Computational Investigation into the Effects of Platelet Size, Thickness, and Flow on the Tensile Properties of Discontinuous Fiber Composites

4/19/2023

Marco Salviato (UW)

JAMS meeting 2023

JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

Research Team

University of Washington

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Graduate students: Seunghyun Ko, Troy Nakagawa, Zhisong Chen, Collins Davis, James Davey (Total of 12: 2 PhD and 10 master)

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

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Larry Ilcewicz (Sponsor)
Amhet Oztekin (Other)
Cindy Ashforth (Sponsor)

Industry Mentors:

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Michael Larson (Boeing)
Ebonni Adams (Boeing)
Matthew Soja (Boeing)
Scott James (Sekisui Aerospace)

Sponsors

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The Joint Center for Aerospace Technology Innovation

COMPOSITE RECYCLING TECHNOLOGY CENTER

CRTC

compositerecycling.org

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A DURAVANT COMPANY

Introduction

Carbon Fiber Reinforced Composites Market

Primary Structures

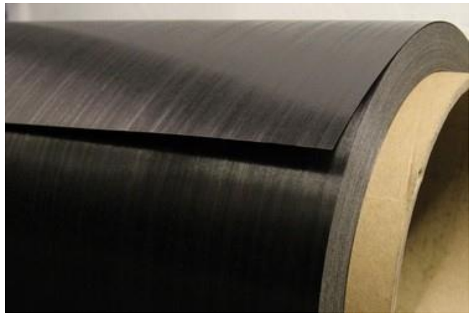
Aviationweek.com

TheGuardian

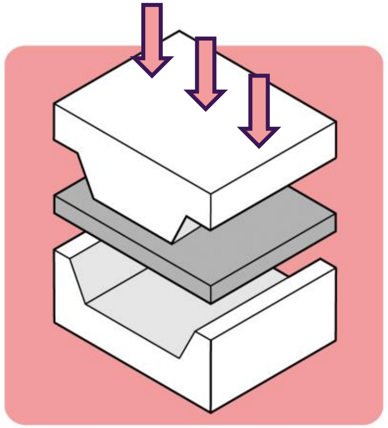
Secondary Structures

Aviationweek.com

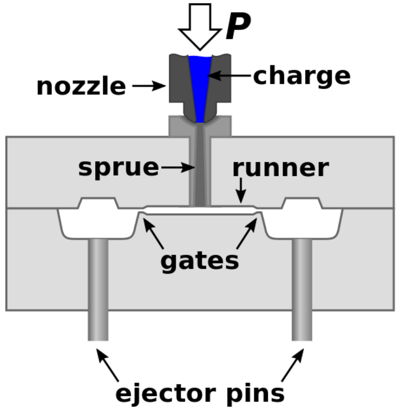
Discontinuous Fiber Composites (DFCs)



Platelet (Chip) based, discontinuous fiber form



Compression molding



Injection molding

Mitsubishi and Toyota

Boeing

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

Project Overview

Challenges for DFCs – Design Guidance

Building Block Approach

Part Level

Design Guidance

Coupon Level

Analysis Tools

Proof Testing

Laminate Level

Laminate Stacking Sequence

Fiber properties

Matrix properties

Interface properties

Random platelets orientations

Platelet geometry

Size Effects

Void content

Project Plan

Experiment: UNIVERSITY of WASHINGTON NIAR

Flat tensile coupons
3D Structures

Experiment: UNIVERSITY of WASHINGTON

Flat tensile coupons

2023

Year 3

2022

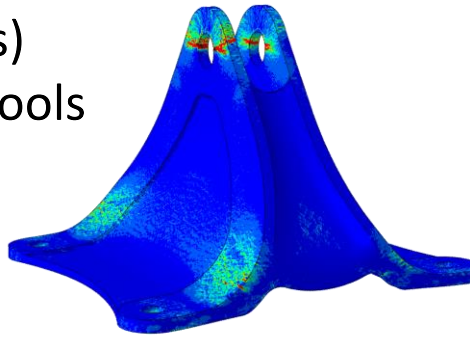
Experiment: BOEING

Flat tensile coupons

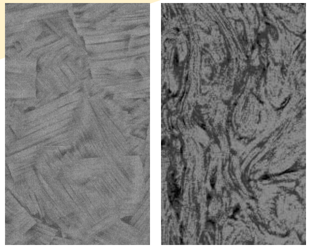
Year 2

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

2021



Year 1



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

2020

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

Project Plan

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Flat tensile coupons

2023

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Flat tensile coupons

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- Execute experiment plan (flat tensile coupons)
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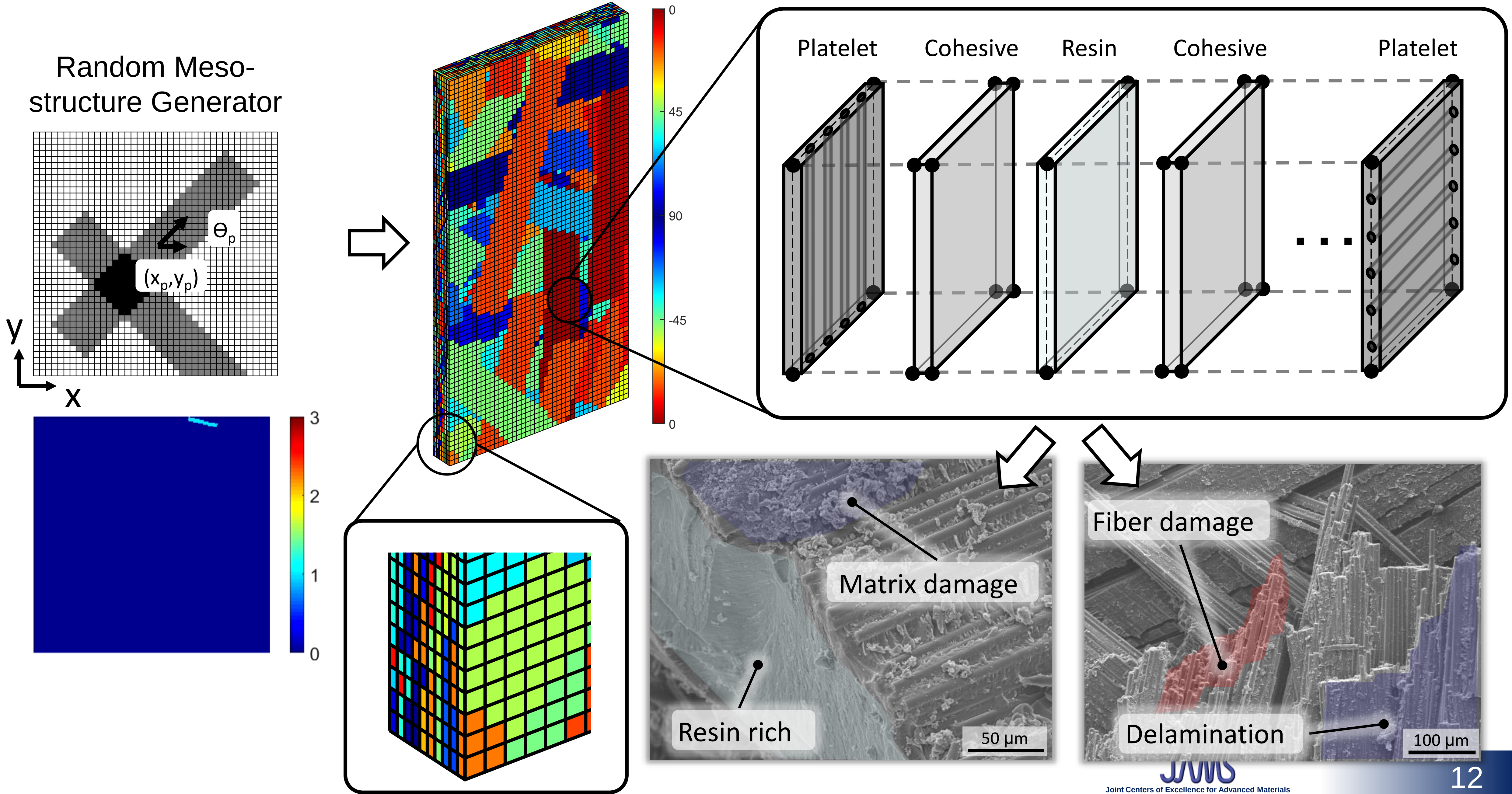
Year 1

2020

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

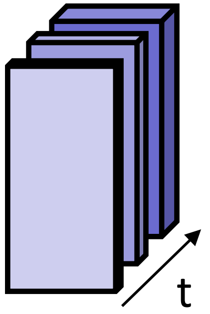
Year 1 (2020-21) Summary

Finite Element Framework



Key Conclusions from Year 1 Study

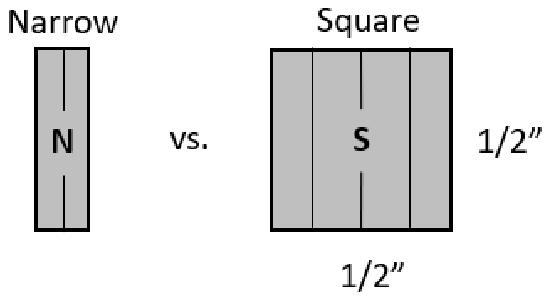
(1) Significant thickness effect



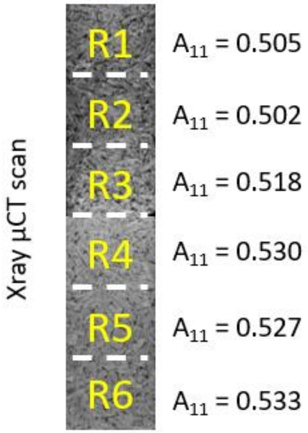
data concentrated at thickness 0.15”

Wide range of thicknesses: 0.065” to 0.25”

(2) Significant platelet width effect



(3) Significant Platelet Orientation Effect



Only at thickness 0.15”

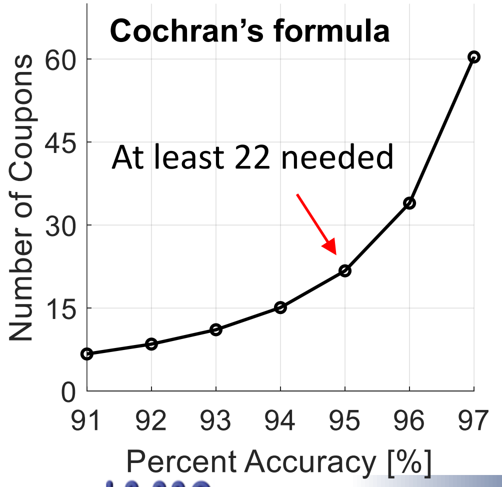
Both platelets + all thicknesses

(4) Significant flow effect

Low flow (flat)

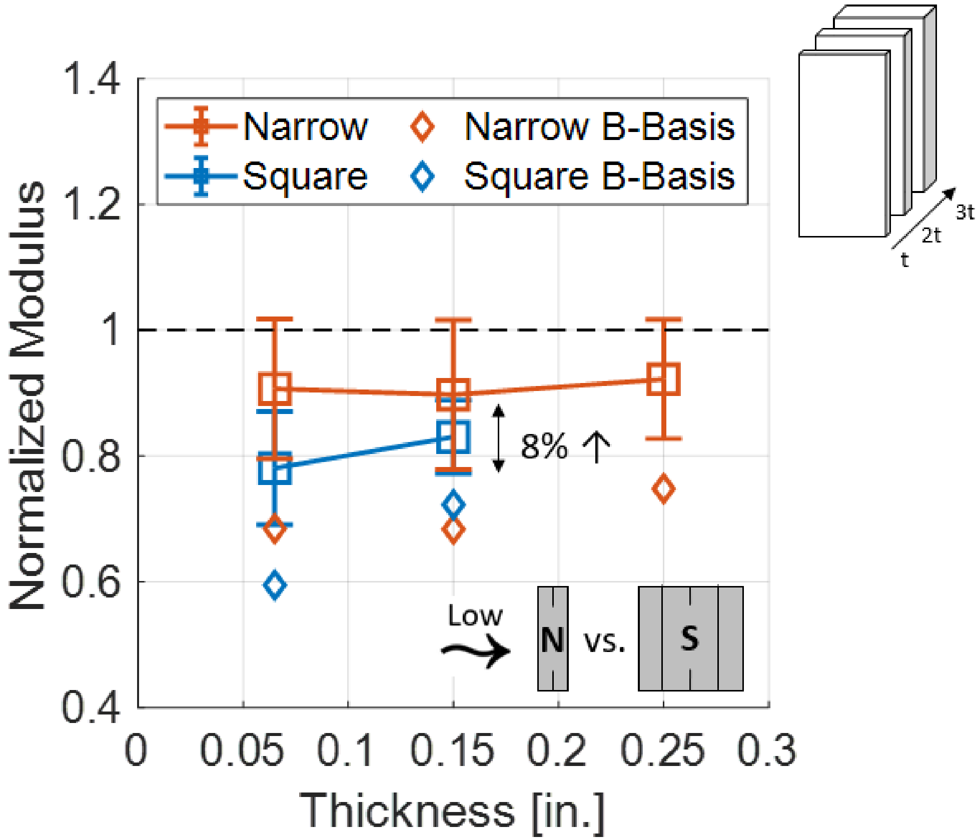
High flow (forks)

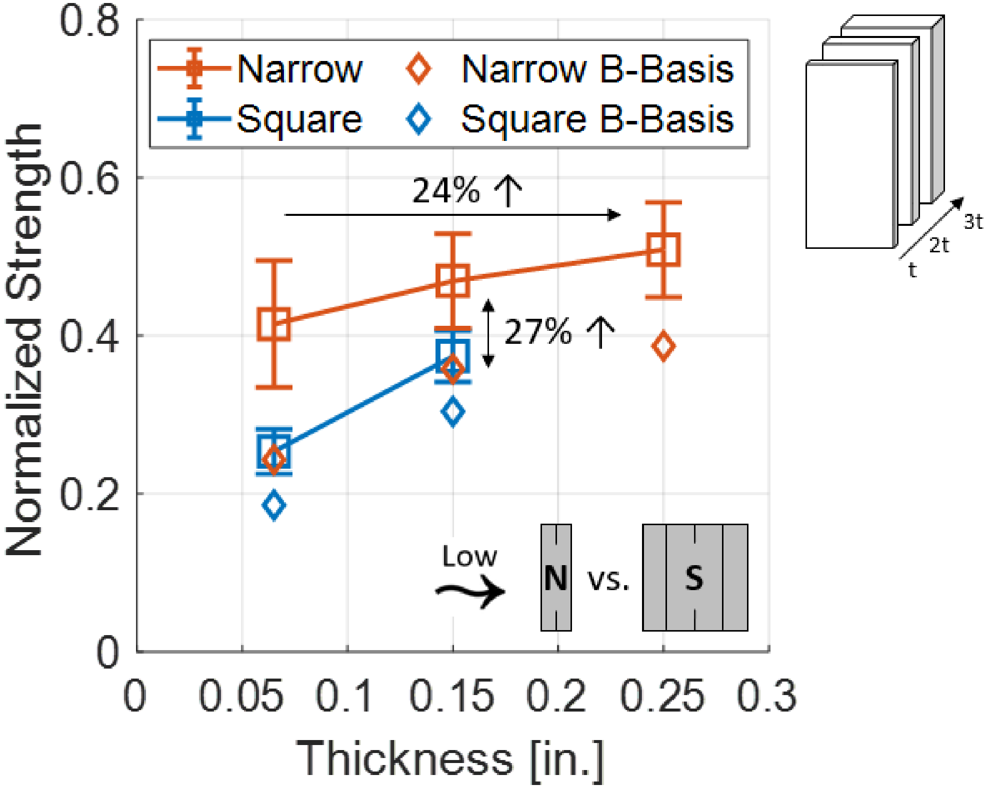
(5) Number of tests in literature was not statistically significant



Year 2 (2021-22) Summary

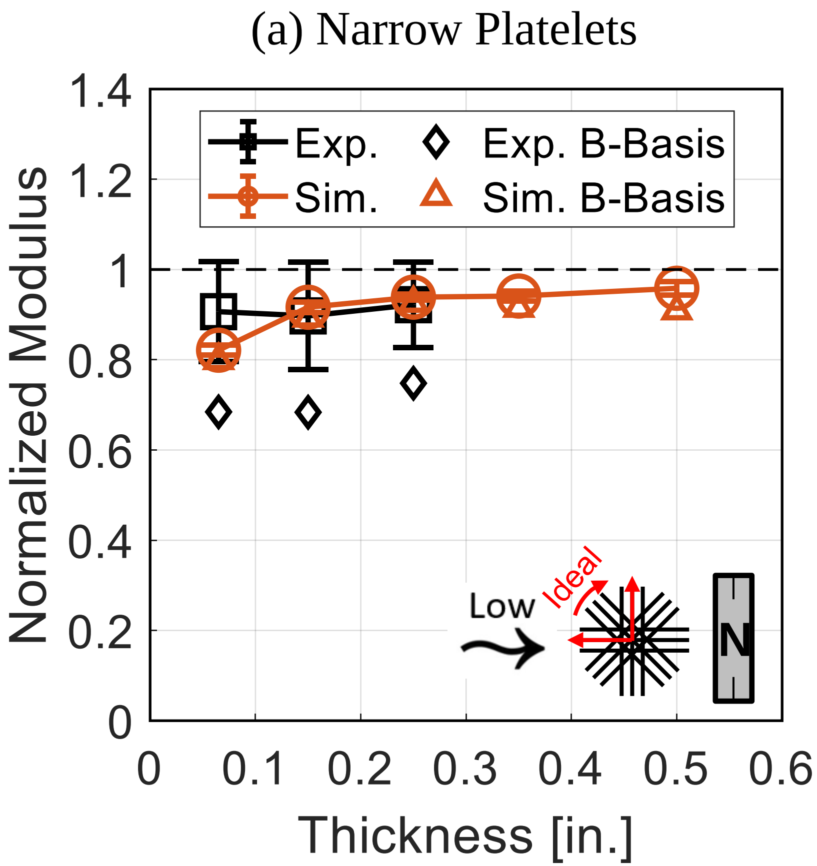
Tensile Modulus/Strength

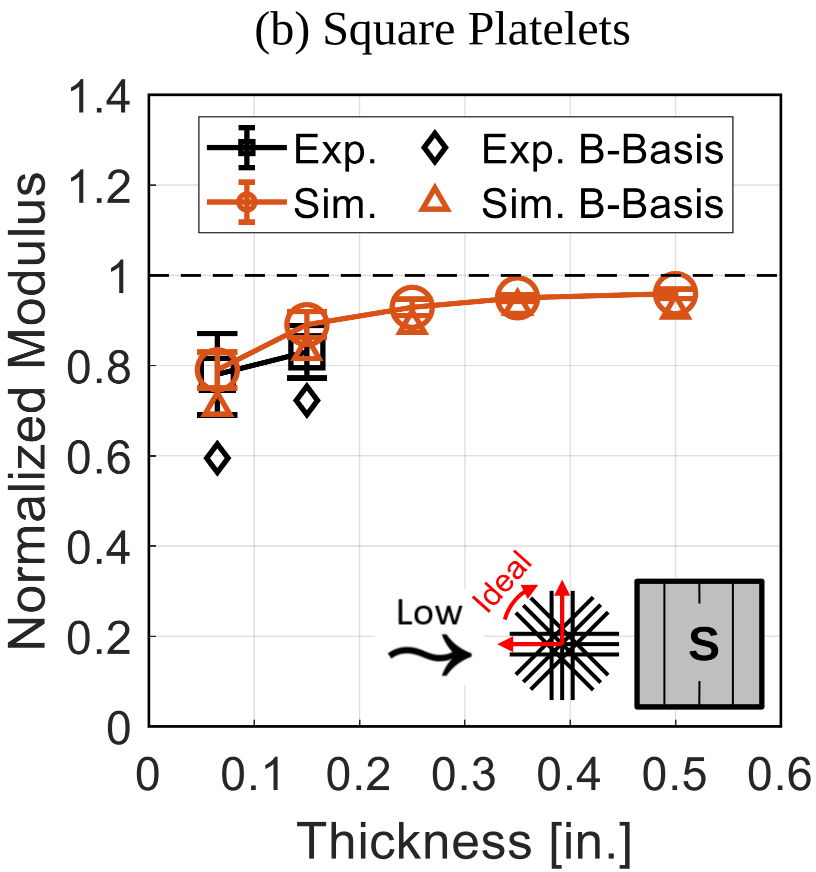


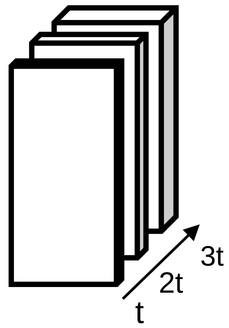


1. Narrow and square platelets had insignificant modulus thickness effects.
2. Narrow and square platelets had significant strength thickness effects.
3. The narrow platelets outperformed the square platelets.

Simulation result: Tensile modulus

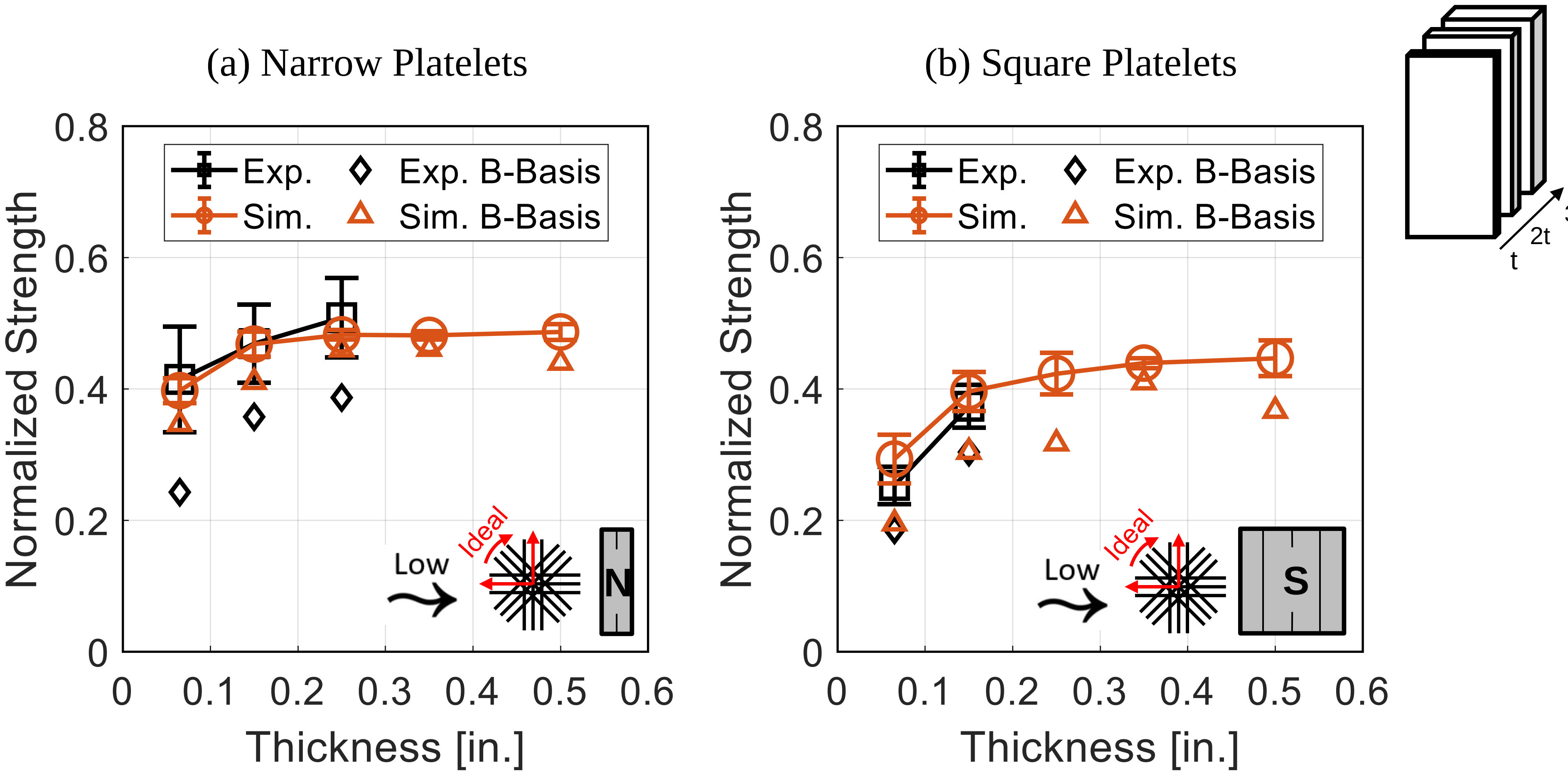






- Simulations capture the thickness effect precisely.
- At the saturated thickness, the modulus difference between the narrow and square is negligible.
- Using the ideal random orientations, the model underpredicts the CoVs (12% vs 2%).

Simulation result: Tensile strength



- Simulations capture the thickness effect precisely.
- At the saturated thickness, the strength difference between the narrow and square is only 7%.
- Using the ideal random orientations, the model underpredicts the CoVs (13% vs 4%).

Project Plan

Experiment: UNIVERSITY of WASHINGTON NIAR

Flat tensile coupons
3D Structures

2023

Year 3

- Analyze flow effects
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- Execute experiment plan (flat tensile coupons)
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Experiment: BOEING

Flat tensile coupons

2021

Year 1

2020

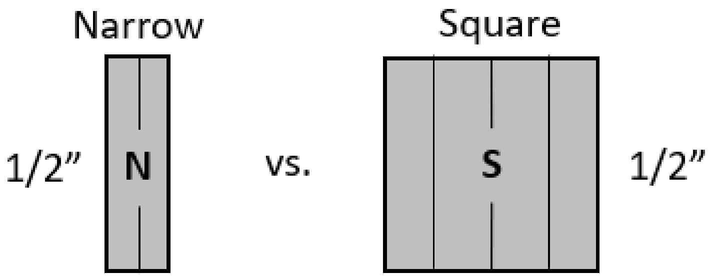
- Utilize existing data from Boeing / Purdue U. (flat tensile coupons)
- Develop computational tools
- Design 2021 experiment plan

Year 3 (2022-23) Summary

Objective

Parameters

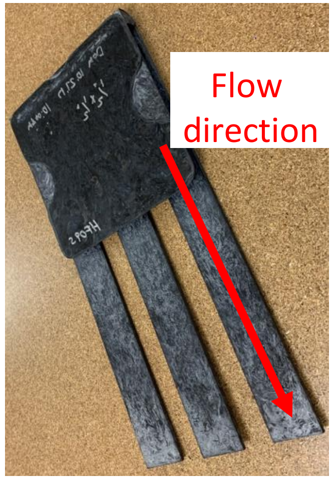
1) Investigate the platelet width effect



(2) Investigate flow effect

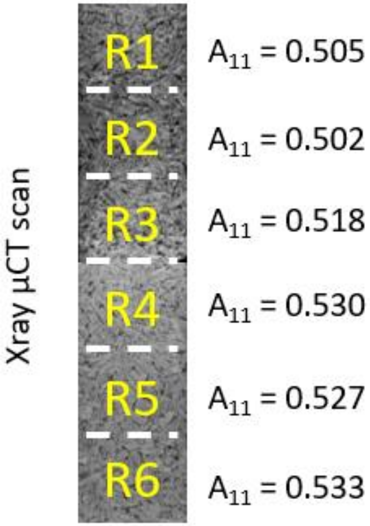
Low flow (flat)

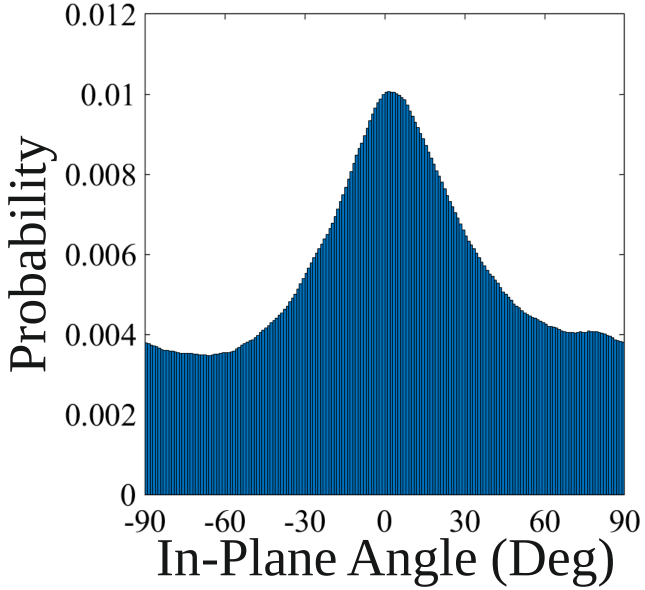
High flow (forks)



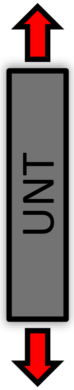
Numerical

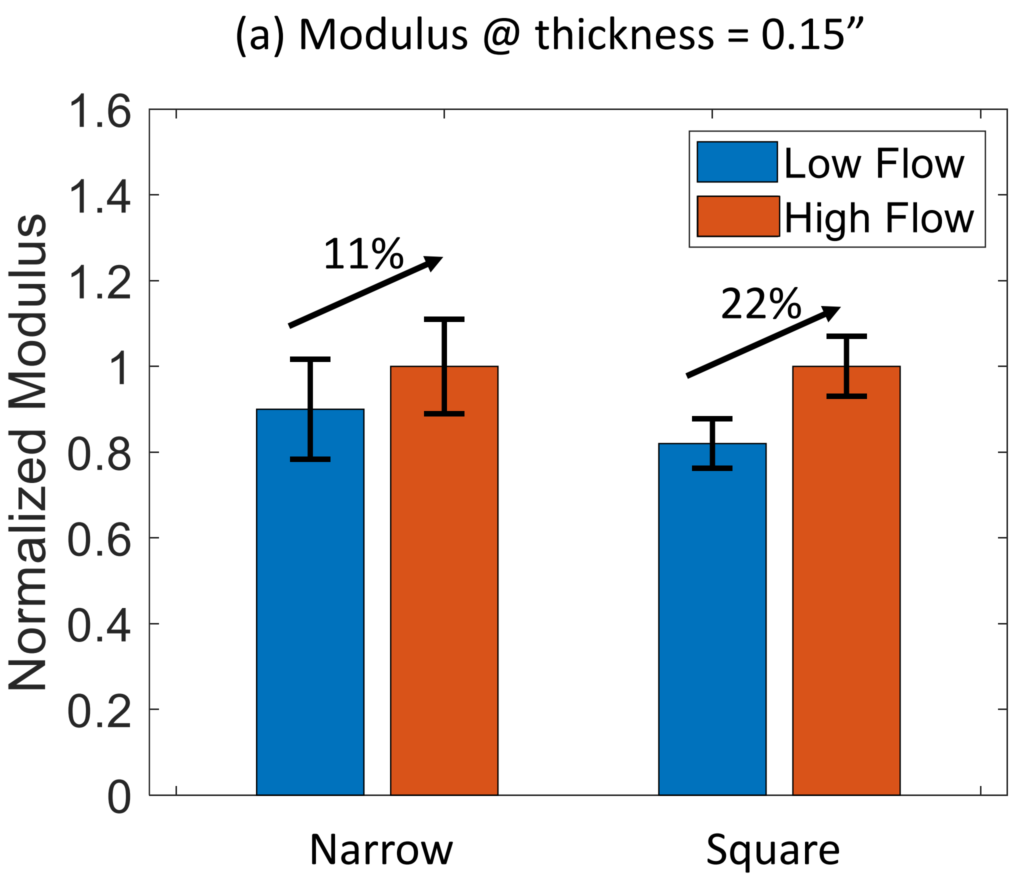
3) Study of platelet orientations using a μCT scan

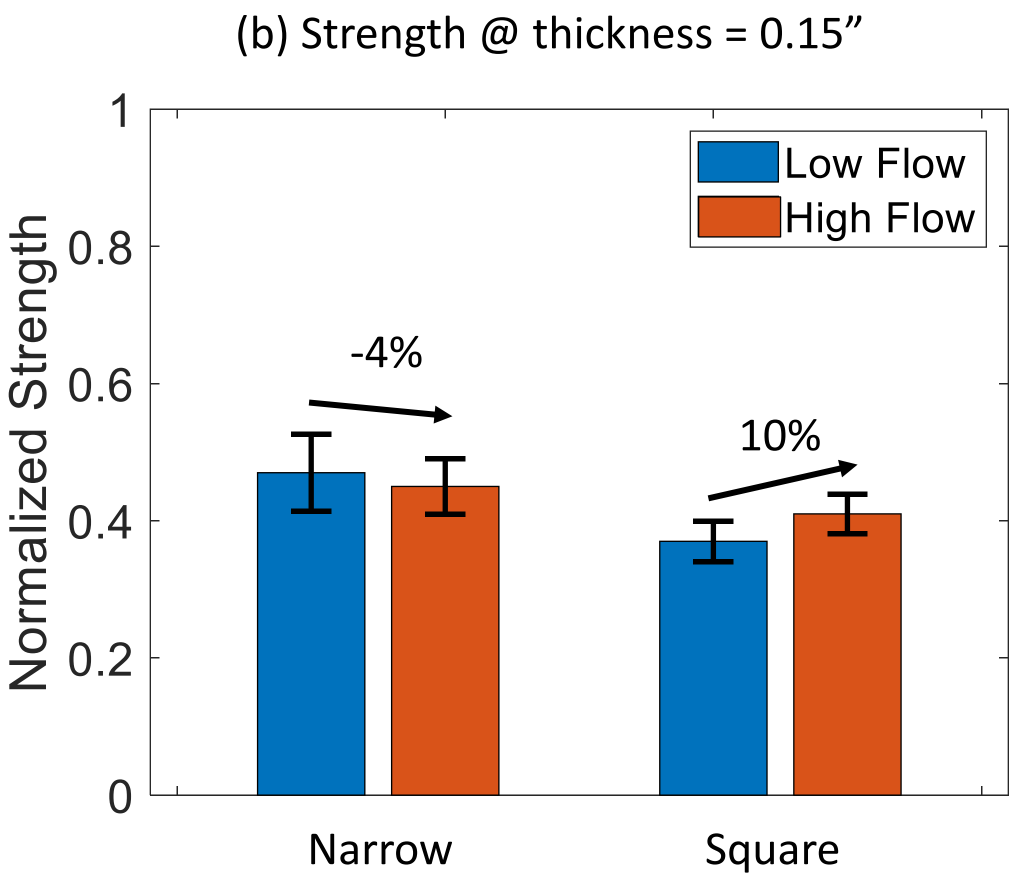




Flow effect in UNT (Experimental)





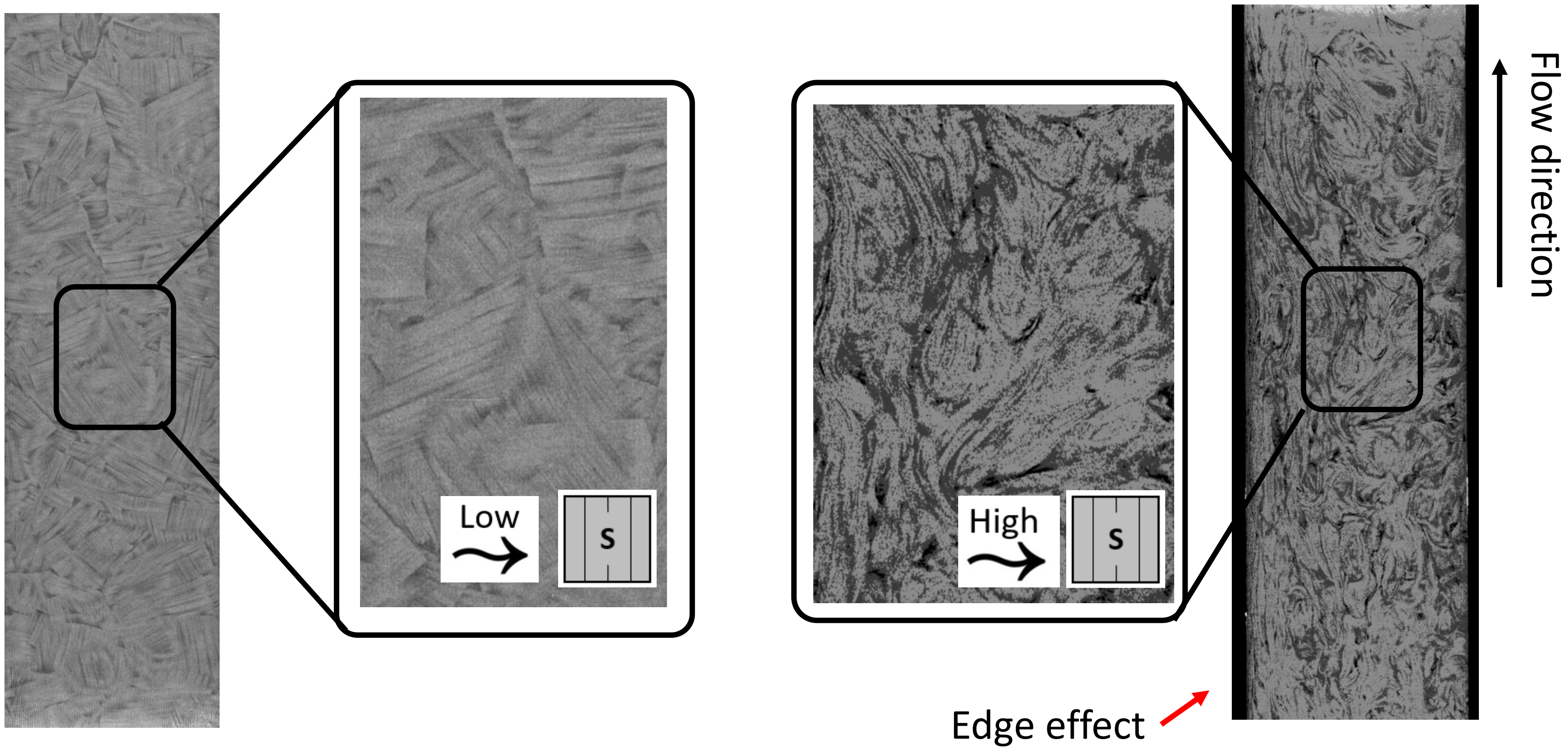


High flow condition promotes the modulus due to favorable platelet orientations but hard to make conclusion on the strength. We may need larger number of test coupons.

Flow effects in the Square platelets

(a) Low flow (square platelets)

(b) High flow (square platelets)

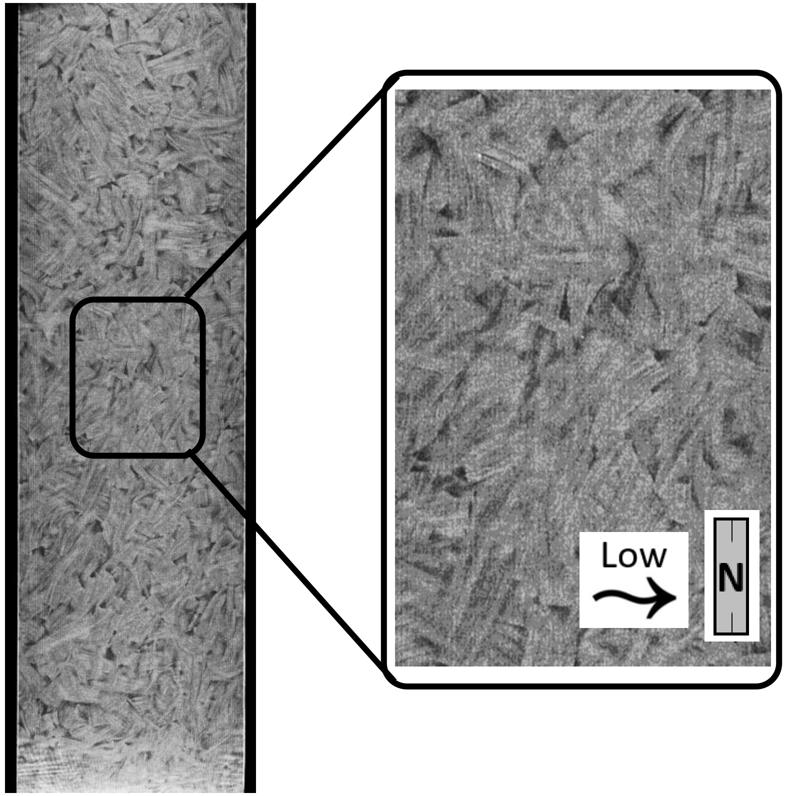


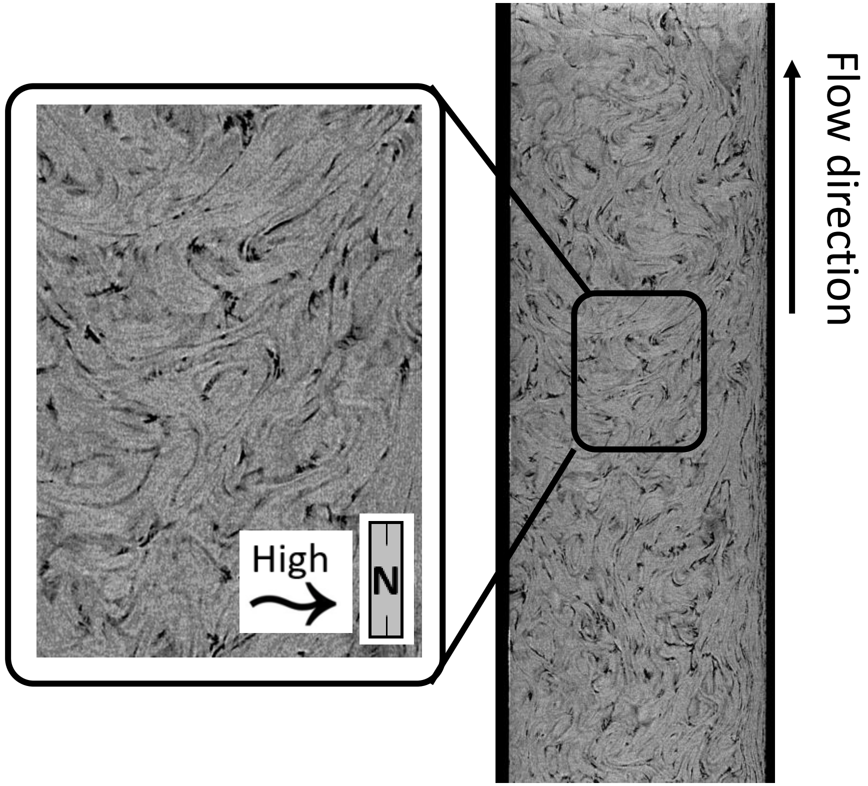
	Normalized Modulus	Normalized Strength	A_{11} mean	A_{11} CoV	# of Scans
Low Flow	0.82 ± 7.0%	0.37 ± 8%	**0.49 (44.5°)**	9.2	5
High Flow	1.0 ± 7.0%	0.41 ± 7%	**0.62 (51.9°)**	7.7	5
Perc. Increase [%]	22%	10%	**27%**	-	-

Flow effects in the Narrow platelets

(a) Low flow (narrow platelets)

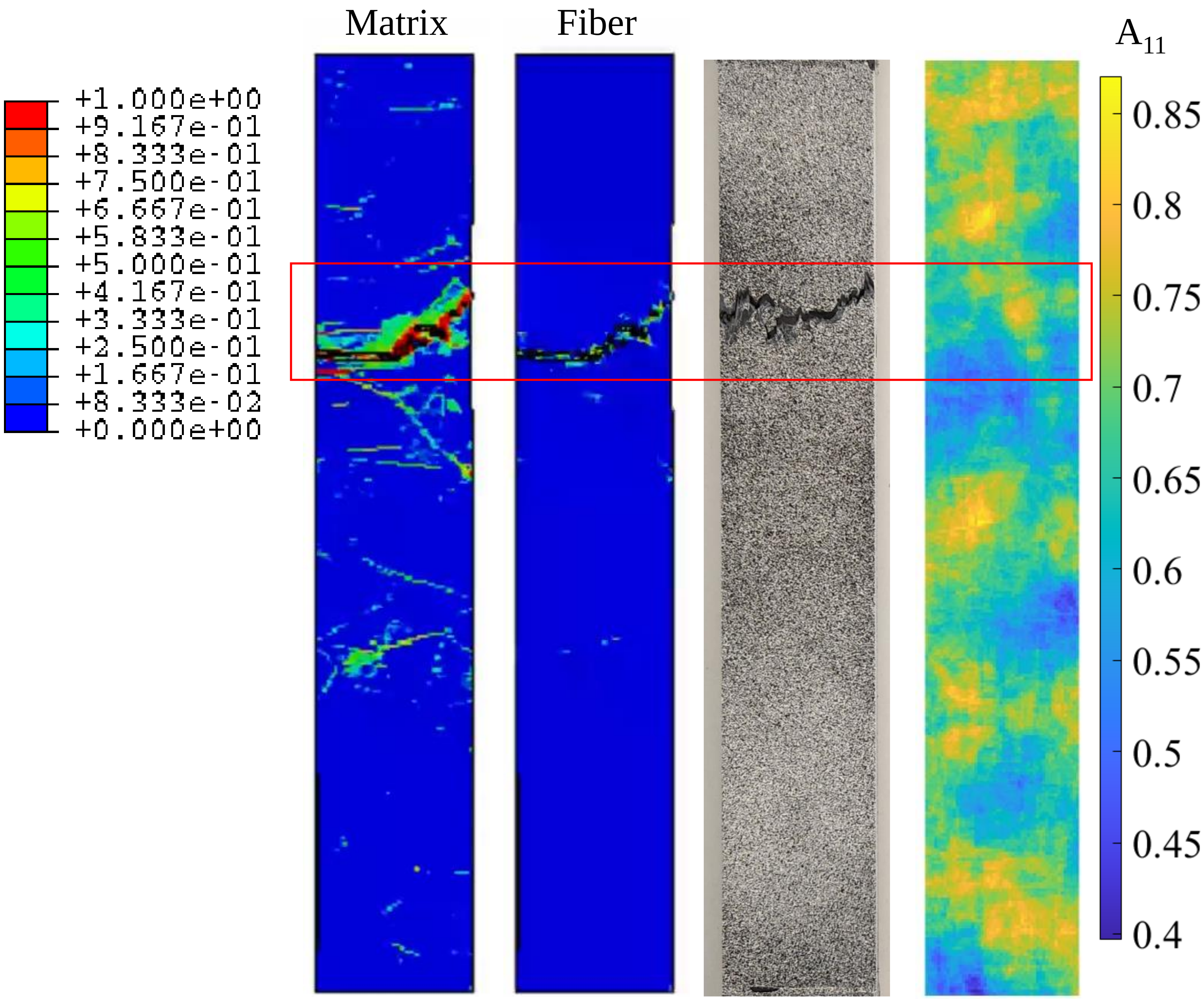
(b) High flow (narrow platelets)





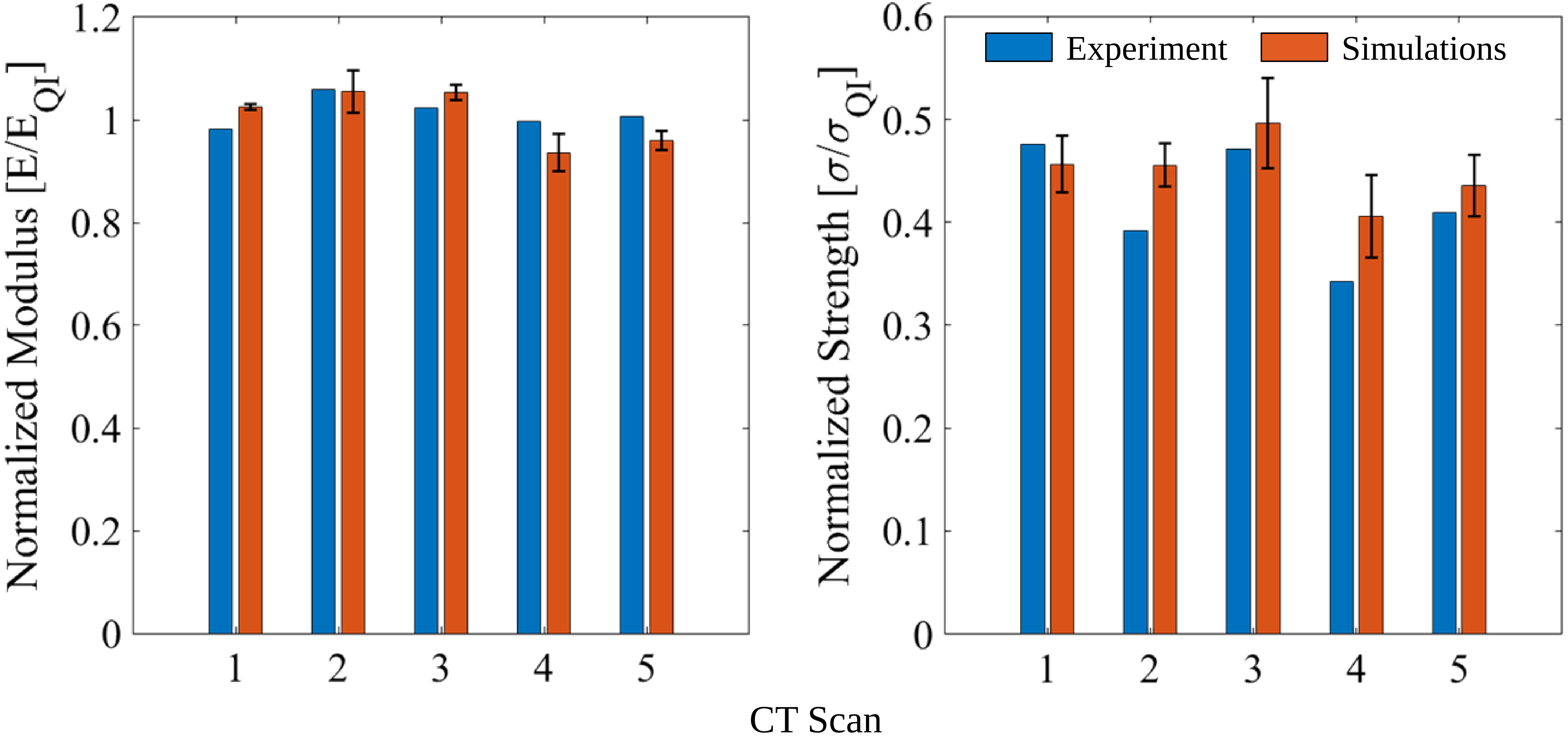
	Modulus	Strength	A_{11} mean	A_{11} CoV	# of Scans
Low Flow	0.9 ± 13%	0.47 ± 12%	**0.49 (44.5°)**	4.8	3
High Flow	1.0 ± 11%	0.45 ± 9%	**0.63 (52.5°)**	5.8	5
Perc. Increase [%]	11%	-4%	**29%**	-	-

Square Platelet High Flow



Failure location matches with experiments

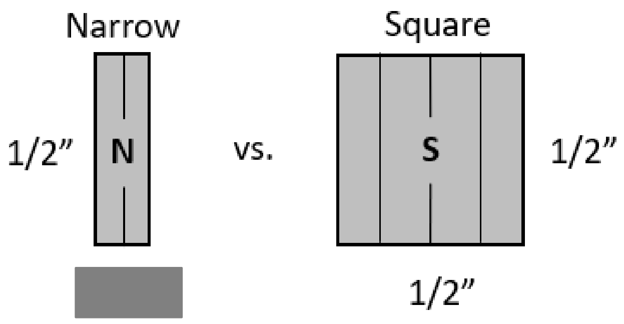
Square Platelet High Flow

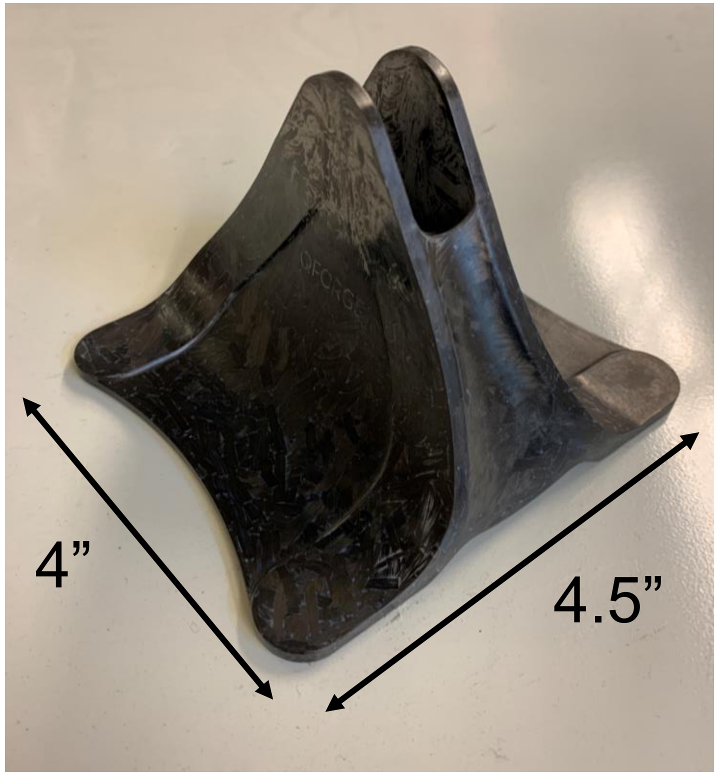


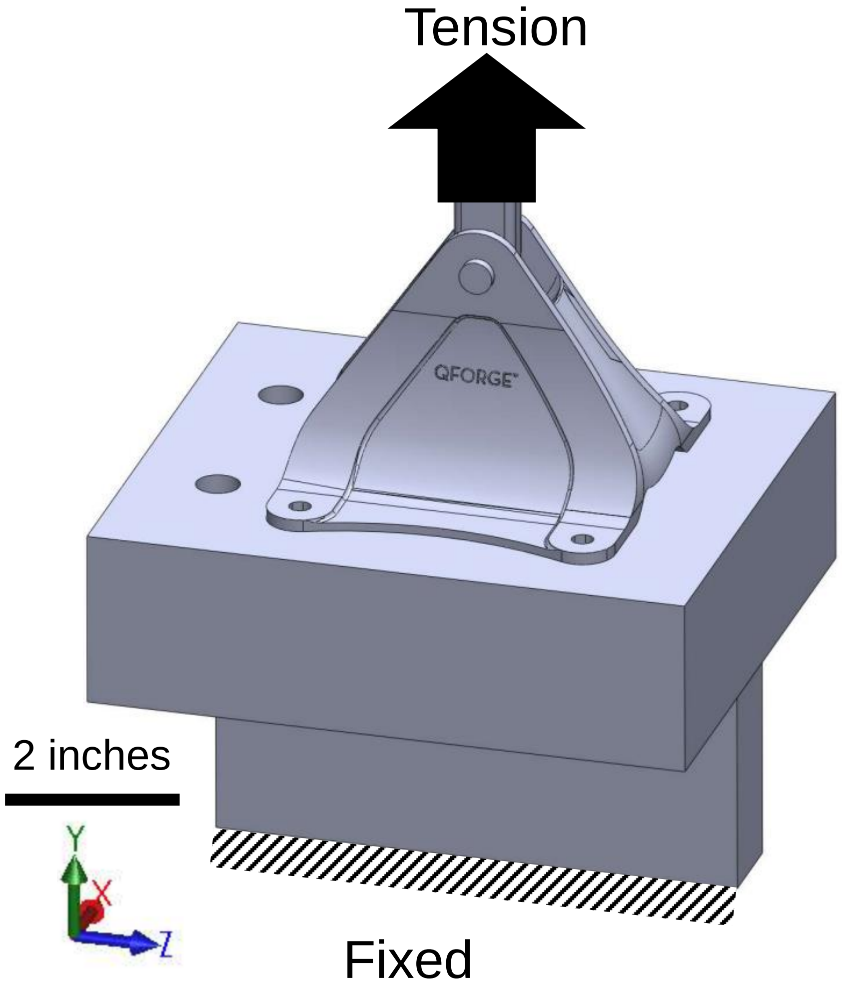
	CT 1	CT 2	CT 3	CT 4	CT 5
Modulus	4.37	-0.28	2.92	-6.31	-4.73
Strength	-4.06	15.13	5.24	16.96	6.23

Percent difference to experiments

Sekisui Bracket Test Configuration

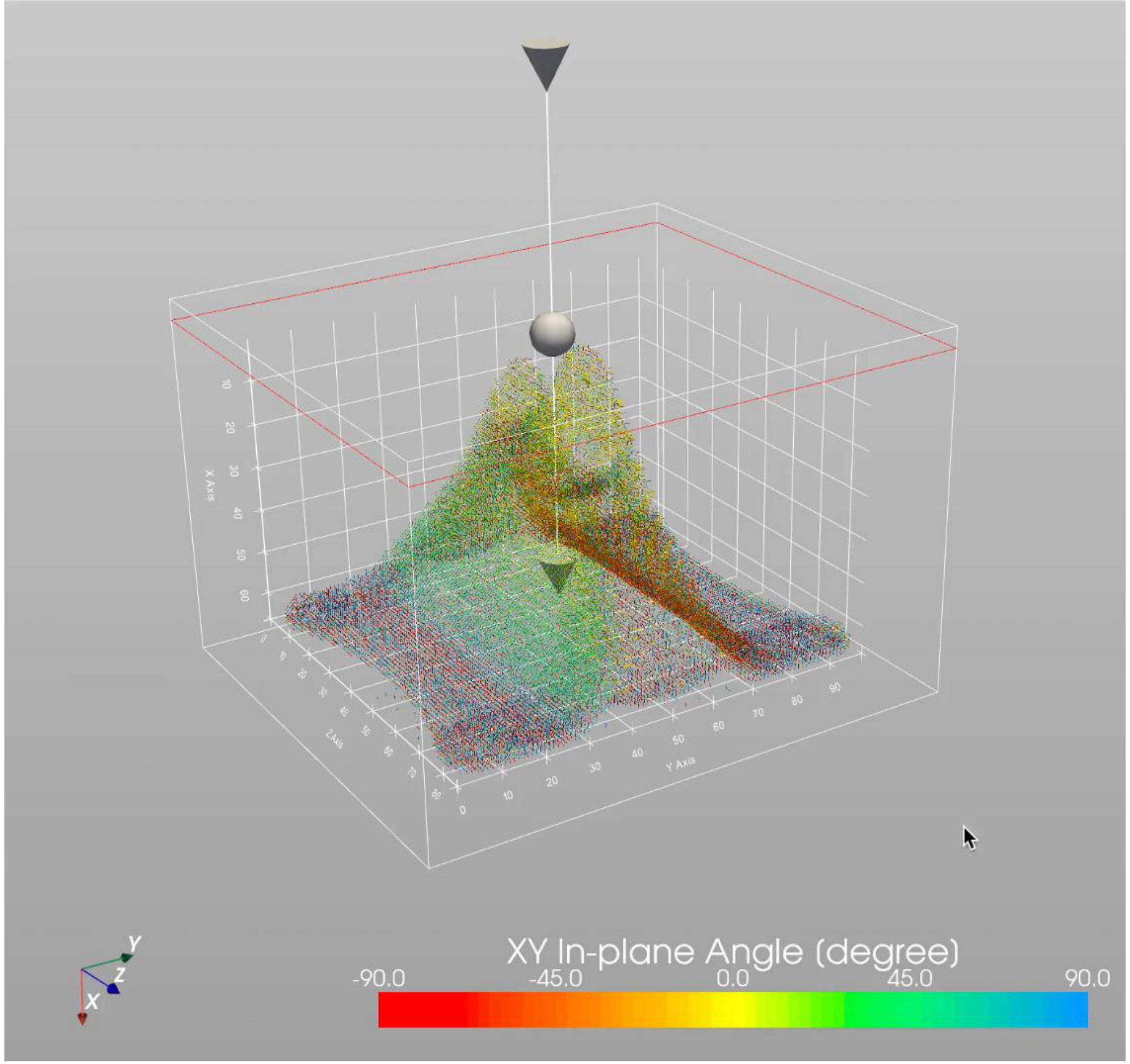


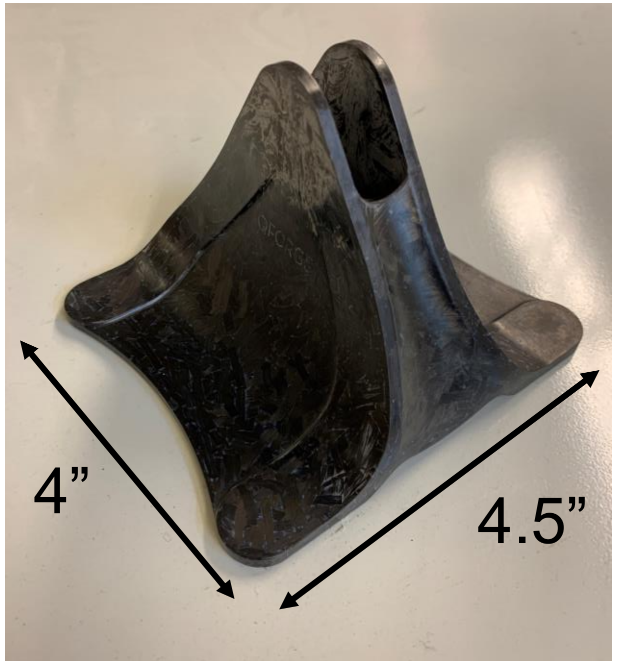




- Testing 2 configurations of the Sekisui QForge Bracket
    1. Square Platelet (14 brackets)
    2. Narrow Platelet (14 brackets)
- DIC at the top load pin where we think failure will occur

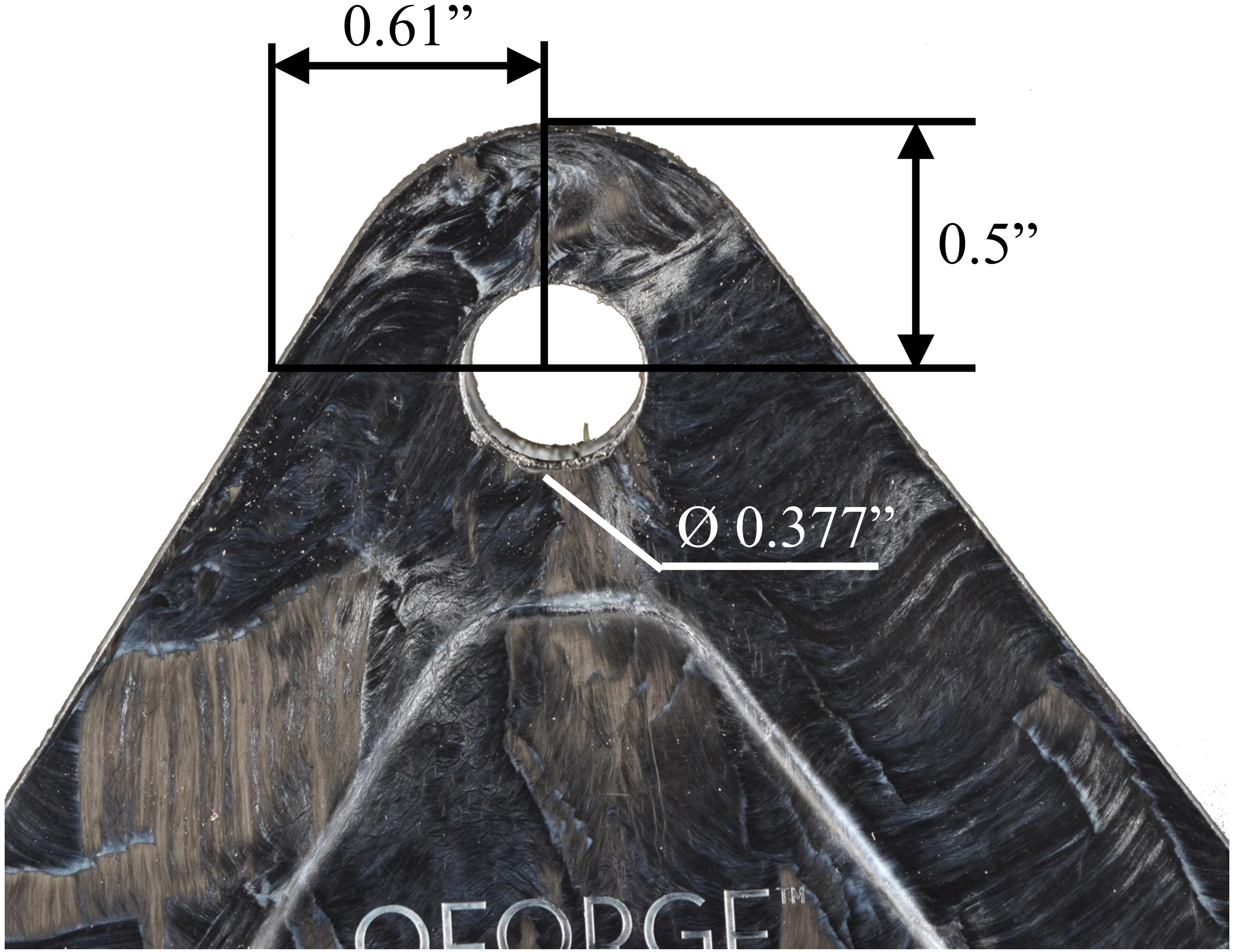
Sekisui Bracket

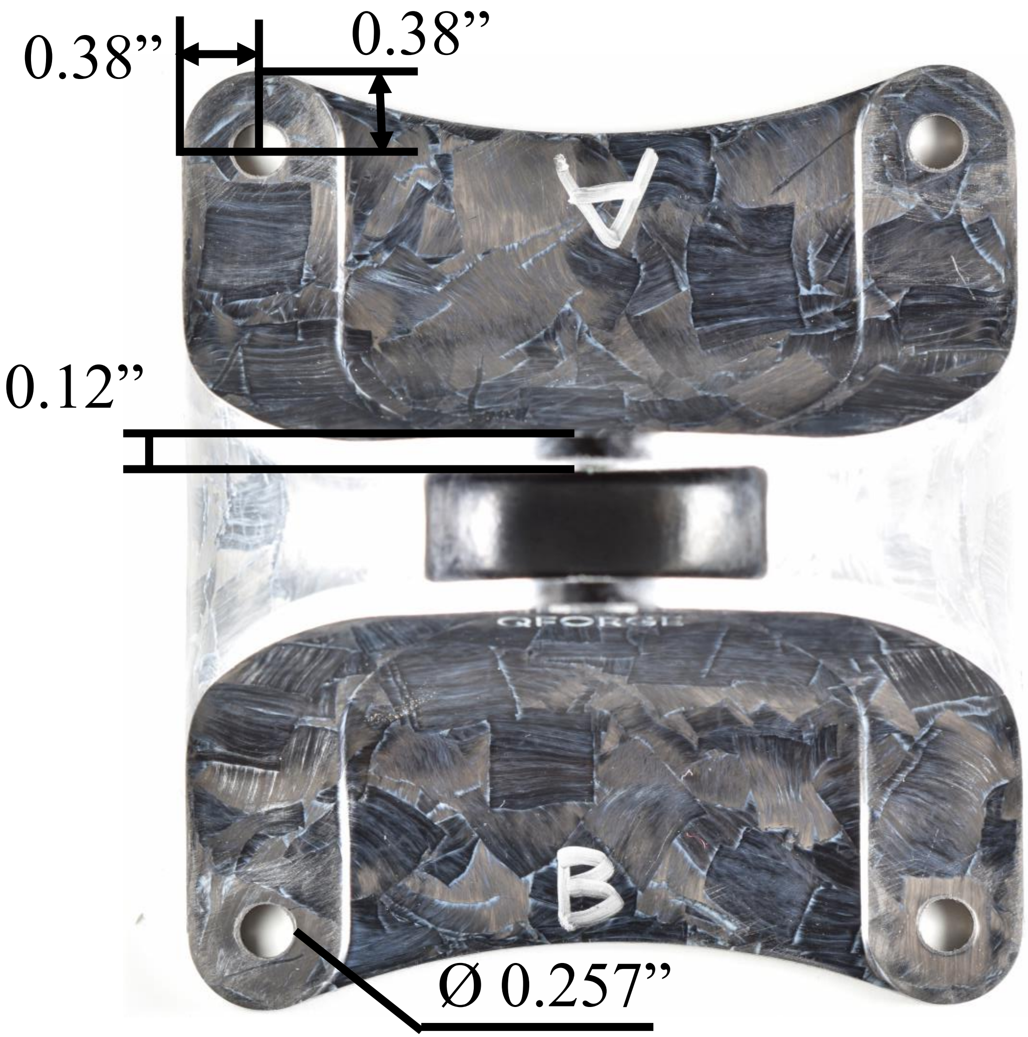




- Fiber angle vector
- Base is aligned going in, along Y-axis (red and blue)
- Top is aligned along the X-axis (Yellow)

Sekisui Bracket Dimensions

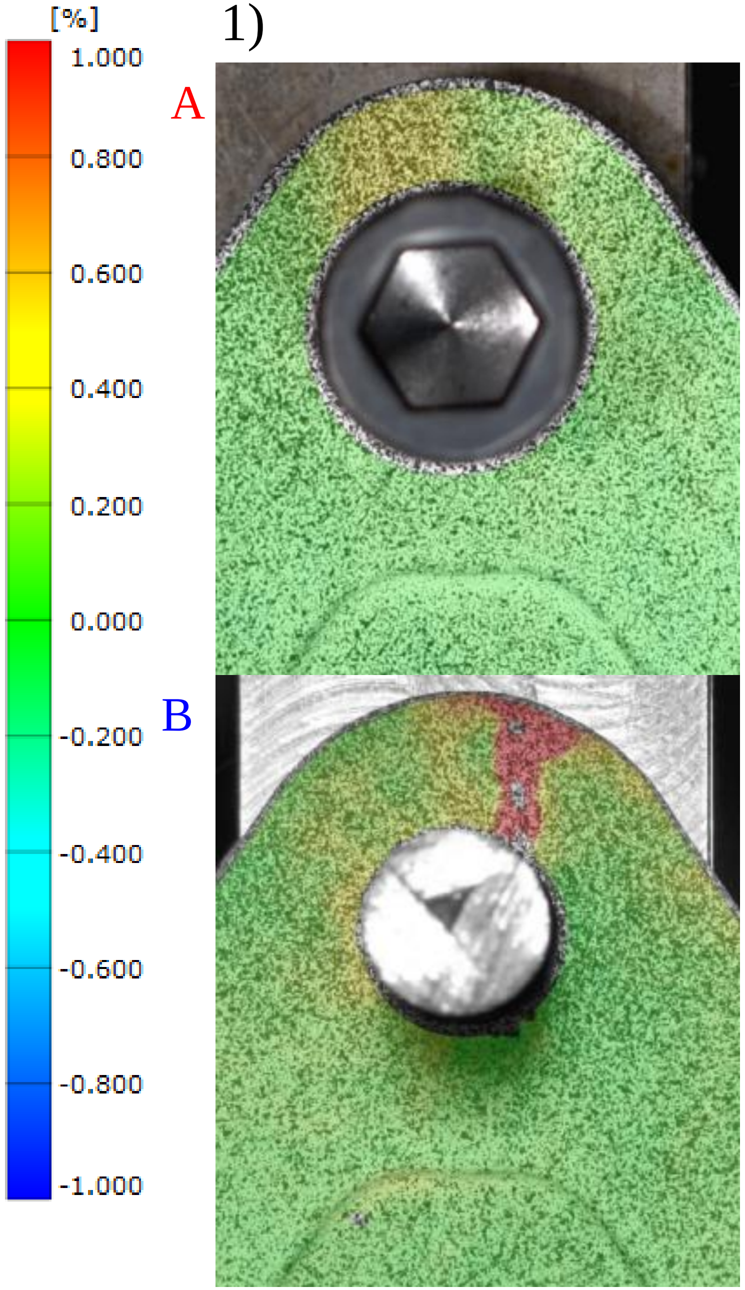


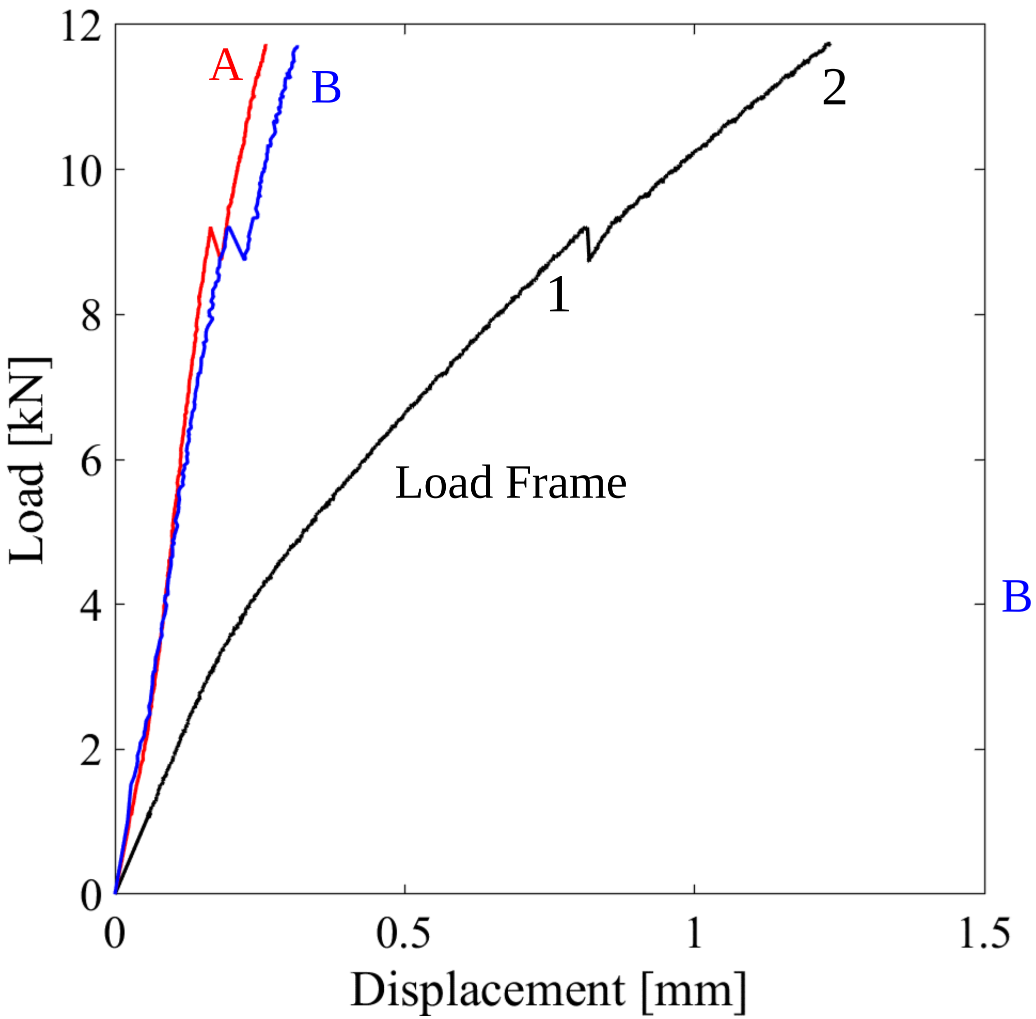


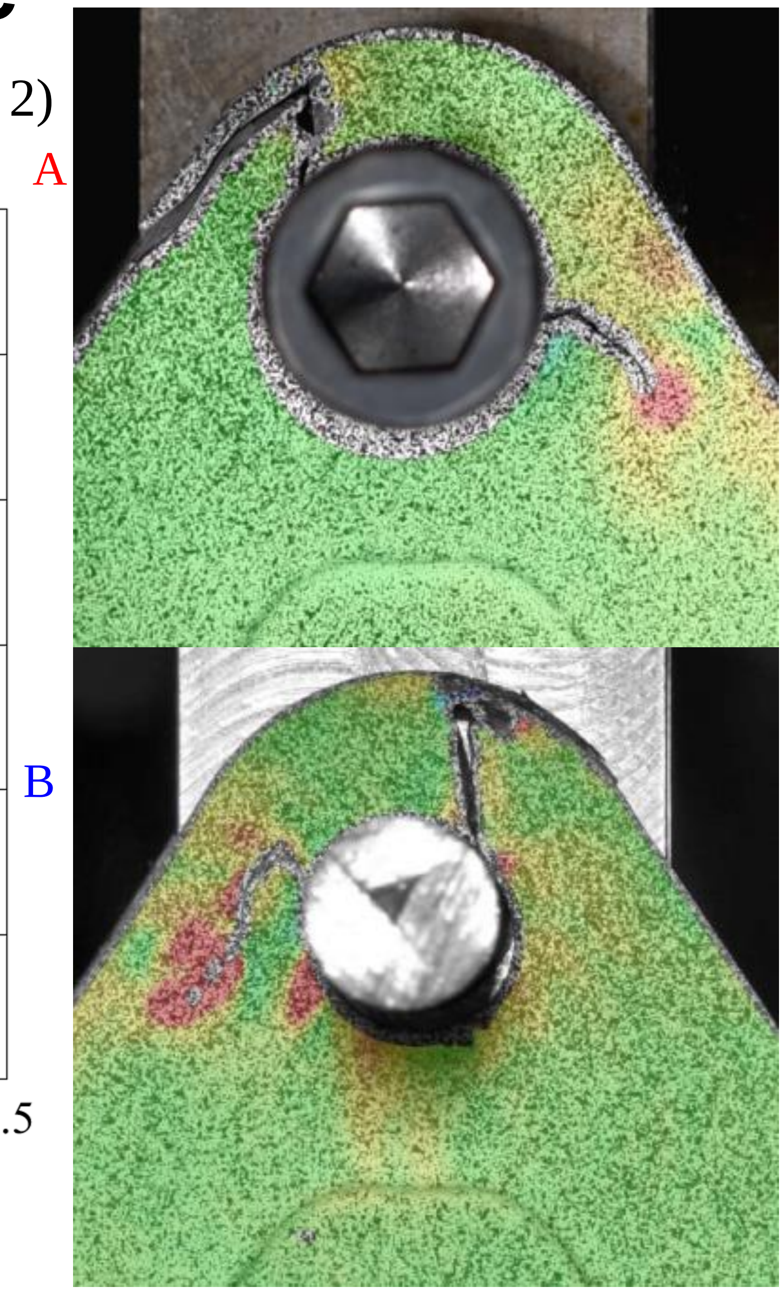
3/8” bolt cut to the nonthreaded part and used as a pin

1/4” bolt are used to fasten base

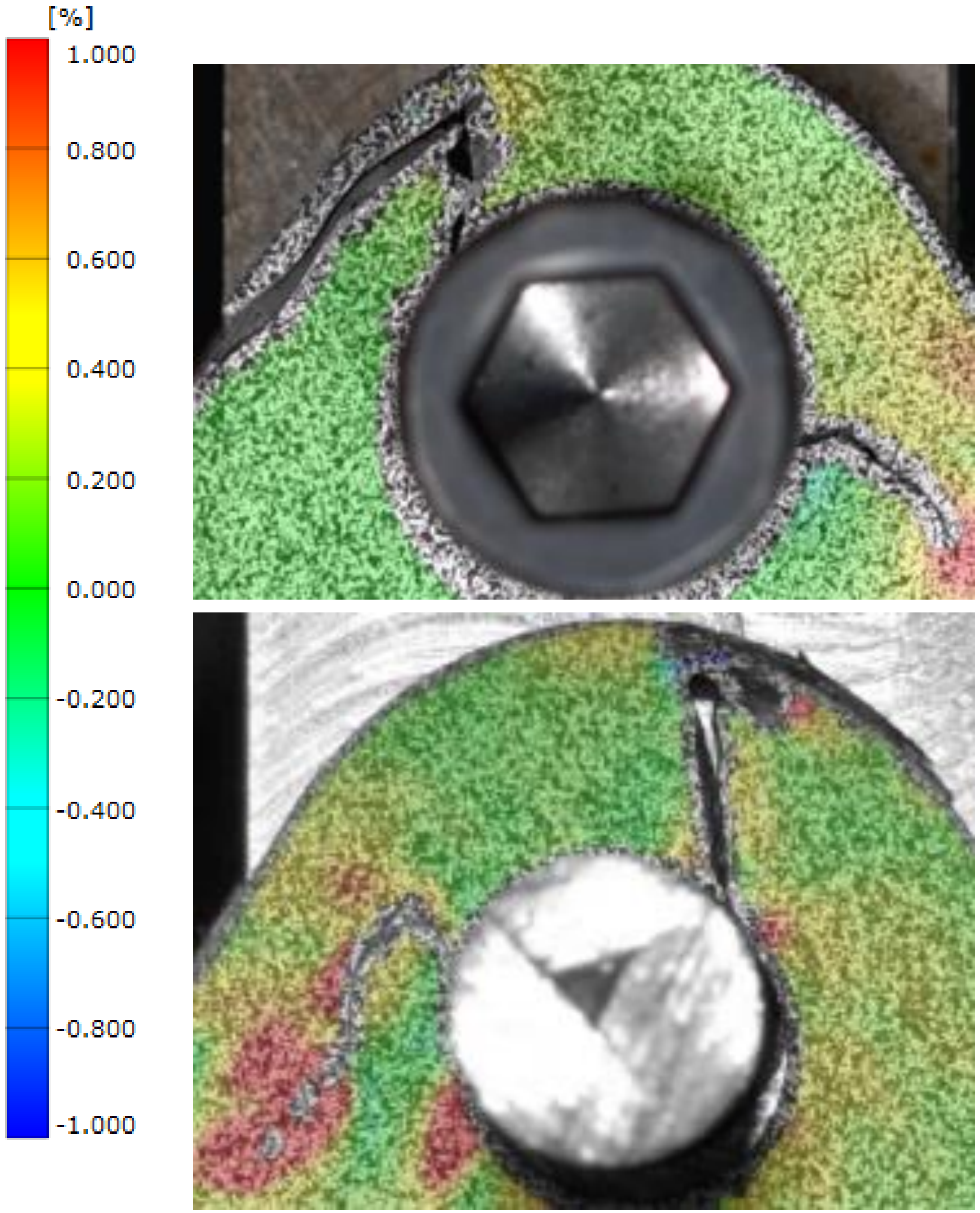
Sekisui Bracket NP Fracture

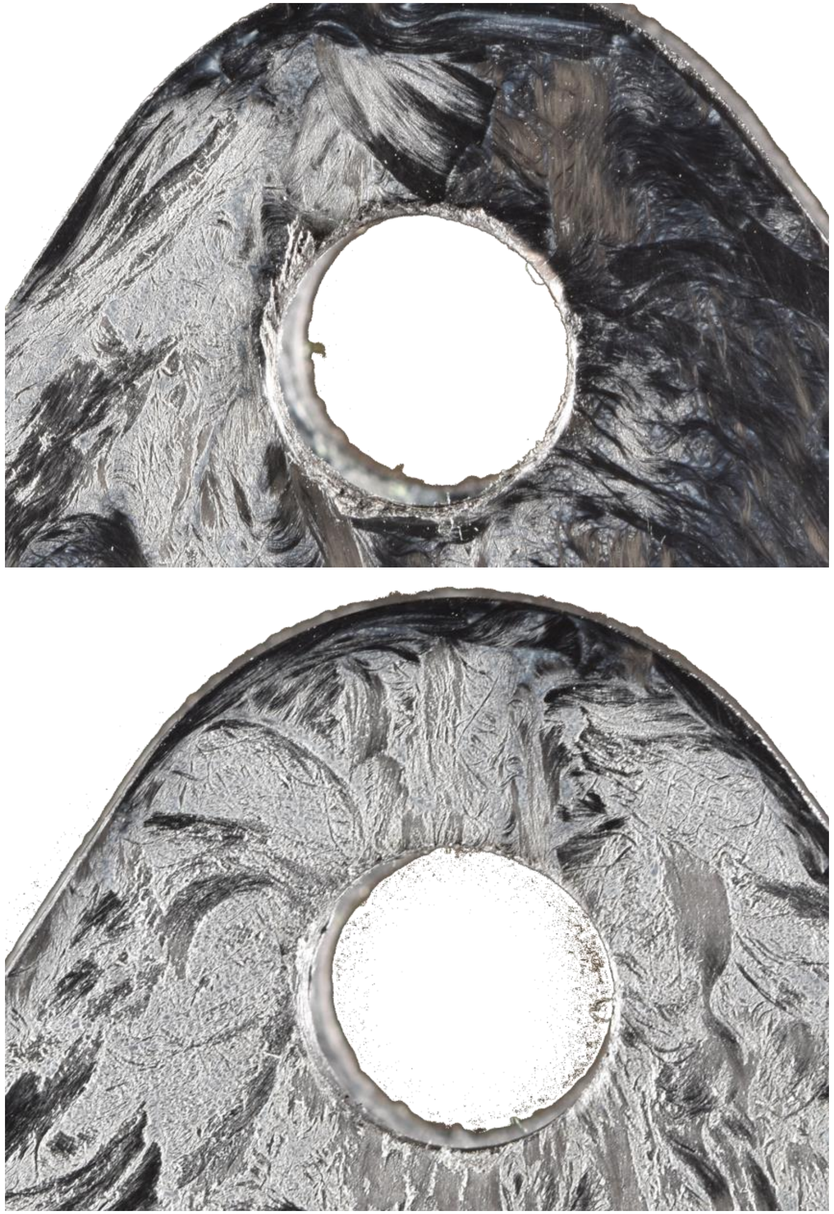




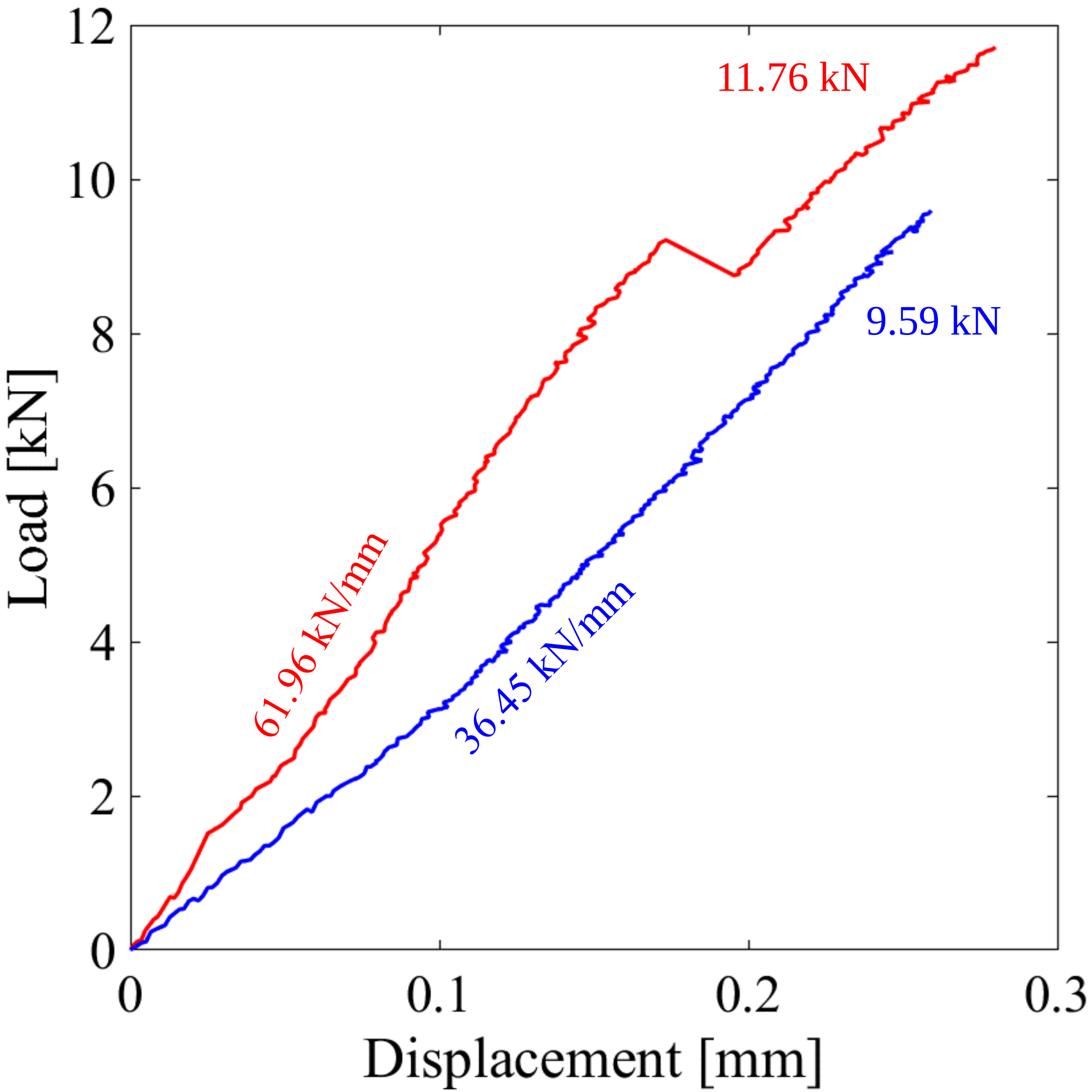


Sekisui Bracket NP Fracture



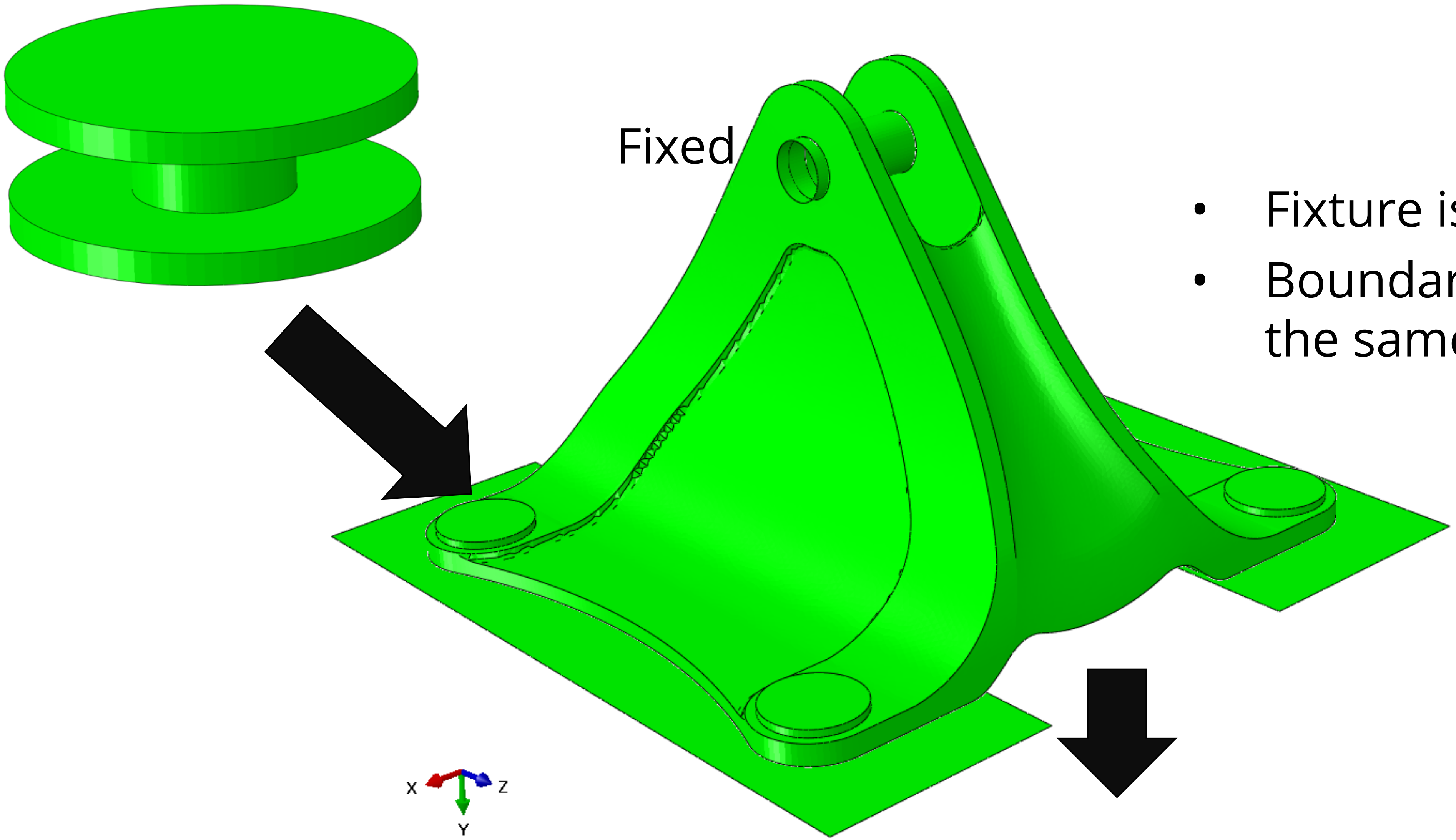


Sekisui Bracket NP vs SP



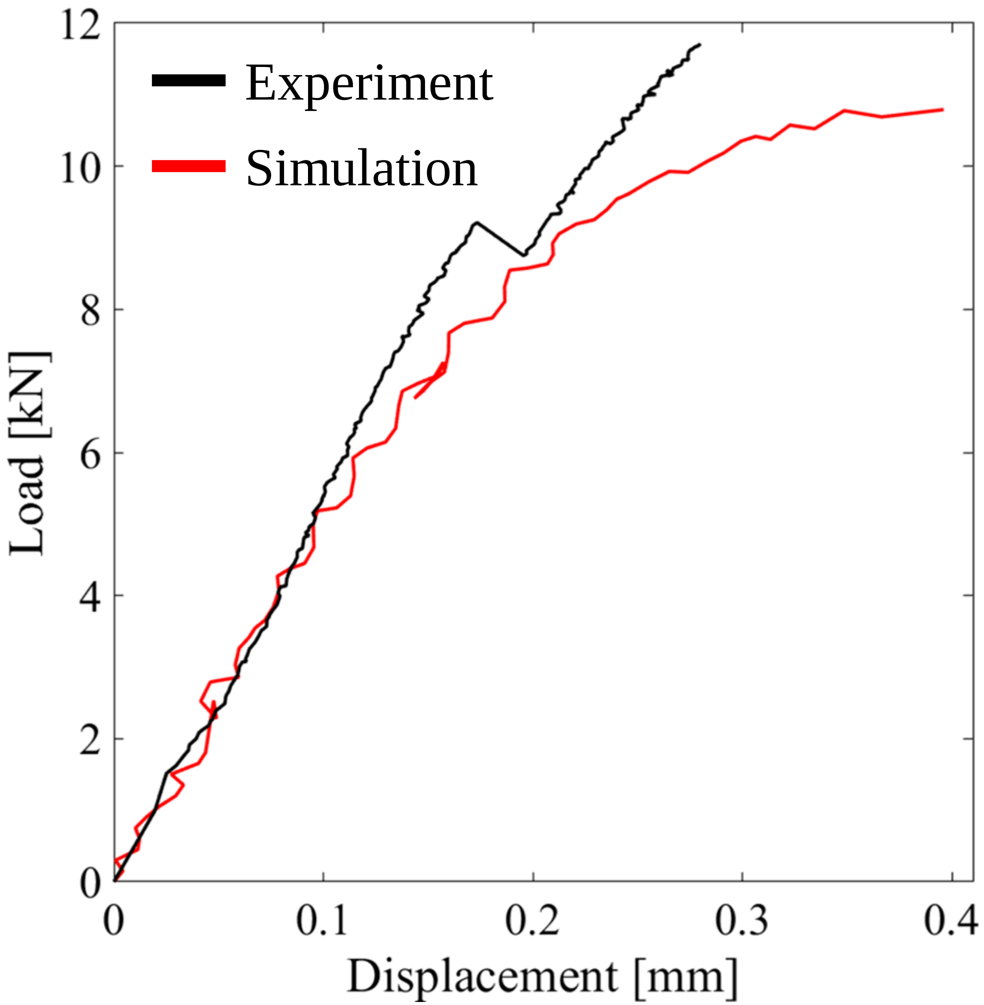
- Displacement from DIC averaged between the two sides
- Narrow platelet bracket is stiffer and stronger
  - Stiffness percent difference: 51.85%
  - Strength percent difference: 20.28%
- This is similar to the UNT specimen
  - 0.15" coupon had an 8% and 27% difference in stiffness and strength respectively
- Some difference could also be due to voids or flow effects

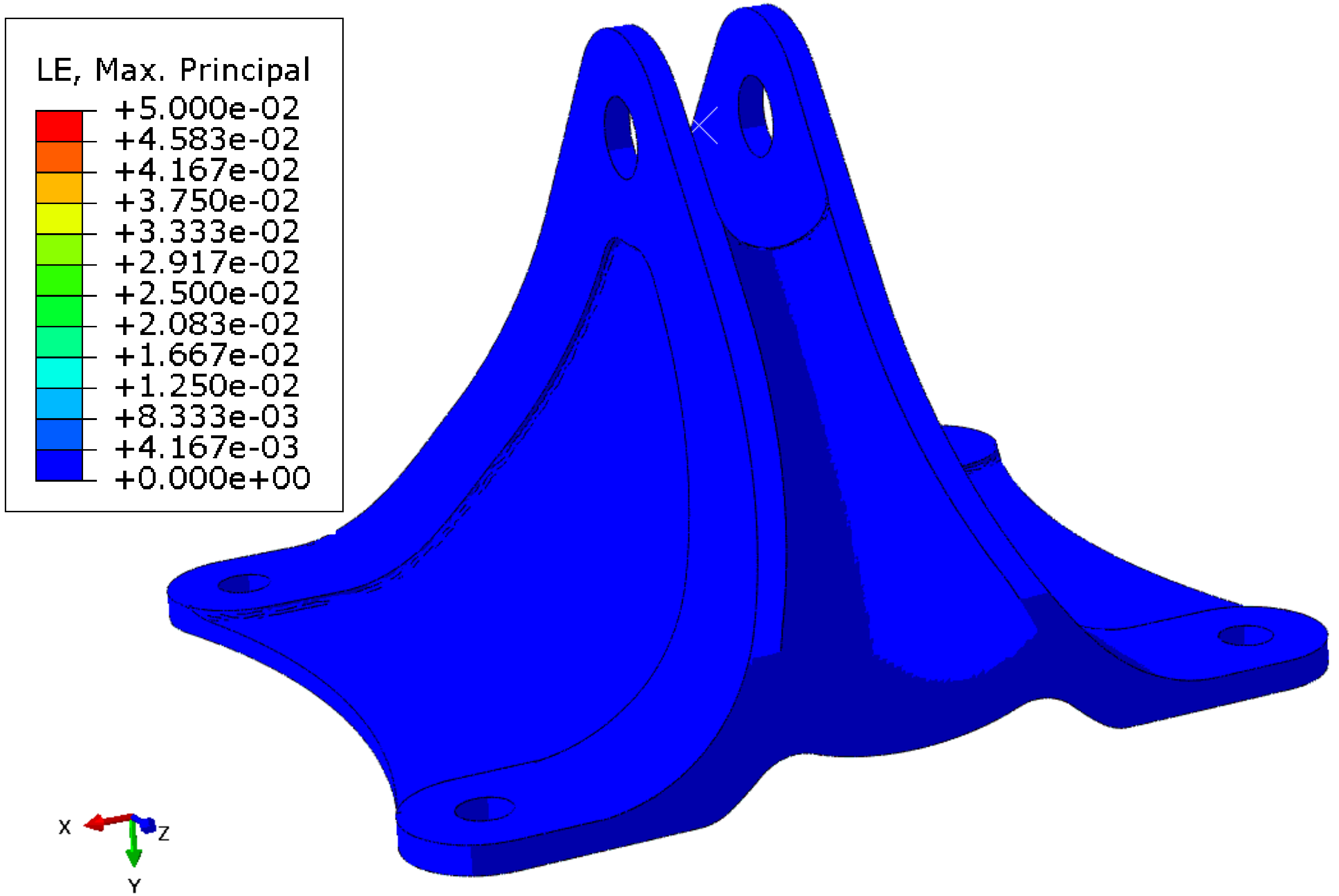
Simulation of Tension test



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

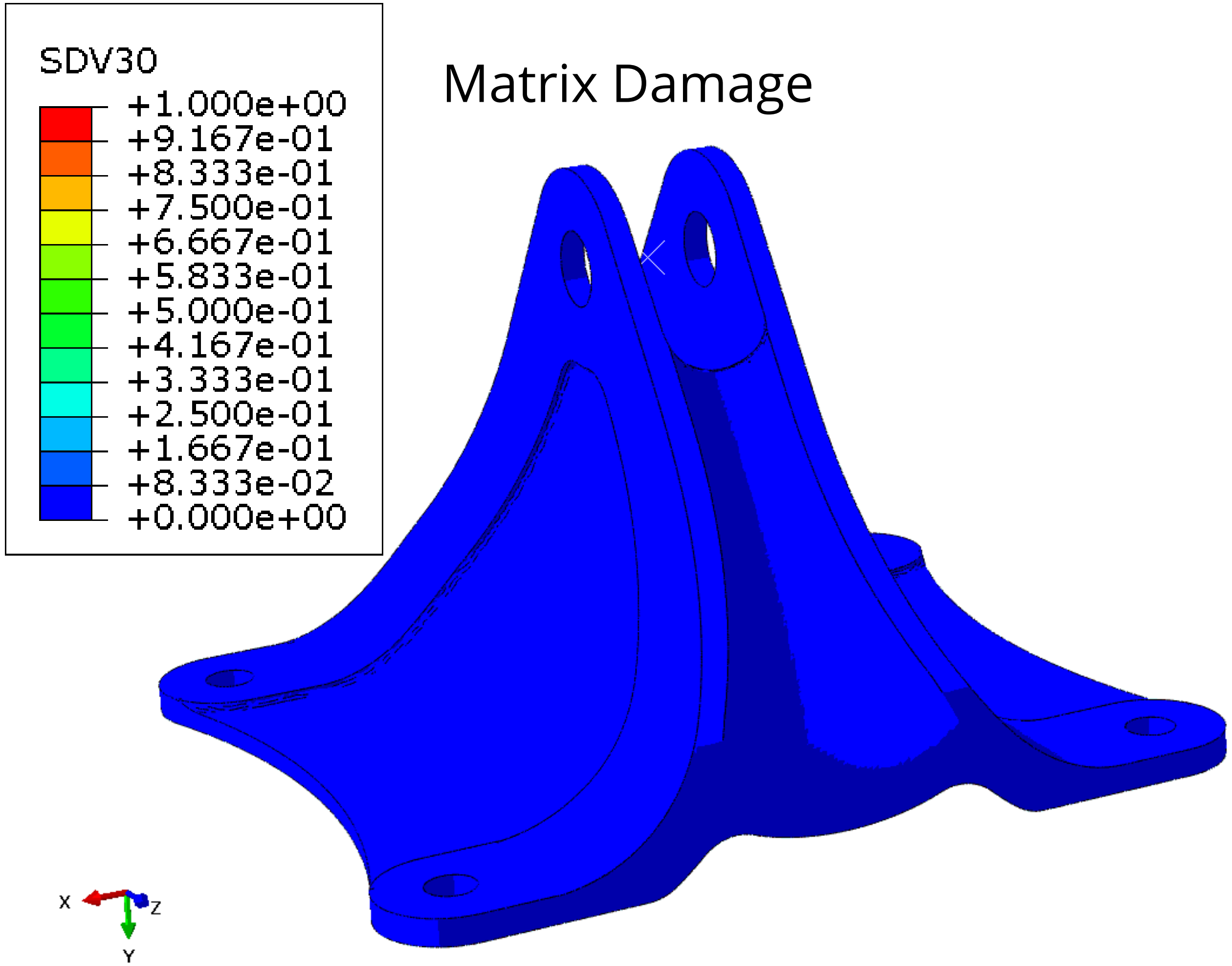
Tension Simulation Results

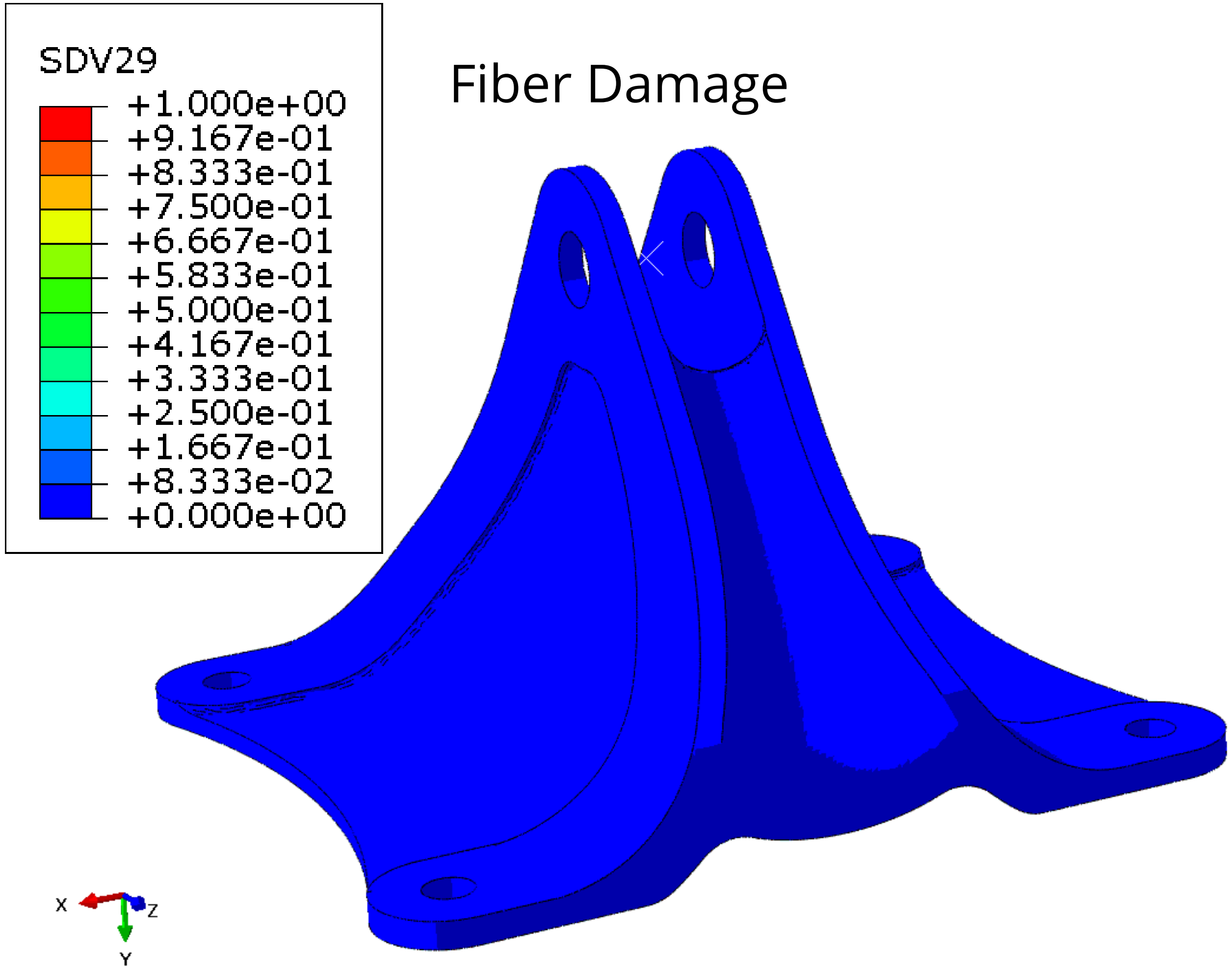




- Stiffness matches and strength under predicted by 8%
- Calibrate material properties

Tension Simulation Results – Damage Variables



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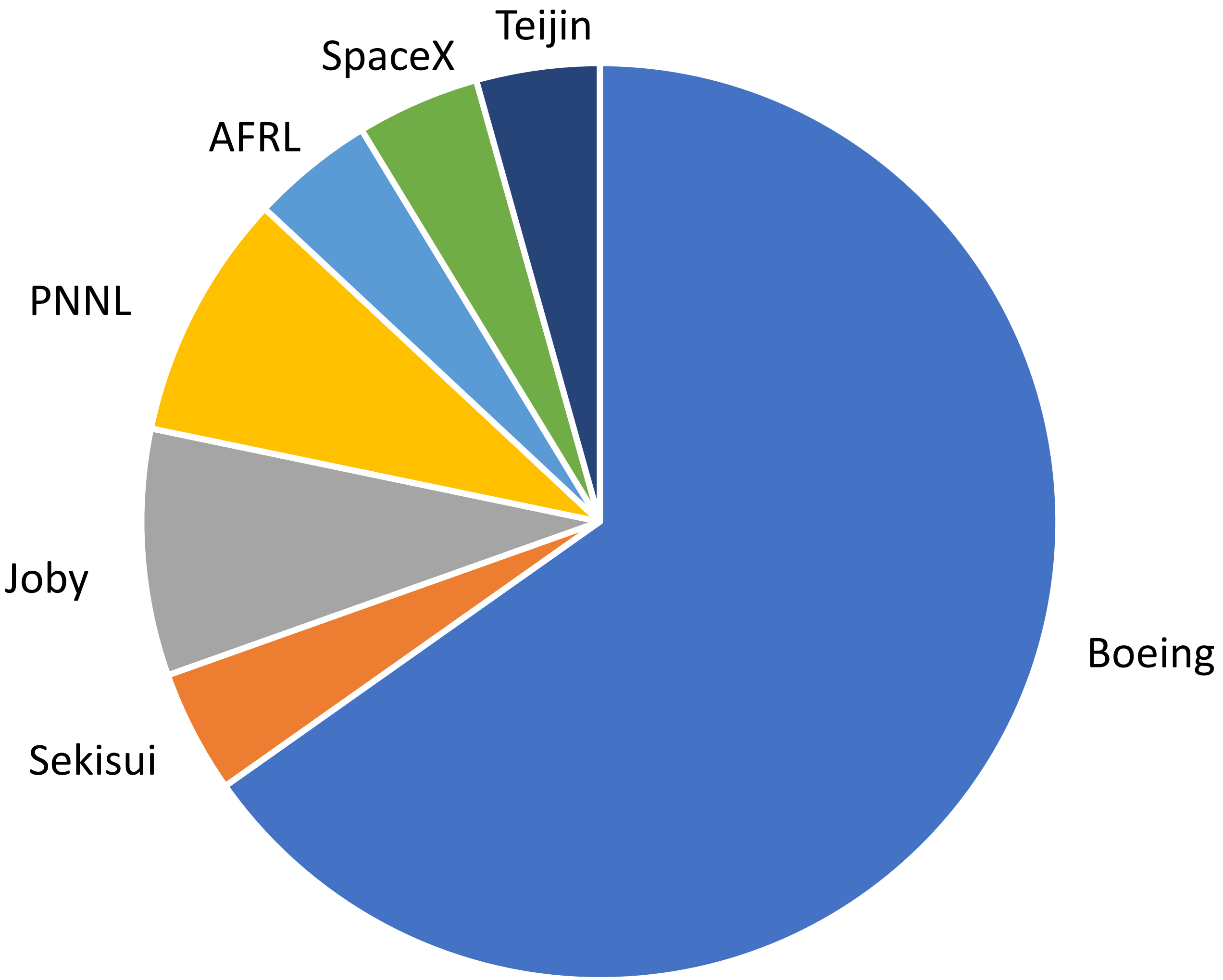
Career Opportunities



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