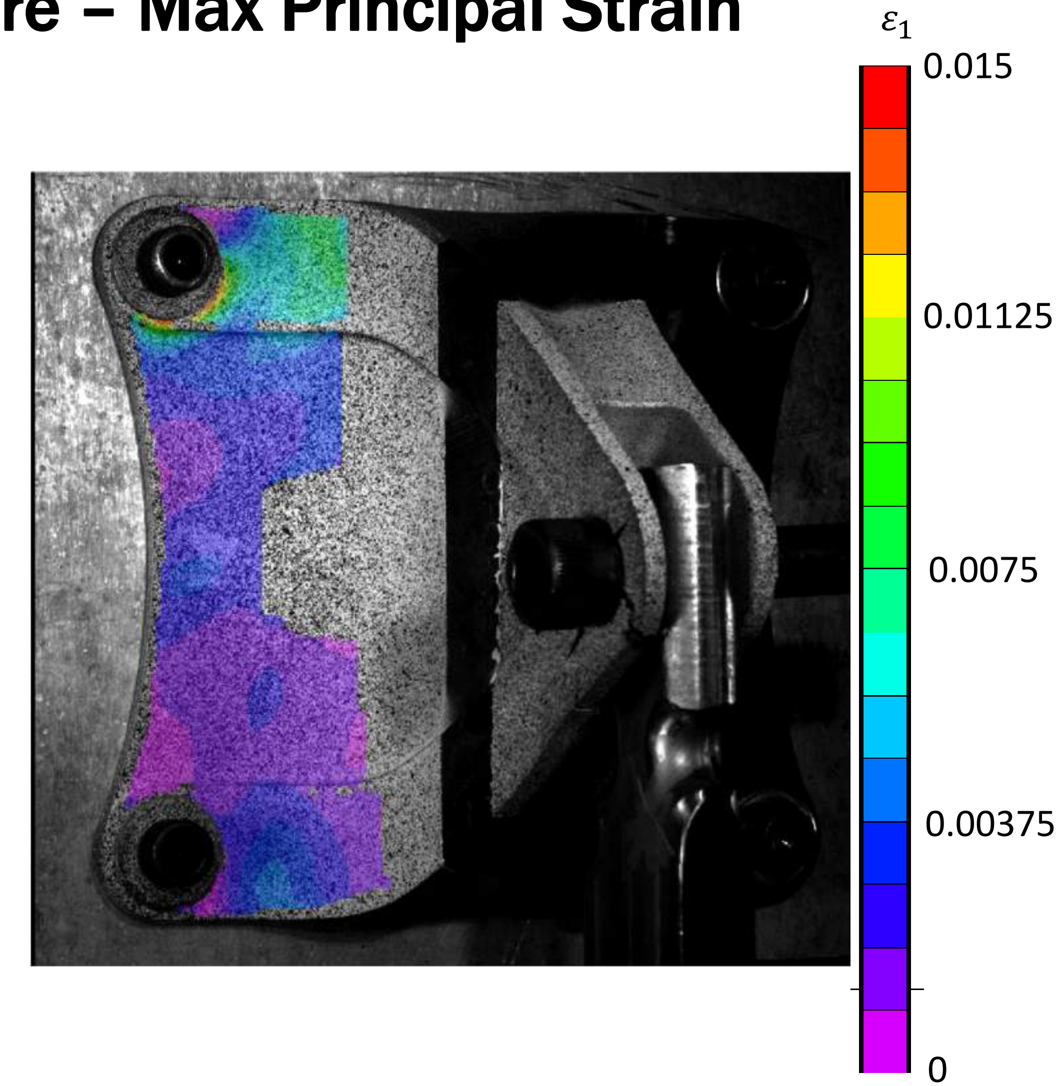


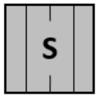
Narrow Platelet Sekisui Failure 1



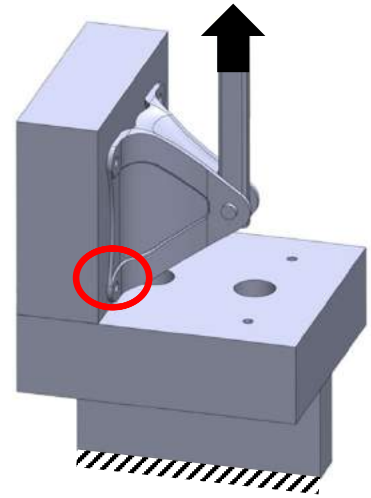
b) SP Loading Hole Failure – Max Principal Strain

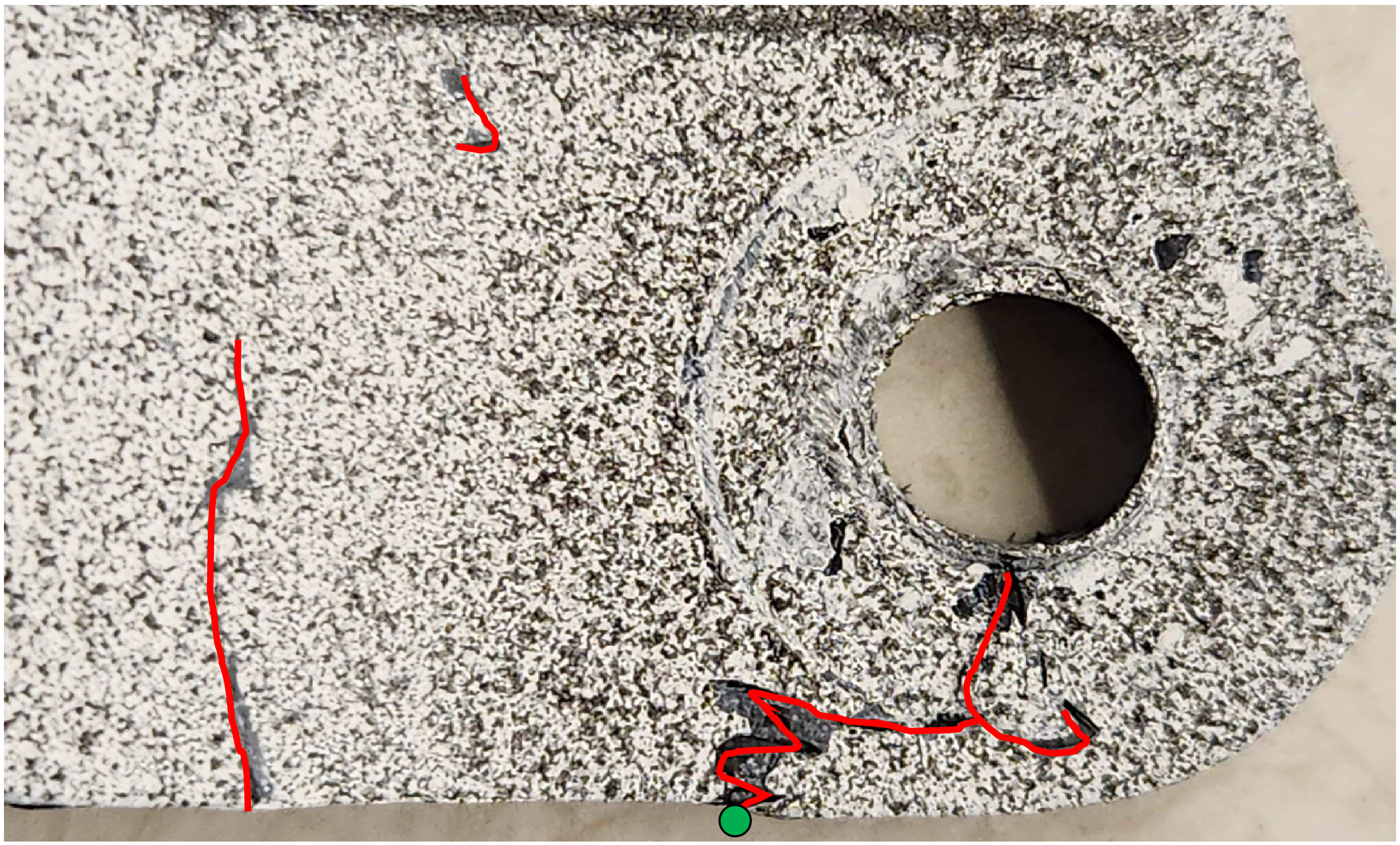


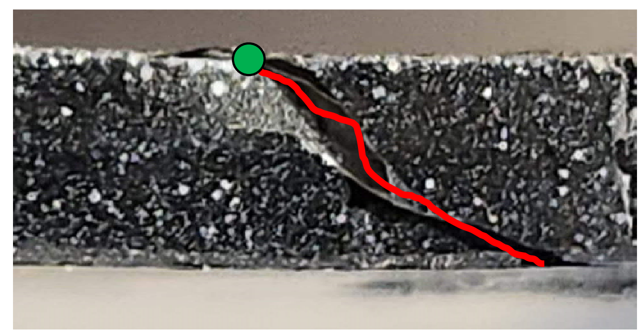


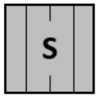


Square Platelet Sekisui Failure 1









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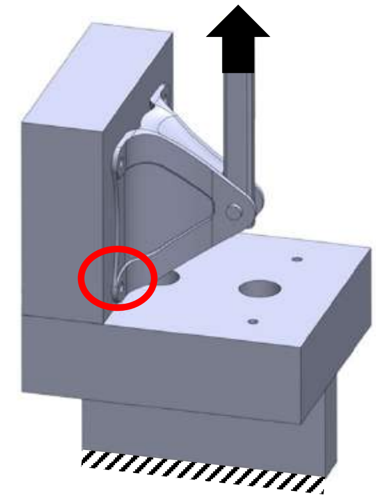

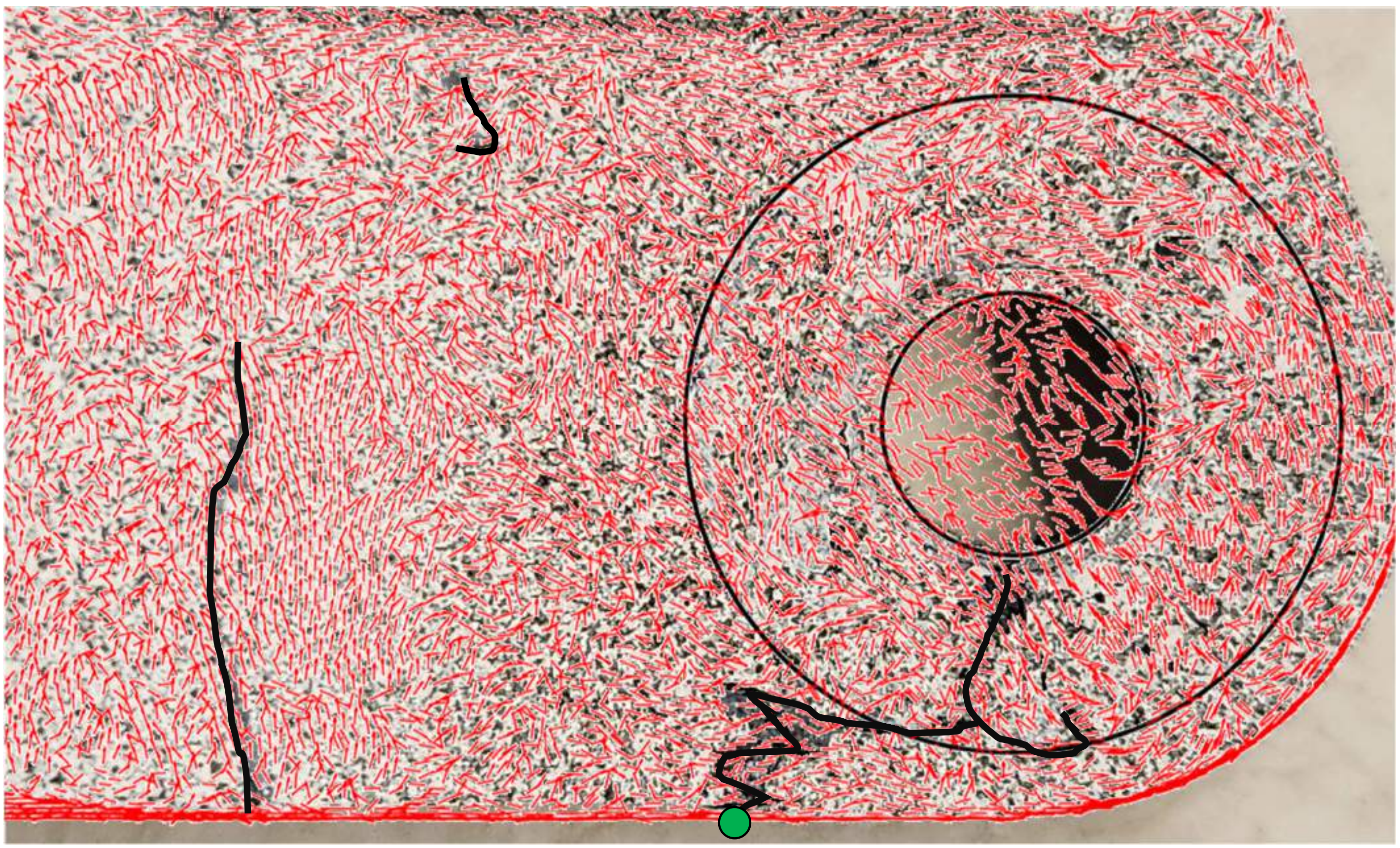

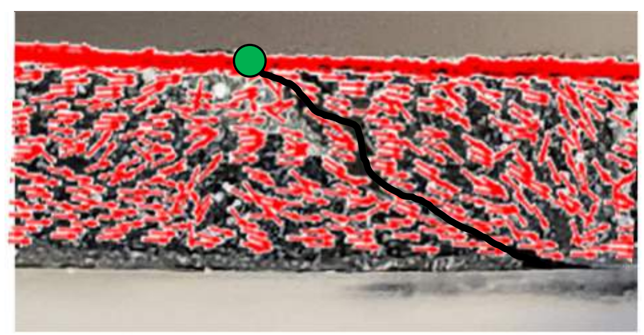

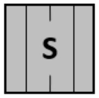

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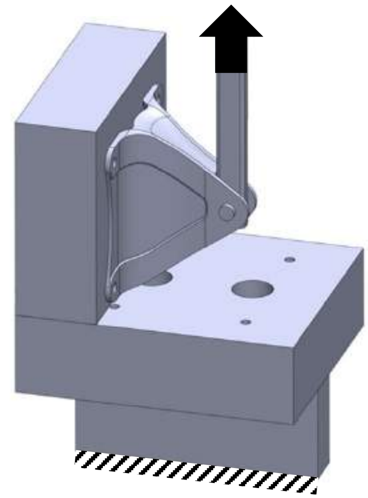

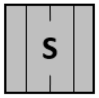

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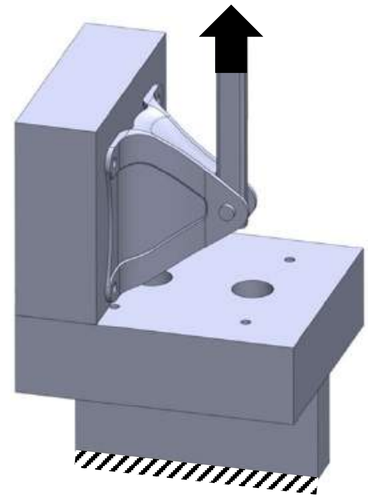
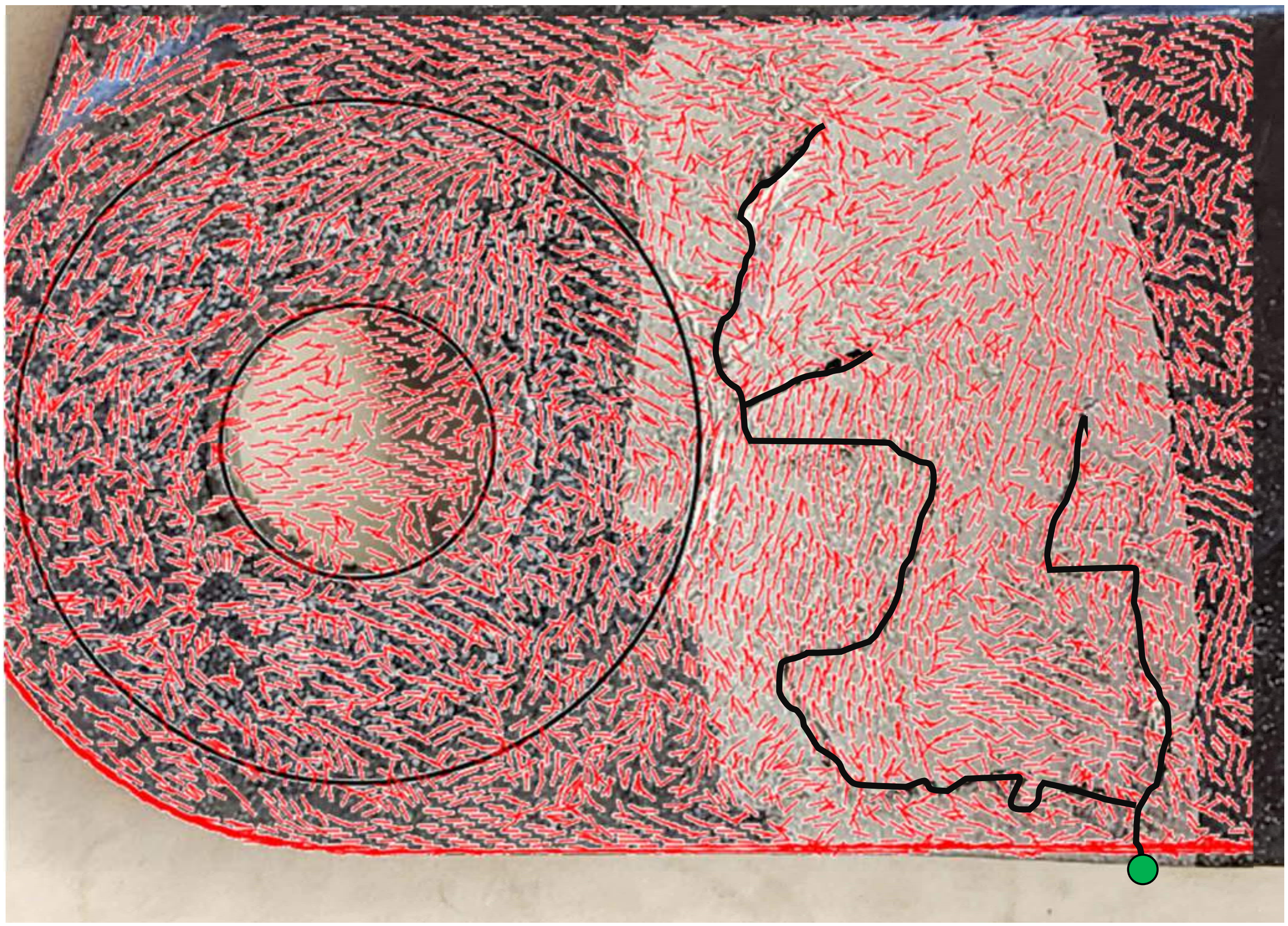
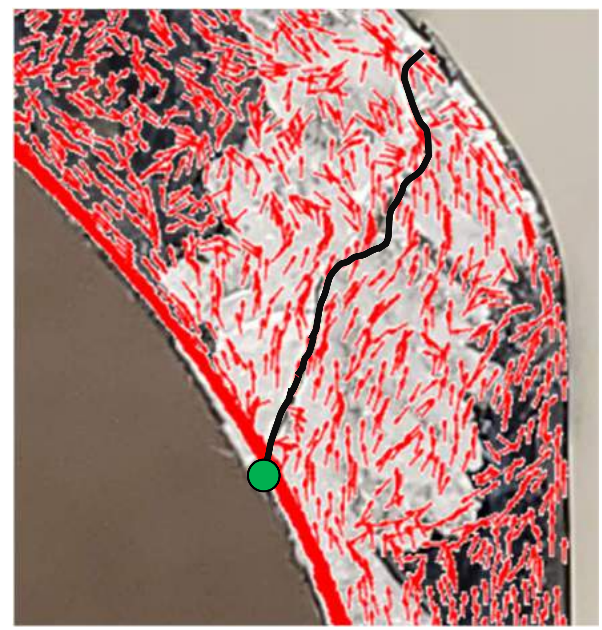
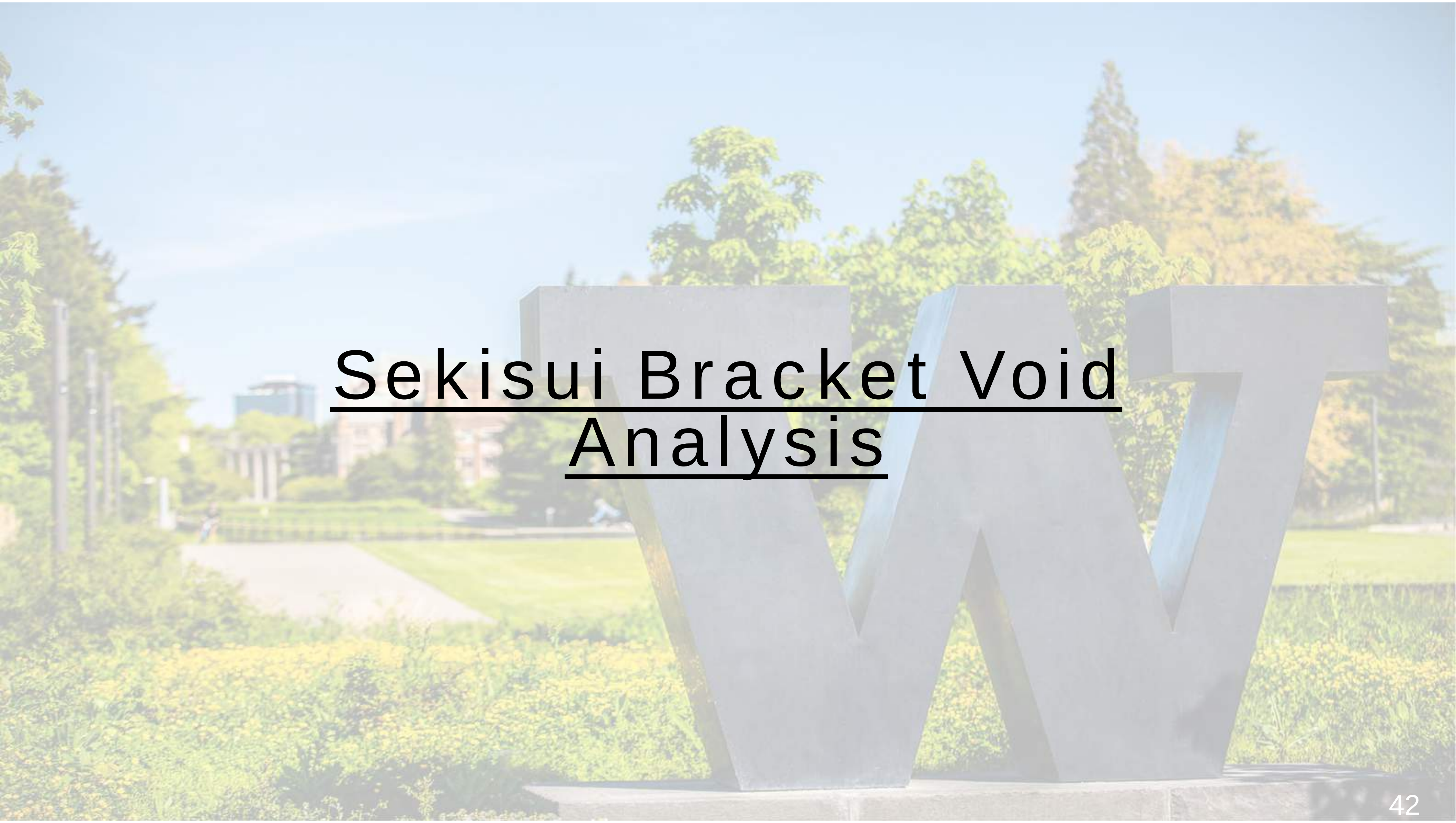


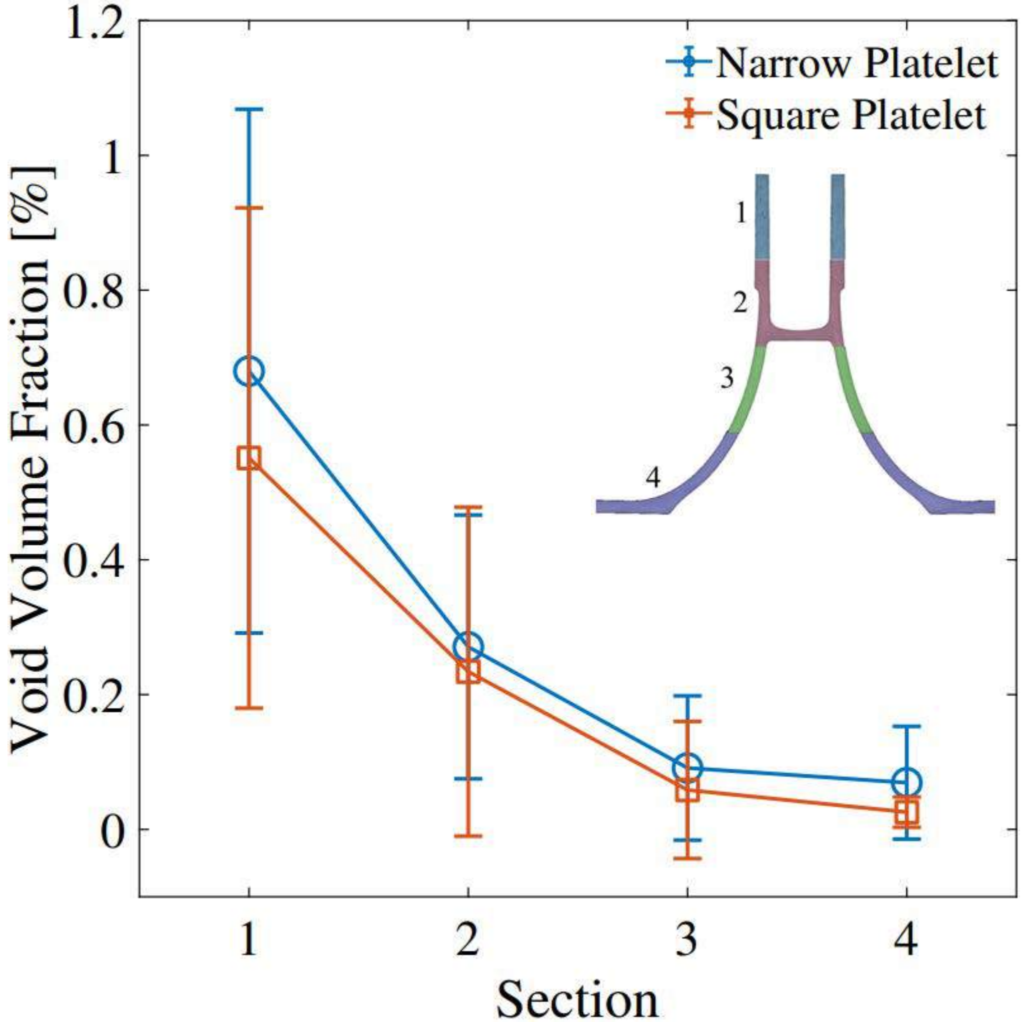






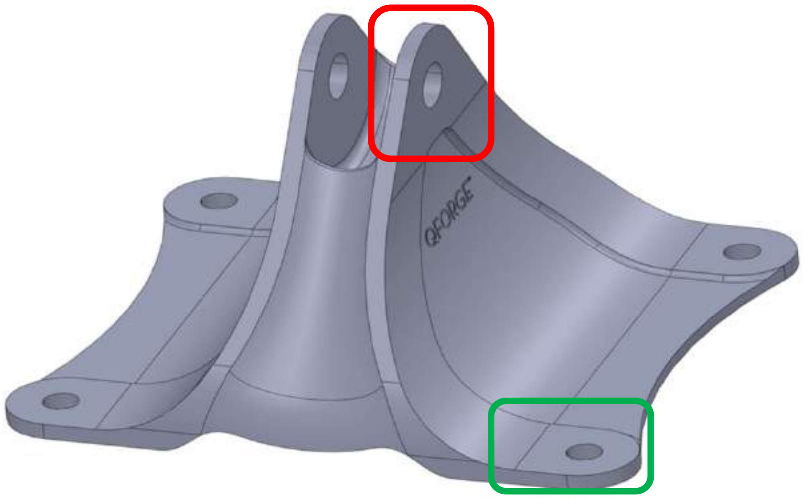
Sekisui Bracket Void Analysis

Bracket Void Content

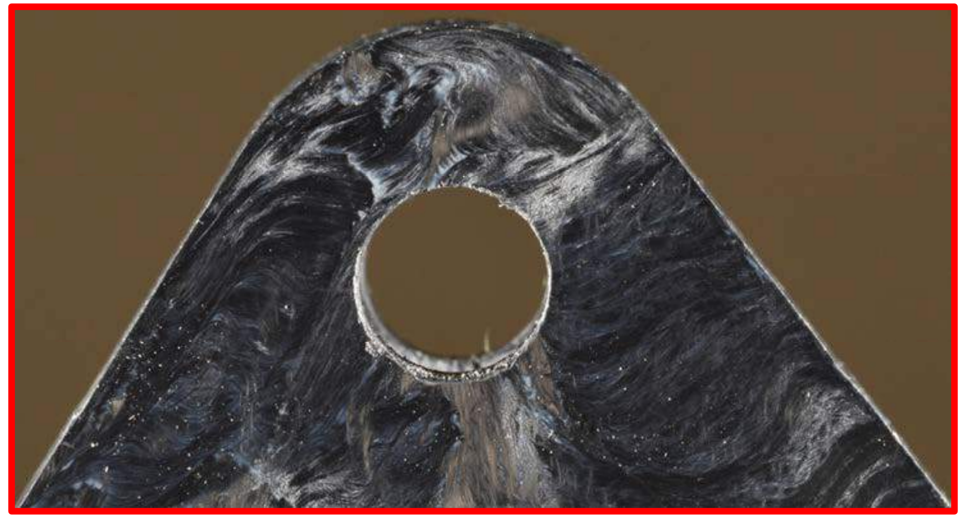


	Section			
	1	2	3	4
SP	0.55±0.37	0.23±0.24	0.06±0.10	0.03±0.02
NP	0.68±0.39	0.27±0.20	0.09±0.11	0.07±0.08

- The top of the bracket has a higher void content at the bottom due to flow
- Narrow platelet brackets have a slightly higher void content, but the variation is high

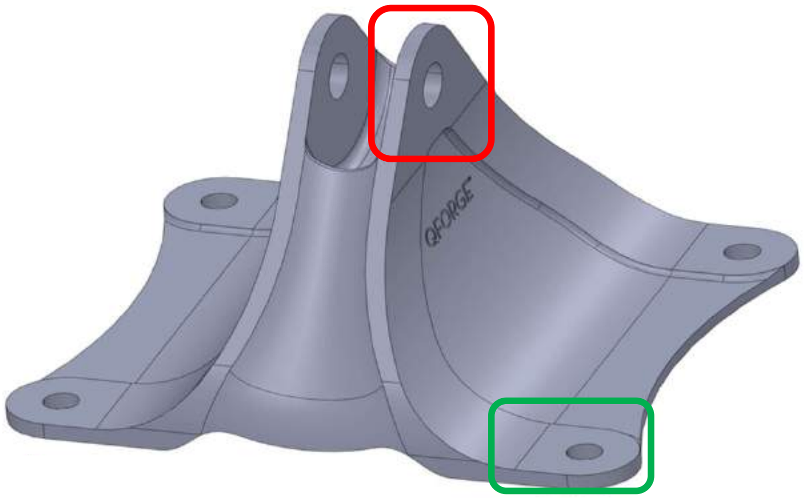


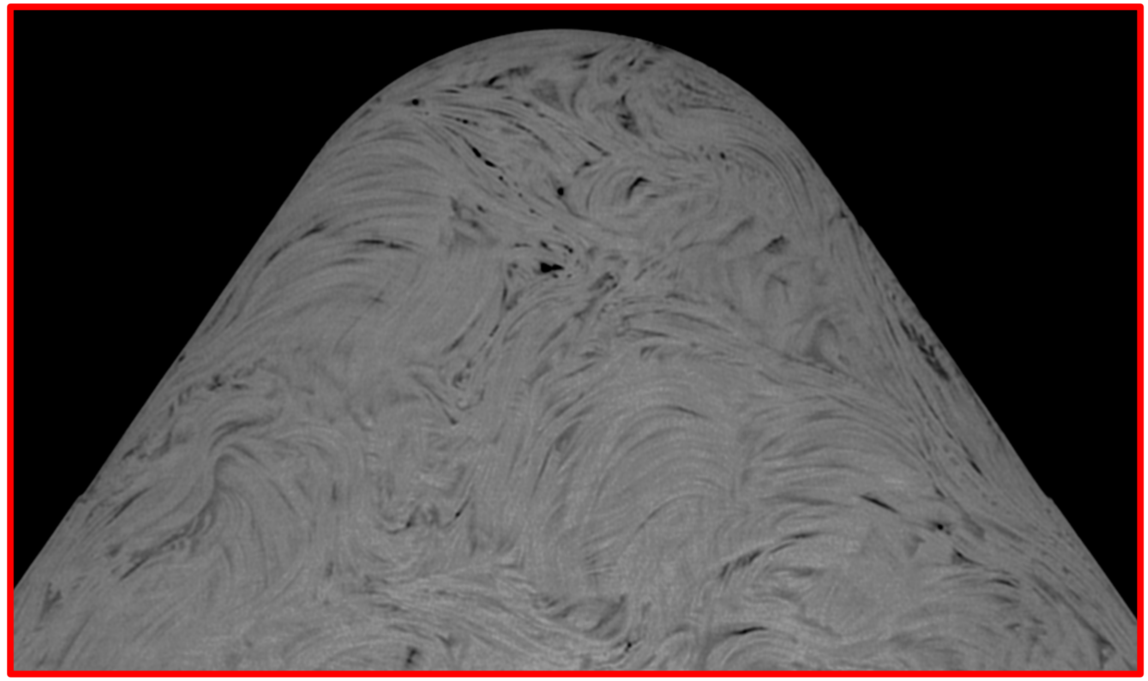
Bracket Flow

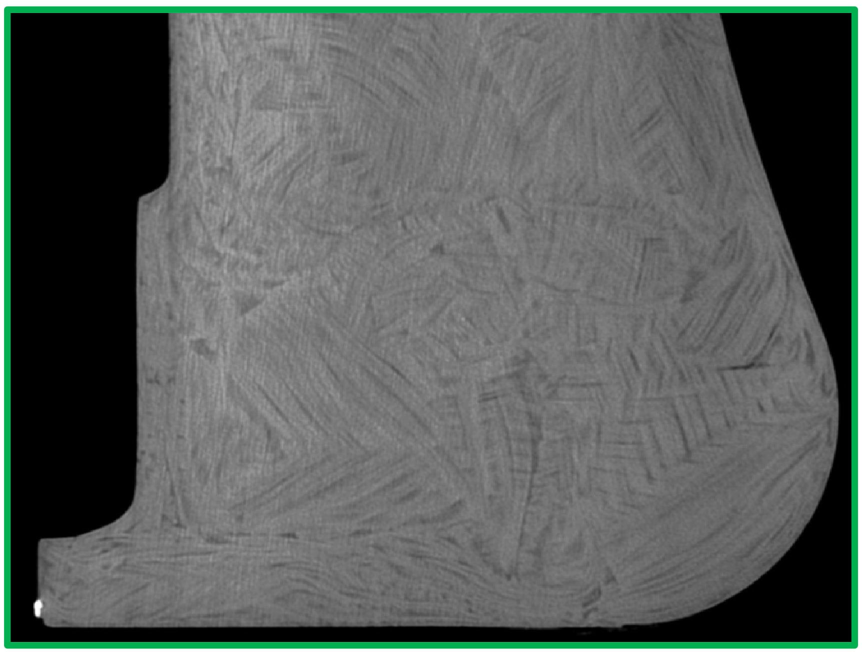


- Top of bracket (red) has platelet flow, indicated by fiber curvature
- Bottom of the bracket (green) has little to no flow

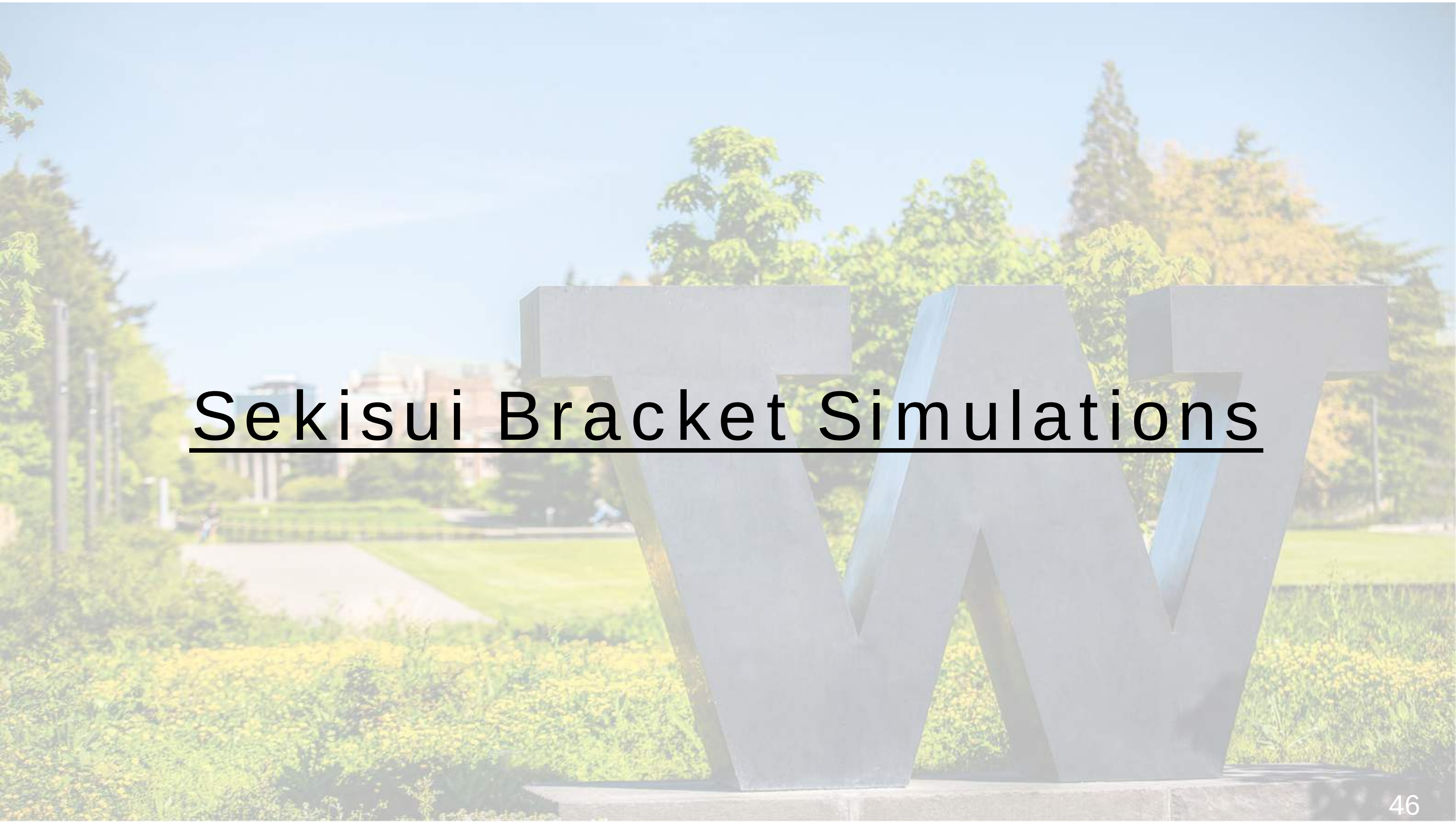
Bracket Flow





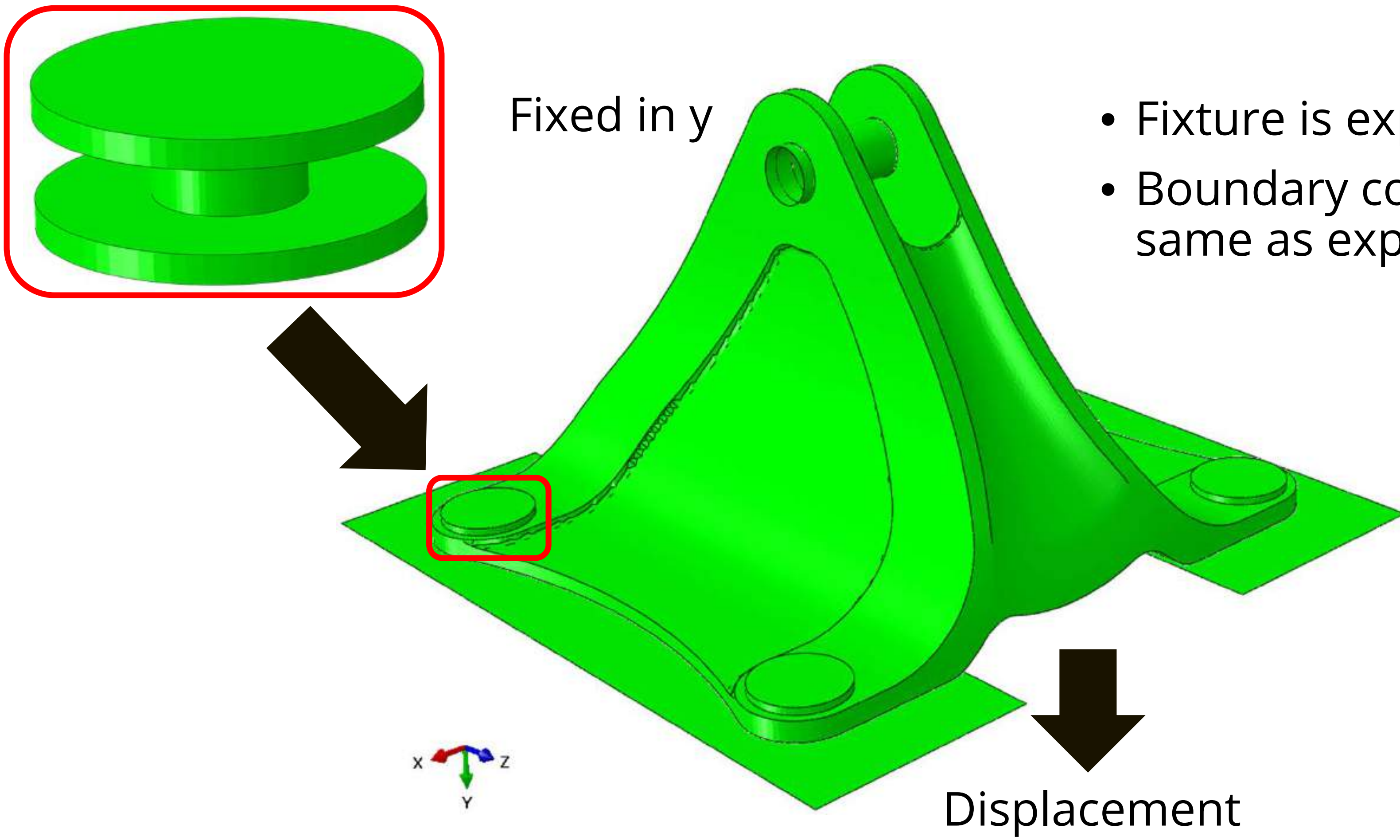


- Top of bracket (red) has platelet flow, indicated by fiber curvature
- Bottom of the bracket (green) has little to no flow



Sekisui Bracket Simulations

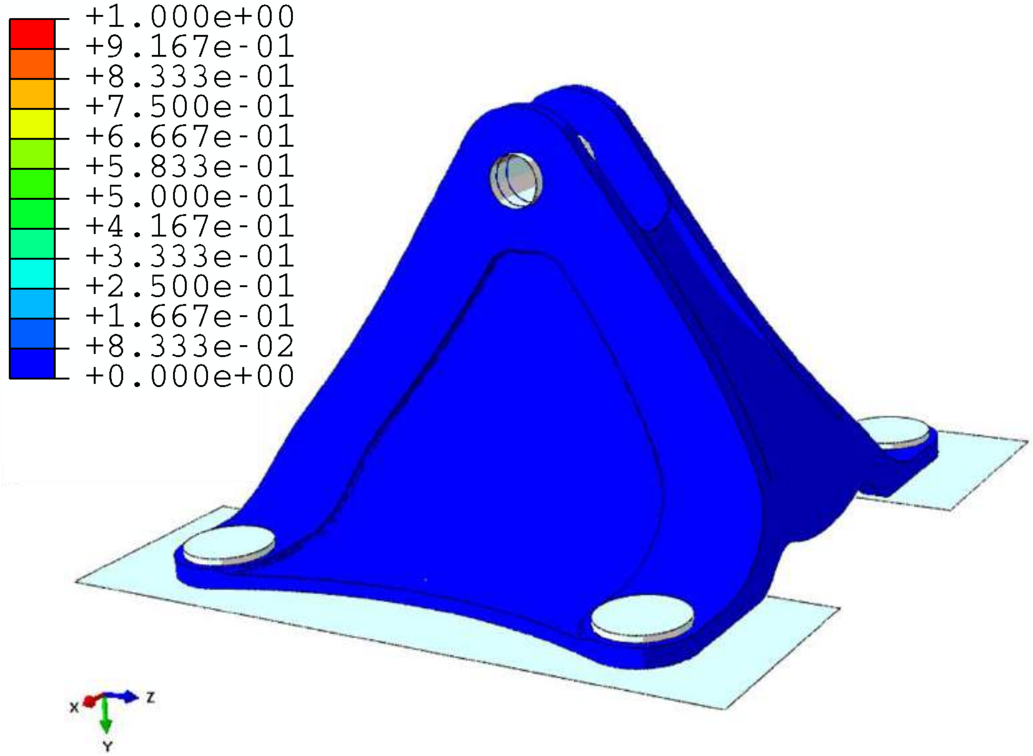
Simulation of Tension Tests



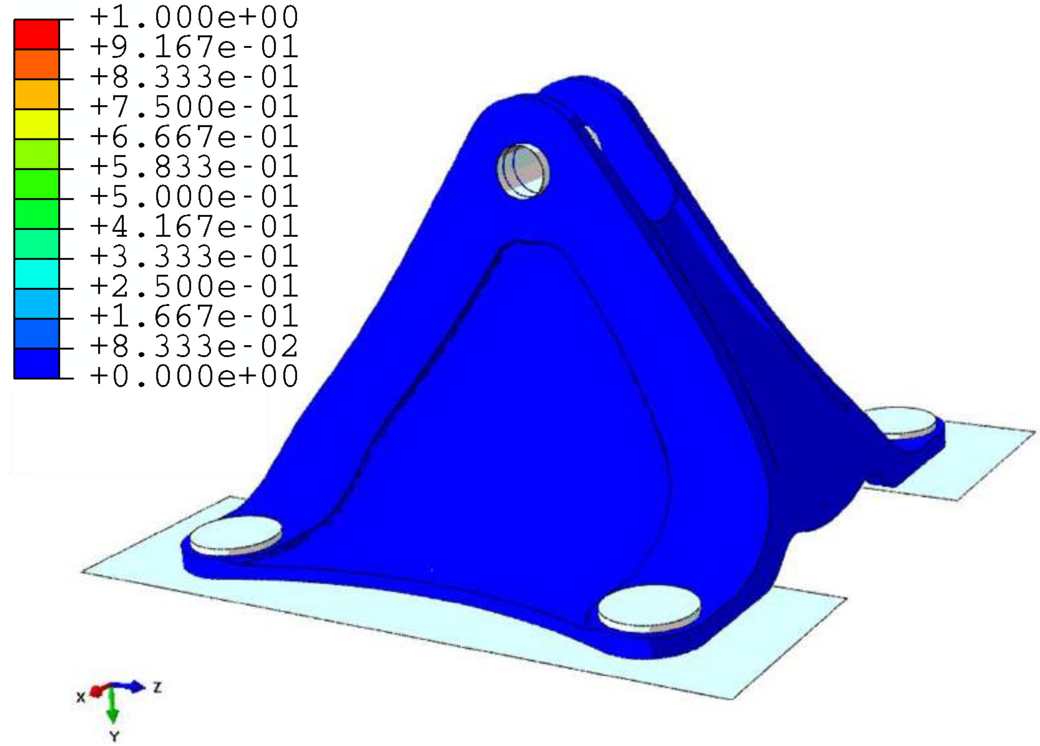
- Fixture is explicitly modeled
- Boundary conditions are the same as experiment

Simulation of Matrix and Fiber Damage

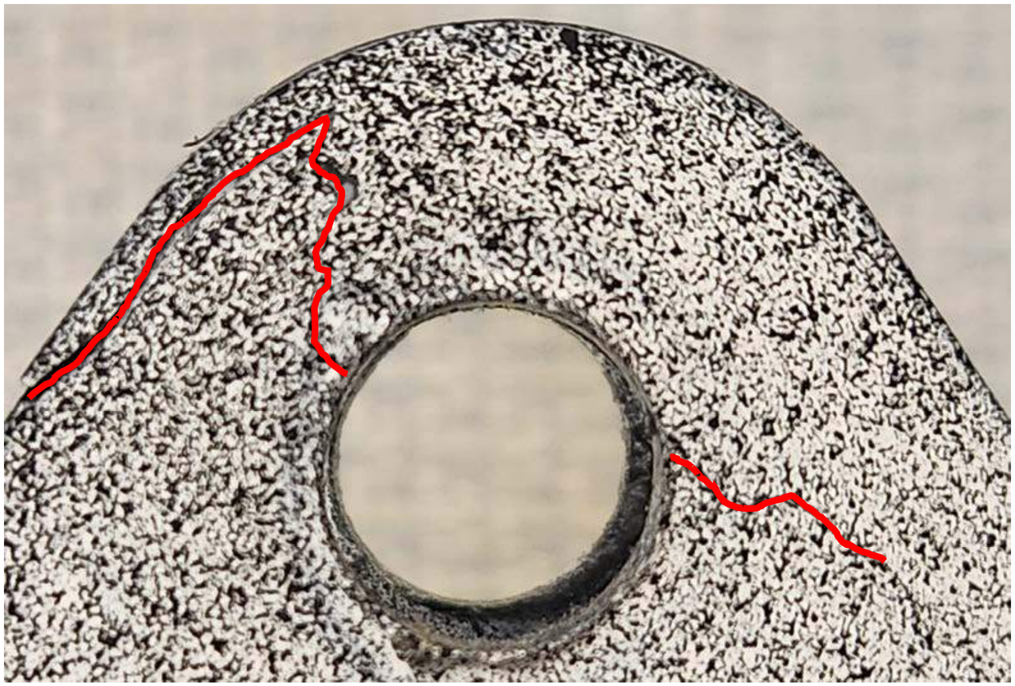
Matrix Damage

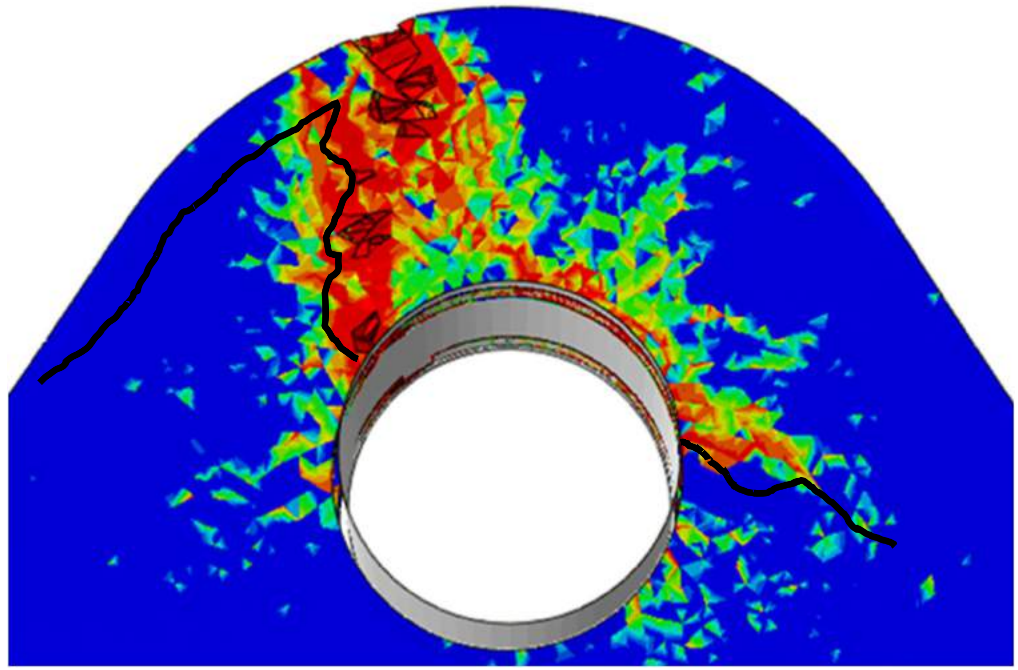


Fiber Damage



Narrow Platelet Sekisui Failure





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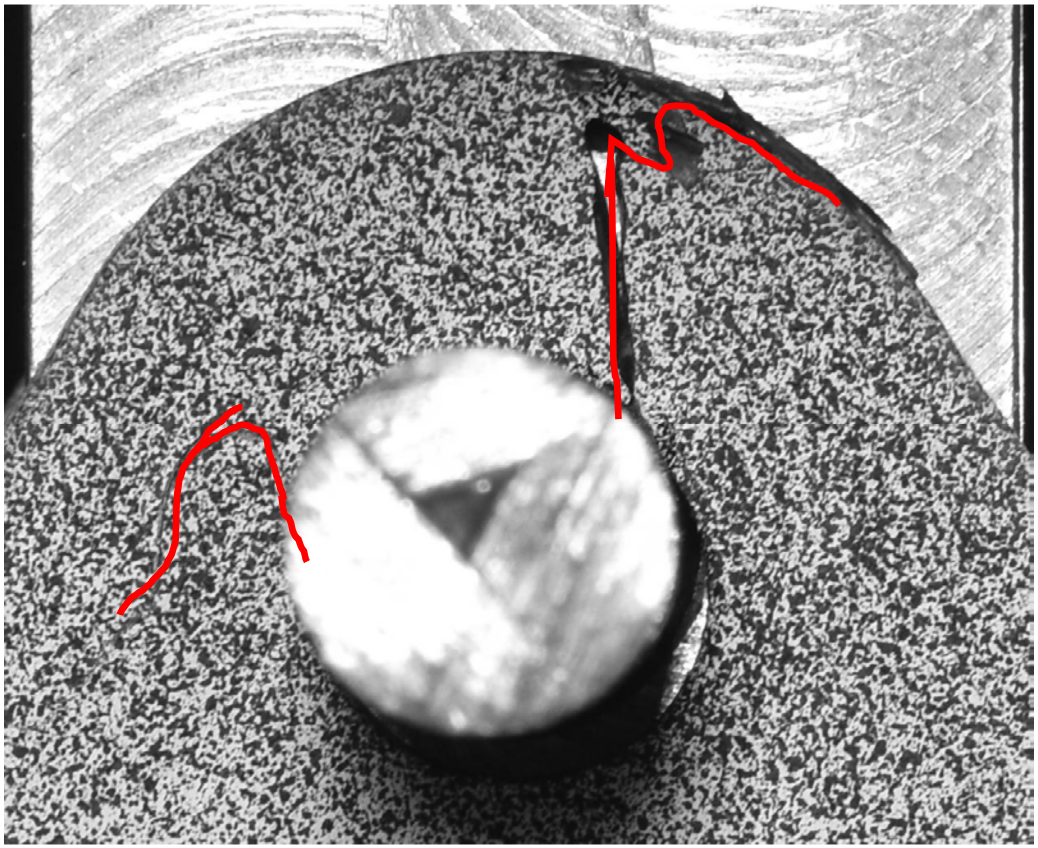
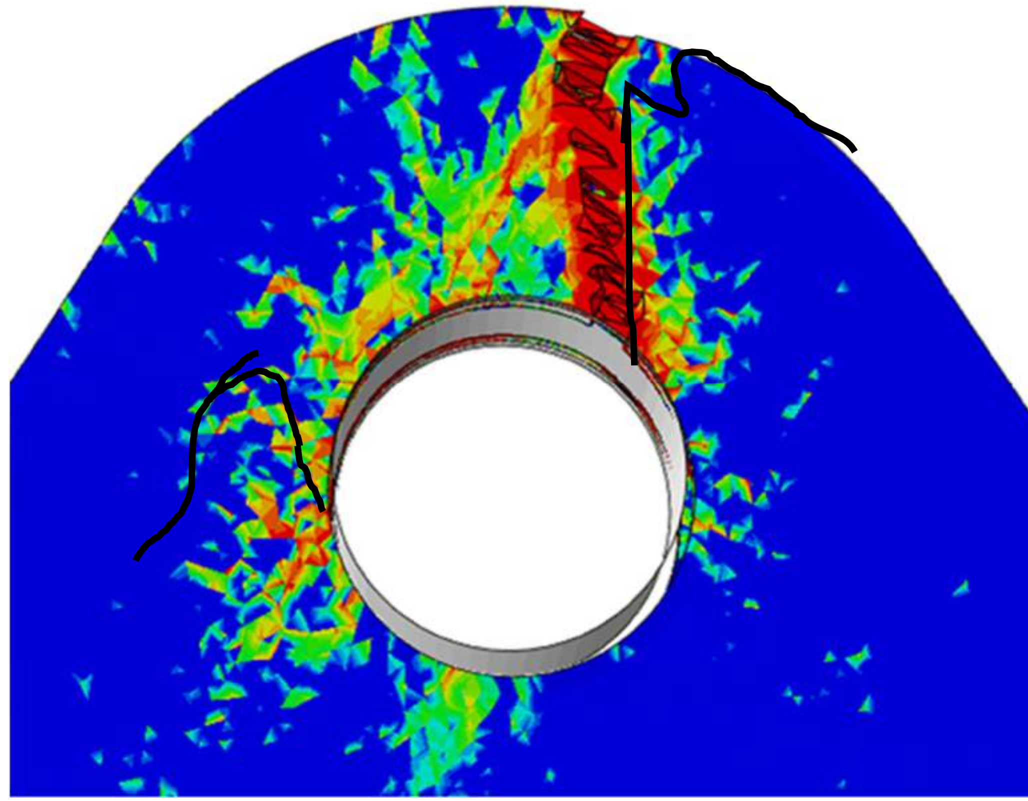
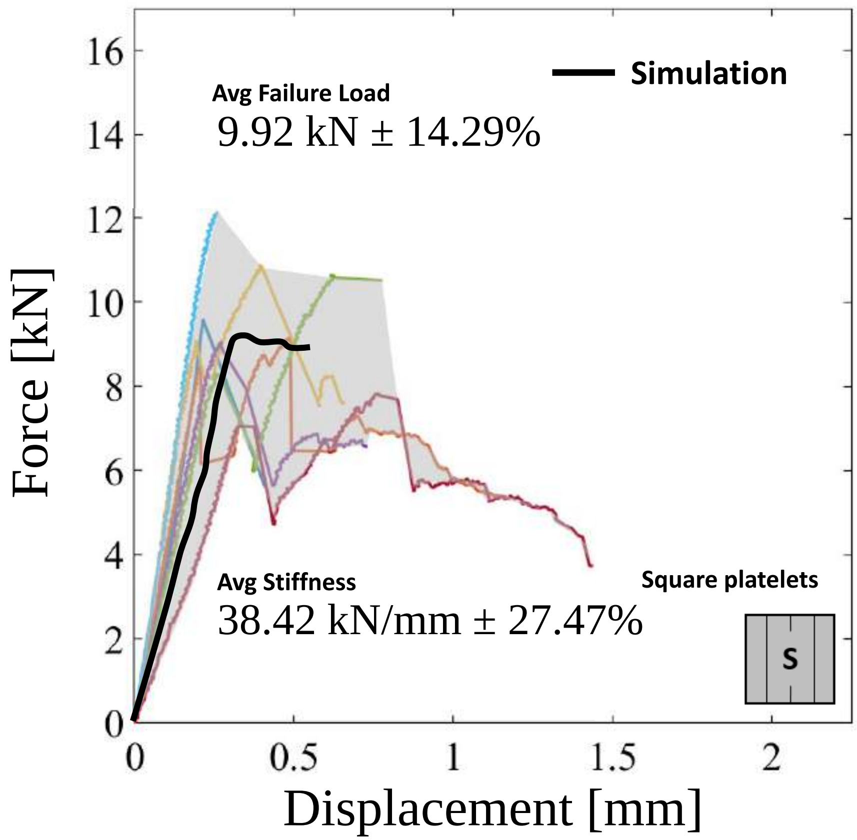
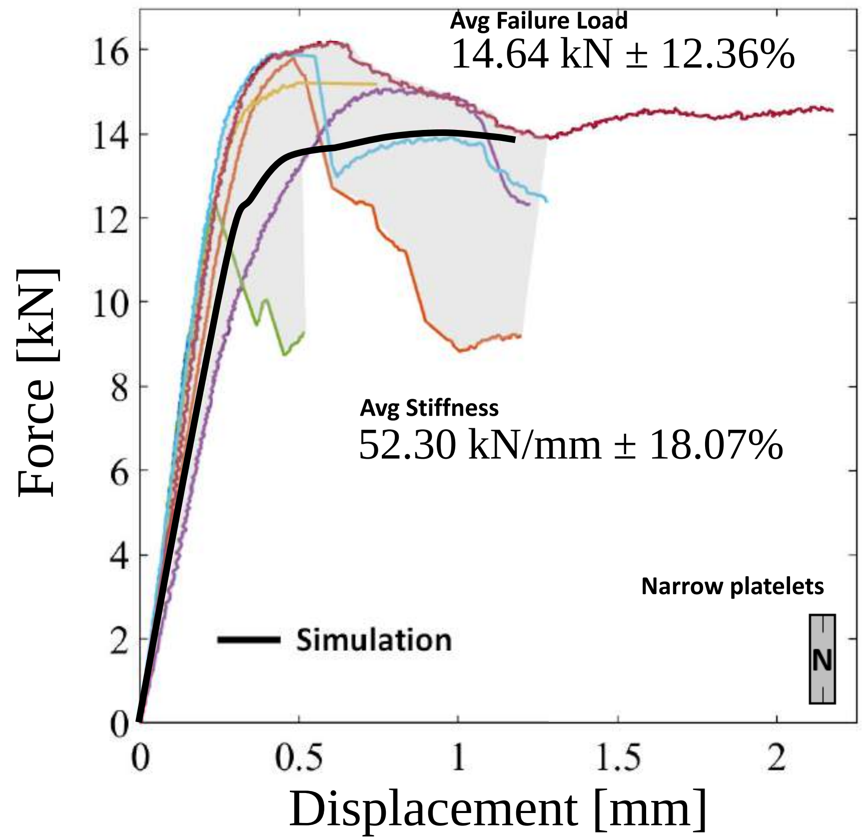
Narrow Platelet Sekisui Failure



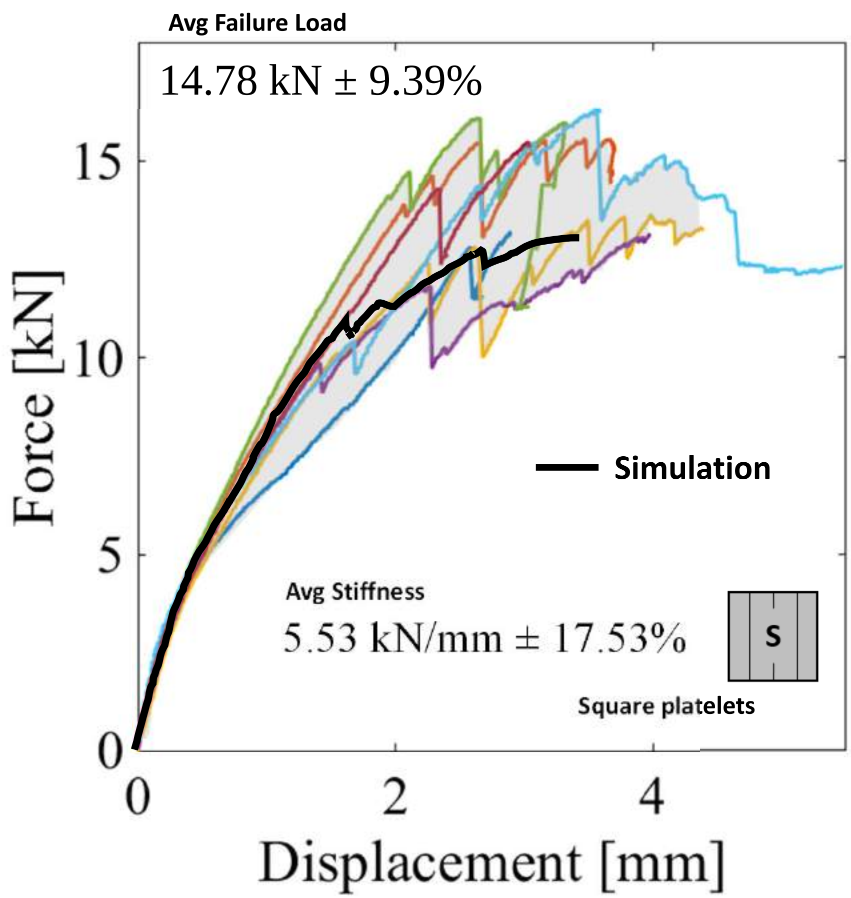


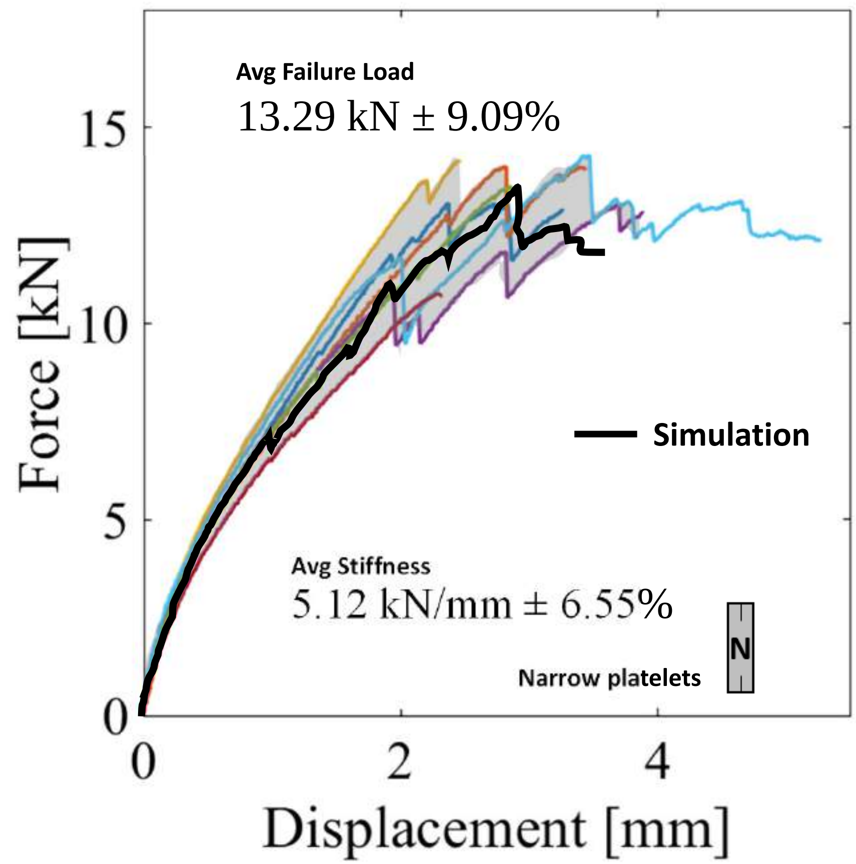
Simulation vs Experiments (tension)





Simulation vs Experiments (bending)





Stiffness (Square Platelets)

	Tension	Bending
Experiments	38.42 ± 27.5%	5.53 ± 17.5%
FEM	40.2 ± 17.2%	6.43 ± 12.5%

Failure load (Square Platelets)

	Tension	Bending
Experiments	9.92 ± 14.3%	14.78 ± 14.4%
FEM	9.1 ± 11.5%	16.3 ± 10.5%

Stiffness (Square Platelets)

	Tension	Bending
Experiments	53.30 ± 18.3%	5.12 ± 6.6%
FEM	56.3 ± 23.5%	5.8 ± 11.5%

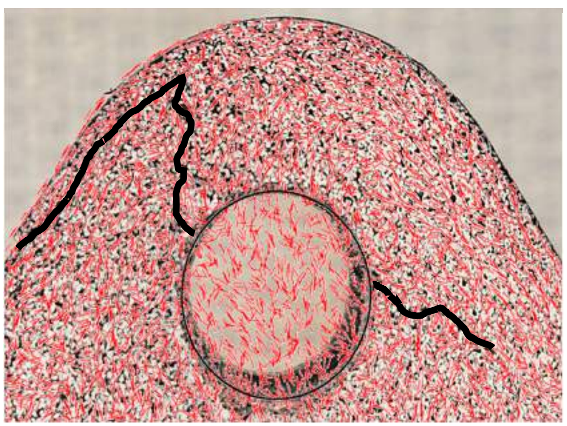
Failure load (Square Platelets)

	Tension	Bending
Experiments	14.64 ± 12.4%	13.29 ± 9.1%
FEM	15.7 ± 15.2%	15.3 ± 7.5%

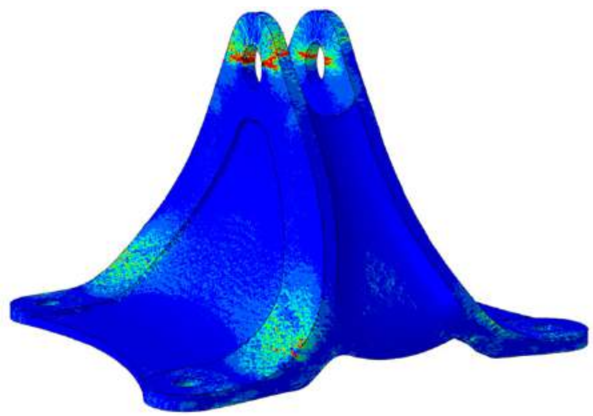
Ongoing work

Can we use the model to generate design allowables?

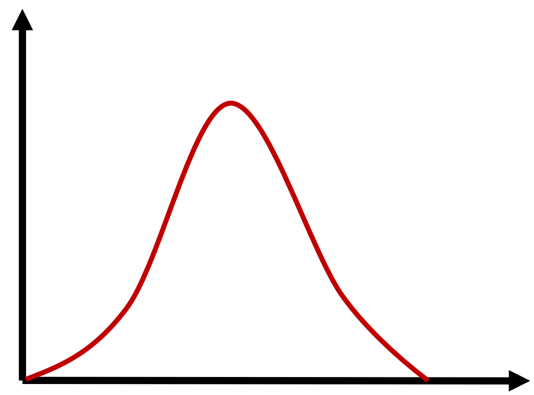
1. Extract statistical distribution of fiber orientation from X-ray CT



2. Construct digital samples and perform Montecarlo simulations



3. Calculate design allowables

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Experimental and Computational Investigation into the Use of Discontinuous Fiber Composites to Manufacture a Bracket

5/22/2024

Marco Salviato (UW)

JAMS meeting 2024