Image-based inertial high strain rate tests

Dr Lloyd FLETCHER, Prof. Fabrice PIERRON

Faculty of Engineering and Physical Sciences
University of Southampton, UK
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


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Stress from acceleration: the IBII test

- Inertial impact test
- Equilibrium of blue sub-system

\[ \sigma_{11} (x_1^0, t) = \rho x_1^0 a_1 (x_1^0, t) \]

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

Image-Based Inertial Impact (IBII) test

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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

www.matchid.eu
Experimental configuration

- Aluminium 6061-T6
- Nylon sabot
- Impactor
- Waveguide
- Camera trigger

Thickness: 2.5 mm
50 mm
32 mm
25 mm
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: $\sim 2 \text{ km.s}^{-1}$
- 2 Mfps, total video time: 64 $\mu$s
Kinematic data

![Graphs showing kinematic data](image)

- $\delta_x$ [mm], Time: 14.0 $\mu$s
- $a_x$ [m/s$^2$], Time: 14.0 $\mu$s
- $\epsilon_x$ [mm/m], Time: 14.0 $\mu$s
- $d\epsilon_x/dt$ [s$^{-1}$], Time: 14.0 $\mu$s
Stress-strain curve

Small Poisson’s effect because of $90^\circ$ configuration $\sigma_y \approx E_{yy} \varepsilon_y$
Modulus - 1/2

![Graph showing Elastic Modulus E_{xx} (GPa) vs X position (mm)]
Modulus – 2/2

Transverse modulus (GPa)

Spec. 1 | Spec. 2 | Spec. 3 | Spec. 4 | Spec. 5

9.28 GPa (CV: 2.8 %)

QS ref: 7.90 GPa

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Fracture analysis – 1/4

- The ‘stress gauge’

\[
\sigma_{11}(x_1^0, t) = \rho x_1^0 a_1(x_1^0, t)
\]

- The ‘linear stress gauge’

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

- Linear in \(x_2\)
Fracture analysis – 2/4

\[ \sigma(\varepsilon) \]

\[ \varepsilon_x [\text{mm.m}^{-1}] \quad t = 36.50 \mu s \]

\[ a_x [\text{m.s}^{-2}] \quad t = 36.50 \mu s \]

\[ d\varepsilon_x/dt [\text{s}^{-1}] \quad t = 36.50 \mu s \]
Fracture analysis – 3/4

- Fracture criterion

Fracture location

Stress from linear stress gauge

Stress from strain

Plot as a function of time

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Fracture analysis – 4/4

![Graph showing stress-strain relationship with a peak at 72.5 MPa]

- **A Avg \( \sigma_x \) (MPa)**
- **SG,A**
- \( \sigma(\epsilon) \) \_A,avg

**Frame**

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**Dynamic tensile strength**

- **Spec. 1**: 60 MPa
- **Spec. 2**: 80 MPa
- **Spec. 3**: 70 MPa
- **Spec. 4**: 80 MPa
- **Spec. 5**: 70 MPa

**78.3 MPa** (CV: 12 %)

**QS ref.**: 38.1 MPa

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Off-axis IBII test

Shear properties?

\[
\sigma_{12}(x, t) = \rho \frac{S}{b} a_1(x, t)
\]

\[
\sigma_{22}(x, t) = \rho \frac{S}{b} a_2(x, t)
\]

45° off-axis test

PhD Mr Sam Parry
45° off-axis test

PhD Mr Sam Parry

Strain rates: $\sim 1000 - 2000 \text{ s}^{-1}$
Interlaminar properties – 1/2

- Interlaminar tension

PhD of Mr Jared Van Blitterswyk

Grid pitch: 0.3 mm

Thickness: 4 mm


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Interlaminar properties – 2/2

- Interlaminar shear

22 mm

PhD of Mr Jared Van Blitterswyk

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

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IBII test on tungsten carbide cermet


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IBII test on adhesives – 1/2
IBII test on adhesives – 2/2

\[ \varepsilon = \frac{\Delta L}{L_0} \]

Outside adhesive

\[ E_{\text{in}} = 10 \text{ GPa} \]
\[ E_{\text{out}} = 12 \text{ GPa} \]

Inside adhesive

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The IBUS test

- Image-Based Ultrasonic Shaking


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

- PMMA, 90º and off-axis composites

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

- Vast design space, new opportunities
  - Successor to Hopkinson bar

- Cameras: \(\uparrow\) performance and \(\downarrow\) in price

- Under microscope

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