MONITORING IMPACT DAMAGE IN COMPOSITES WITH LARGE AREA SENSING SKINS

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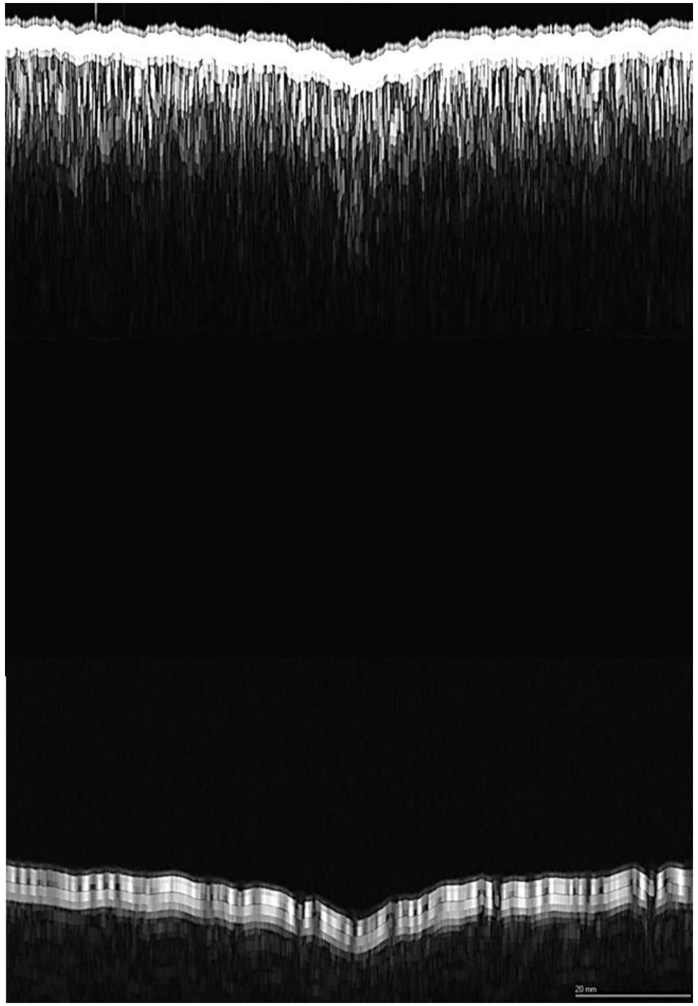
INTRODUCTION

Impact damage detection is a multi-faceted problem

- Can induce a permanent loss in the toughness
- NDT methods commonly incur non-trivial opportunity costs while parts are imaged
  - Ultra-sonic
  - Acoustic Emission



Ultrasonic image of composite blowout damage courtesy of iMAP's lab U of SC.

INTRODUCTION

- The soft elastomeric capacitor (SEC) is a flexible electronic capable of monitoring strain over large areas
  - Respond to changes in the sensor geometry
  - Inherits the mechanical properties of an elastomer
  - Functions as a parallel plate capacitor

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BACKGROUND

$$C = \mu_0 \, \mu_r \, \frac{A}{h}$$

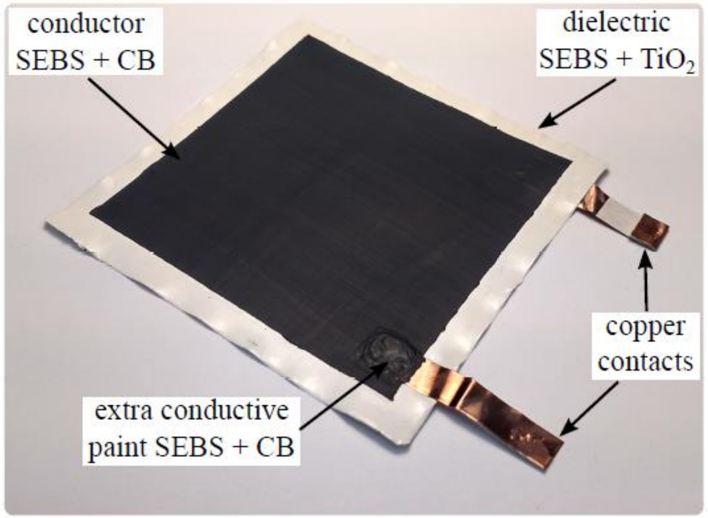
$$\frac{\Delta C}{C_0} = \frac{\left(\frac{A_1}{h_1} - \frac{A_0}{h_0}\right)}{\frac{A_0}{h_0}} = \frac{\mathrm{A_1 h_0}}{\mathrm{A_0 h_1}} - 1$$

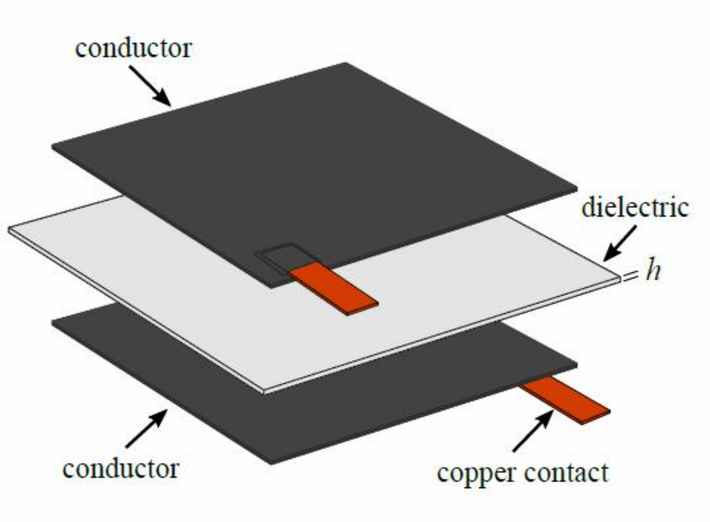
Preservation of Mass:

$$\rho V_1 = \rho V_0 \;\rightarrow A_1 h_1 = A_0 d_0$$

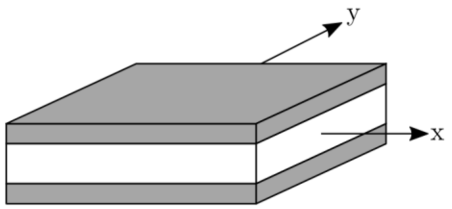
$$\frac{\Delta C}{C_0} = \frac{\mathrm{A_1} A_1 h_1 h_0}{\mathrm{A_0} A_0 h_0 h_1} - 1$$

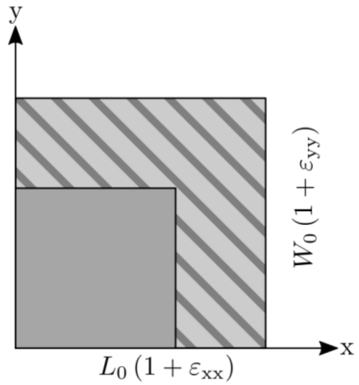
$$= \left(\frac{A_1}{A_0}\right)^2 - 1$$

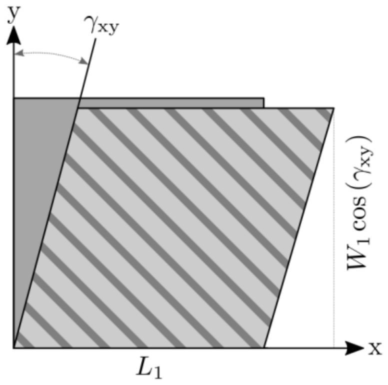




BACKGROUND







$$\frac{\Delta C}{C_0} = \left(\frac{A_1}{A_0}\right)^2 - 1$$

$$\approx \left(\frac{A_0(\varepsilon_{11}+\varepsilon_{22}+1)}{A_0}\right)^2 - 1$$

$$\approx \varepsilon_{11}^2 + \varepsilon_{22}^2 + 2(\varepsilon_{11} + \varepsilon_{22})$$

$$\approx 2(\varepsilon_{11} + \varepsilon_{22})$$

$$A_1 = A_0(1 + \varepsilon_{11})(1 + \varepsilon_{22})cos(\gamma_{12})$$

$$A_1 = A_0(\varepsilon_{11}\varepsilon_{22} + \varepsilon_{11} + \varepsilon_{22} + 1)$$

$$\approx A_0\,(\varepsilon_{11} + \varepsilon_{22} + 1)$$

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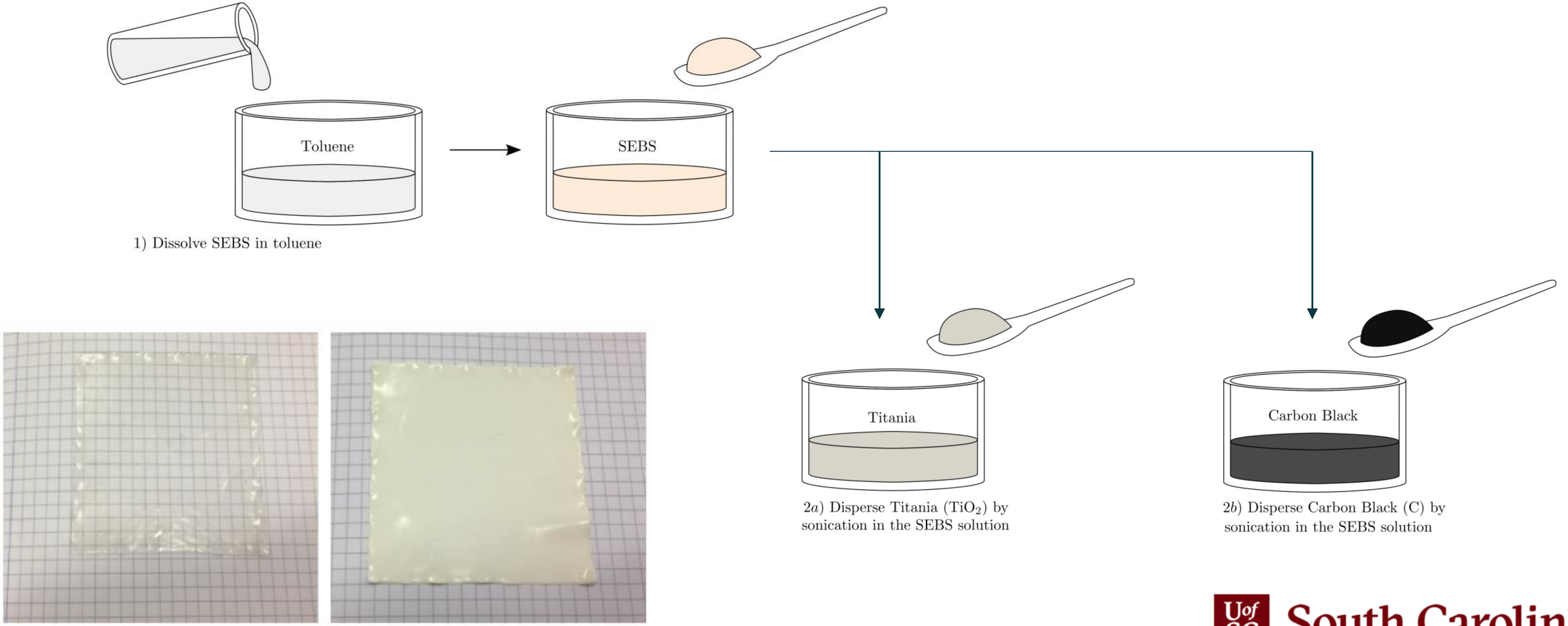
MANUFACTURE



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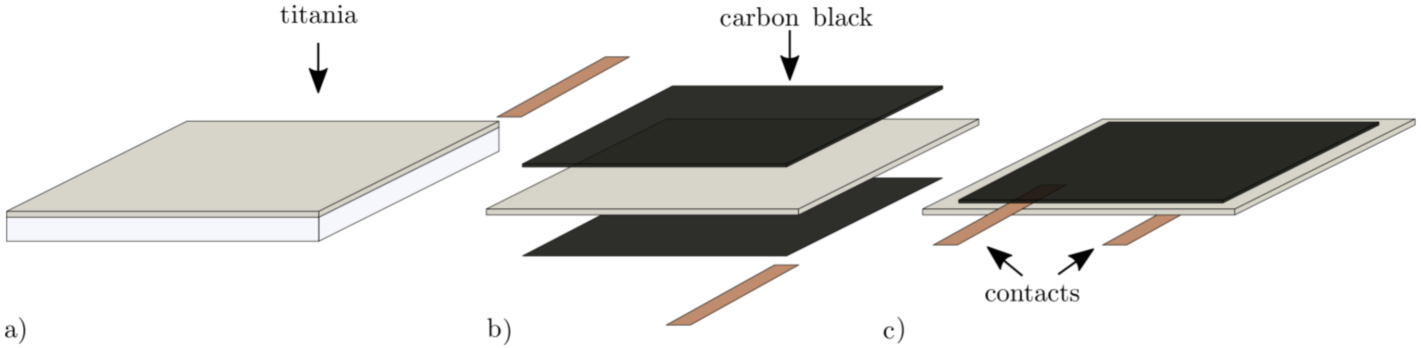
MANUFACTURE



a) The dielectric is drop cast onto a glass pane
b) The carbon black SEBS solution is then painted onto the dielectric in progressive layers
c) Two copper tabs are used for metallic connections to connect to the data acquisition system

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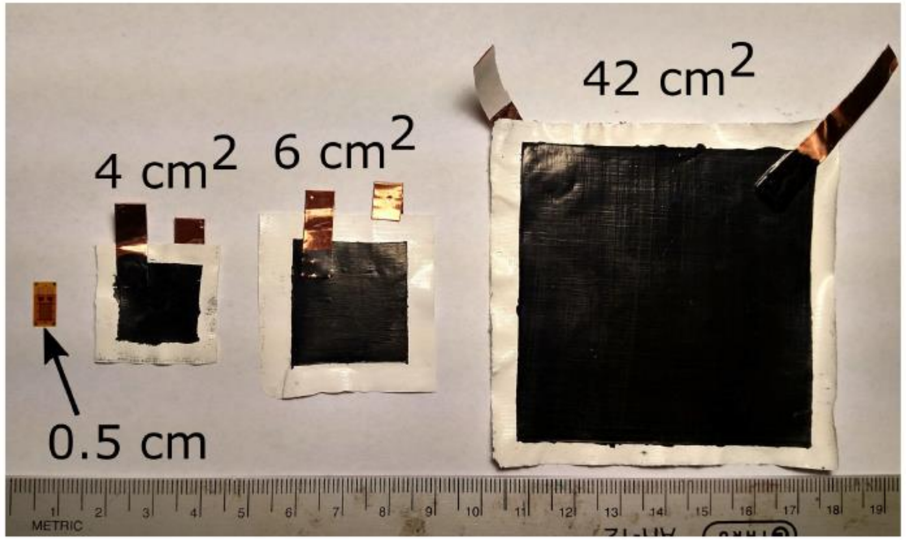
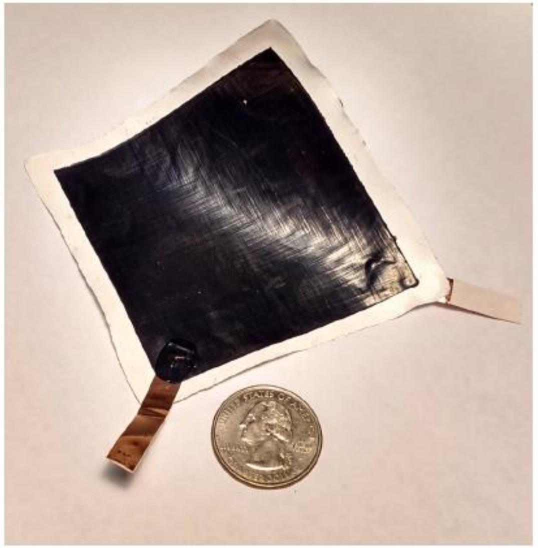
PROPERTIES

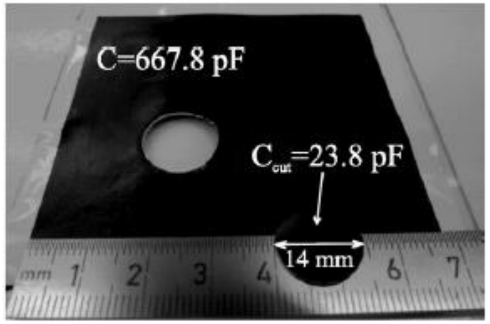
- The manufacture of the SEC makes the scaling of the sensor trivial
- The Elastomer matrix can extend up to 500% its original length

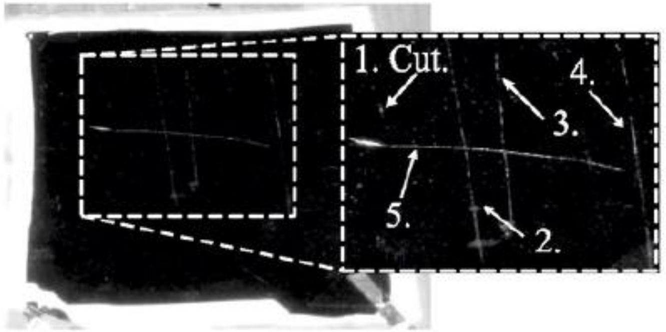


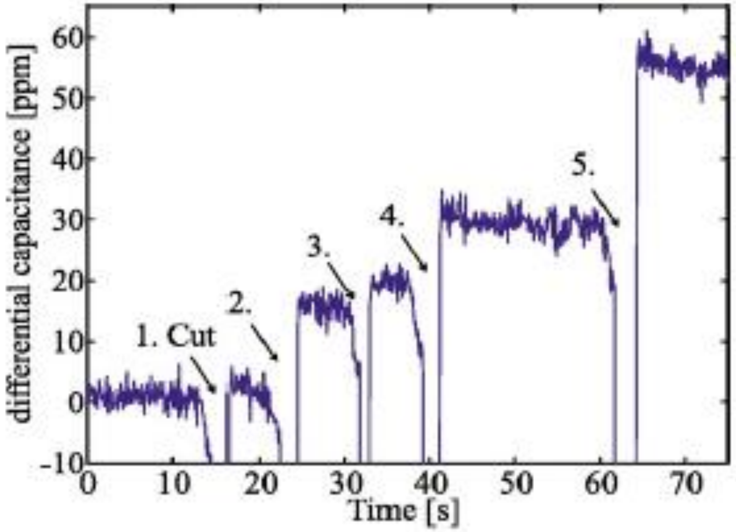


PROPERTIES

- The sensor is quite notably resilient to damage
- Removing sections of the sensor hasn't unduly harm them







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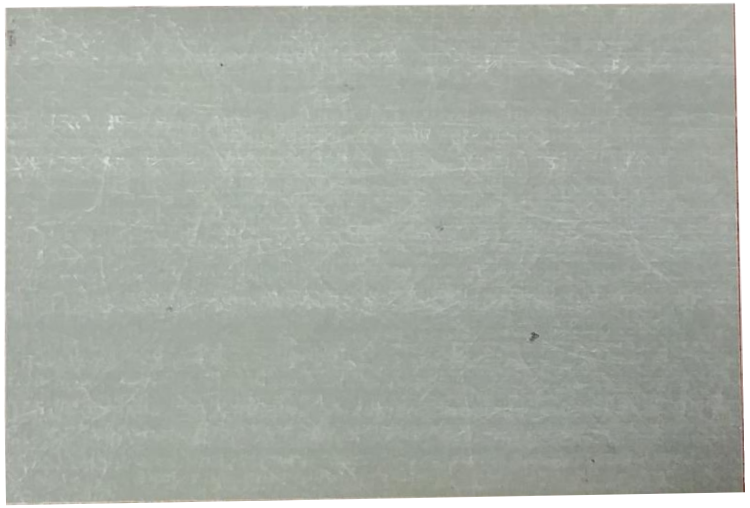
MODEL ENERGY

Assumptions in elastic impact:

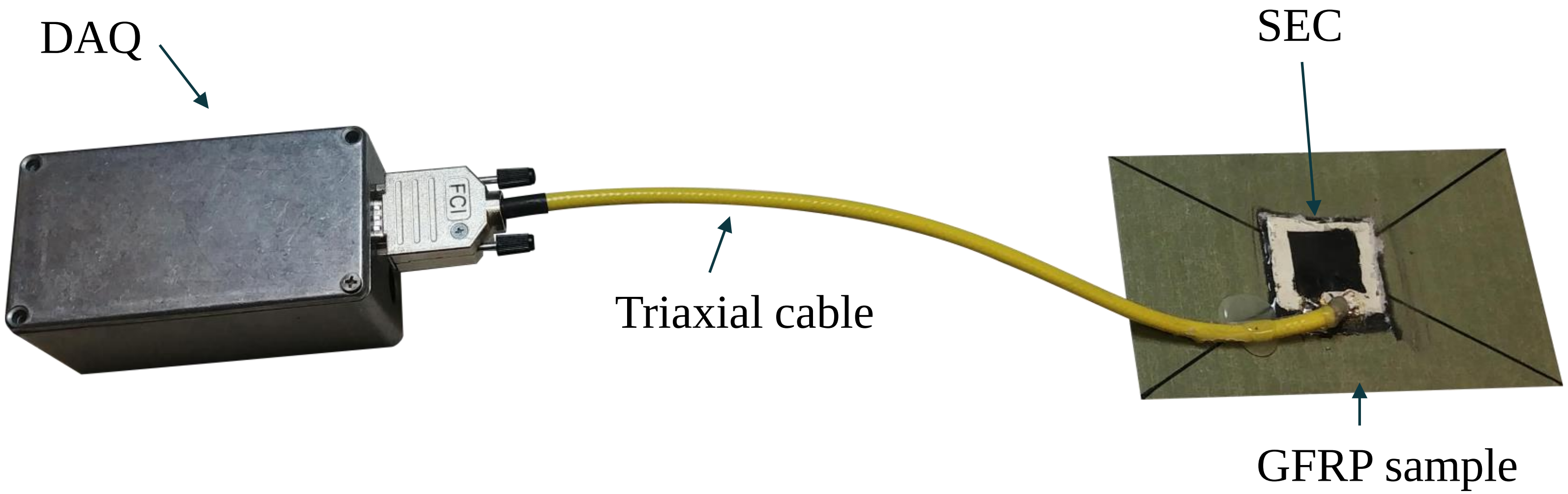
Initial impact energy is equal to the kinetic energy leaving the sample

Assumptions in plastic impact:

Initial impact energy is equal to the kinetic energy minus the retained strain energy

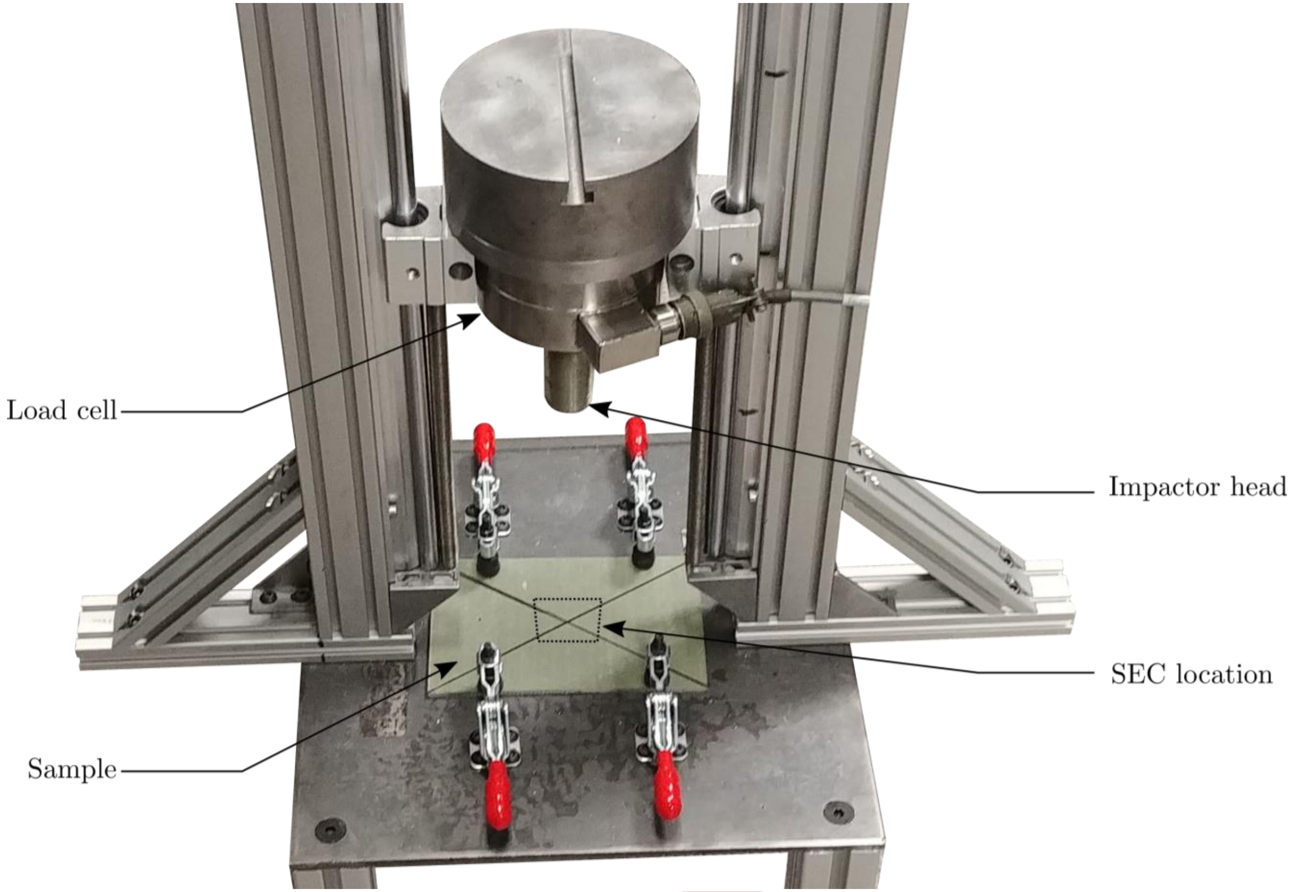


SENSING APPARATUS



DROP TOWER

- GFRP nominal proof resilience of 0.678 J to 4.237 J
- Drop tower with a 6.5 kg impactor



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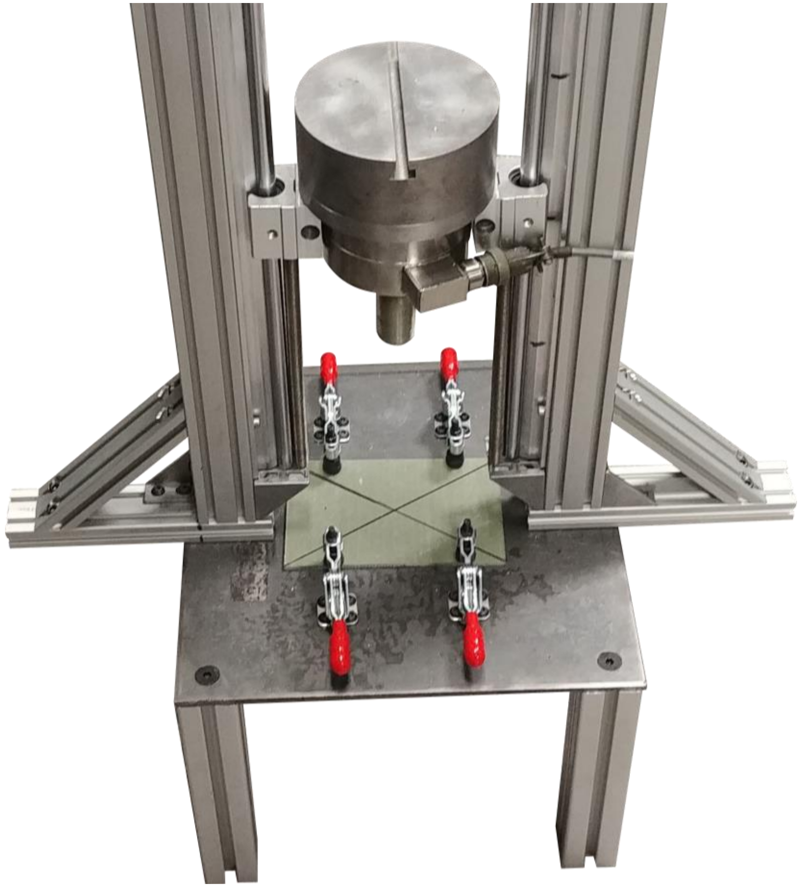
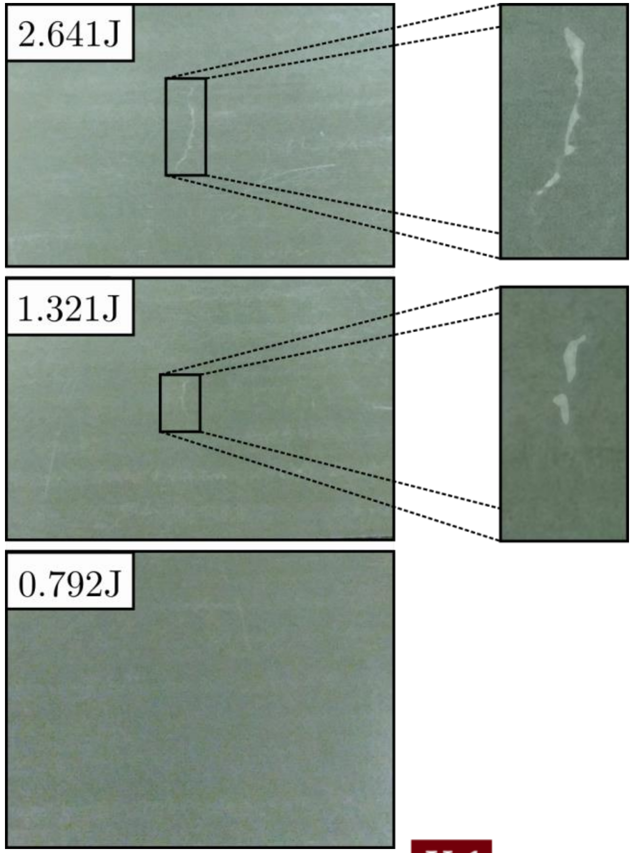
DROP TOWER



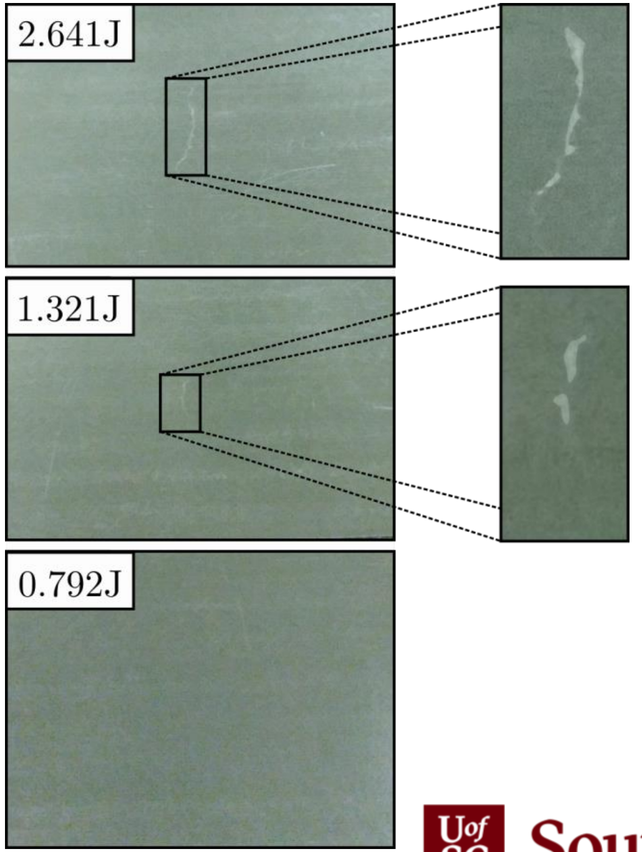


DROP TOWER

GFRP nominal proof resilience of 0.678 J to 4.237 J

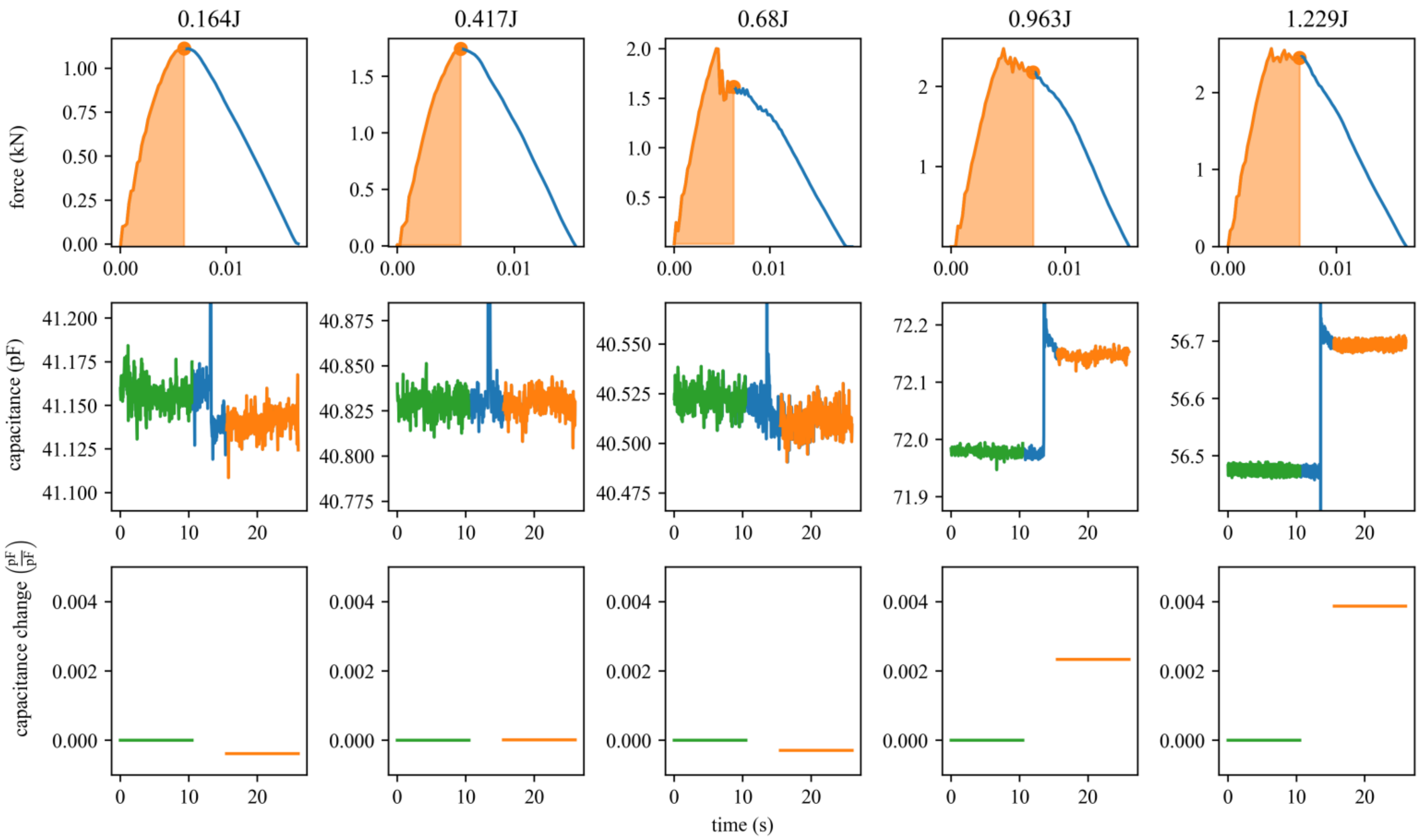
However, testing showed minor crack initiation after 1.32J though not a full failure of the plate

Testing range chosen of 0.25 J to 1.5 J over 5 impact event



RESULTS

- First row: the load cells measure for each individual impact
- Second row: the measured capacitance measures and where the data omits the 2 second before and after the impact
- Third row: the normalized change in capacitance of the region before and after.



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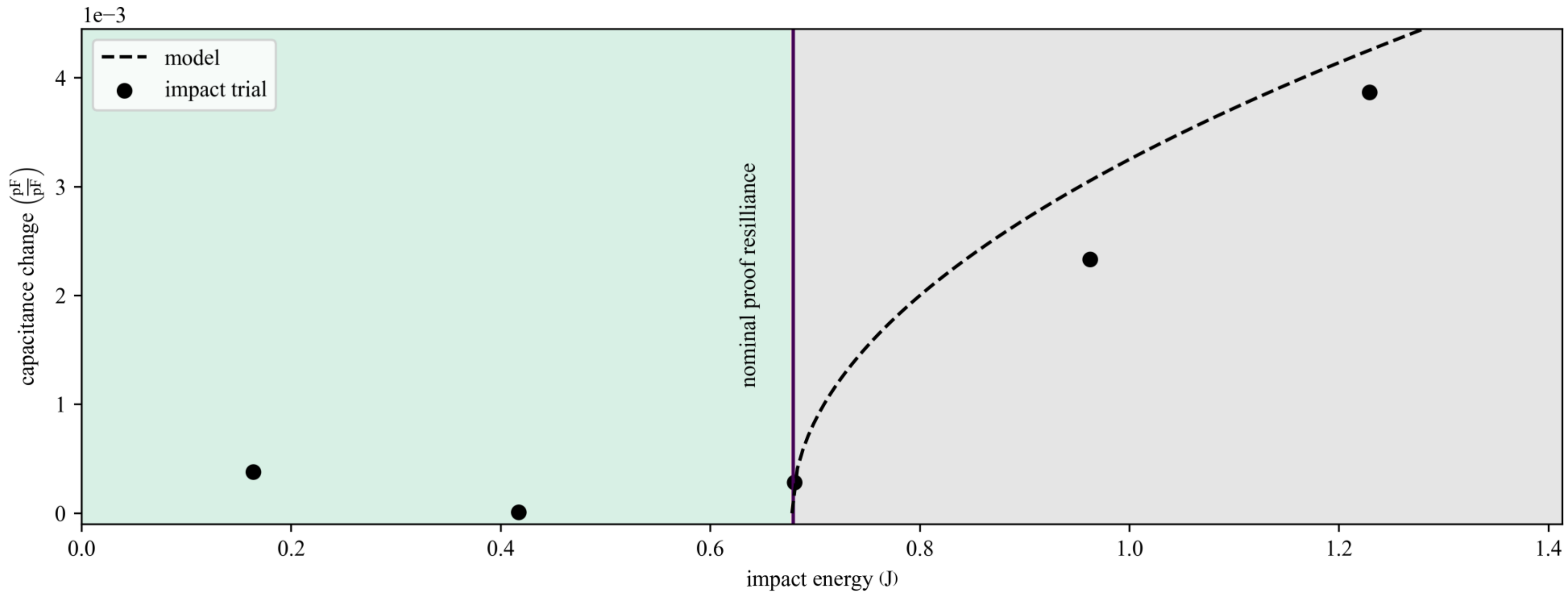
RESULTS

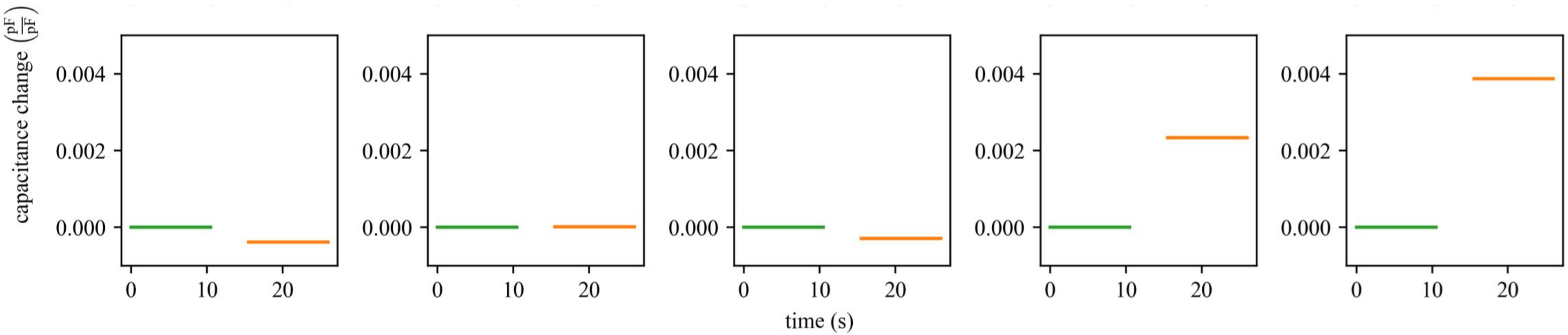

1e−3
model
impact trial
nominal proof resilliance
capacitance change $\left(\frac{pF}{pF}\right)$
0
1
2
3
4
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
impact energy (J)

CONCLUSIONS

The GFRP can be expected to respond in three domains:

- Pure elastic responses that are non-hysteric
- Small plastic deformations due to failure in the resin
- Larger deformations post-fracture where the Glass fiber fails

CONCLUSIONS



Impacts above the proof resilience are expected to store energy as deformations. These would be registered in the be the SEC as a sustained increase in capacitance where sub fracture impacts would be registered no sustained change in capacitance by the SEC (i.e. state-based damage detection).

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ACKNOWLEDGEMENTS

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FURTHER READING ON THE SEC

- Li, Jian, et al. *Strain-based Fatigue Crack Monitoring of Steel Bridges using Wireless Elastomeric Skin Sensors*. No. FHWA-KS-19-01. 2019.
- Liu, Han, et al. "Numerical Investigation of Auxetic Textured Soft Strain Gauge for Monitoring Animal Skin." *Sensors* 20.15 (2020): 4185.
- Laflamme, Simon, and Jian Li. "Field Deployment of Sensing Skin on a Steel Bridge for Fatigue Crack Localization and Assessment." (2019).

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THANKS!

Questions: Alexander Vereen

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