BSSM The British Society for Strain Measurement

UNIVERSITY OF Southampton

Warwick University, July 9th 2019

Image-based inertial high strain rate tests

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www.photodyn.org

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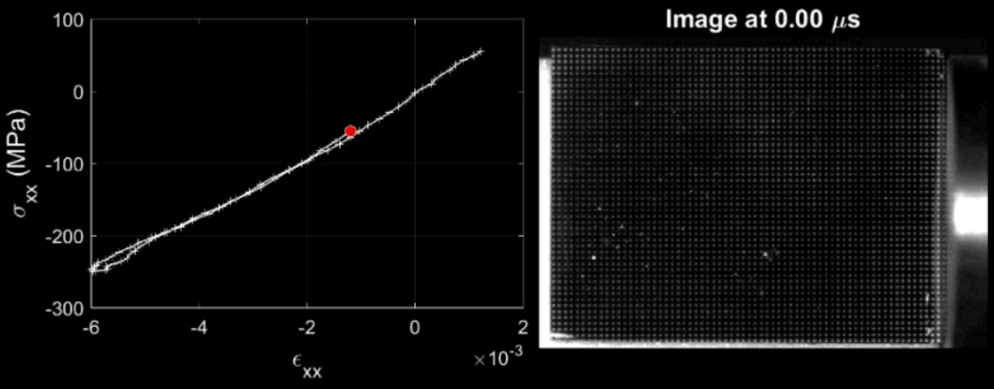
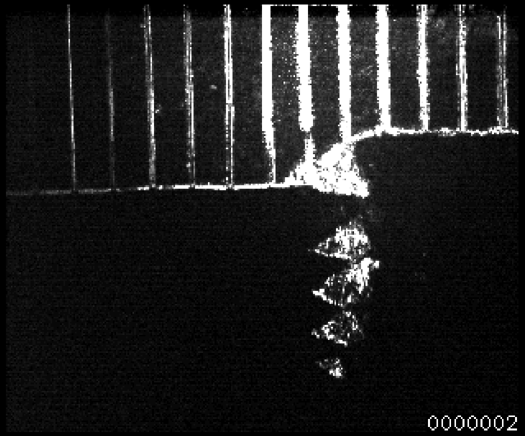


Introduction – 1/3

- High strain rate material behaviour
  - Very important for many engineering applications

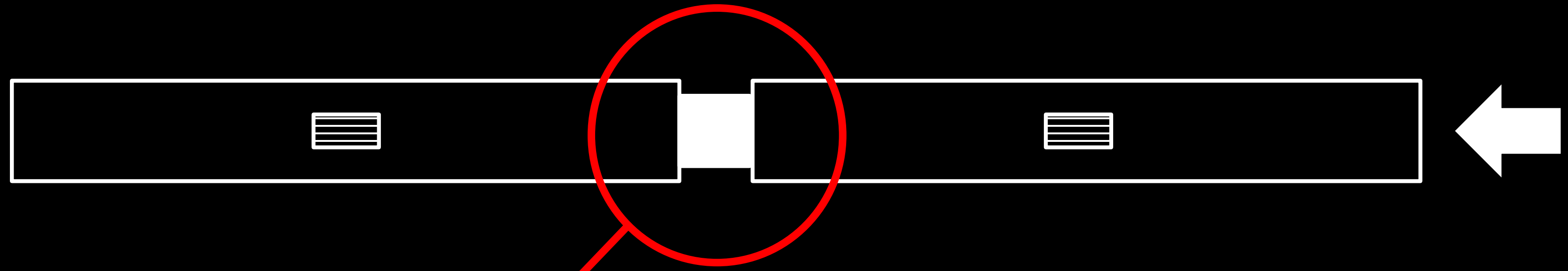


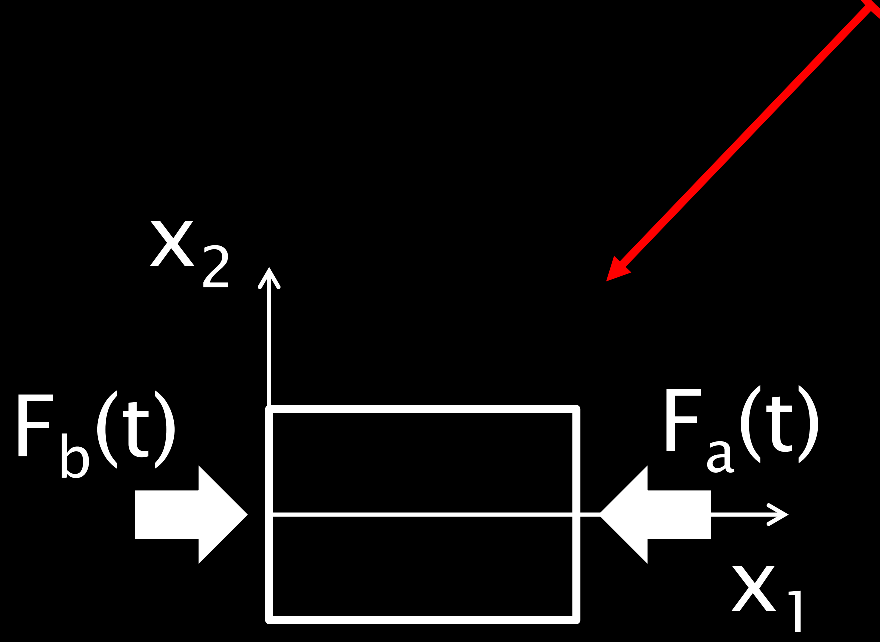
  - Highly strain rate dependent

- Need for specific test methods

Introduction – 2/3

- Kolsky bar (or SHPB)



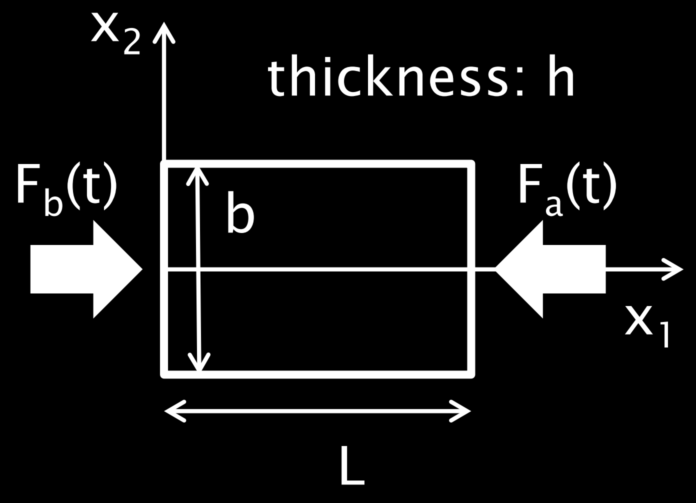


Analysis requires $F_a = -F_b$
(quasi-static equilibrium)

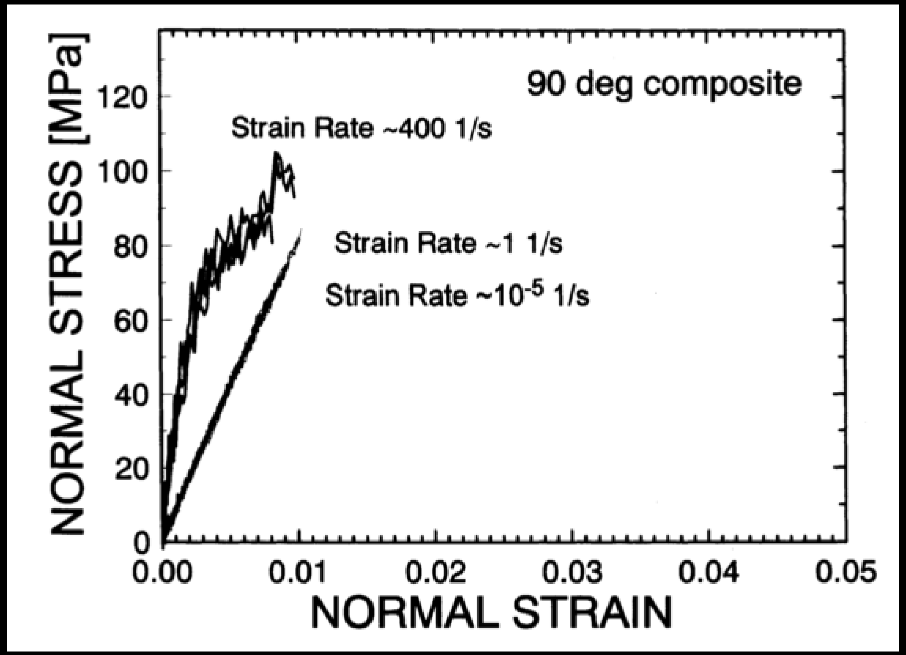
Introduction – 3/3

- Inertia limited!

$$(F_a + F_b) = \rho \int_V a_1 dV$$



- 90° UD tensile testing
  - Low strains to failure
  - Low wave speeds
- Literature data
  - Limited strain rates (a few 100s s^{-1})
  - Poor quality data

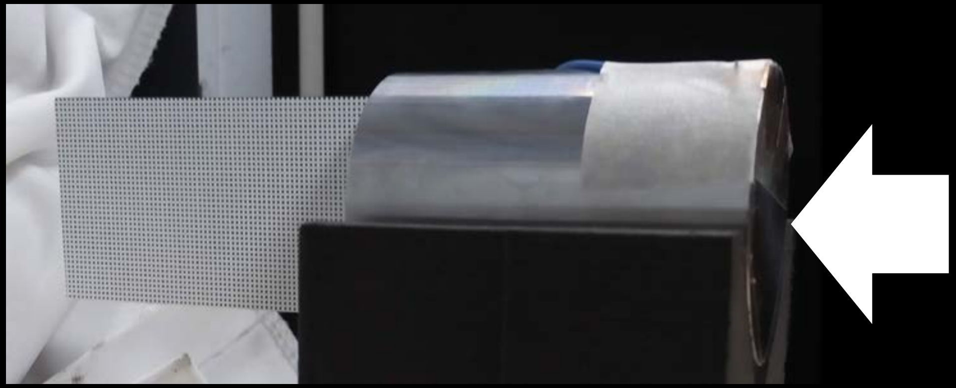


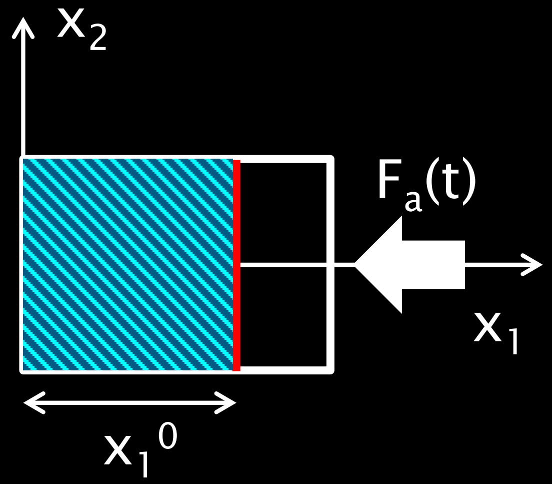
Gilat, A., Goldberg, R. K., & Roberts, G. D. (2002). *Composites Science and Technology*

Stress from acceleration: the IBII test

- Inertial impact test
- Equilibrium of blue sub-system

$$\boxed{\overline{\sigma_{11}}^{x_2}(x_1^0,t)=\rho x_1^0\,\overline{a_1}(x_1^0,t)}$$





- Full-field strain measured
  - Stress-strain curves can be obtained

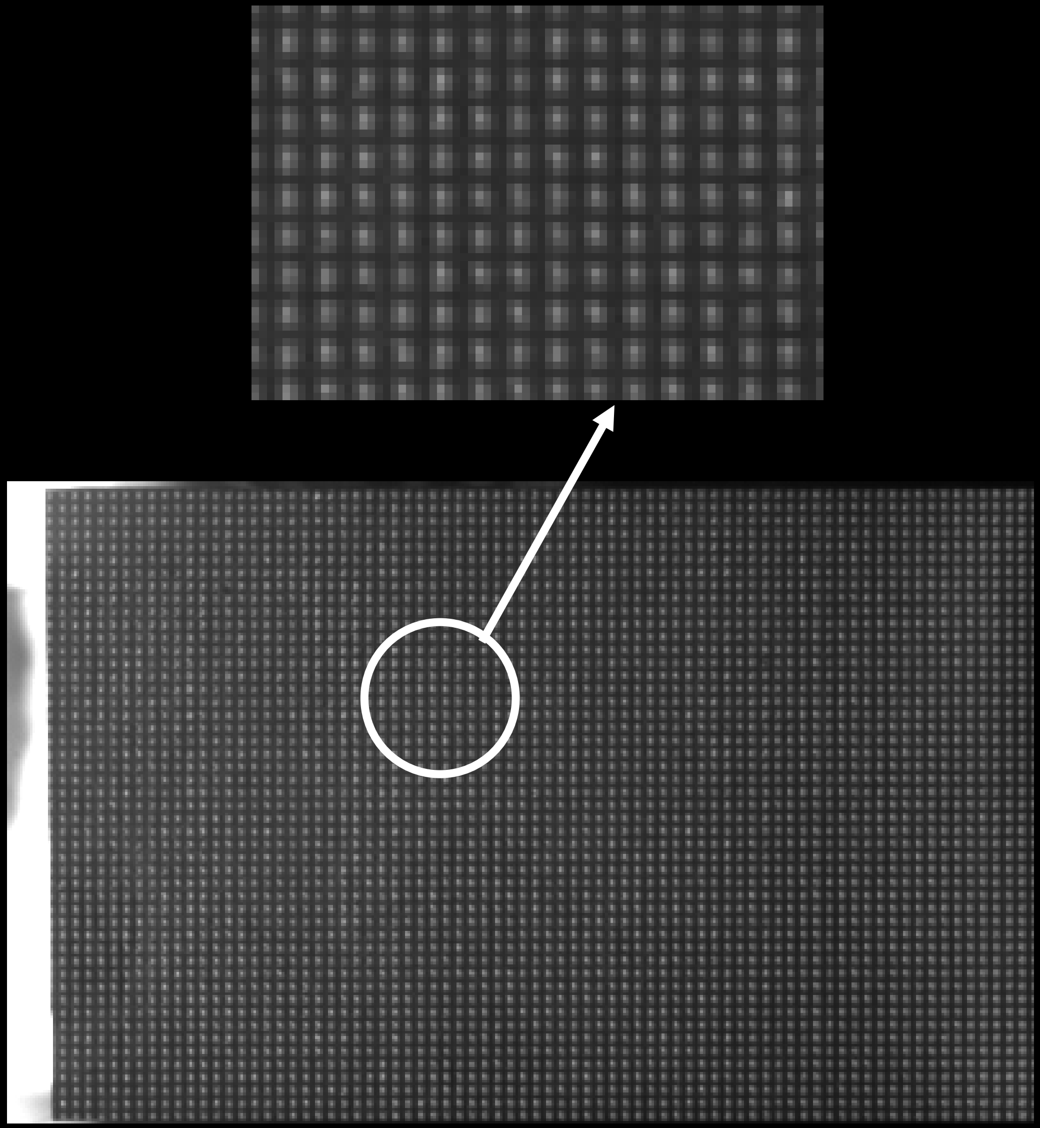
Image-Based Inertial Impact (IBII) test

IBII tests on UD composites

- SolvaLite™ 730 Prepreg Carbon Fiber Reinforced Thermoset $[90]_{10}$ 2.5 mm thick
- Grid method, 0.68 mm pitch, 5px/period (alt. to DIC)
- Grid printed directly on specimens, white ink

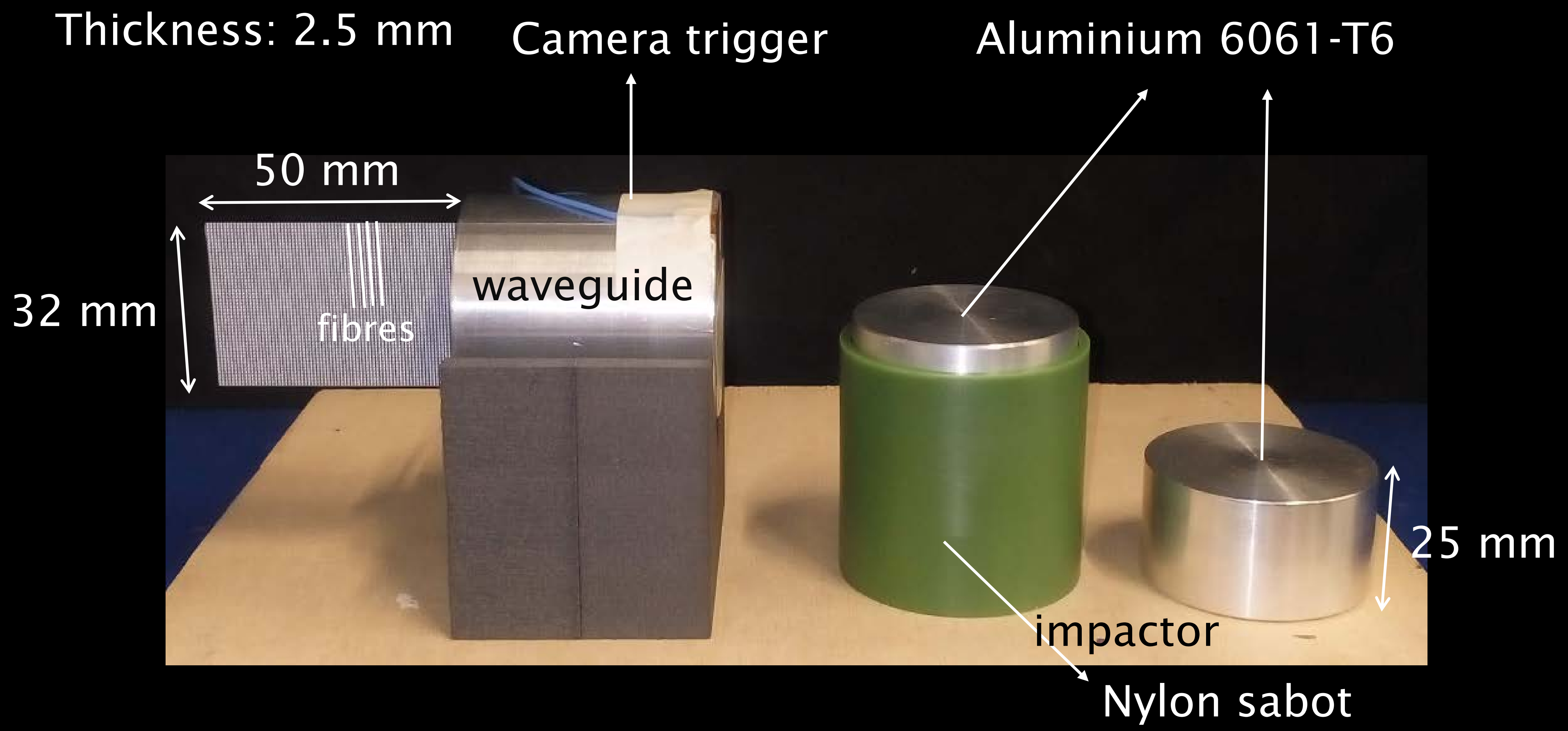
MatchID Metrology beyond colors

www.matchid.eu



Fletcher L., Van Blitterswyk J., Pierron F., J. of Dyn. Behav. of Mat., 5(1):65-92, 2019

Experimental configuration

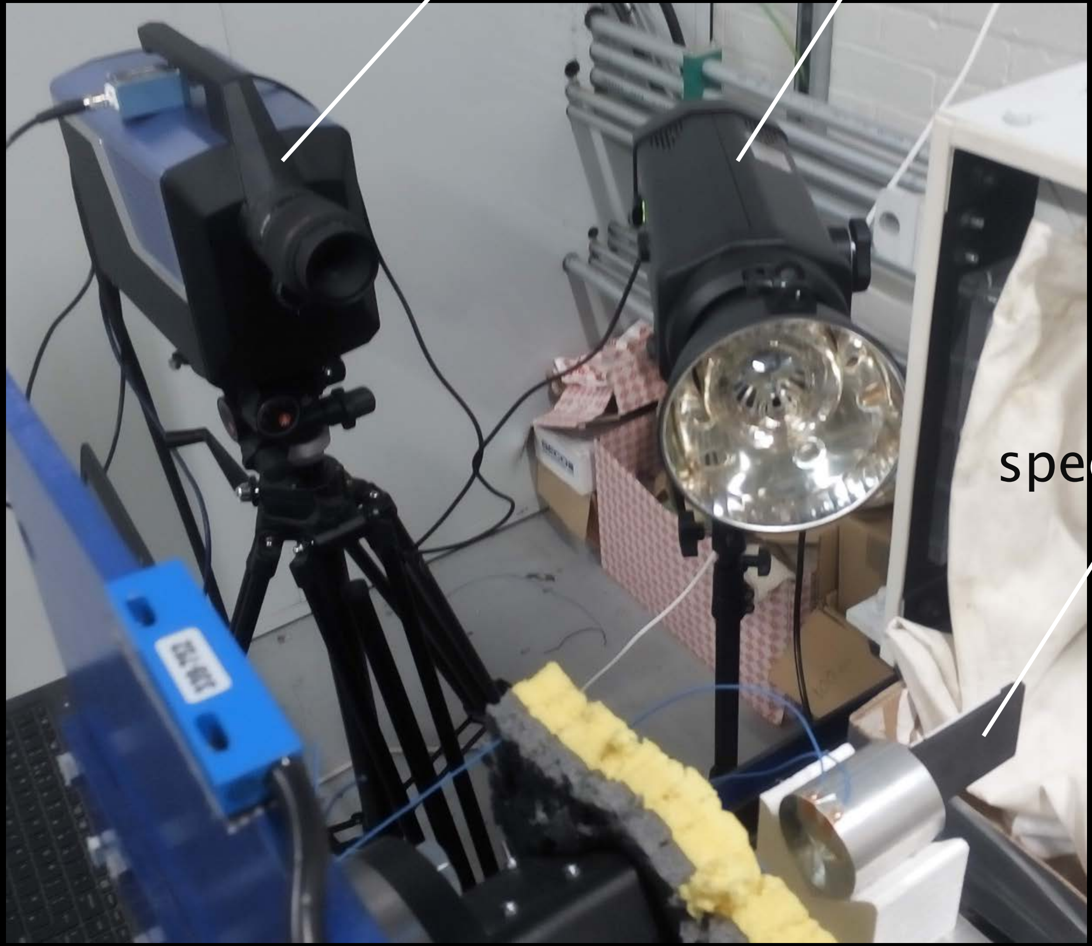


Experimental set-up

- Impact speed: 30 to 40 m.s^{-1}

Shimadzu HPV-X
(400 x 250 pixels)
2 Mfps

Flash light

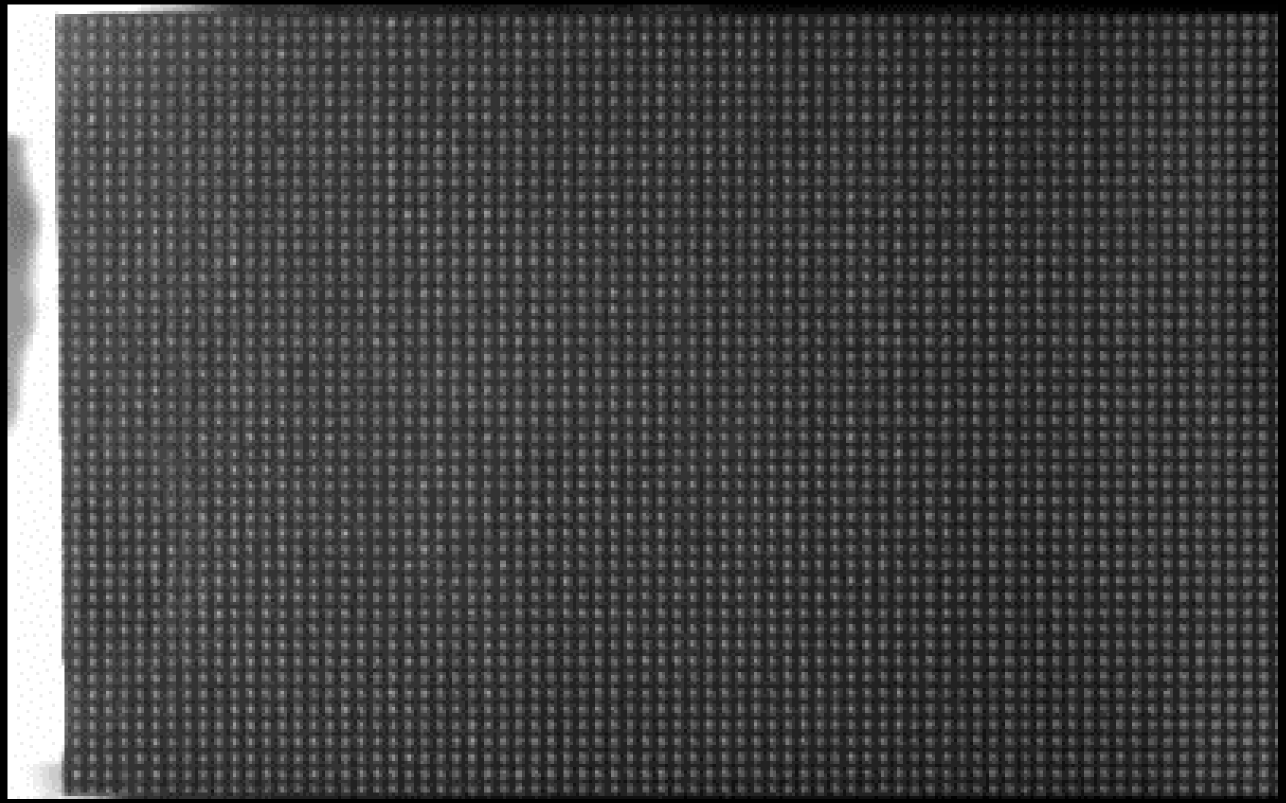


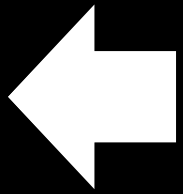
specimen

Real time

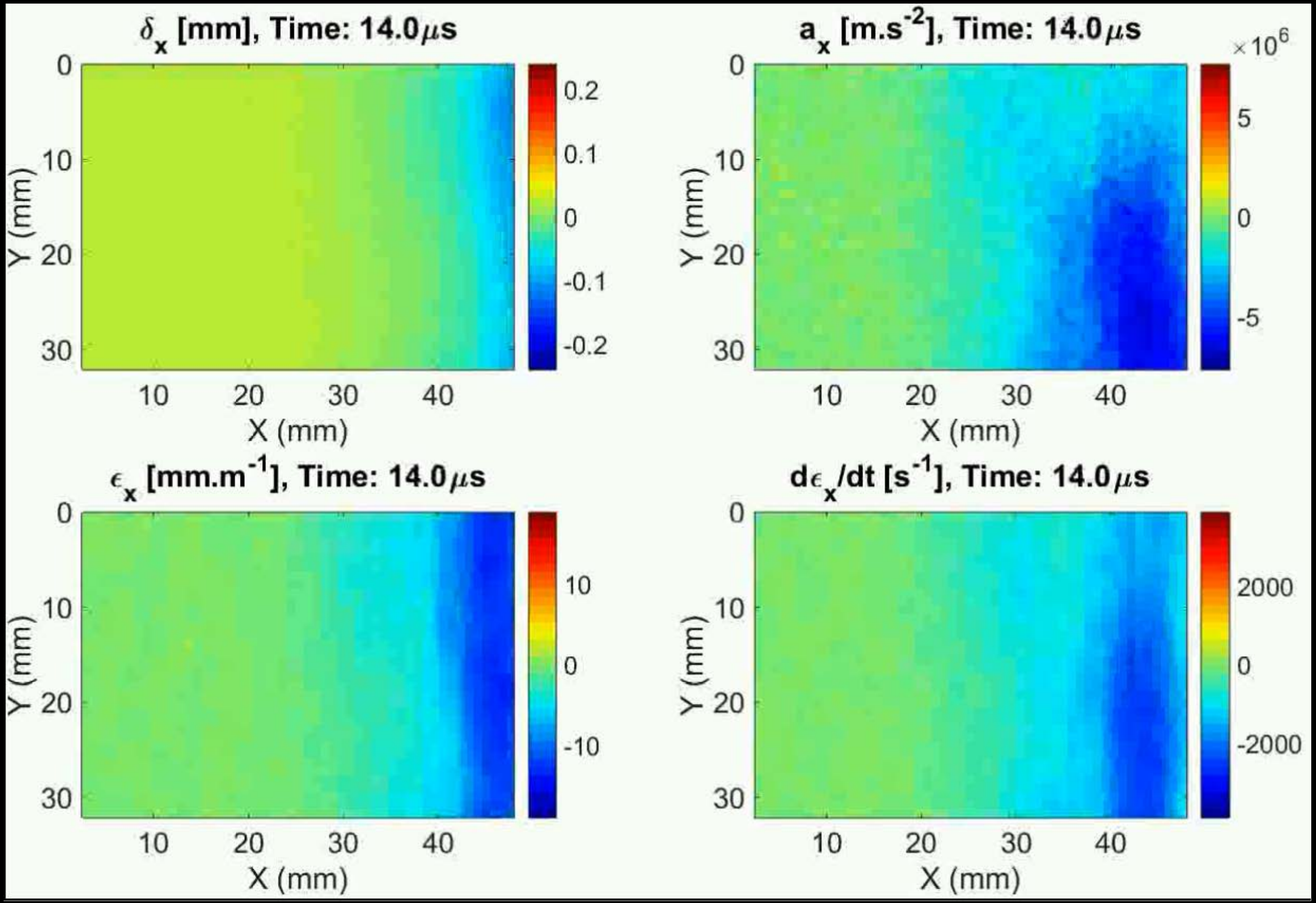
Raw images

- Wave speed: ~2 $km.s^{-1}$
- 2 Mfps, total video time: 64 μs



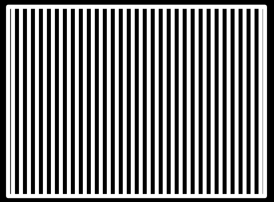


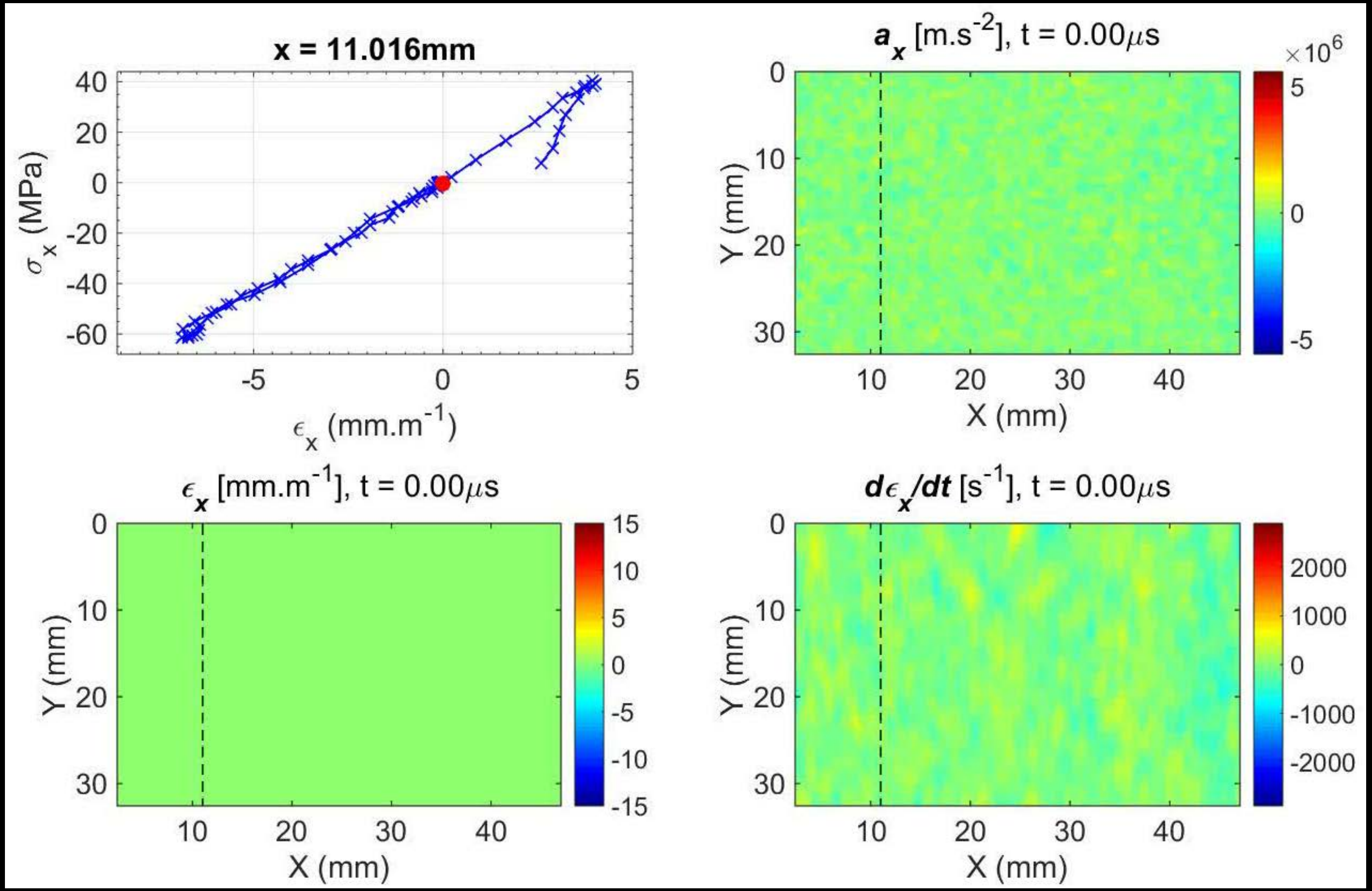
Kinematic data



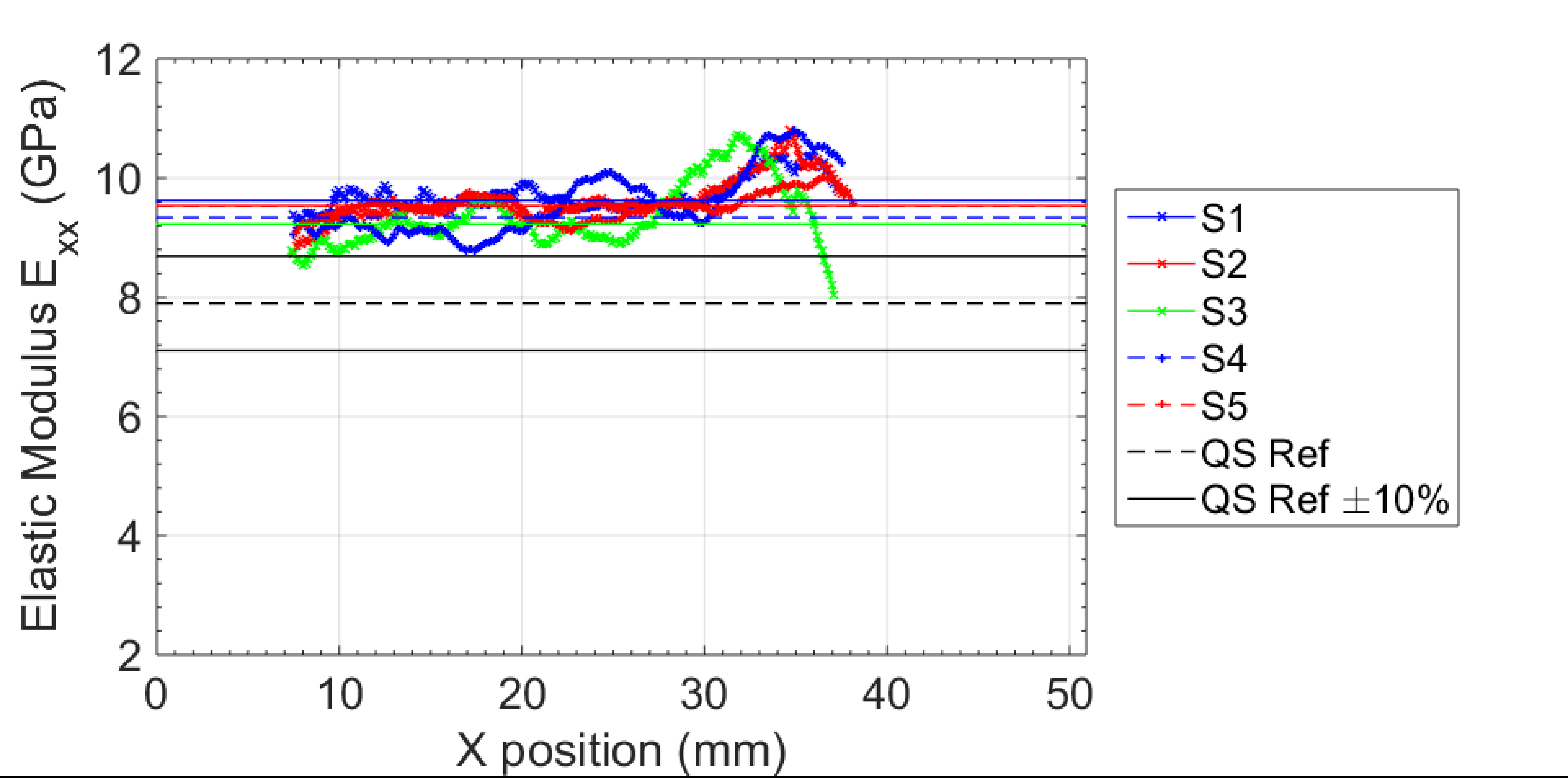
Stress-strain curve

Small Poisson's effect because of 90° configuration $\sigma_y \approx E_{yy}\varepsilon_y$



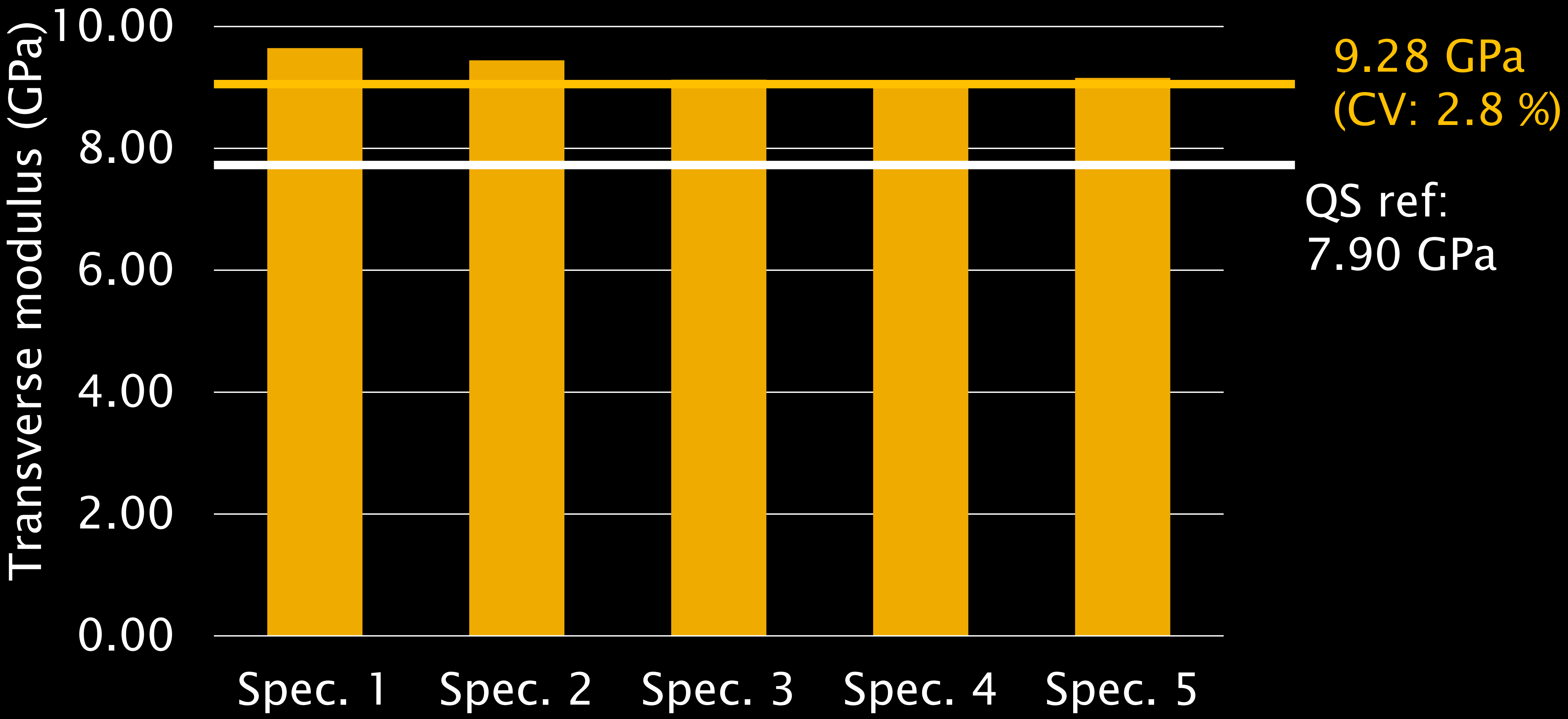


Modulus - 1/2



Elastic Modulus E_{xx} (GPa)
12
10
8
6
4
2
0
10
20
30
40
50
X position (mm)
S1
S2
S3
S4
S5
QS Ref
QS Ref ±10%

Modulus – 2/2

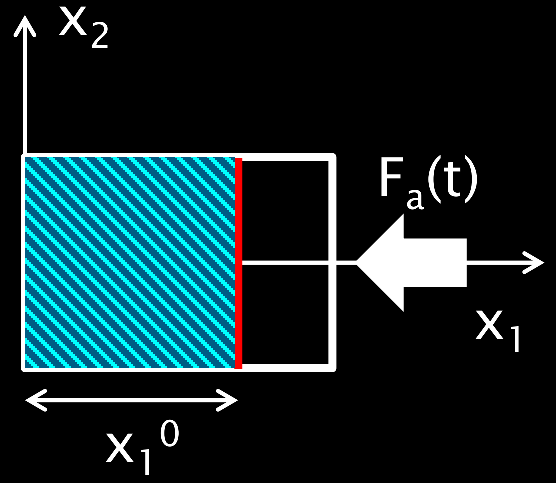


Transverse modulus (GPa)
10.00
8.00
6.00
4.00
2.00
0.00
Spec. 1
Spec. 2
Spec. 3
Spec. 4
Spec. 5
9.28 GPa
(CV: 2.8 %)
QS ref:
7.90 GPa

Fracture analysis – 1/4

- The 'stress gauge'

$$\overline{\sigma_{11}}^{x_2}(x_1^0, t) = \rho x_1^0 \overline{a_1}(x_1^0, t)$$

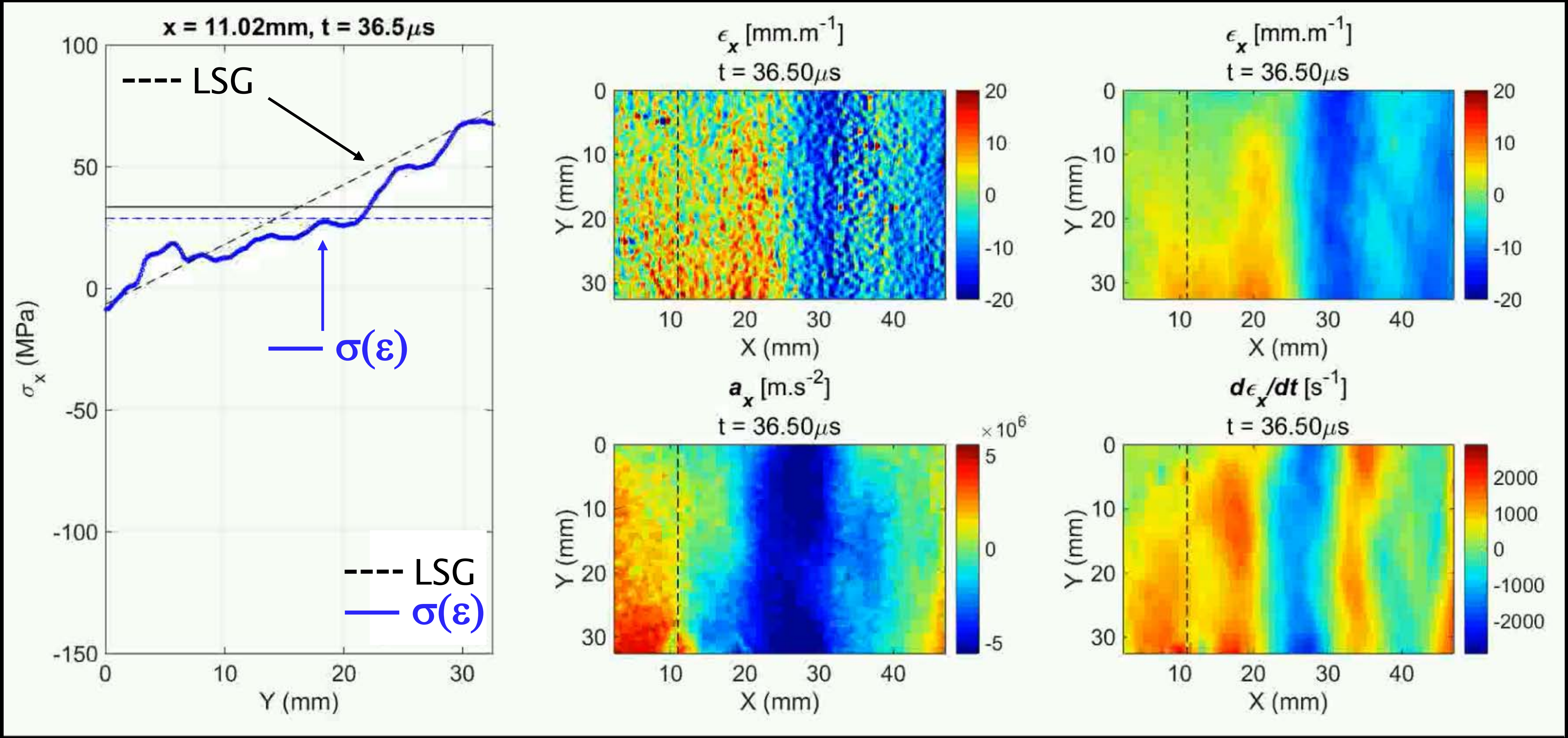


- The 'linear stress gauge'

$$\sigma_{11}^{LSG}(x_1^0, x_2, t) = \rho x_1^0 \overline{a_1}(x_1^0, t) + \frac{12\rho x_1^0 x_2}{w^2}\left(\overline{a_1 x_2} - \overline{a_2 x_1} + x_1^0 \overline{a_2}\right)$$

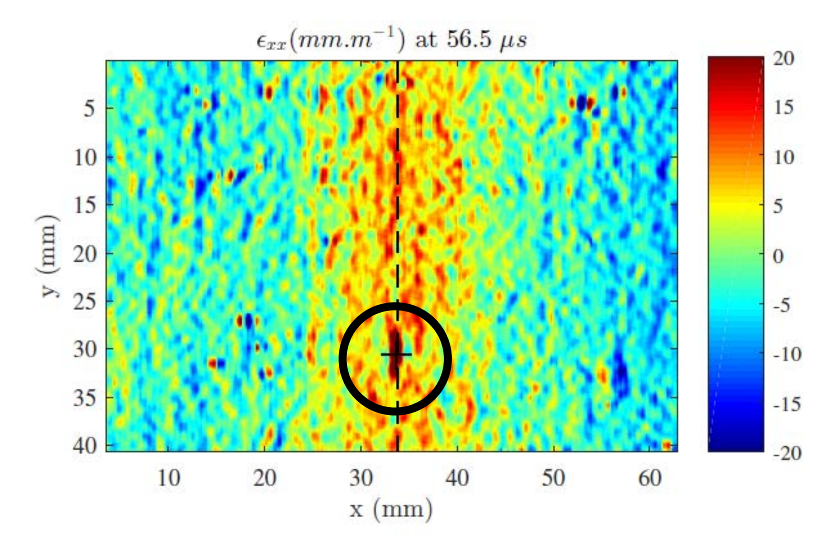
  – Linear in x_2

Fracture analysis – 2/4

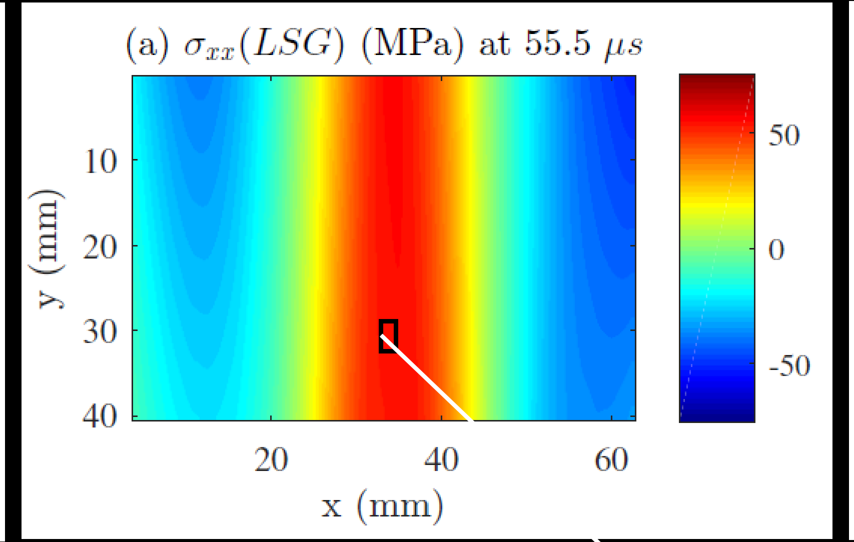


Fracture analysis – 3/4

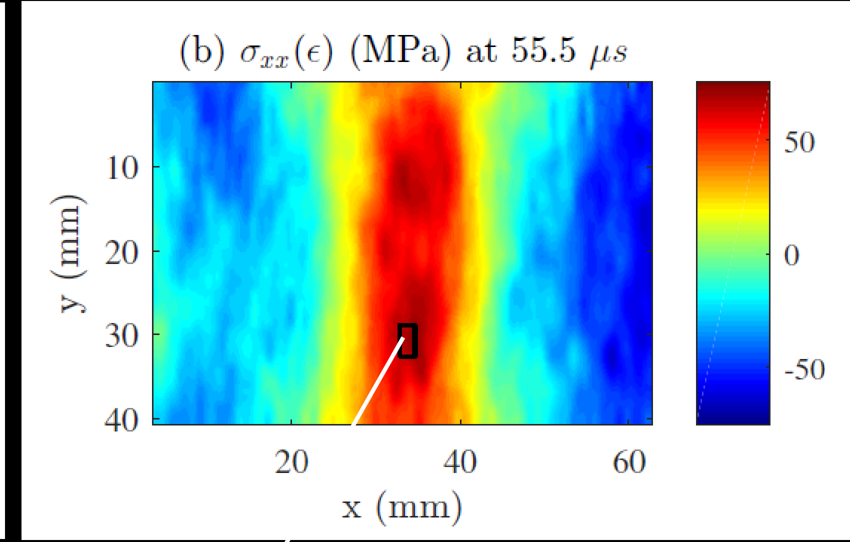
- Fracture criterion



Fracture location



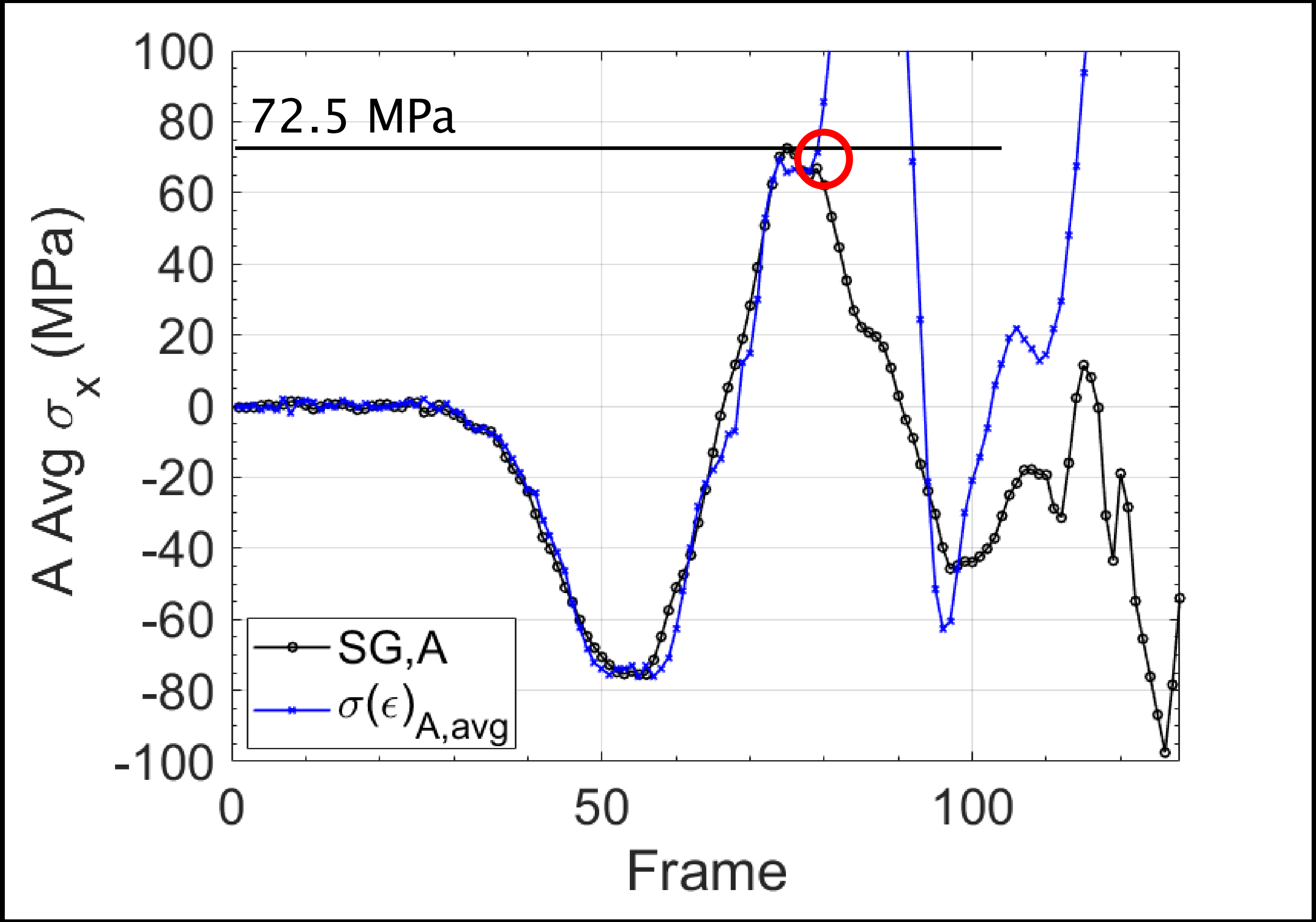
Stress from linear stress gauge



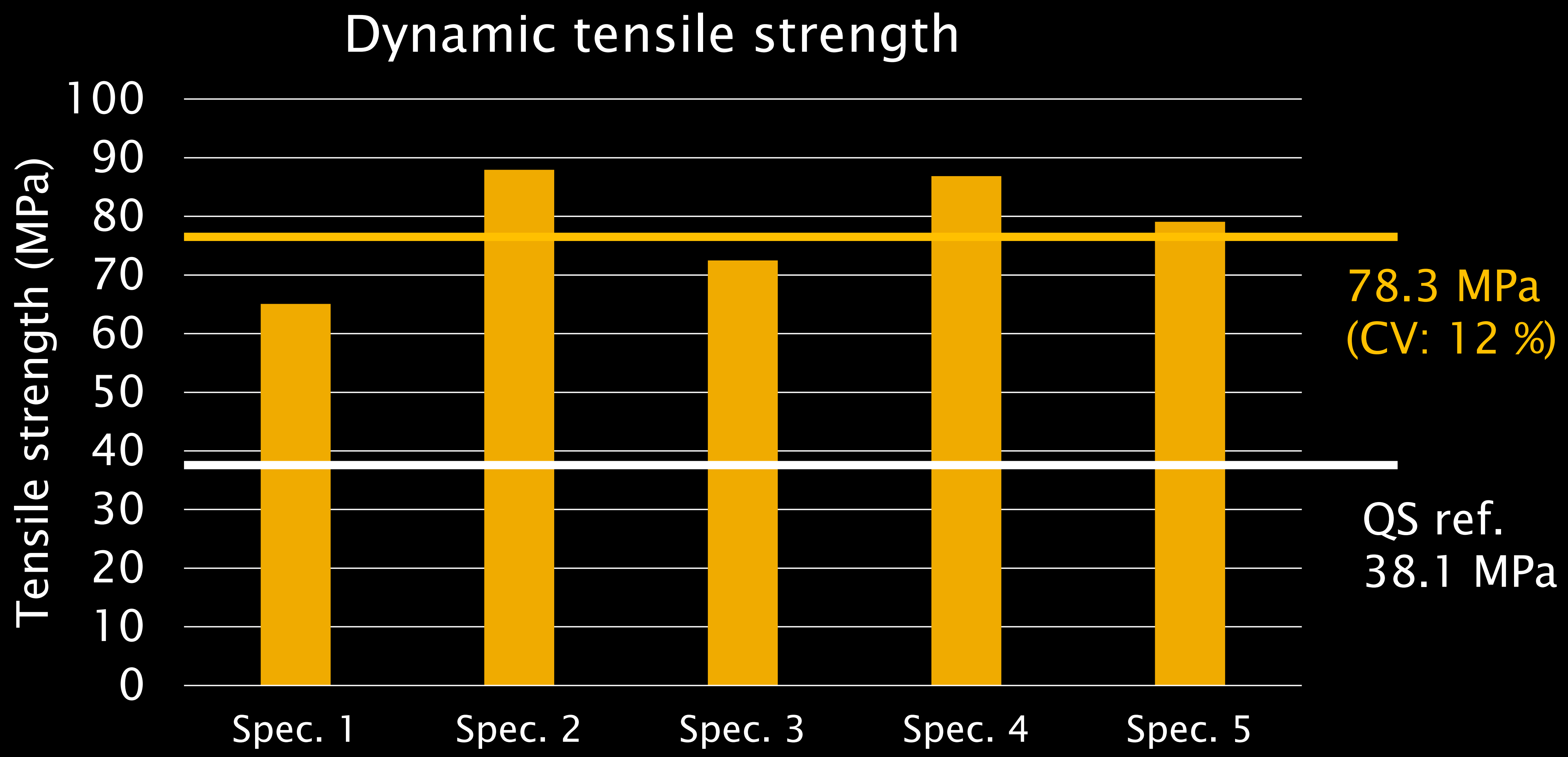
Stress from strain

Plot as a function of time

Fracture analysis – 4/4



Strength identification

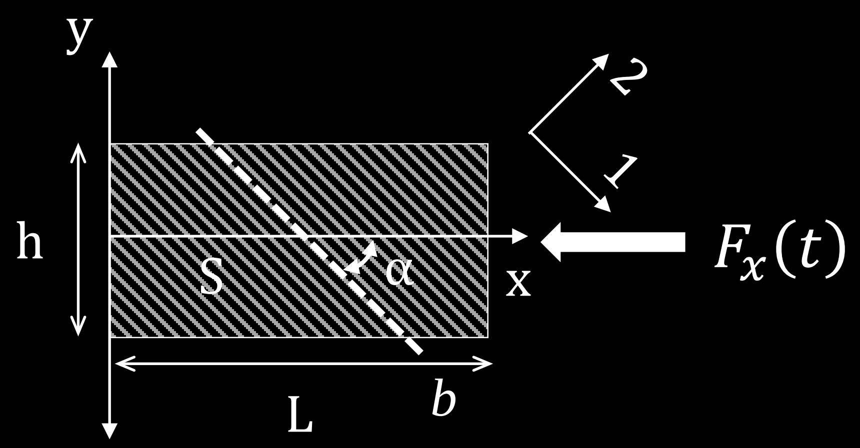


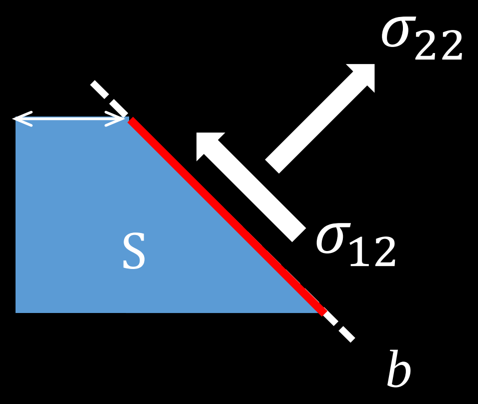
Off-axis IBII test

- Shear properties?

$$\overline{\sigma_{12}}^{x_1}(x,t) = \rho \frac{S}{b} \overline{a_1}(x,t)$$

$$\overline{\sigma_{22}}^{x_1}(x,t) = \rho \frac{S}{b} \overline{a_2}(x,t)$$

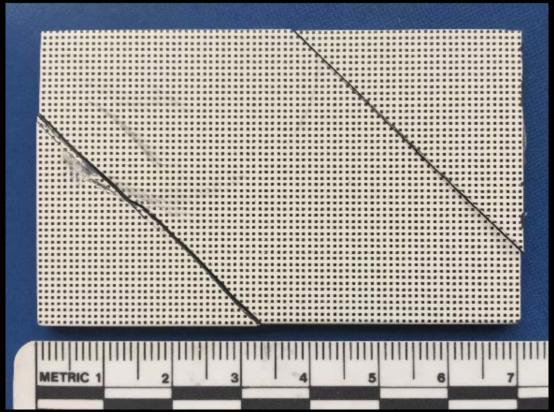


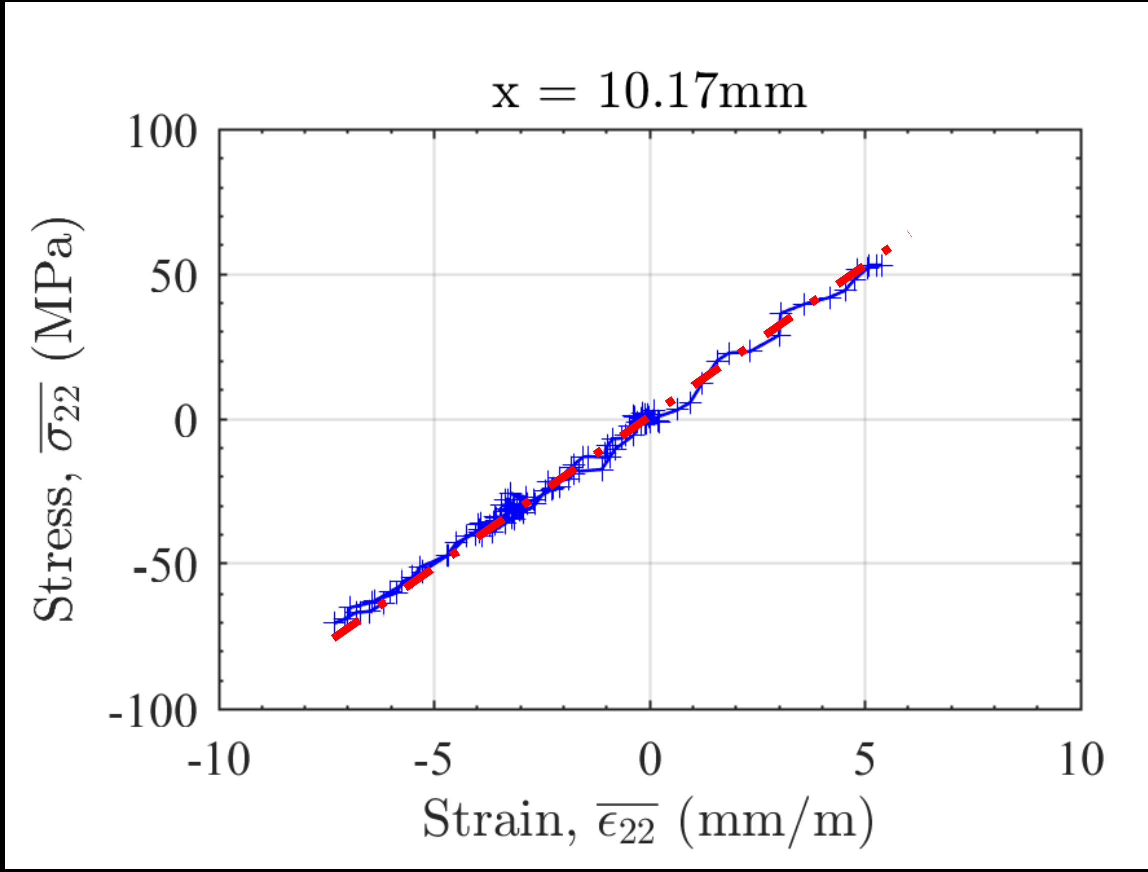


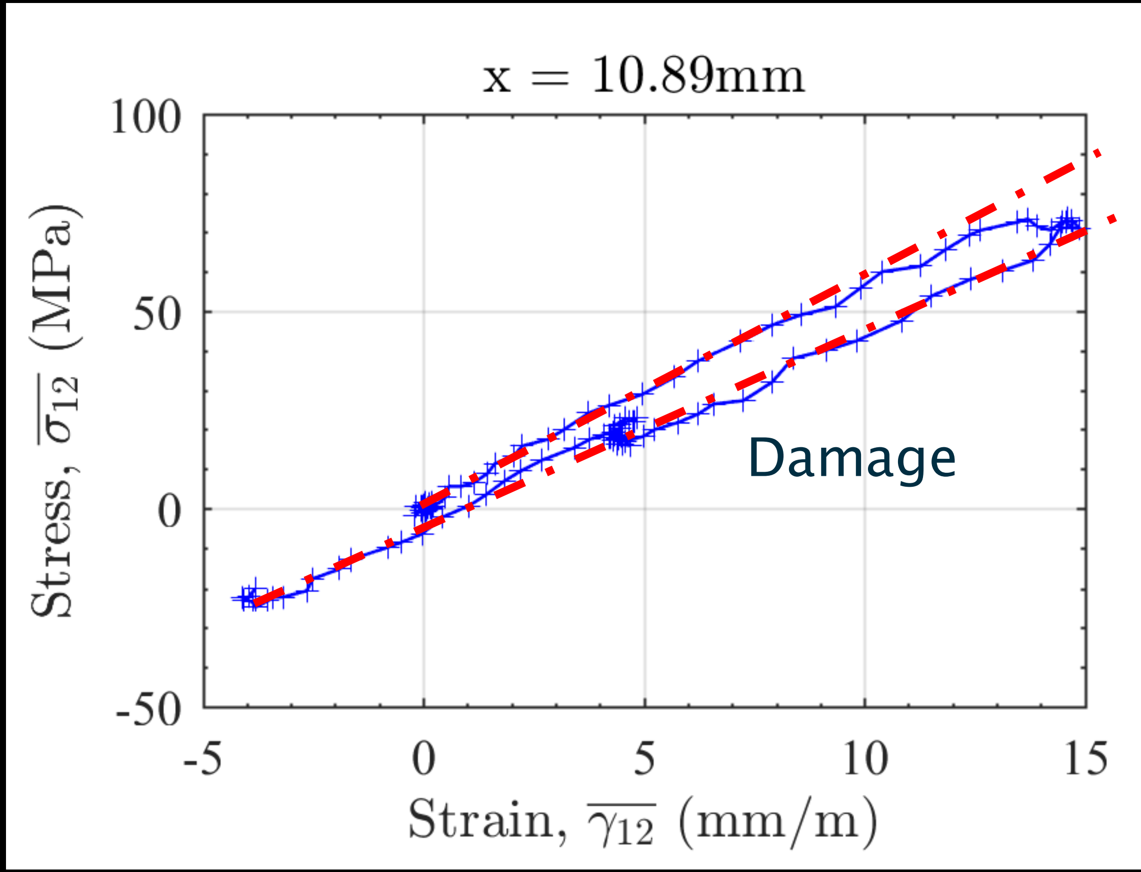
Pierron, F., & Fletcher, L. (2019). Generalized stress-strain curves for IBII tests on isotropic and orthotropic materials. Journal of Dynamic Behaviour of Materials. Vol. 5, Issue 2, pp. 180-193

45° off-axis test

PhD Mr Sam Parry

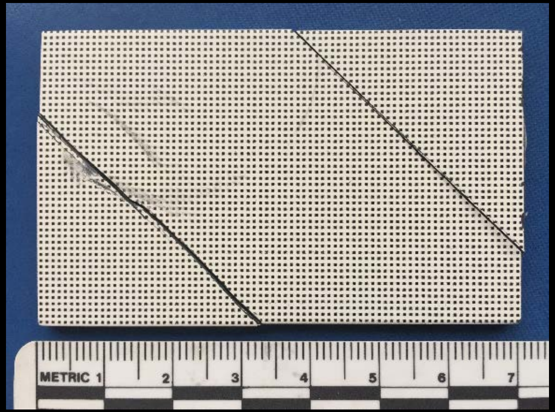




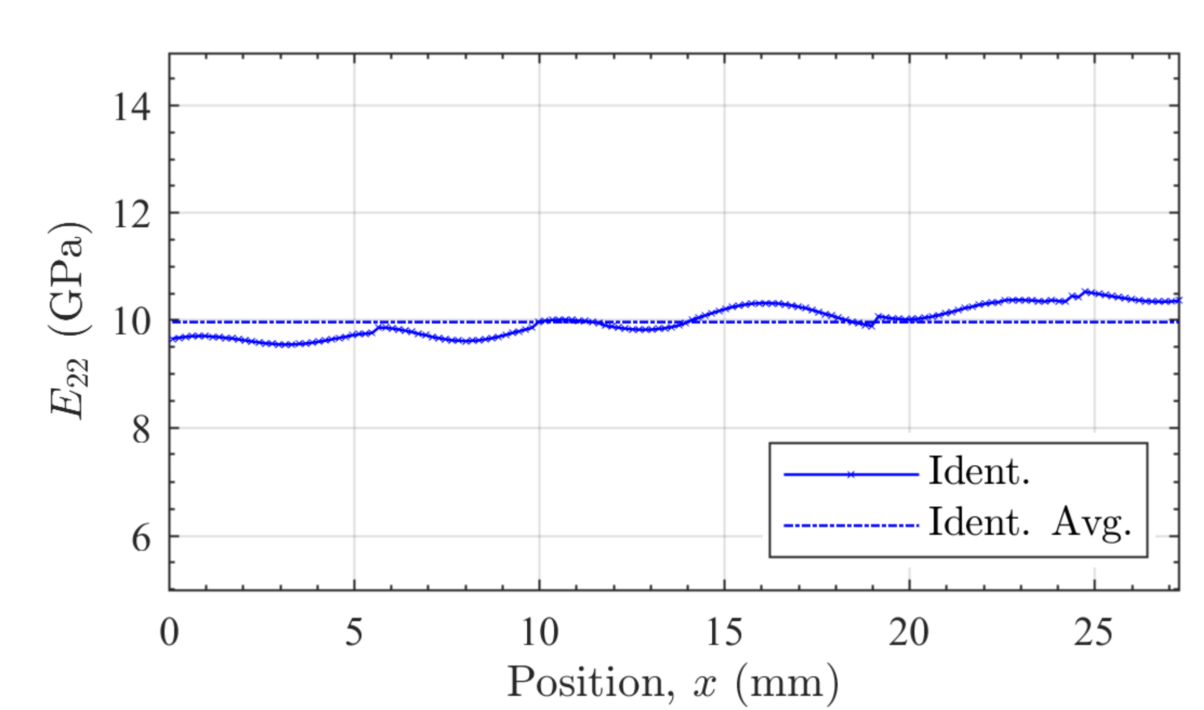


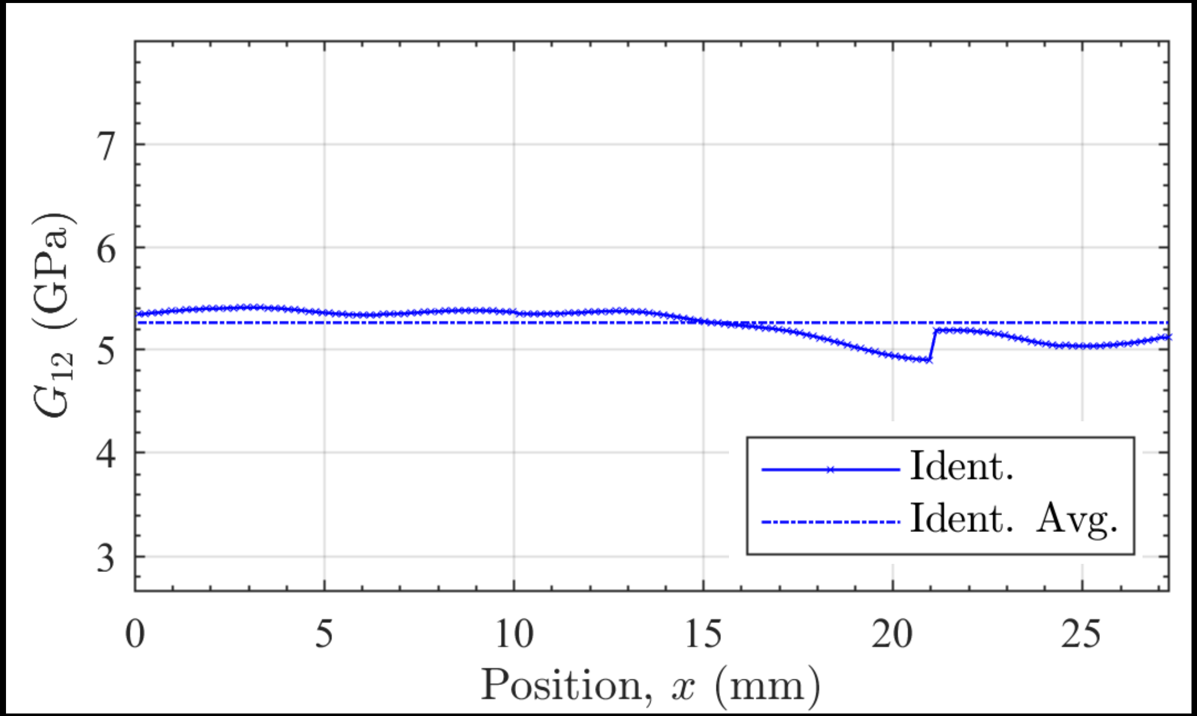
45° off-axis test

PhD Mr Sam Parry



Strain rates: ~1000 – 2000 s^{-1}





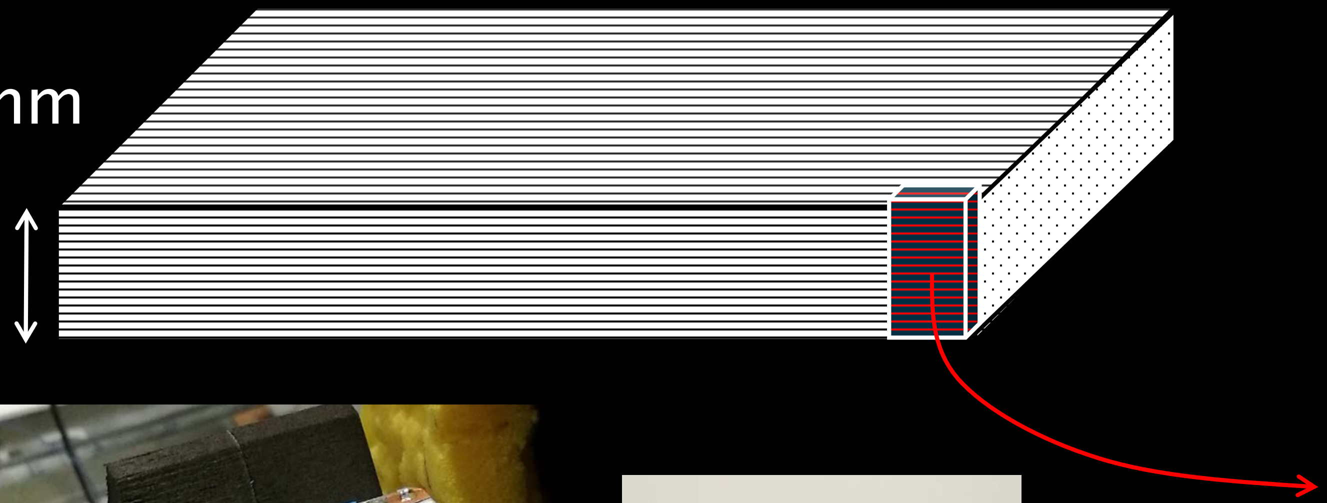
Interlaminar properties – 1/2

- Interlaminar tension

PhD of Mr Jared Van Blitterswyk

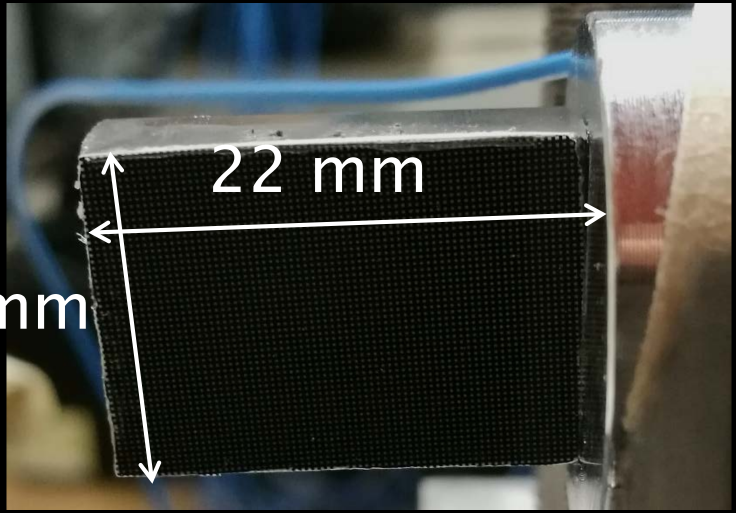
Grid pitch: 0.3 mm

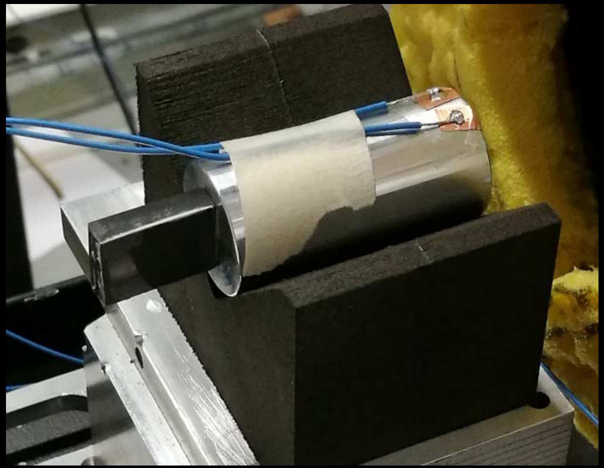
22 mm



Thickness: 4 mm

15 mm



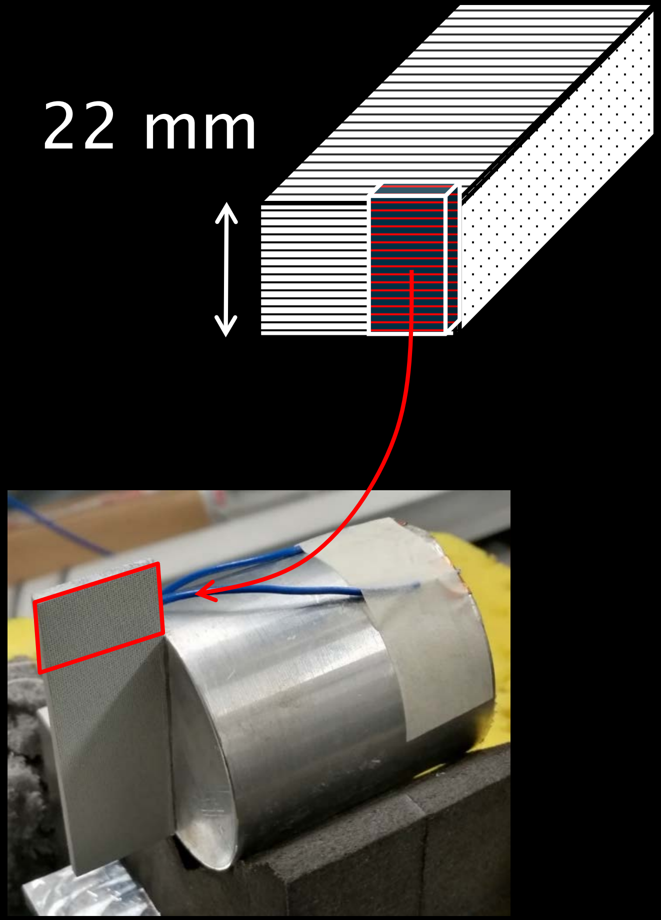


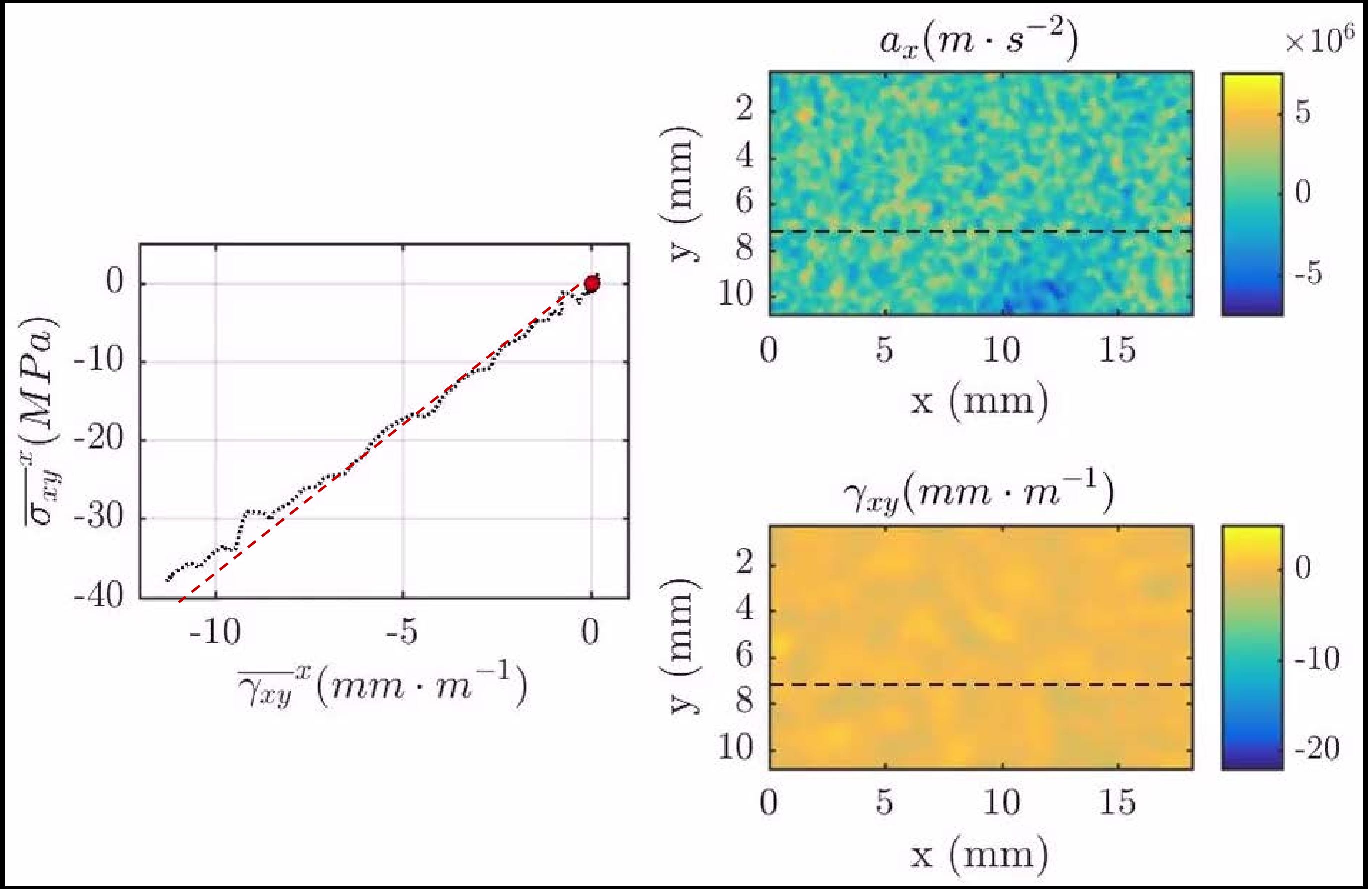
Van Blitterswyk J., Fletcher L., Pierron F., J. of Dyn. Behav. of Mat., 4(4):543-572, 2018

Interlaminar properties – 2/2

- Interlaminar shear

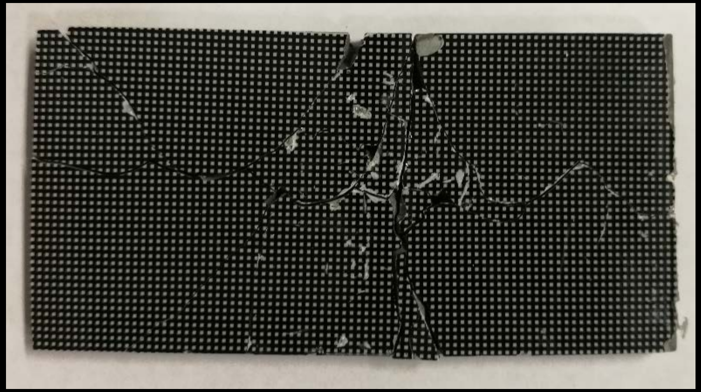
PhD of Mr Jared Van Blitterswyk

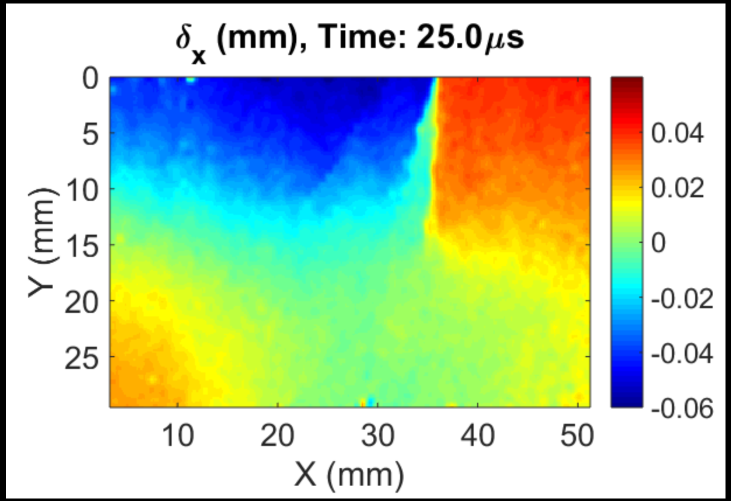




Van Blitterswyk J., Fletcher L., Pierron F., in preparation, 2019

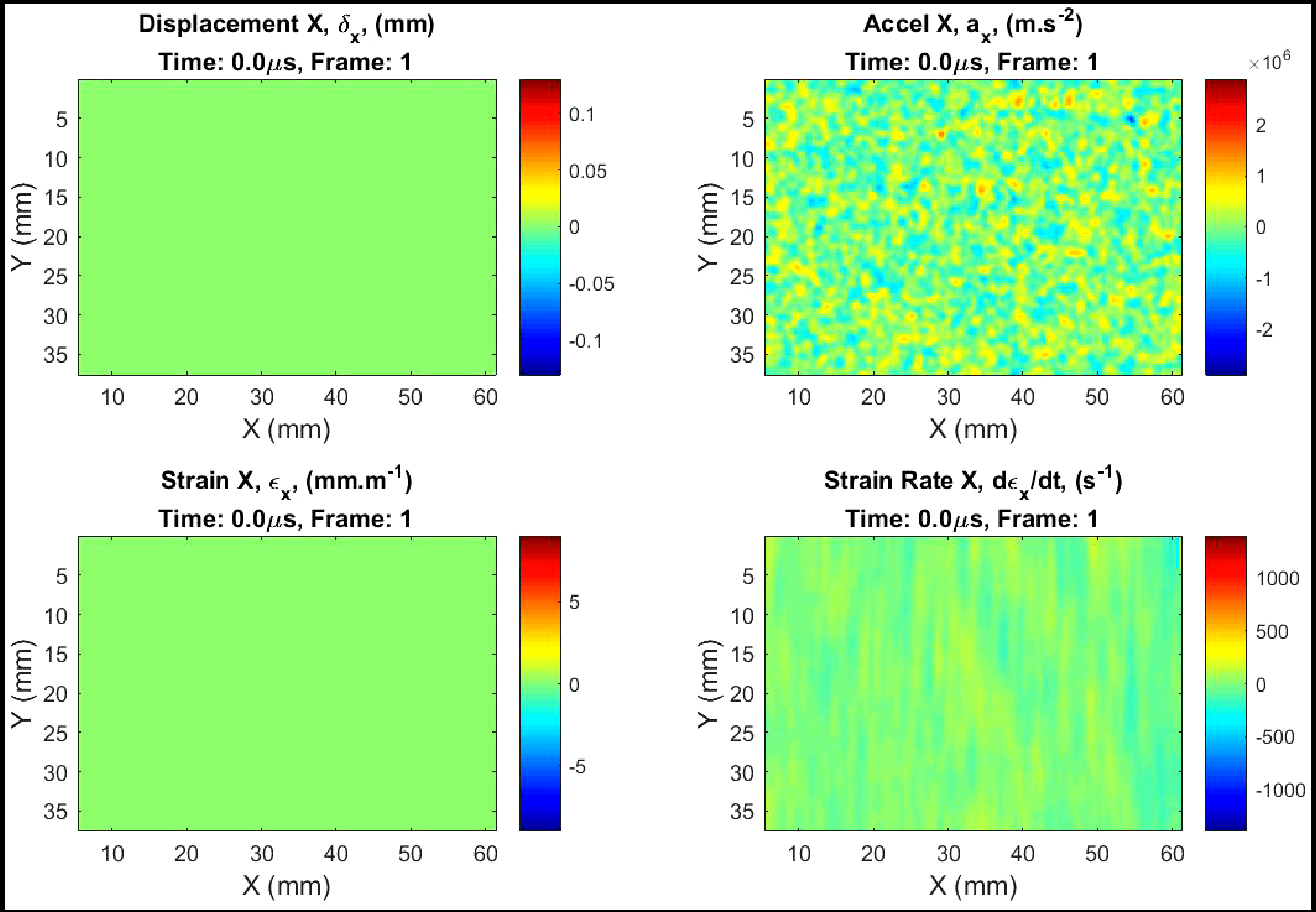
IBII test on tungsten carbide cermet

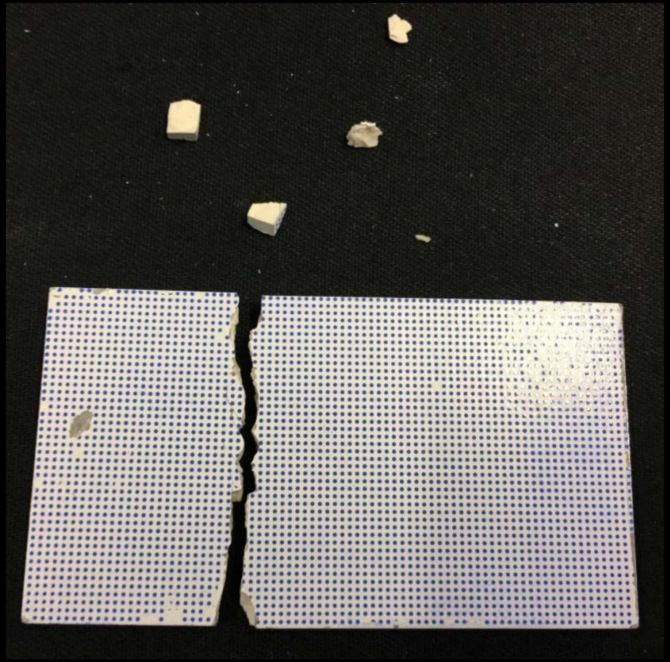




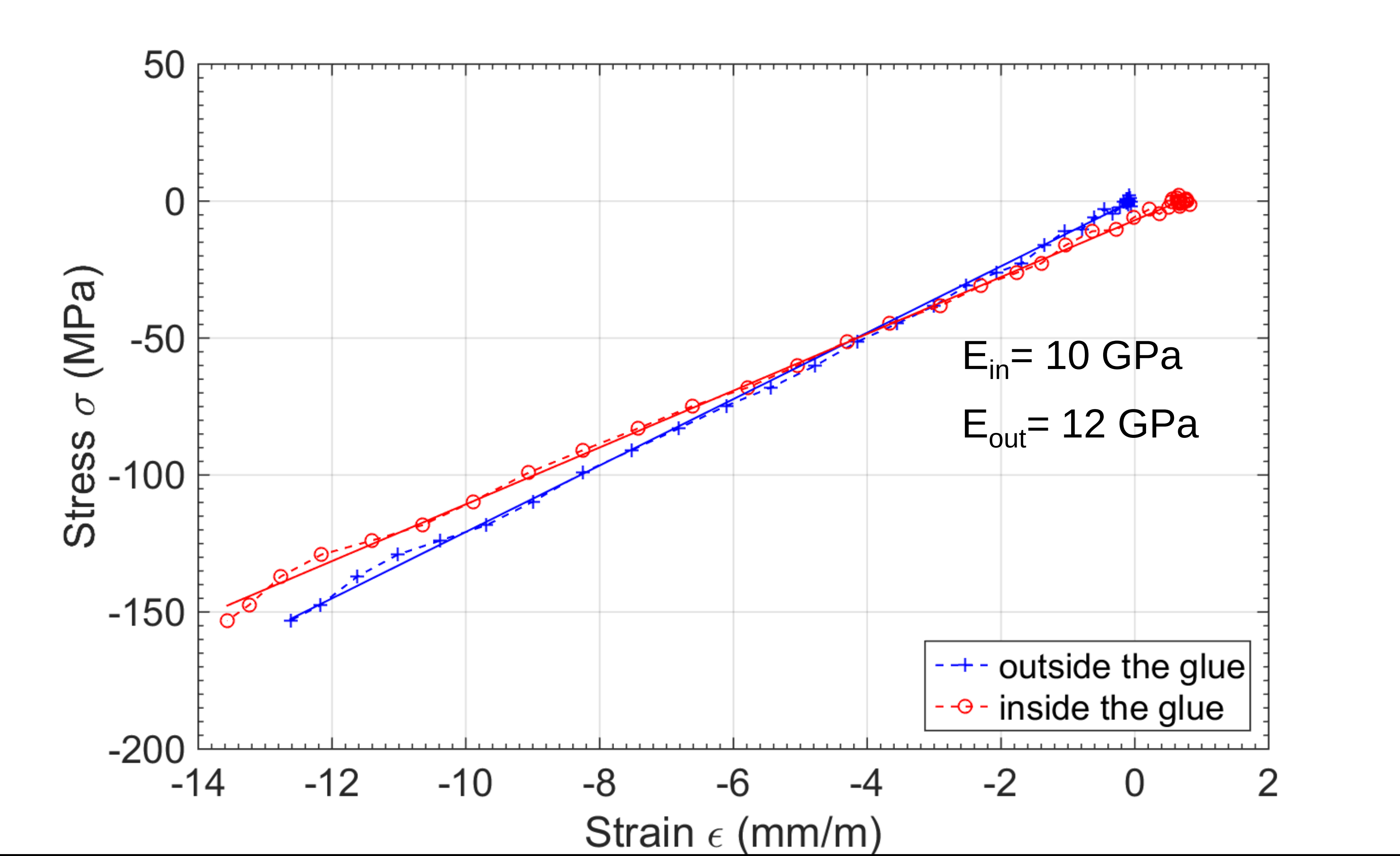
Fletcher L., Pierron F., J. Dyn. Behav. Mat., 4(4):481-504, 2018.

IBII test on adhesives – 1/2

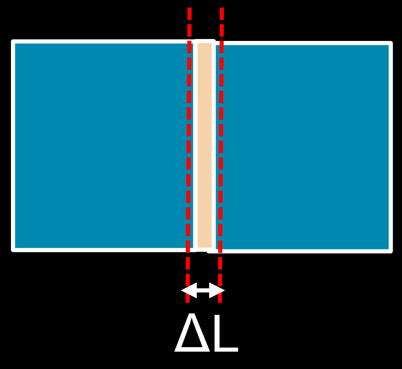




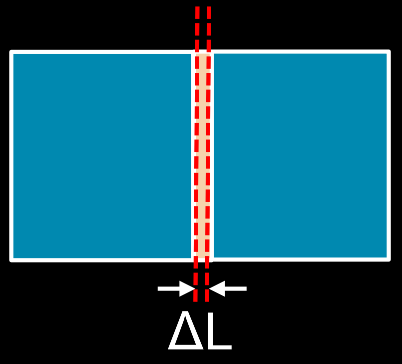
IBII test on adhesives – 2/2



Outside adhesive



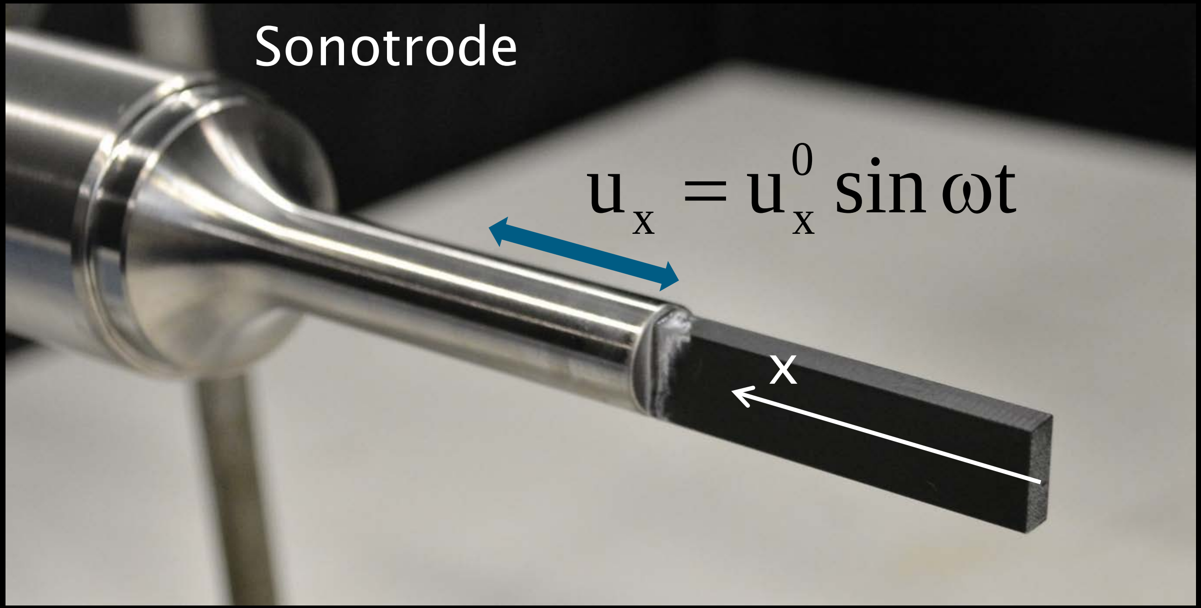
Inside adhesive



$\varepsilon = \Delta L / L_0$

The IBUS test

- Image-Based Ultrasonic Shaking



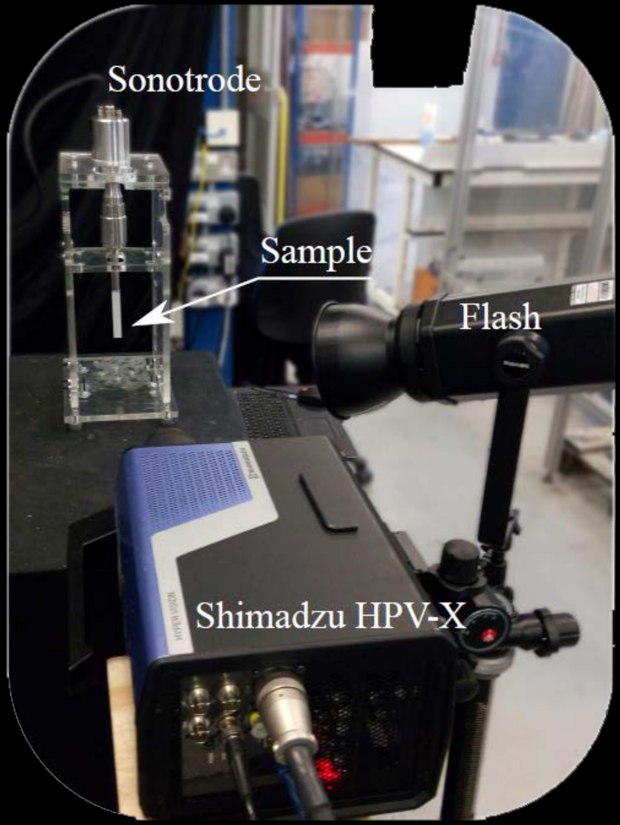
Specimen bonded onto sonotrode (superglue)

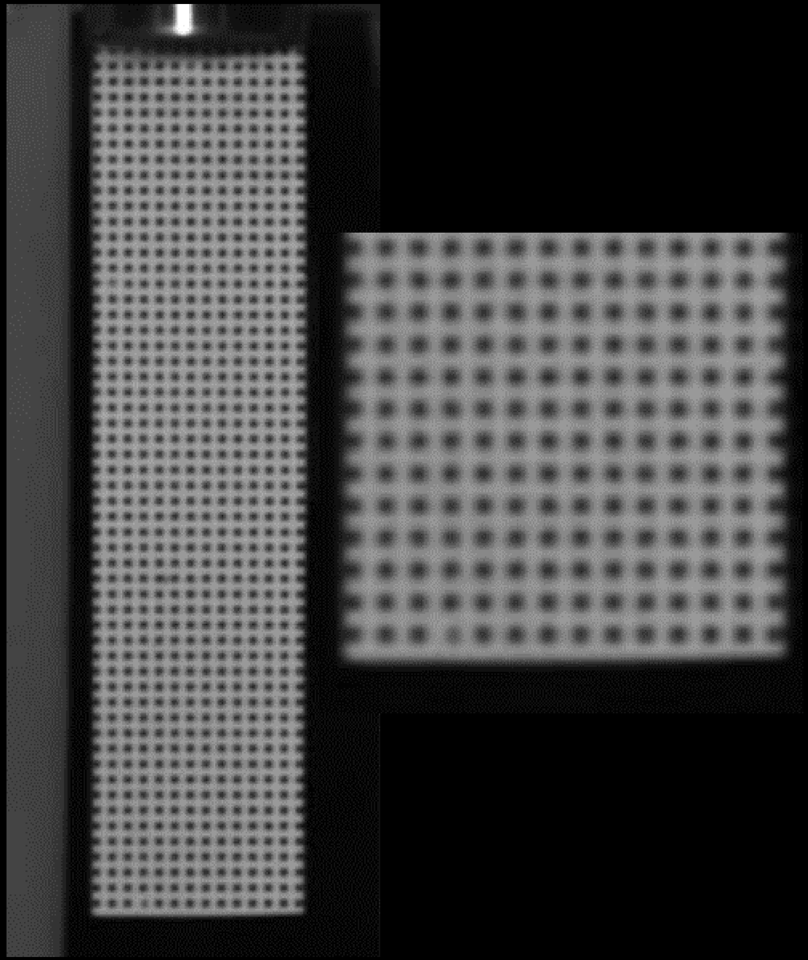
First long. mode, 20 kHz (up to ±60mm)

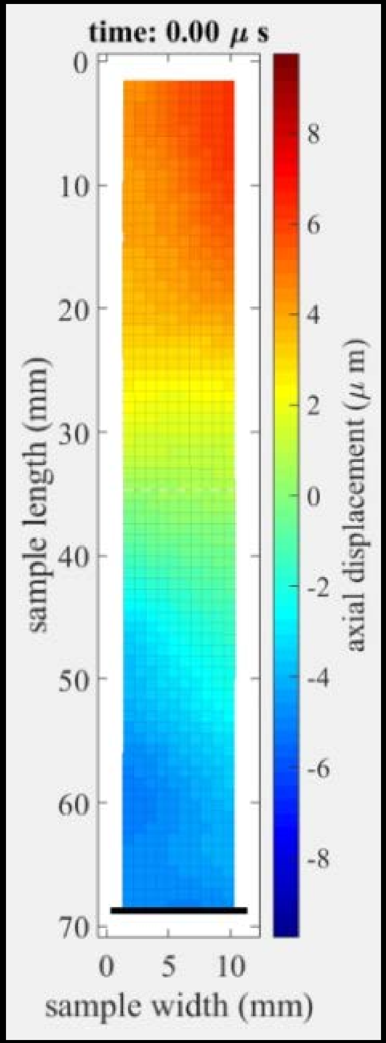
Seghir, R., & Pierron, F. (2018). A novel image-based ultrasonic test to map material mechanical properties at high strain-rates. *Experimental Mechanics, 58(2), 183-206.*

The IBUS test

- PMMA, 90º and off-axis composites







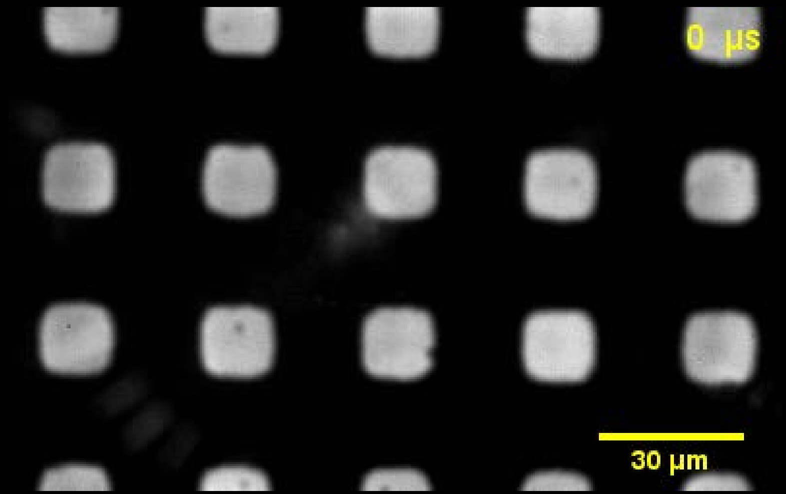
Dr Xavier Régal

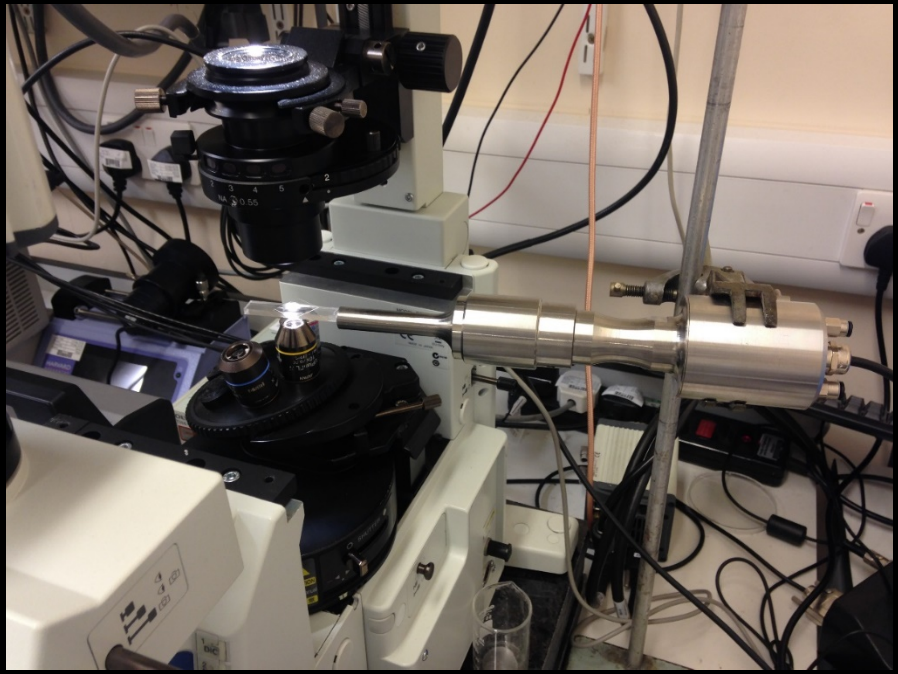
Shimadzu HPV-X: 2 Mfps (400 x 250 pixels), 128 images

Outlook

- Vast design space, new opportunities
  - Successor to Hopkinson bar
- Cameras: ↗ performance and ↘ in price
- Under microscope

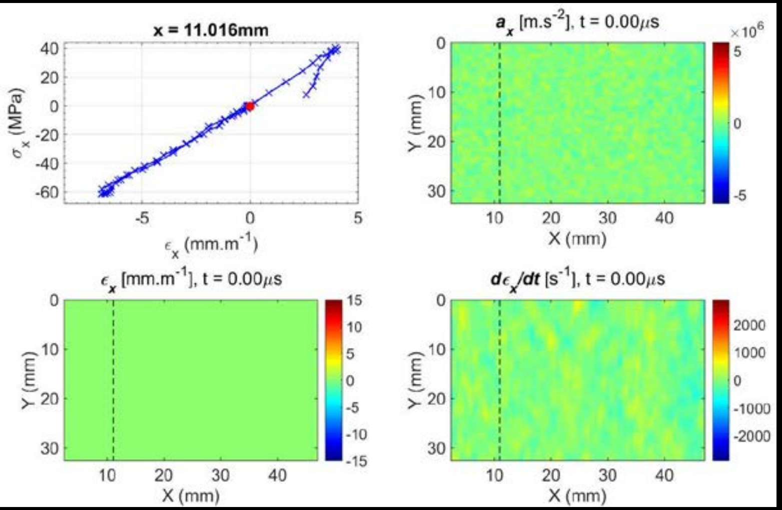
Dr Alex Marek





Sponsors - Acknowledgements

- EPSRC – Established Career Fellowship (2014 – 2019)
- US AFOSR / EOARD
  Grants FA9550-15-1-0293 and FA9550-17-1-0133
- Royal Society Wolfson Research Merit Award (2012-2017)
- Solvay for supplying test specimens



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