Effect of Stitch Seam Orientation on the Mode I Fracture Energy of Stitched Composites

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Outline of Discussion

- **Objective and motivation**
- **Experimental methodology**
  - Materials and fabrication
  - Resin infusion
  - Specimen geometry
  - Test setup
- **Results**
  - Load-displacement response
  - Strain energy release rates
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- **Conclusions**
- **Questions**

Objective and Motivation

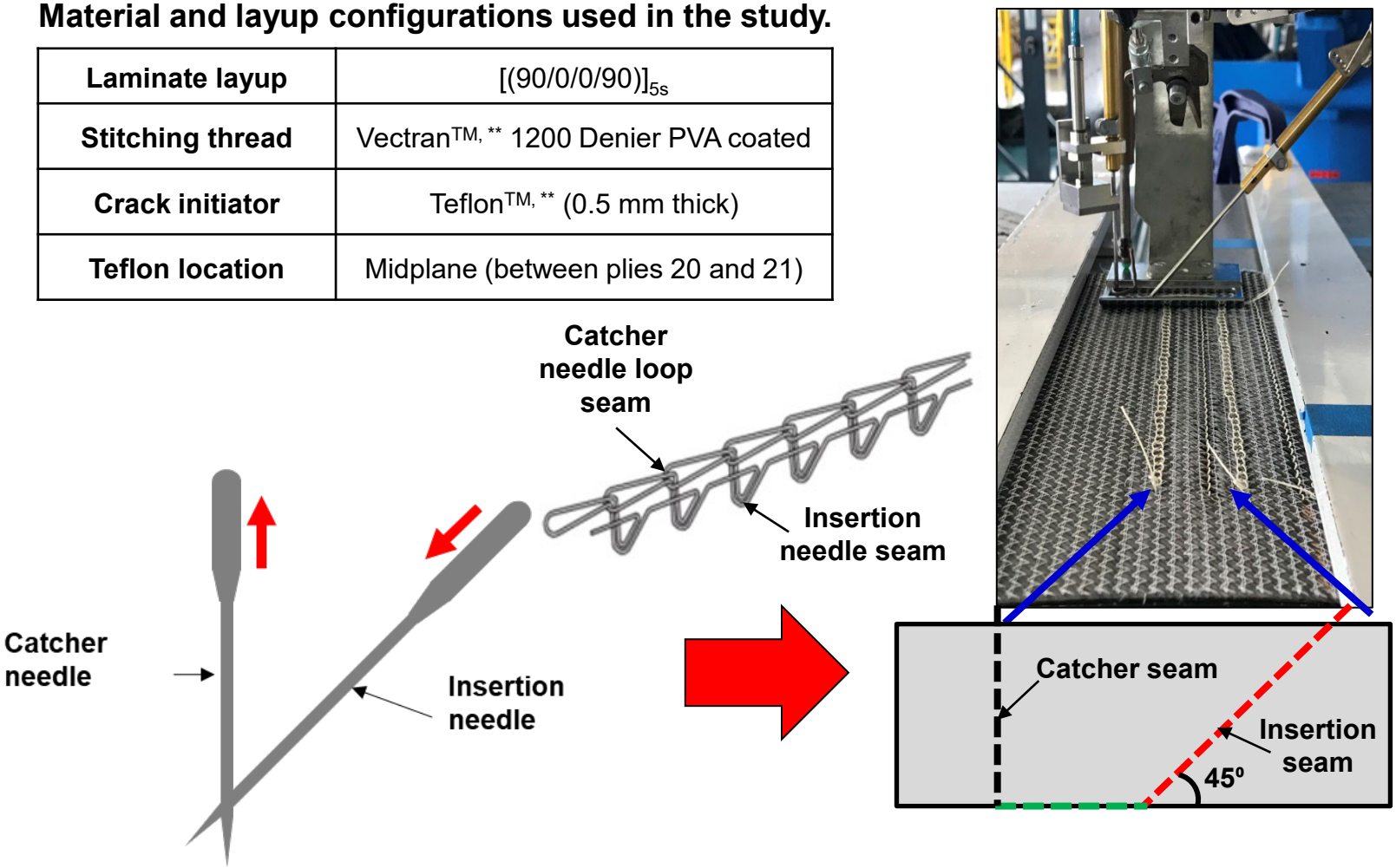
- **Objective**
  - Fabricate stitched double cantilever beam (DCB) specimens
  - Investigate the influence of stitch orientation on the fracture behavior
- **Motivation**
  - Polymer matrix composites (PMCs) have excellent in-plane mechanical properties
  - PMCs have low interlaminar strength, which results in delamination
  - Delamination may be reduced using through-the-thickness reinforcement
  - One-sided stitching approach is useful to simplify stitching process, but exhibits directional dependence

Stitching robot with a modified chain stitching head.

Materials and Fabrication

Material and layup configurations used in the study.

Laminate layup	$[(90/0/0/90)]_{5s}$
Stitching thread	Vectran™, ** 1200 Denier PVA coated
Crack initiator	Teflon™, ** (0.5 mm thick)
Teflon location	Midplane (between plies 20 and 21)



One-sided stitching geometry (left) and one-sided stitching on a dry preform using a stitching robot (right).

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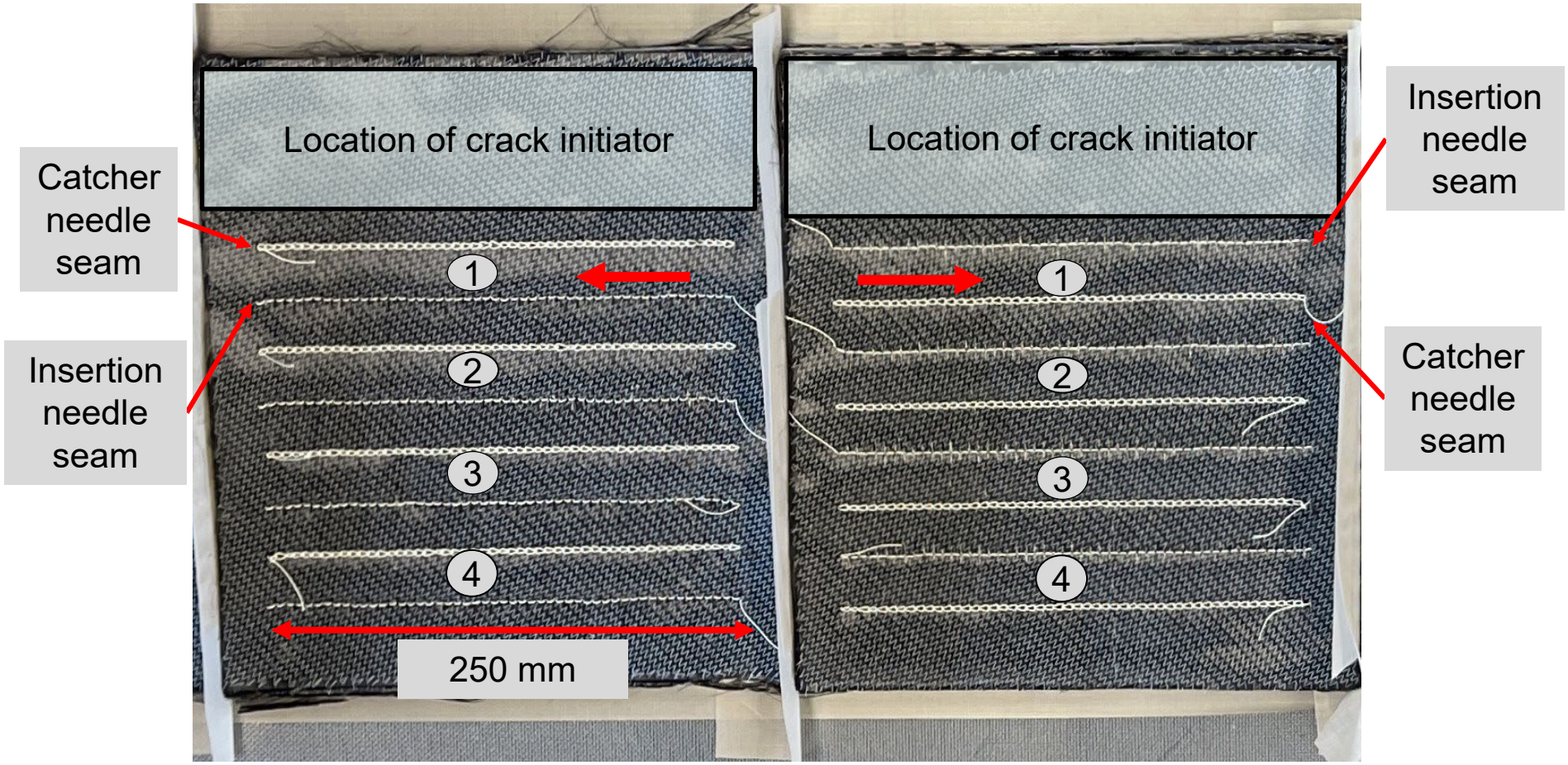
Stitched Panel

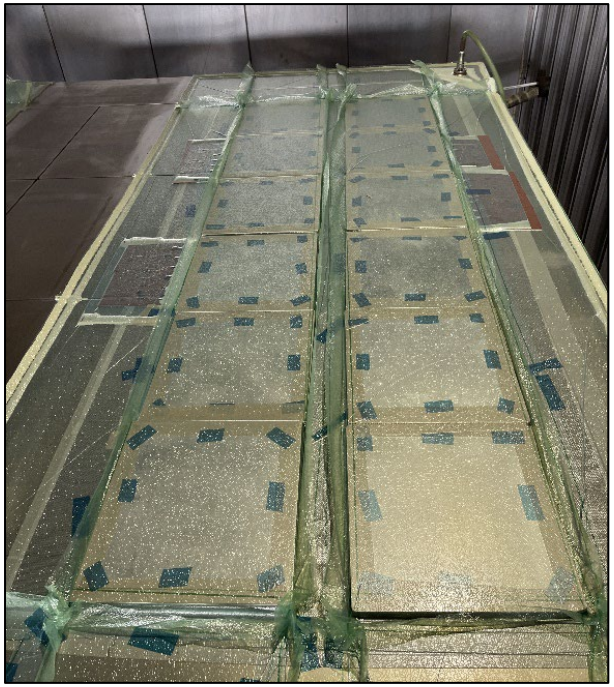


(a) (b)

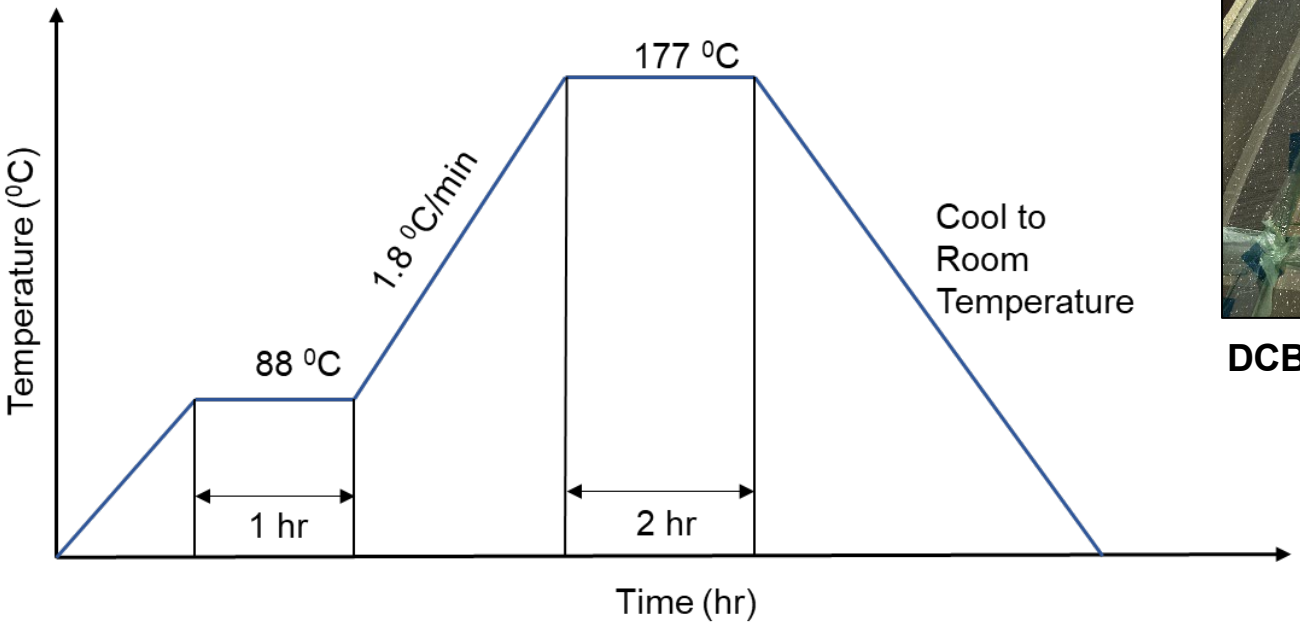
Modified chain stitching with (a) catcher seam closest to the crack initiator and (b) insertion seam nearest to the crack initiator.

Resin Infusion

- Hexcel Hiflow™,** 1078 resin
- Vacuum assisted resin transfer molding (VARTM)



DCB panels under vacuum bagging.



Cure temperature cycle used for the stitched preforms.

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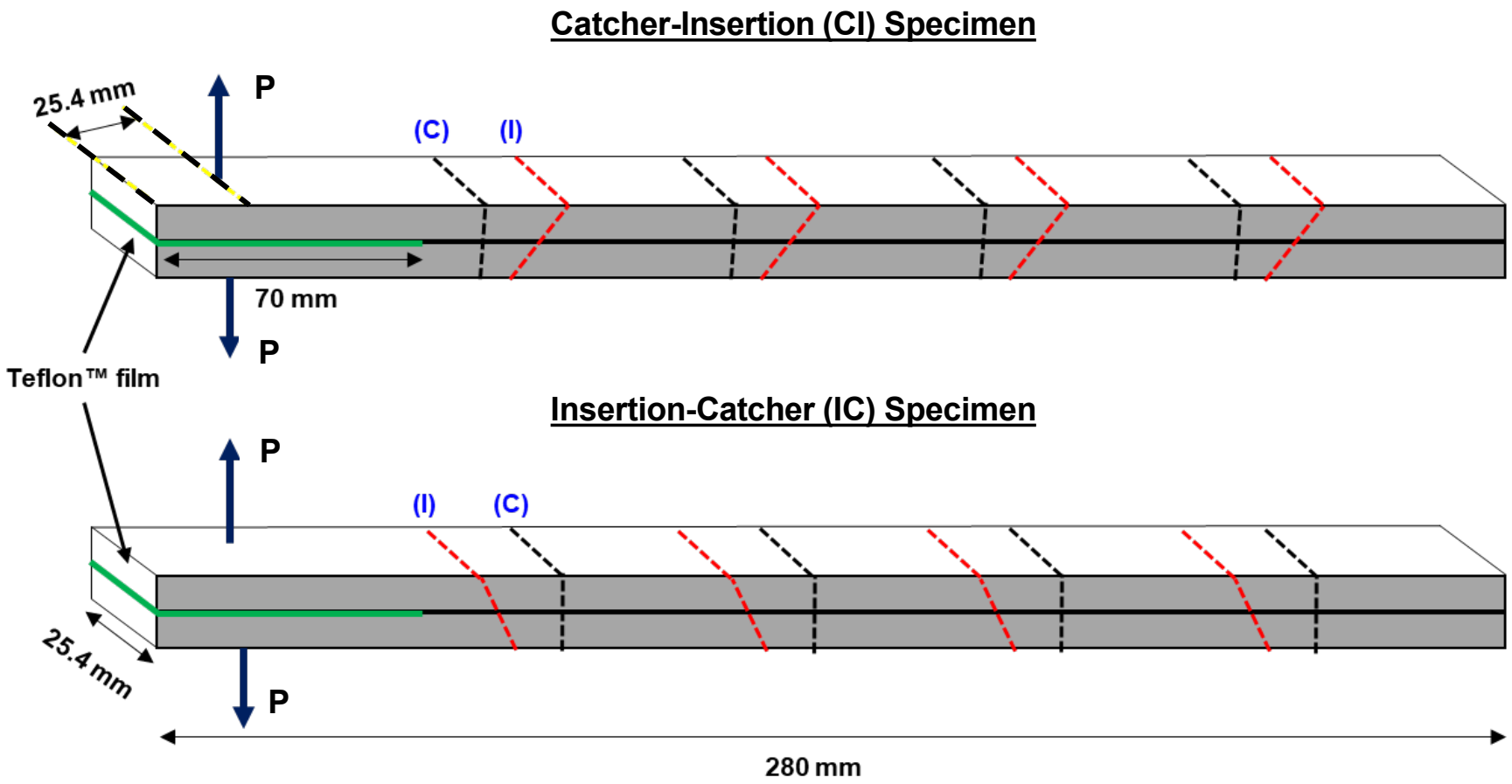
Specimen Geometry



(C) Catcher seam (90°) ----

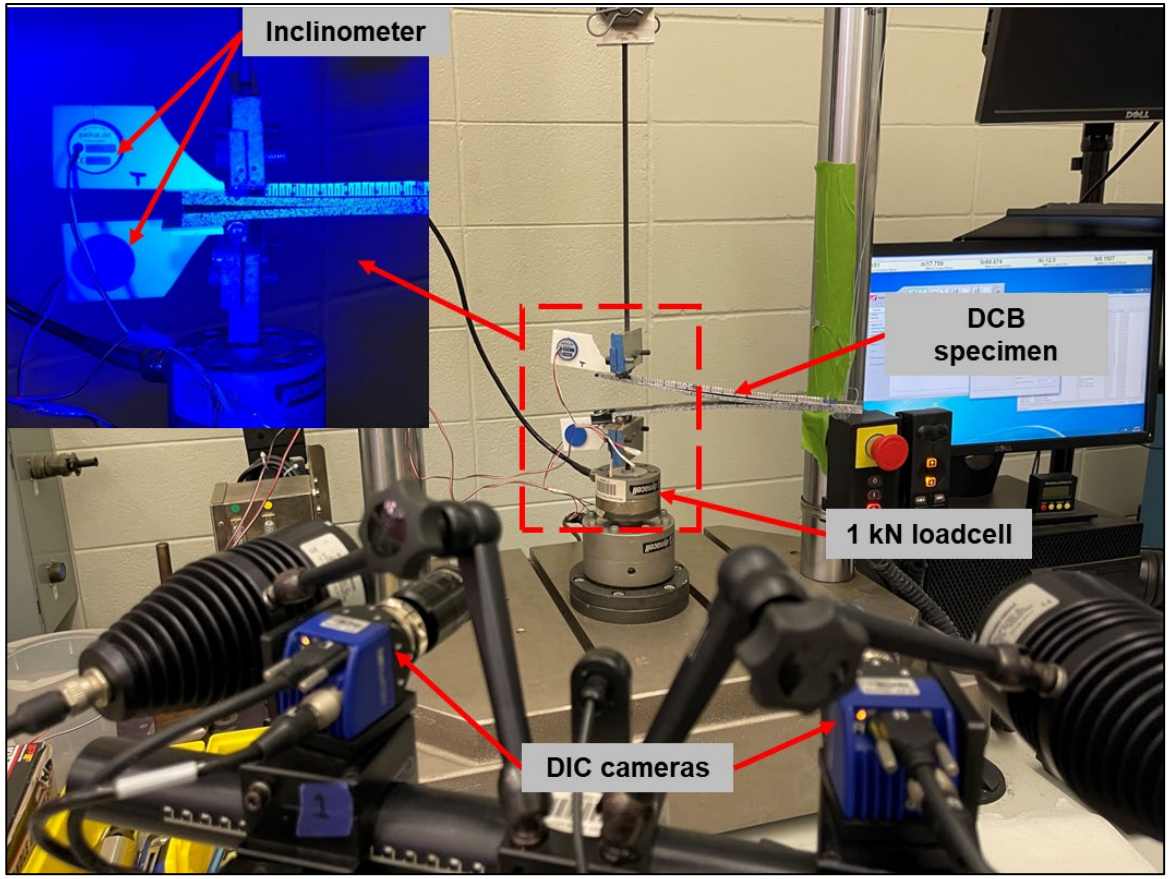
(I) Insertion seam (45°)----

P= Applied load

DCB specimen with different stitch seam orientations.

Test Setup

- **DCB test**
  - ASTM D5528-13
  - Displacement control [1 mm/min]
  - 1 kN load cell
- **Angle measurements**
  - Two inclinometers
  - Additively manufactured mounts
- **Surface crack growth monitoring**
  - ARAMIS 3D DIC cameras
  - 3 Hz data acquisition frequency



DCB test setup.

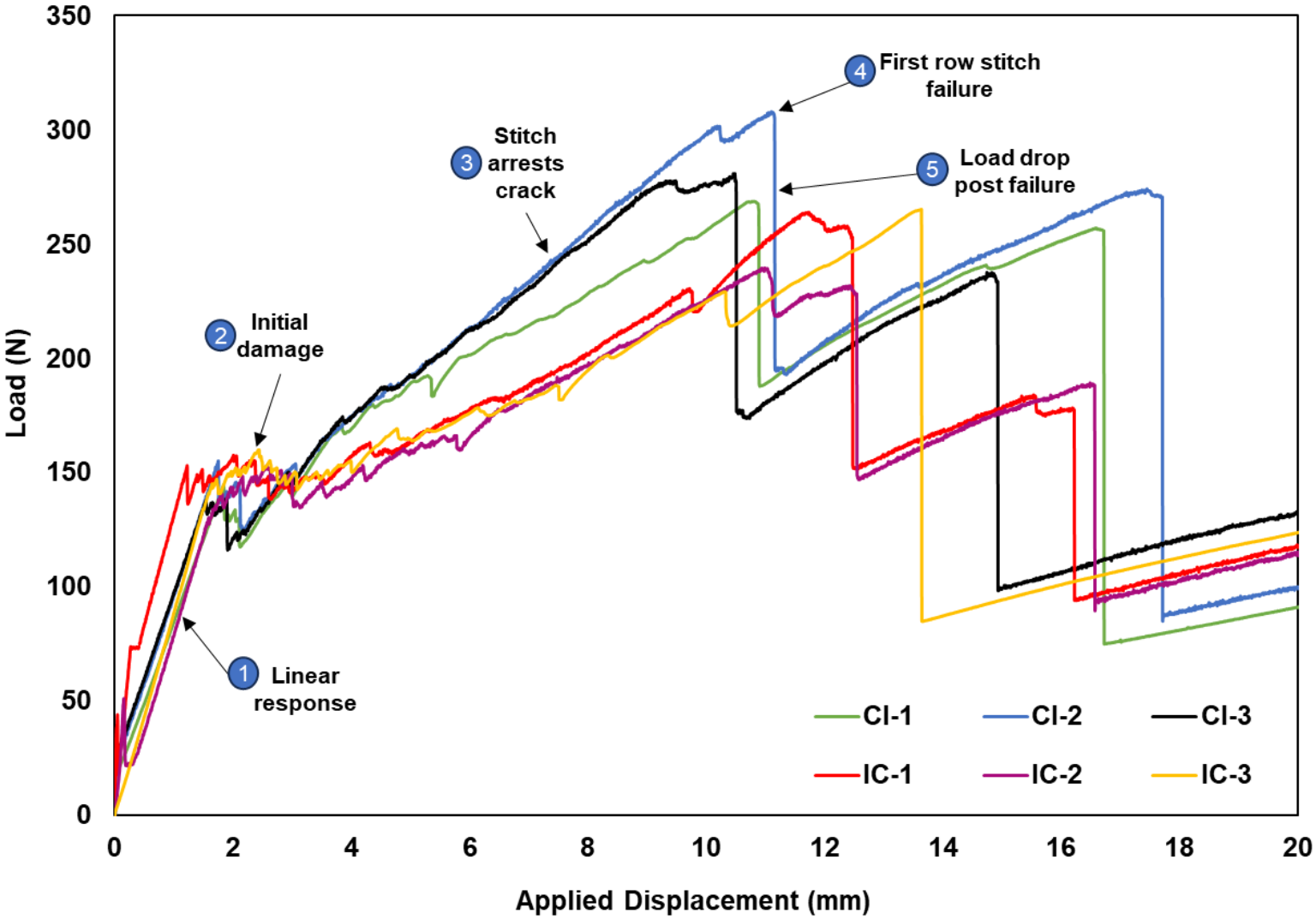
Strain Energy Release Rate (SERR)

- **SERR estimation**
  - J-integral approach
  - Based on a slender double cantilever beam specimen with a uniform rectangular specimen

$$J = \frac{2P\theta}{b} \qquad (1)$$

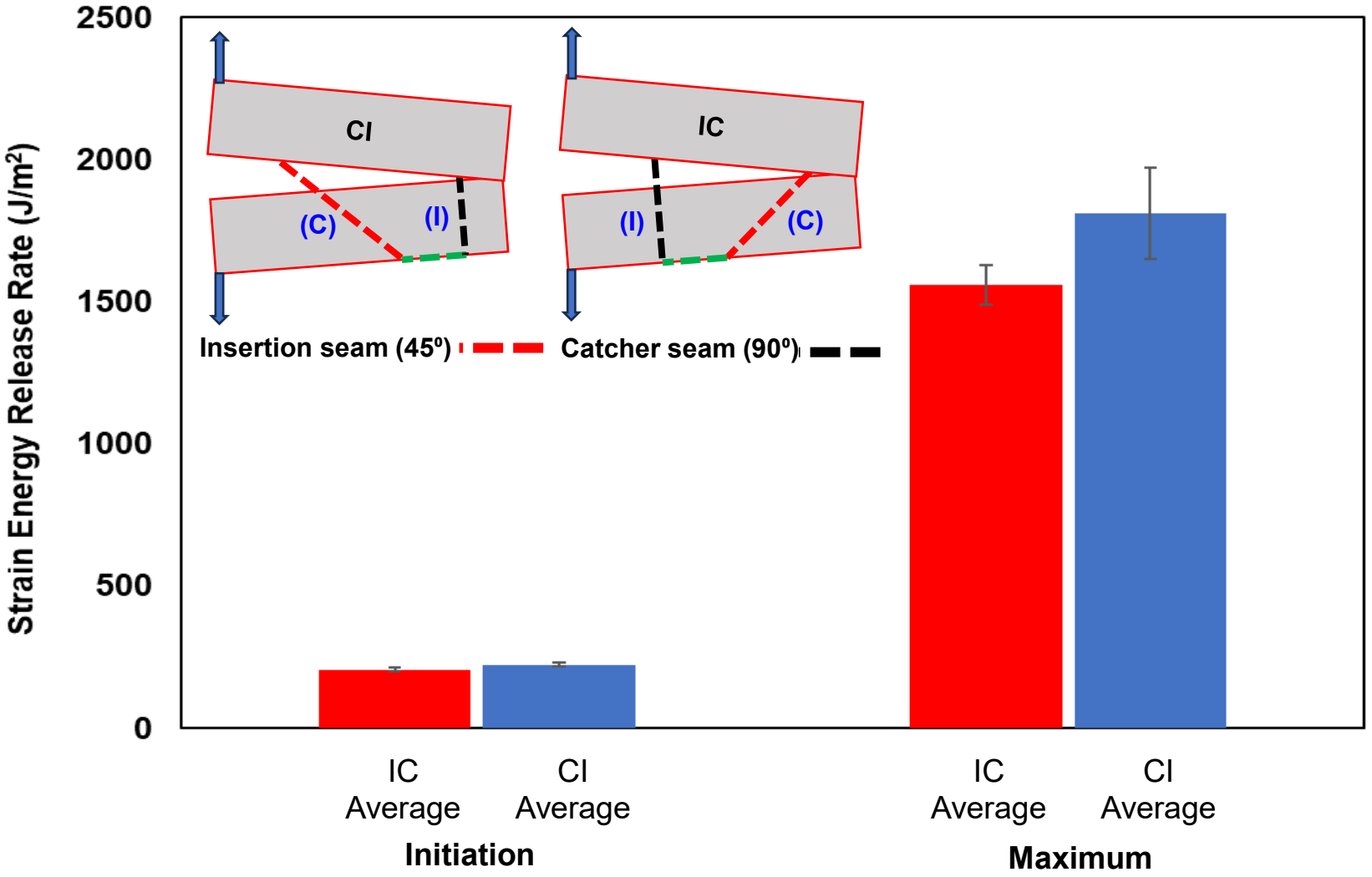
where
P = applied load
b = width of the specimen
θ = measured angle at the load-application point

Load-displacement Response



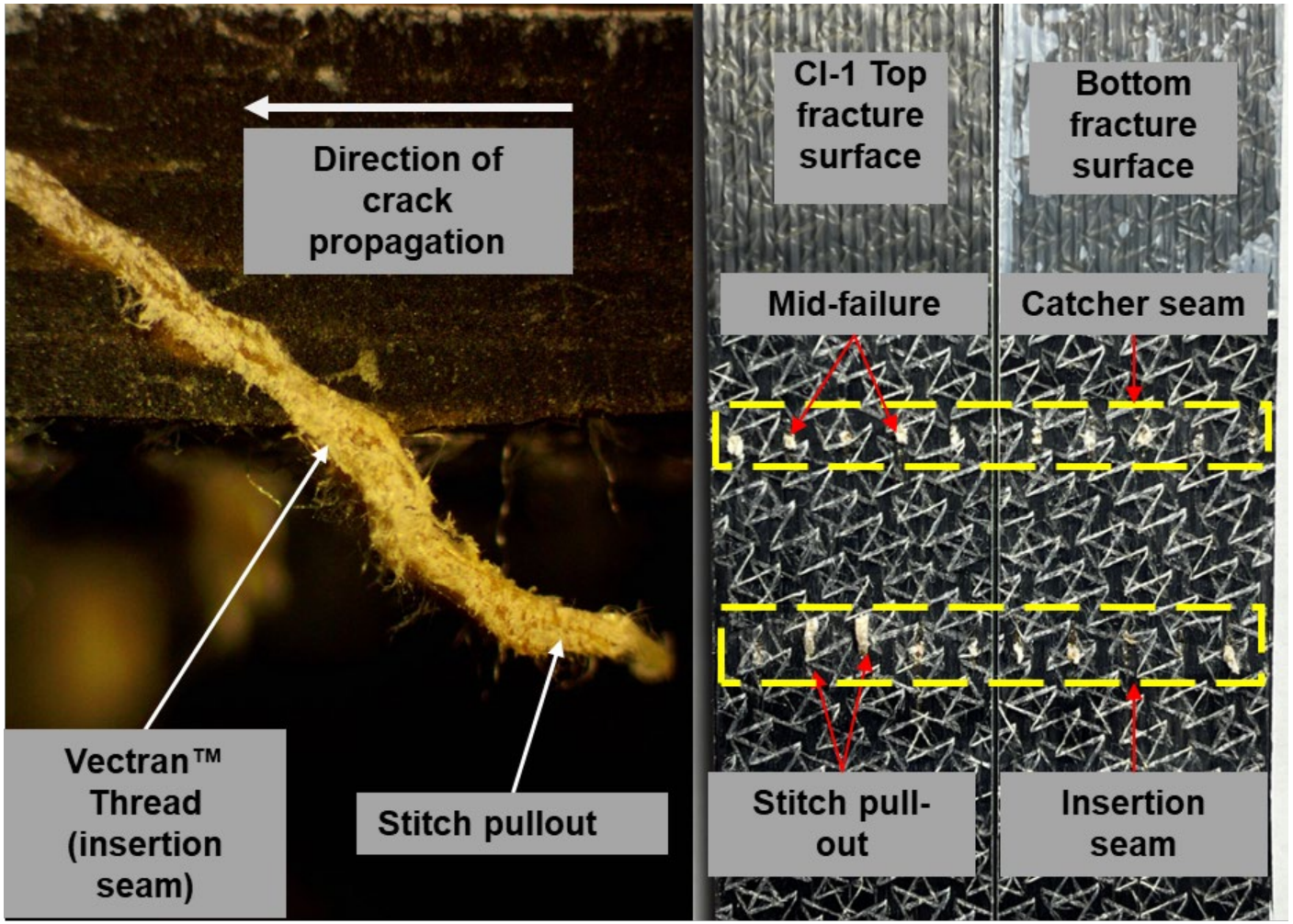
Load-displacement response of the DCB specimens.

SERR



SERR of the DCB specimens at initiation and first stitch failure.

Stitch Failure



(a) (b)

Stitch failure (a) due to pull-out in specimen CI-1 and (b) different stitch failure types in top and bottom fracture surface of specimen CI-1.

Conclusions

- J-integral method was used to estimate SERR of DCB specimens
- A 154% increase in SERR was observed in stitched specimens, as compared to initiation (unstitched region)
- CI specimens have a 15% increase in SERR compared to IC specimens
- The increase in SERR observed in CI specimens is because the 90º stitches began to bridge the crack front first
- The stitches failed at the midplane for the IC specimens
- The CI specimens had multiple types of failure, such as stitch pull-out and stitch thread failure at the midplane

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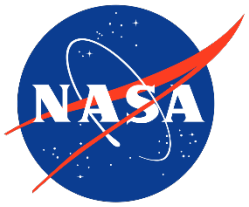
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