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Interlaminar Crack Propagation in 3D-Printed Plastics Using High Speed DIC

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Announcements

ASME International Mechanical Engineering Congress & Exposition
November 8-14, 2019
Salt Lake City, UT

USU is ~1.5 hours North of SLC

Presentation-Only Abstracts due July 22
(Track 11: Mechanics of Solids, Structures, and Fluids)

Over 40 topic areas, including:
11-13: Quantitative Visualization of Fracture and Failure
11-15: Mechanical Characterization in Extreme Environments
11-18: In-Situ Techniques in Experimental Mechanics
...plus many others!

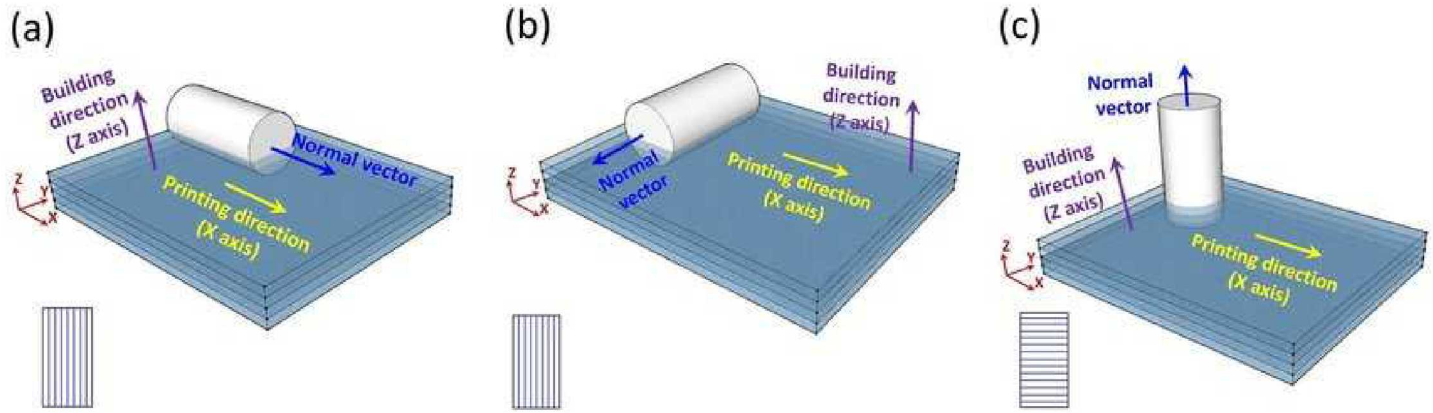
3D Printing

- 3D Printing is currently used to produce structural parts
- Need for characterization of properties for 3D printed materials [1]
- Little research on how 3D printed material fails under high loading rate

[2]

Print Orientation

- Print orientation affects part strength
- Unknown how laminar structure effects failure energy of 3D printed parts [3]



[4]

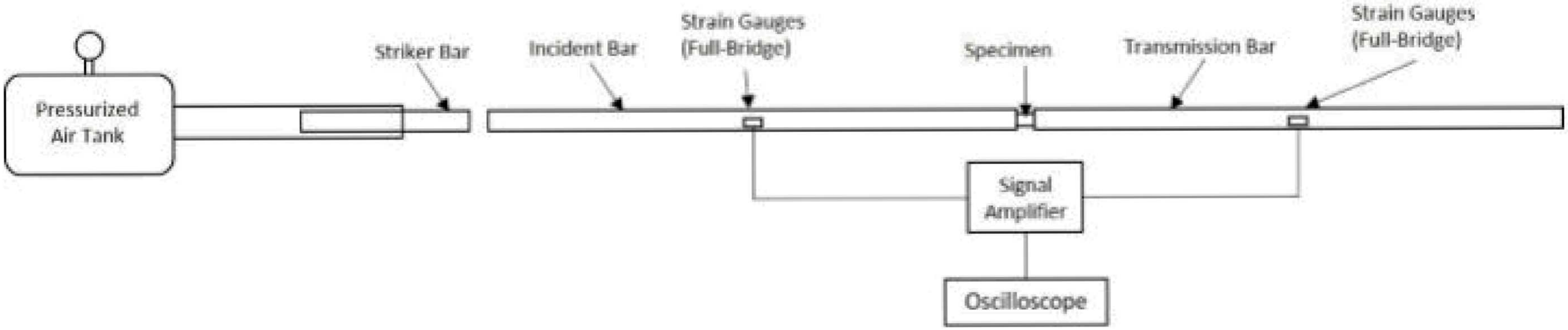
[1] 2fprototypes., www.2fprototypes.net/prototype/customized-on-demand-cnc-machining-service.html

[2]D. L. Bourell and J. J. Beaman, "A Brief History of Additive Manufacturing and the 2009 Roadmap for Additive Manufacturing: Looking Back and Looking Ahead," p. 7, 2009.

[3] K. M. Ashtankar, et al. "RAPID PROTOTYPING STYRENE (ABS) PARTS. Unknown how laminar structure effects failure energy of 3D printed parts

[4] Li Wantg, 2017, "The mechanical and photoelastic properties of 3D printable stress-visualized materials", Scientific Reports.

Background: Kolsky Bar

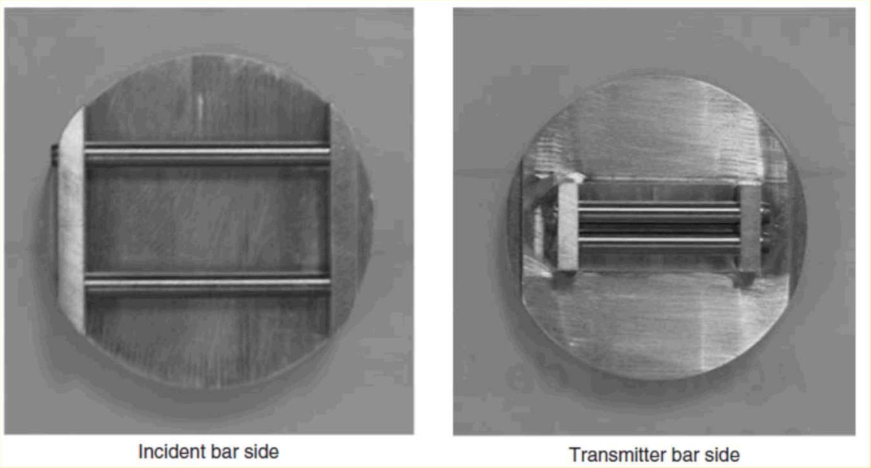


<u>Method for Kolsky Bar</u>

- Stress wave travels hits the specimen
- Wave travels through the transmission bar
- Reflected wave travels back through the incident bar
- Strain gauges detect stress waves
- Data used to calculate loading rate, and failure energy

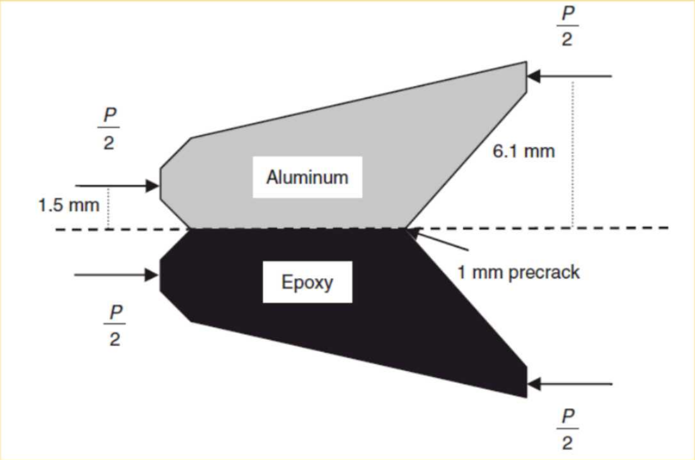
Background: Butterfly Specimen

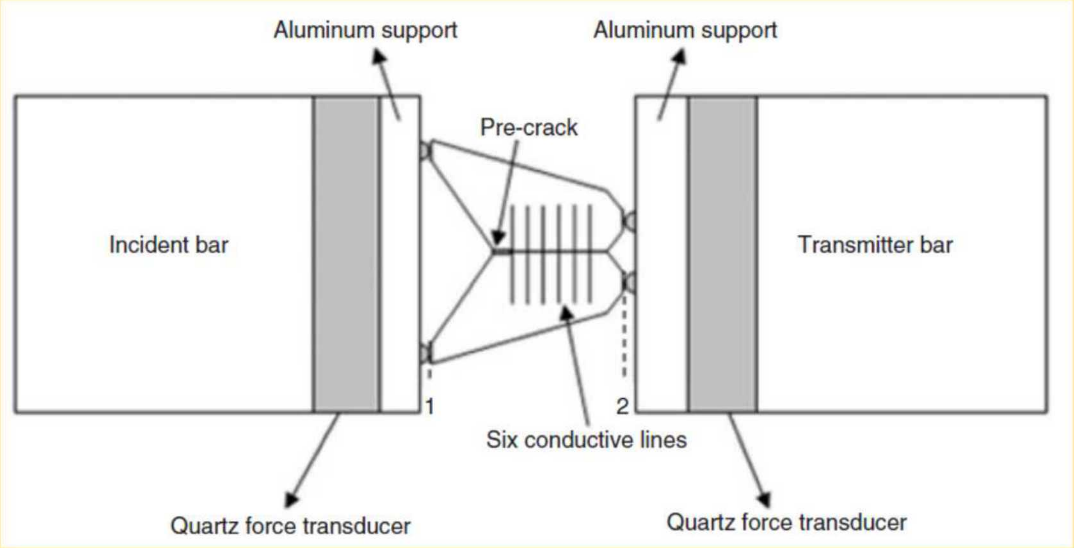
[5] Chul Jin Syn and W. W. Chen, "Surface Morphology Effects on High-Rate Fracture of an Aluminum/Epoxy Interface," *Journal of Composite Materials*, vol. 42, no. 16, pp. 1639–1658, Aug. 2008.



<u>Alternative Specimen</u>

- Used conductive paint to determine when crack had broken circuit path

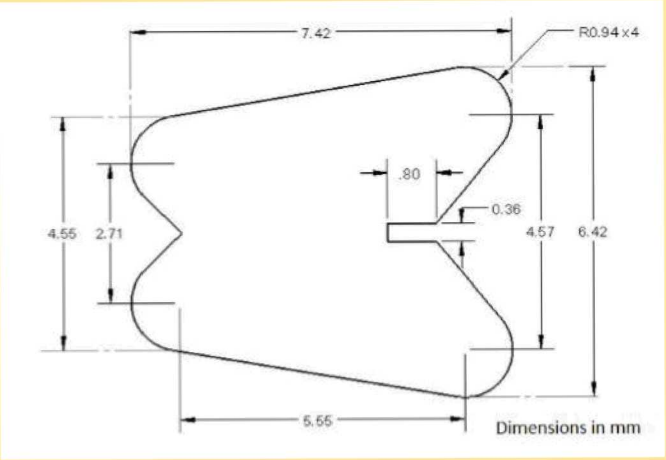


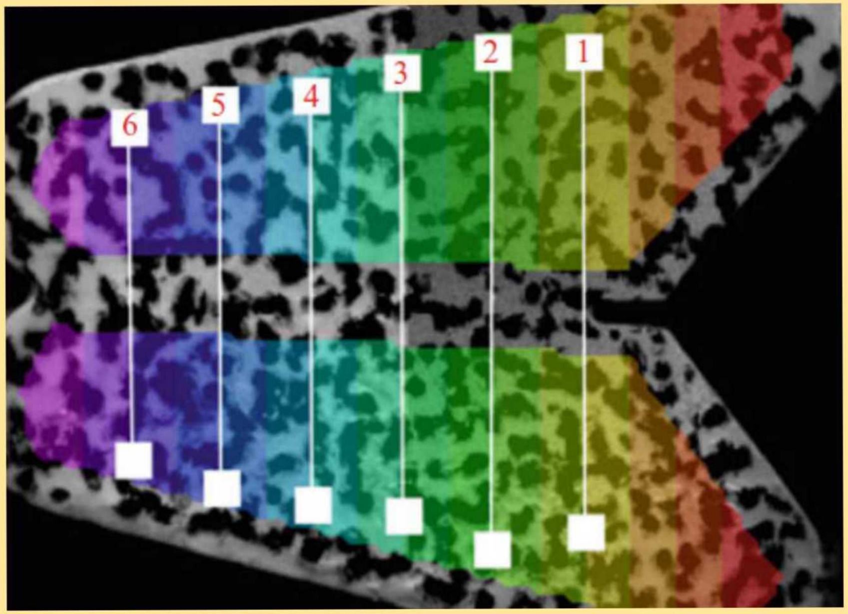


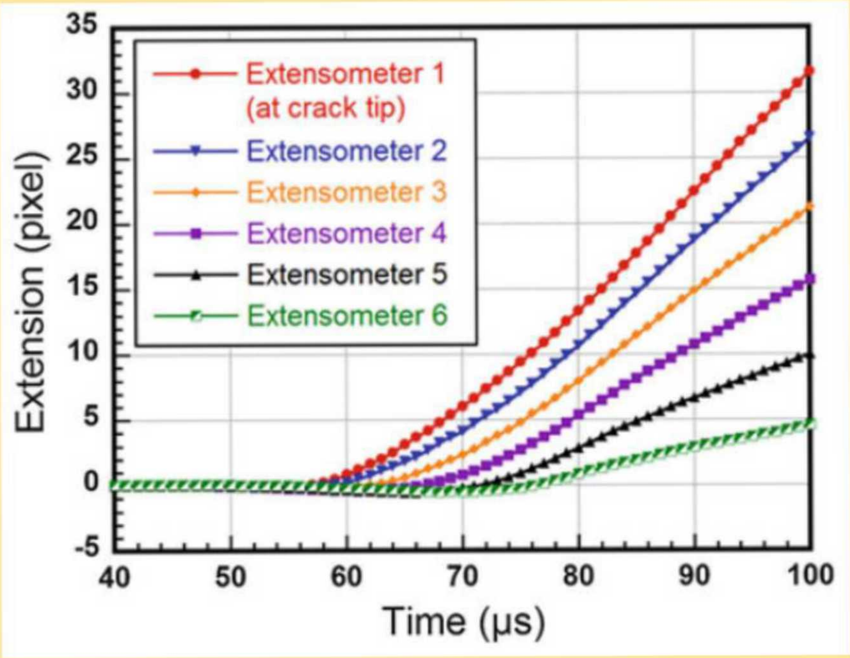
Background: Butterfly Specimen

[6] Whittie et al, 2012 SEM Annual Conference

- Whittie developed a four-point bend specimen to characterize crack propagation rates during high-rate fracture
- Specimen design reduces misalignment error
- Used to study fracture in cross-linked epoxies.



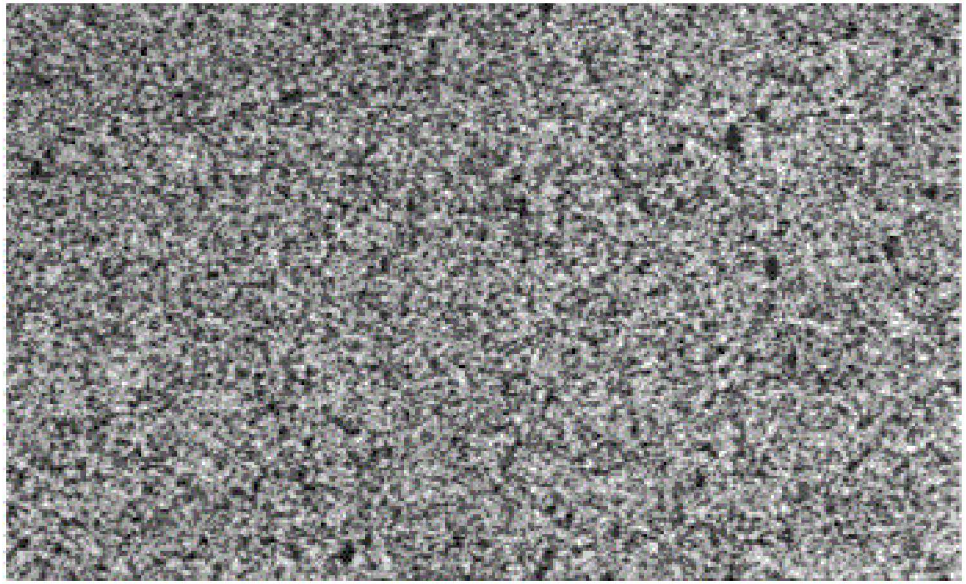




Background: Why use DIC

Digital image correlation(DIC) is advantageous because:

- Time scale is determined by the Camera
- Lens allows for a smaller scale length measurements
- Other measurement techniques are difficult at high speeds
- Non-contact
- Measures full field displacements of pixel subsets (full field strains)



Hung, Po-Chih, Volohin A. S., 2003, “In-plane strain measurement by digital image correlation”, Journal of the Brazilian Society of Mechanical Sciences and Engineering

Experimental Setup

Kolsky bar with speckled butterfly specimen in between incident and reflected bar

Shimadzu HPV-X2 high-speed camera with Tonika macro 100mm f2.8 lens positioned 10 in. from the specimen

Full bridge Vishay strain gauges wired to an oscilloscope, amplifier, and camera

Kolsky bar at Owen Kingstedt's lab University of Utah

Experimental Procedure

Butterfly specimen tested in Kolsky bar X, Y, and Z orientations

Material is 3D printed abs plastic

Loading rates determined from strain gauge data.

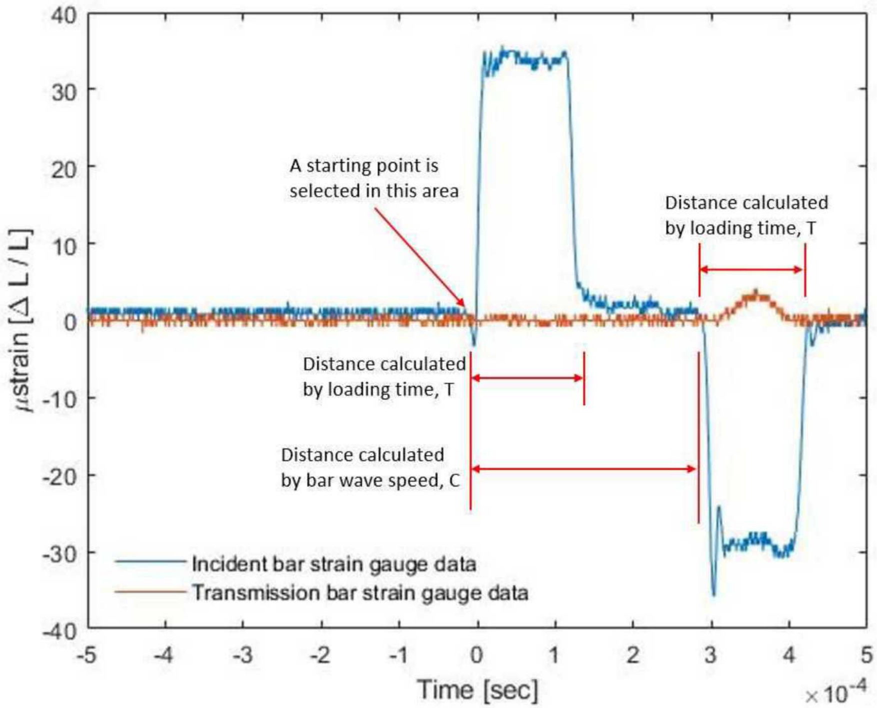
Theoretical wave speed is used to plot strain vs. time data

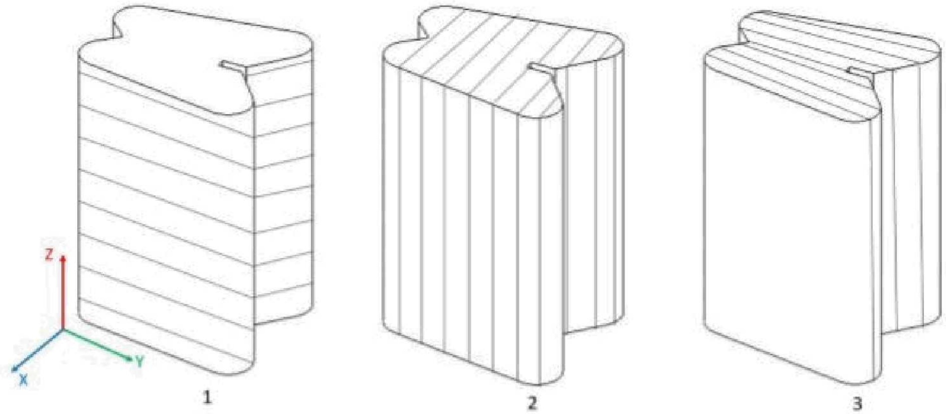
Specimen is painted with a speckle pattern and processed through DIC

Loading rate is calculated using:

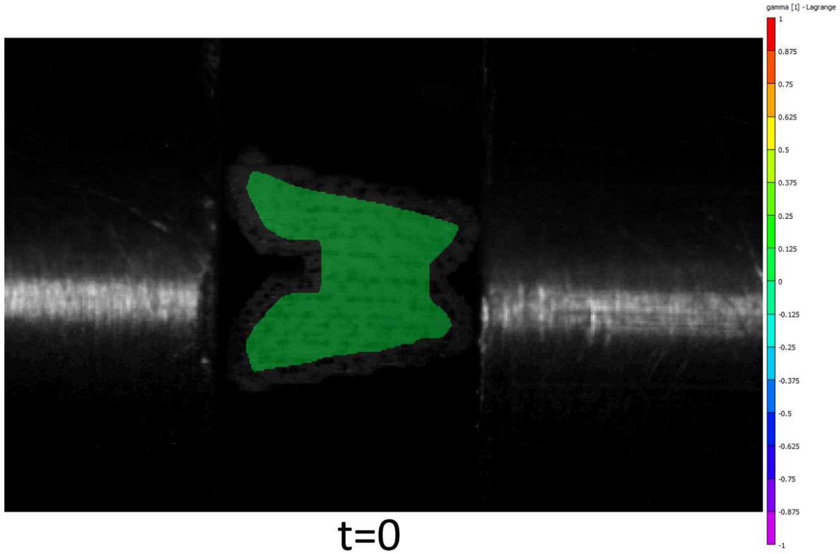
$$P_I = E_b A_b(\epsilon_I + \epsilon_R) \qquad (1)$$

$$P_{II} = E_b A_b \epsilon_T \qquad (2)$$

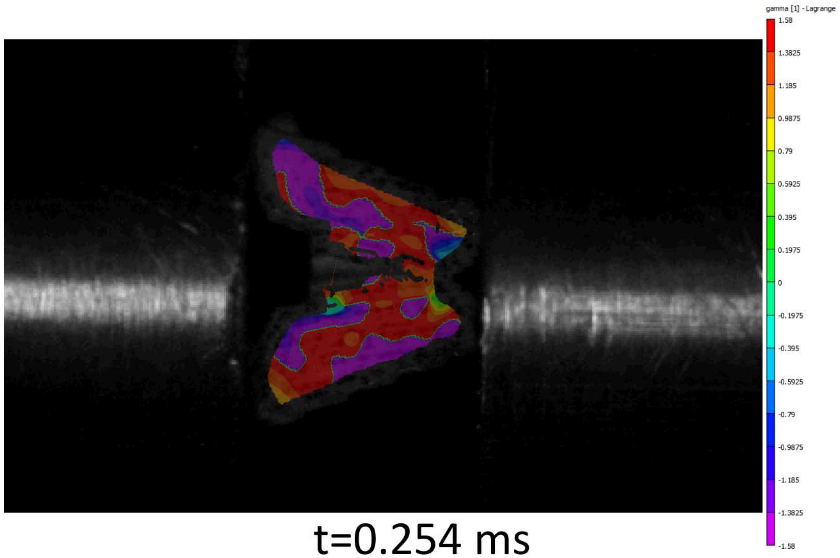




Experimental Procedure



t=0

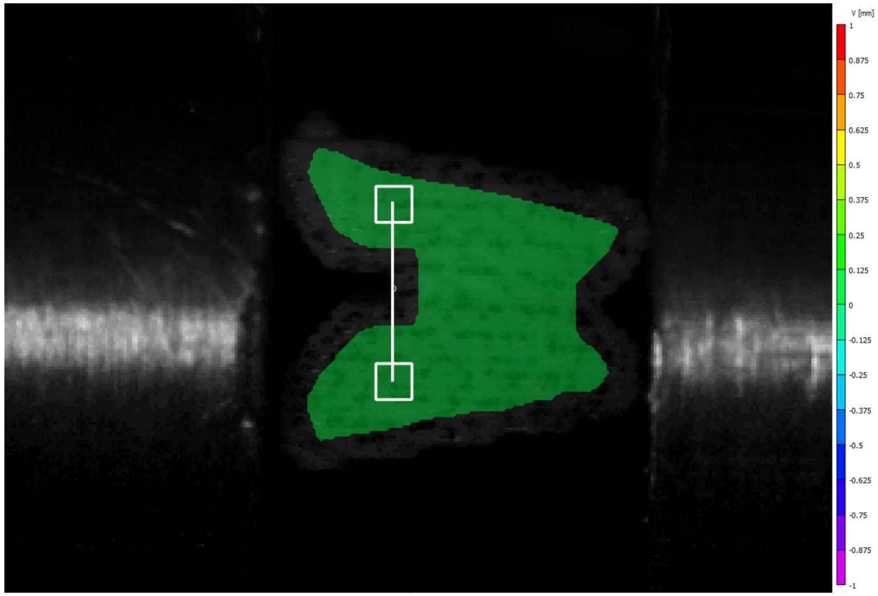


t=0.254 ms

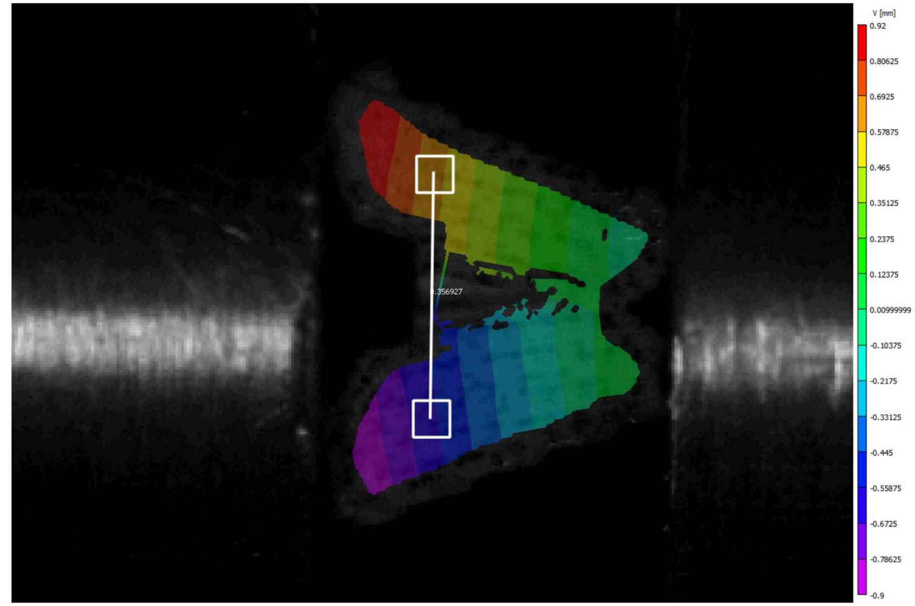
- Subset: 17 pixels – best subset based off speckle size
- Step size: 1 pixel – smaller subset to get more detail around crack
- Exposure Time and Fps chosen based off the late crack formation in the specimen
- Approximately 127 frames per test

Orientation	Psi	Exposure Time (s)	Frames per sec
X	8	1500	500,000
Y	8	1500	500,000
Z	8	1500	500,000

Experimental Procedure



t=0



t=0.254 ms

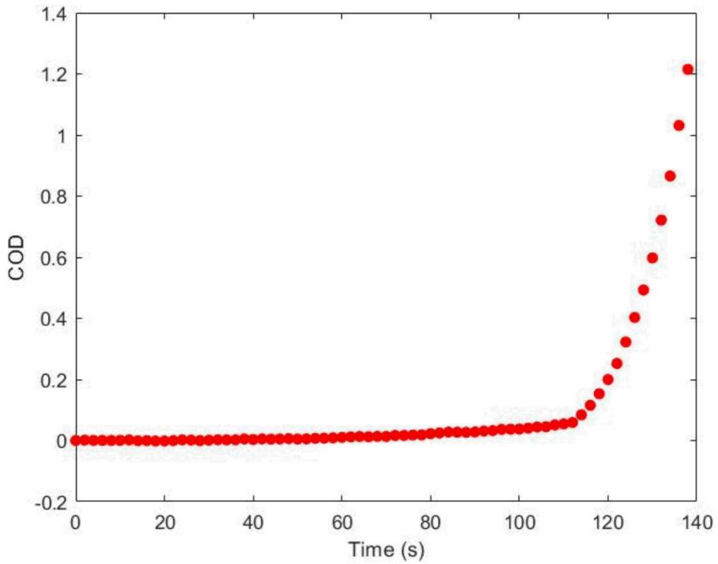
Displacement data from VIC-2D is used to create a digital extensometer to determine COD

Time zero is determined visually with images and then aligned with stress wave data

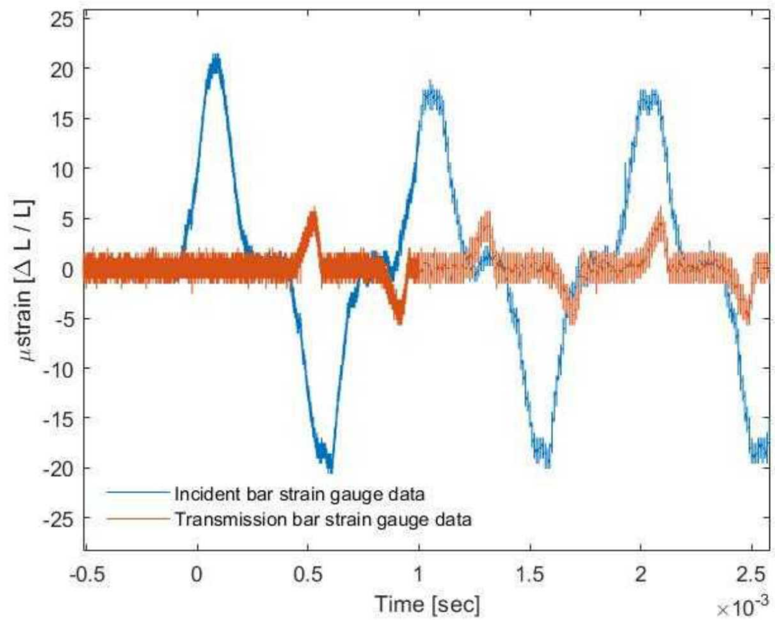
The crack path is tracked in each image. By measuring the displacement of the movement above and below the crack plane COD vs. time can be determined

Failure energy is calculated using COD and loading rate. Failure energy for each orientation will be compared

Preliminary Results: COD X Orientation



Graph of COD from initial loading to fracture

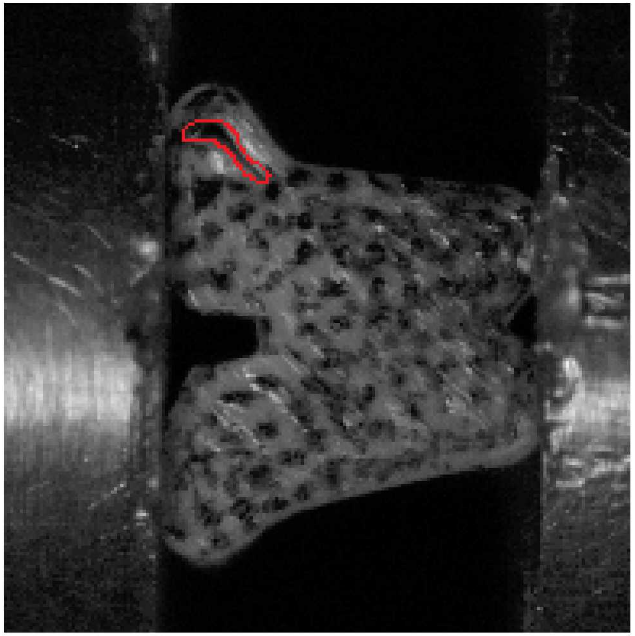


- COD calculated by tracking two points above and below the pre-crack tip
- Failure Energy calculated using force vs. time data and COD

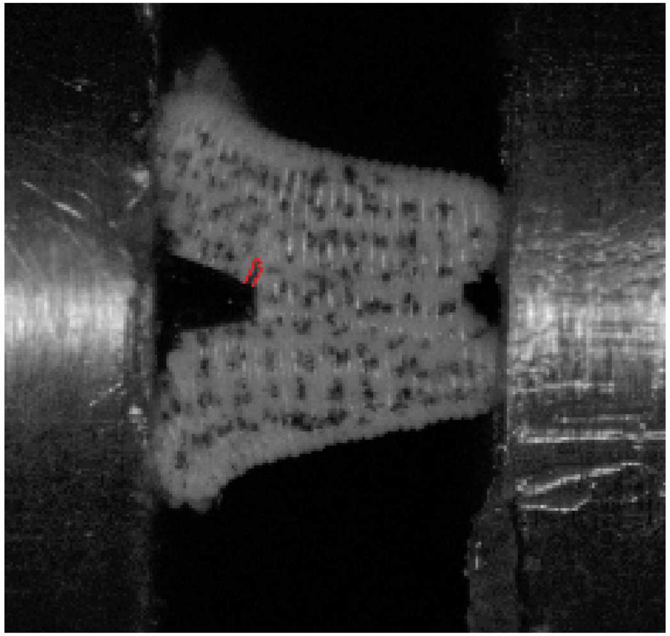
$$FE = \int_{x_0}^{x_{critical}} P(x)dx$$

Preliminary Results (2): COD Y and Z

- Z and Y orientations either didn't crack at 8 Psi or had the wrong crack path
- Possibly due to machining method – cut with 0.5 mm saw



Z Orientation



Y Orientation

Conclusions

Failure Energy:

- $FE = \int_{t_0}^{t_{critical}} P(x)dx$
- Δx and F not in the same direction
- Wasn't apparent from Whittie paper
- More research needed to use this method

Next Steps:

- Test Y and Z Orientation
  - Find better machining method
  - Increase PSI
  - Possible interference from reflected wave

- Kolsky and DIC will still be used to measure Y and Z orientations

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