Strain mapping of composite sandwich structures for wind turbine applications

John Dear, Imperial College London
Amit Puri, Imperial College London
Andy Morris, E.ON Engineering, E.ON UK, Technology Centre
Find Jensen, Wind Energy Department, Risø National Laboratory for Sustainable Energy - DTU

BSSM One-Day Seminar - Core Materials and Sandwich Structures
Department of Engineering, University of Liverpool, Wednesday 2nd April 2008

Imperial College London

e·on UK

Overall Research Aim

- To improve the design of the wind turbine blade structures
- To identify areas most prone to fatigue and other damage
- To identify the best locations for Acoustic Emission (AE) and other sensors
- To provide data that will assist in determining the end-of-life of working blades
- To provide for the design of larger blades needed for the next generation of wind turbines and for maintenance difficulties when the turbines are located offshore

Imperial College London

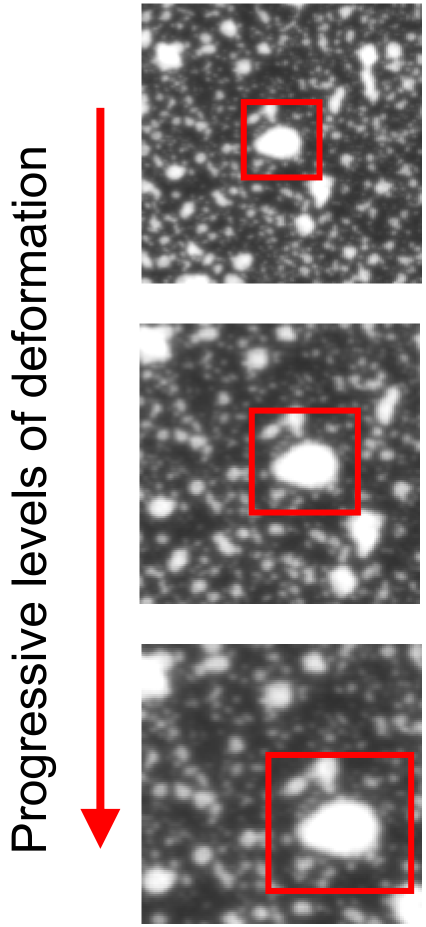
e·on UK

Presentation Overview

- Project Background
- Digital Image Correlation
- Full-Scale Blade Testing
- Flange Panel Results
- Sandwich Panel Results
- Summary and Future Testing
- Questions

DIC Strain Measurement Method

- 2D / 3D full-field surface strain evaluation technique
- GOM ARAMIS software used
- Use of digital cameras
- Arbitrary paint pattern with high contrast
- Image split into squares of pixels – facets
- Relative facet displacement mapped – obtain strain
- 8 bit resolution in correlation method
- Potential for DIC integration into blade inspection and maintenance

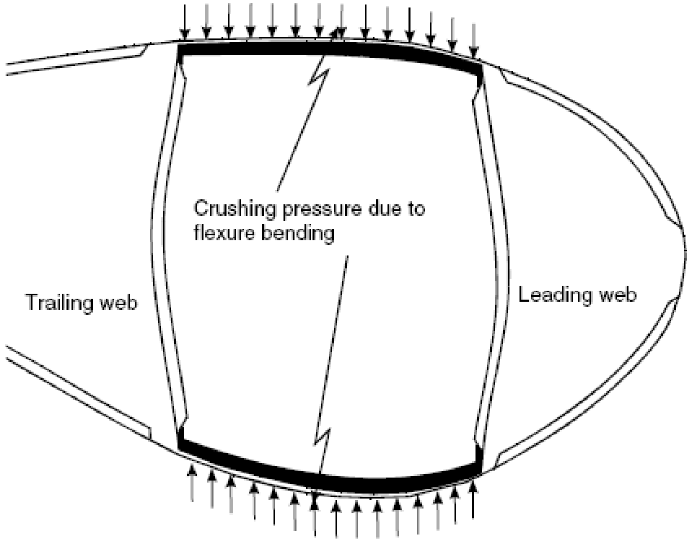


Imperial College London

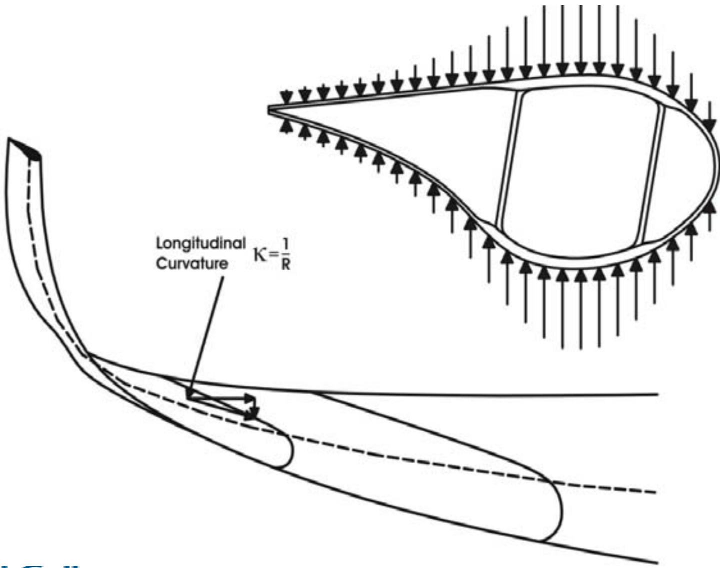
e·on UK

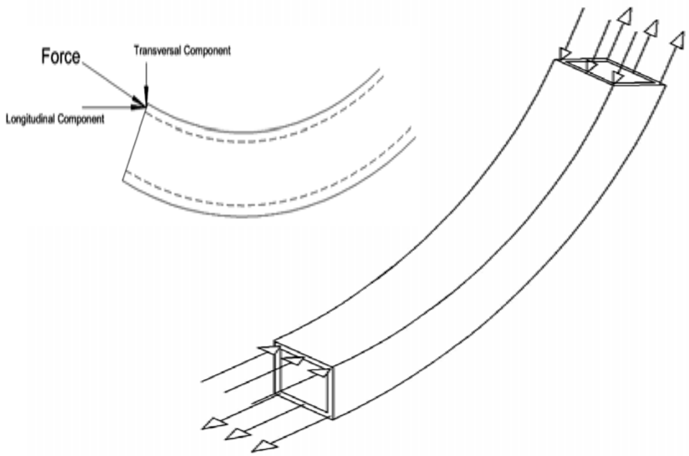
Background

- Hollow profile in blade
- Lightweight materials
- Many different loading types
- Flap-wise loading causes flexure
- Flexural resistance added by box-beam section
- Flexural Loading produces “crushing pressure” - the Brazier effect



Dr Find Jensen et. al. (2006), Composite Structures

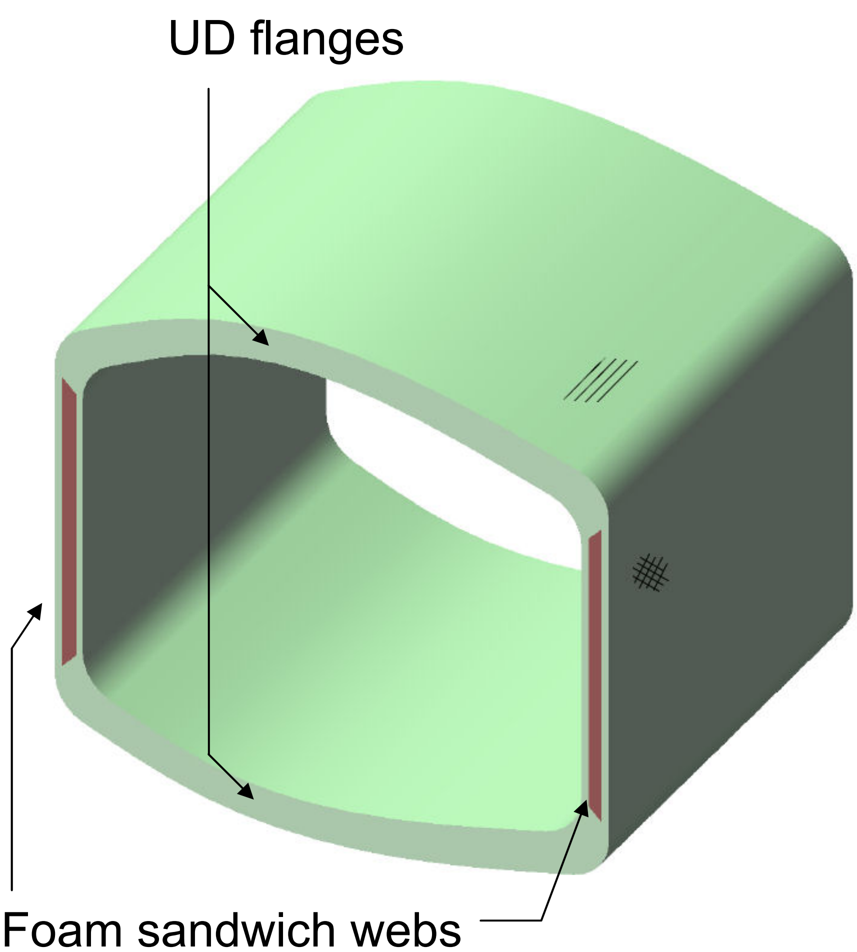




Imperial College London

e·on UK

Box-beam overview



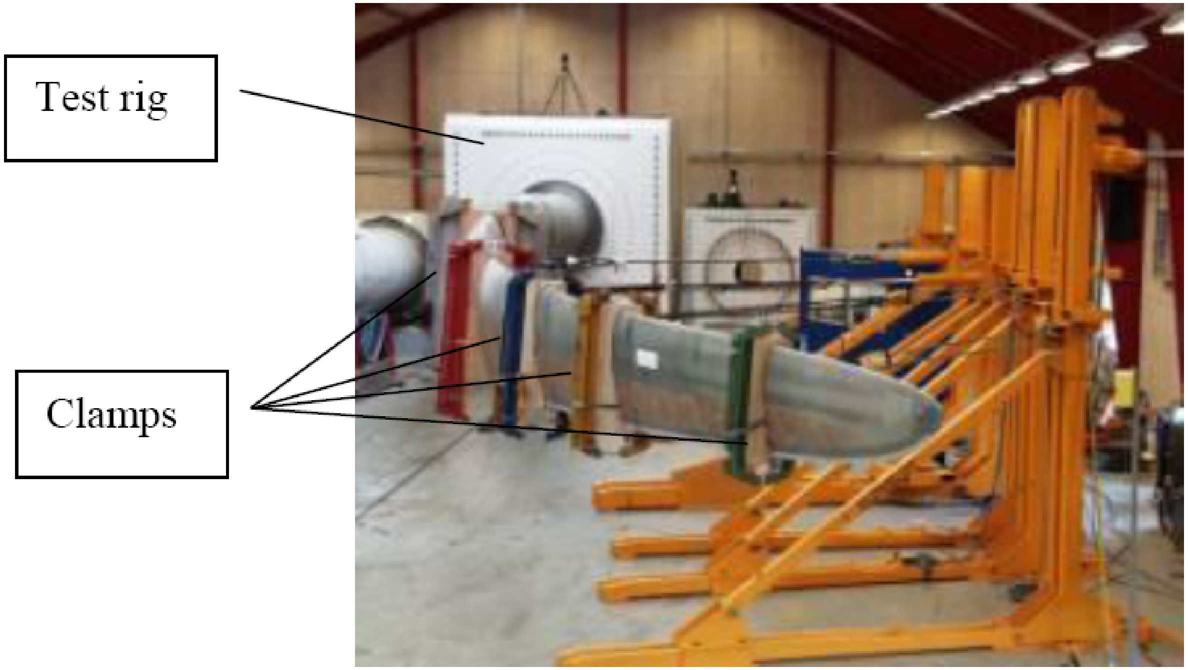
- Lightweight materials:
  - Glass-fibre with epoxy resin
  - PVC foam
- Unidirectional fibres for flange - built up in layers
- $\pm 45^{o}$ biaxial outer layers of flanges
- $\pm 45^{o}$ biaxial layers for webs – foam centre creates sandwich
- Dimensions vary along blade length

Imperial College London

E.ON UK

Full-Scale Blade Testing
Flap-wise loading

- Full-scale flap-wise bending test
- Performed by Dr Find Jensen et al. (Risø – DTU)



Dr Find Jensen et. al. (2008), Risǿ-R-1588(EN),
Risǿ – DTU

Imperial College London

e·on UK

Full-Scale Blade Testing

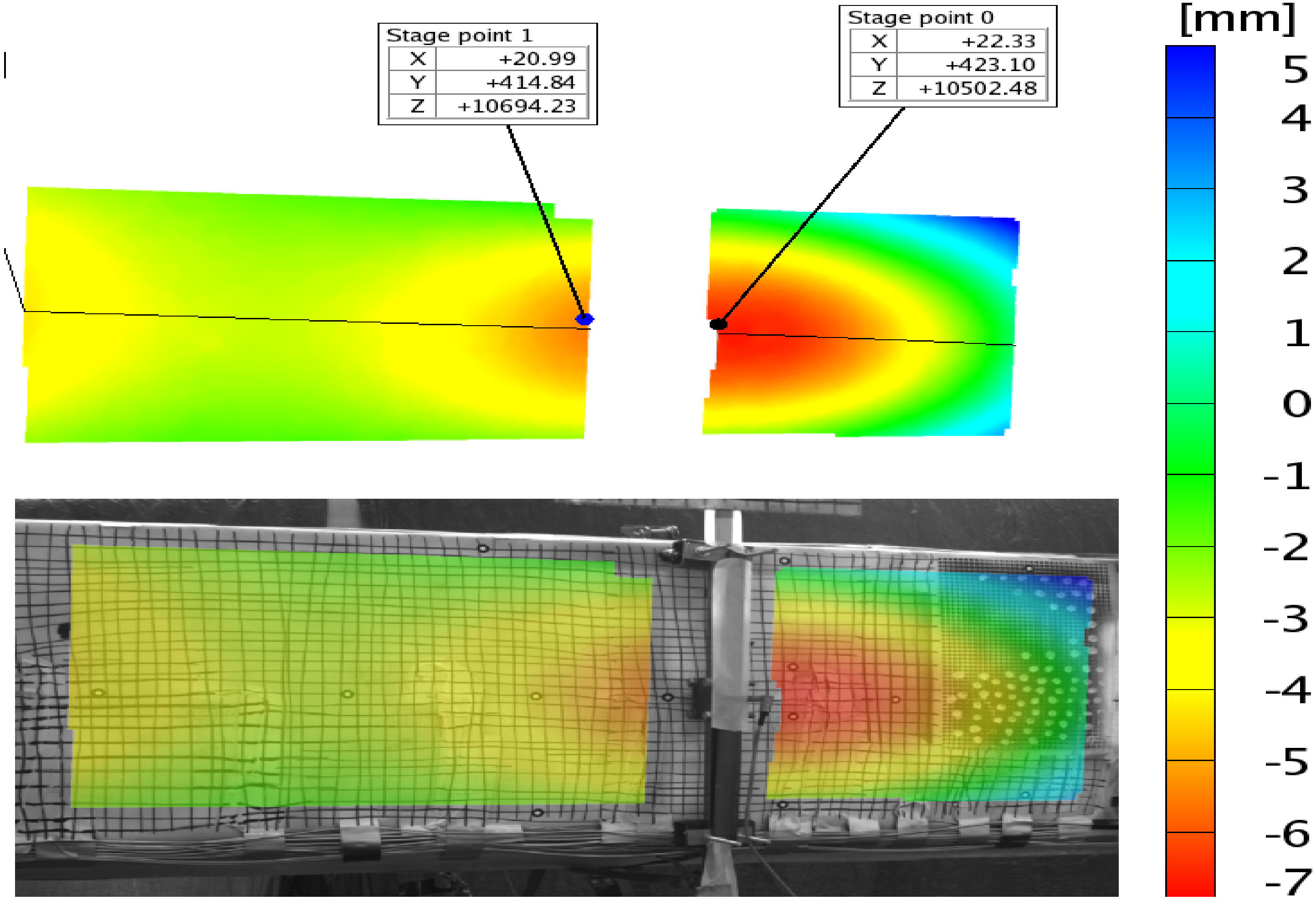
Box-Beam

- Full-scale test of 34 m load carrying box girder
- Performed by Dr Find Jensen et al. (Risø – DTU)

Dr Find Jensen et. al. (2008), Risø-R-1588(EN),
Risø – DTU

Full-Scale Blade Testing

Compression cap deflections



Dr Find Jensen et. al. (2008), Risø-R-1588(EN),

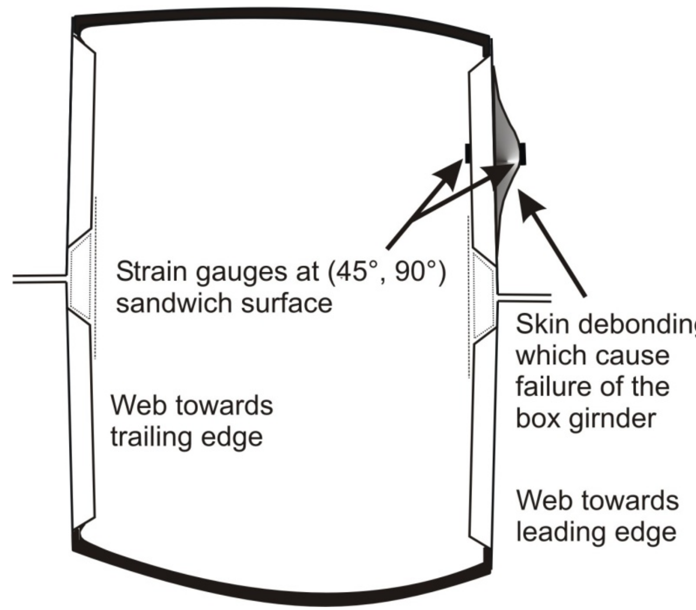
Risø – DTU

Imperial College London

e·on UK

Full-Scale Blade Testing

Initiation of failure in shear web

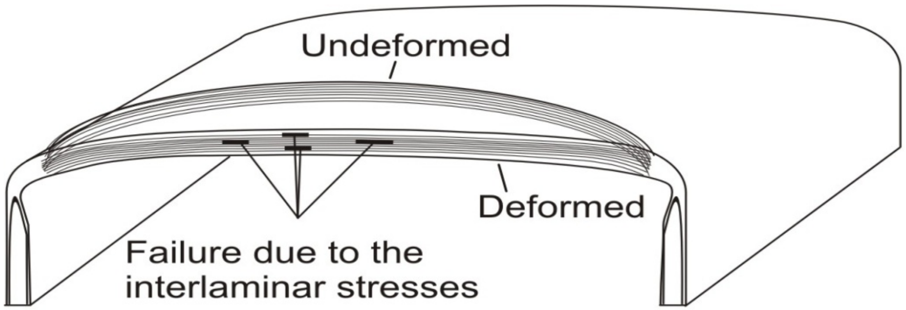


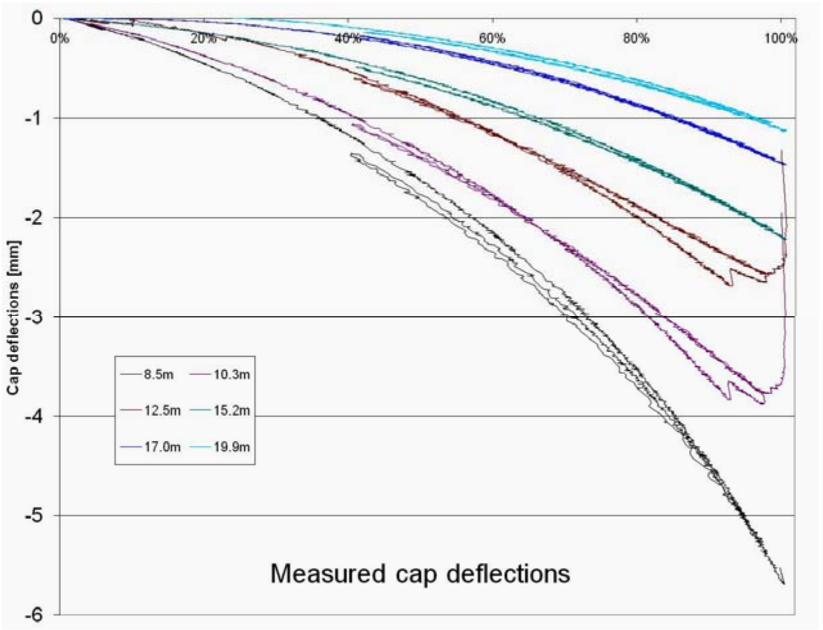
Shear debonding (or wrinkling) of the outer skin leads to ultimate failure

Dr Find Jensen et. al. (2008), Risø-R-1588(EN),
Risø – DTU

Full-Scale Blade Testing

Transverse inter-laminar shear failure critical

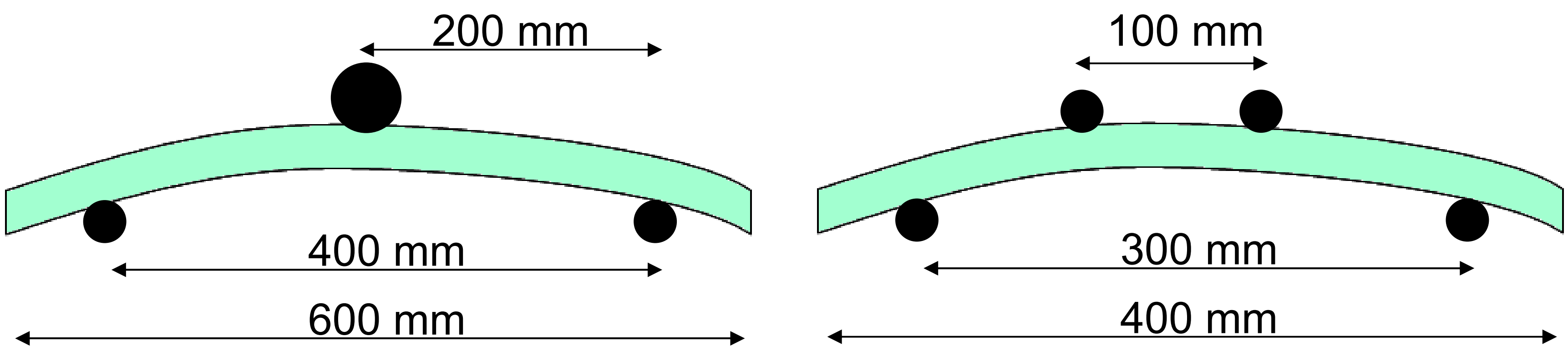




Dr Find Jensen et. al. (2008), Risø-R-1588(EN),

Risø – DTU

Flange Panel Experiments



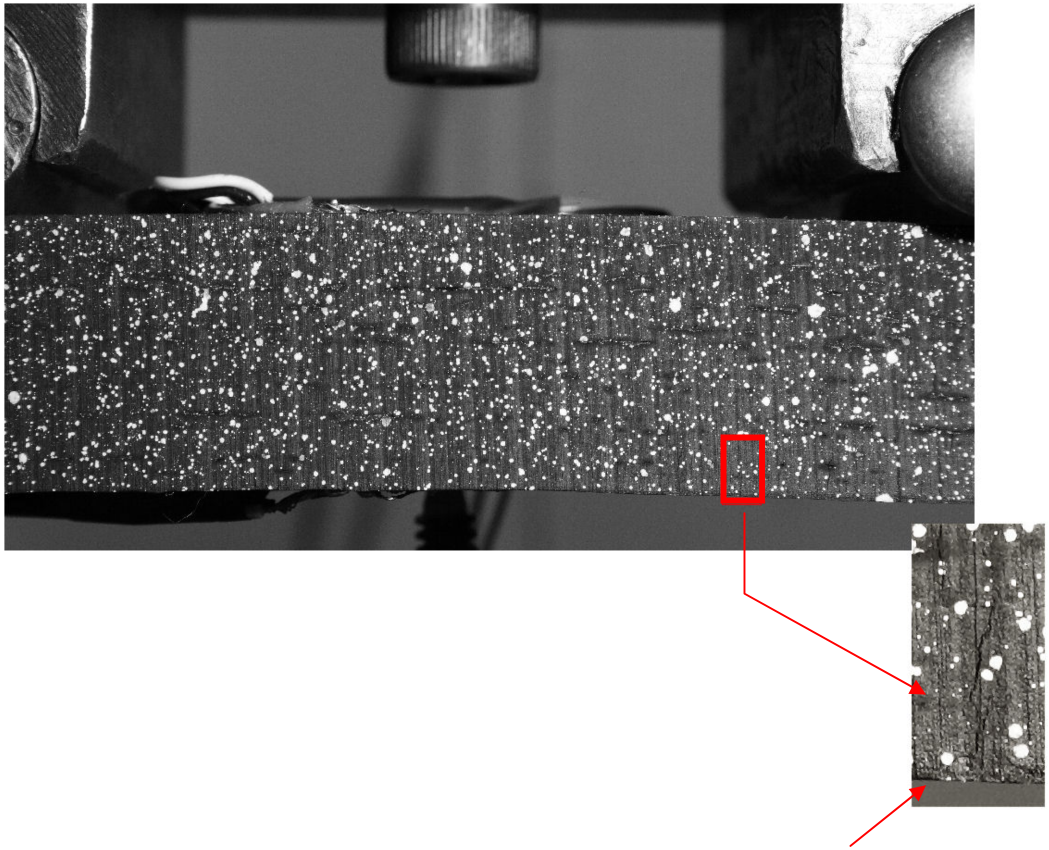
- Three and Four point loading:
  - Symmetric roller positioning
  - Non-symmetric curvature of specimen
- Specimen widths:
  - 3 point – 75mm
  - 4 point – 50 mm

Imperial College London

e·on UK

Flange Panel Results

- Failure at site of maximum tensile stress
- Surface cracks form parallel to UD fibres
- Crack growth up through the UD layers
- Critical point when tensile biaxial layer fails

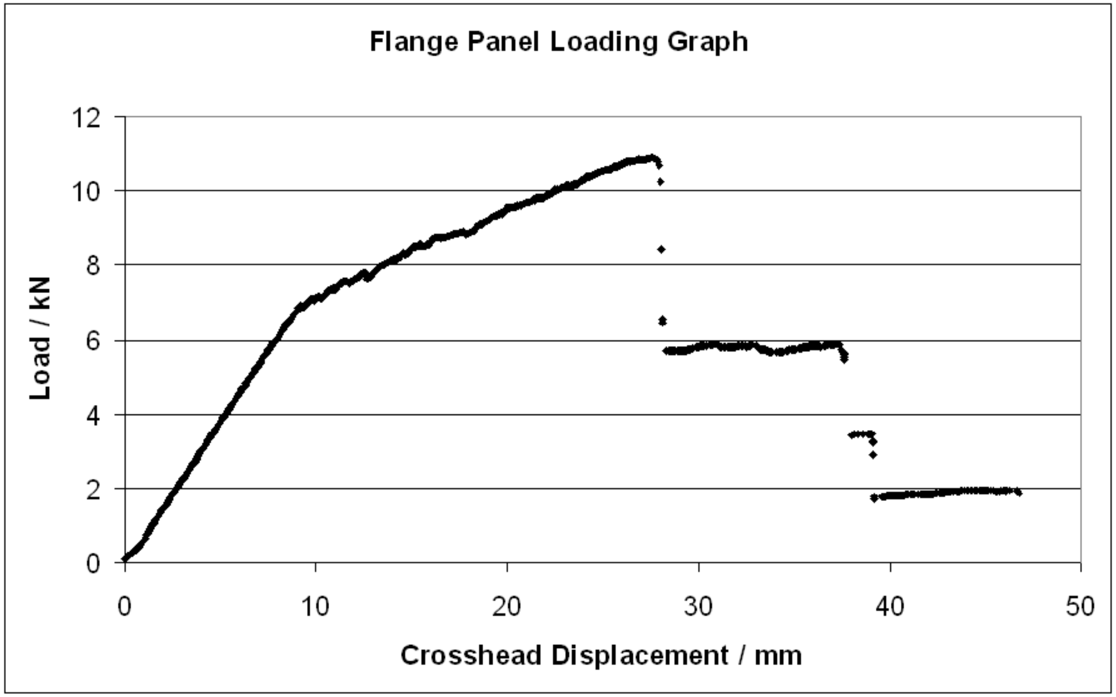


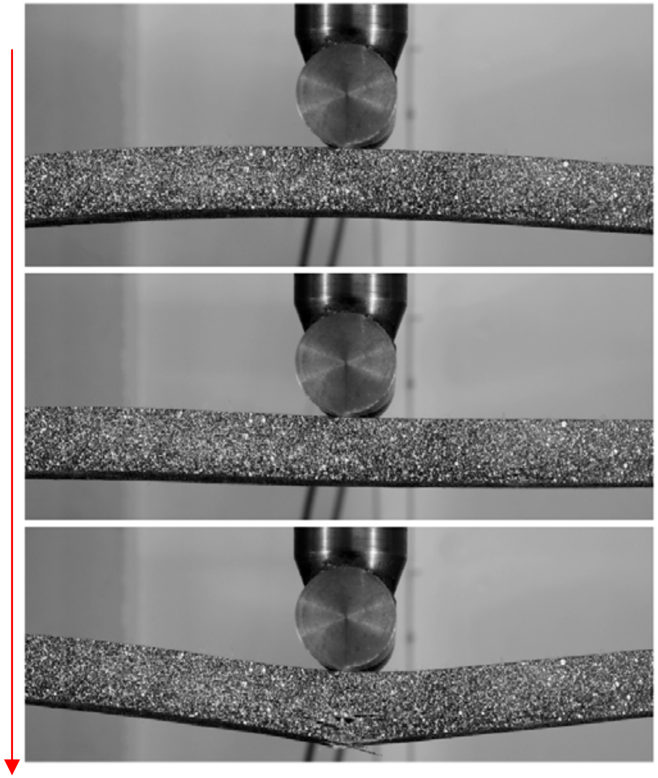
Bottom of specimen – tensile biax layer

Imperial College London

e·on UK

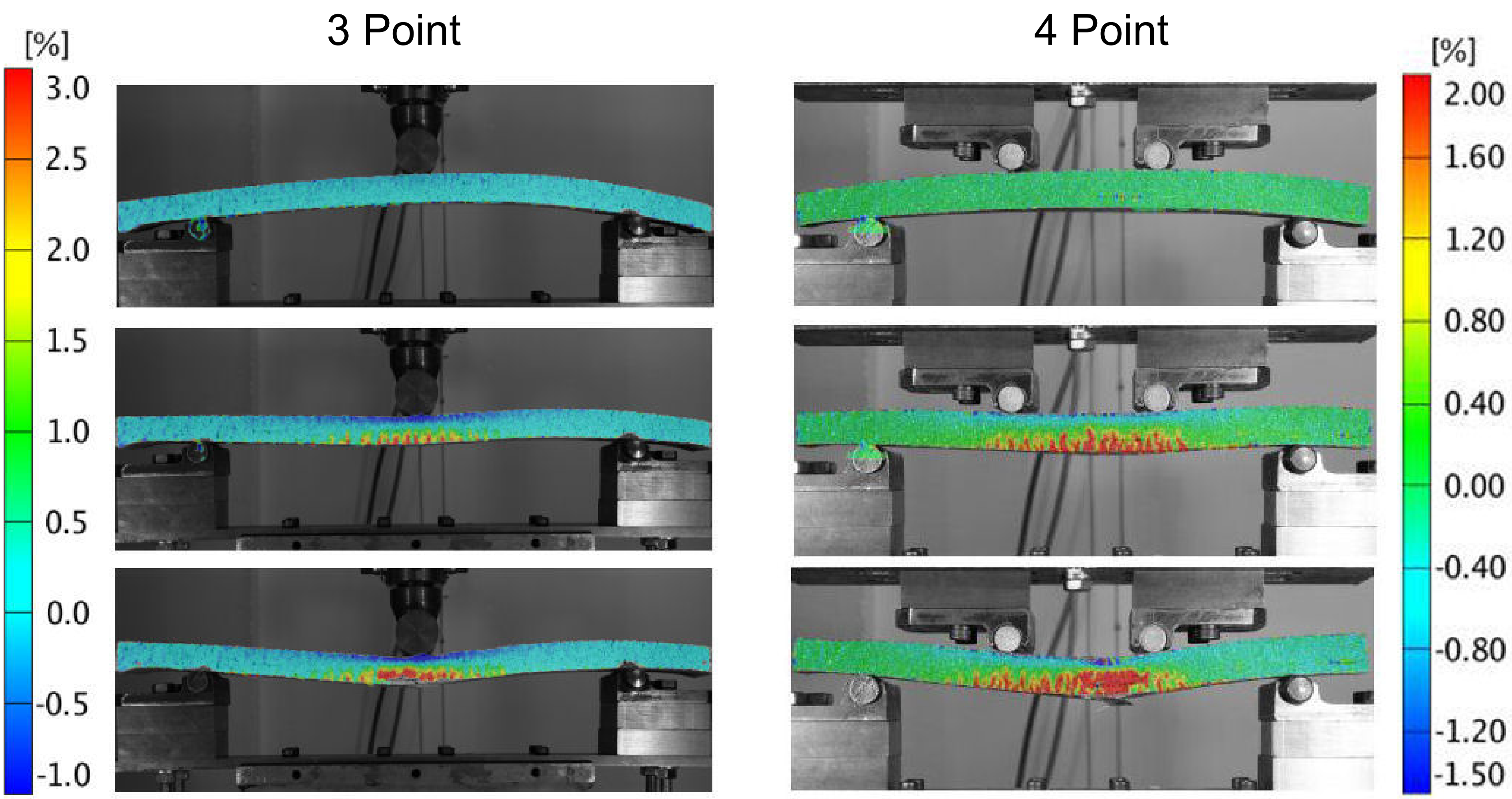
Flange Panel Results





Increasing cross-head displacement

Flange Panel Results

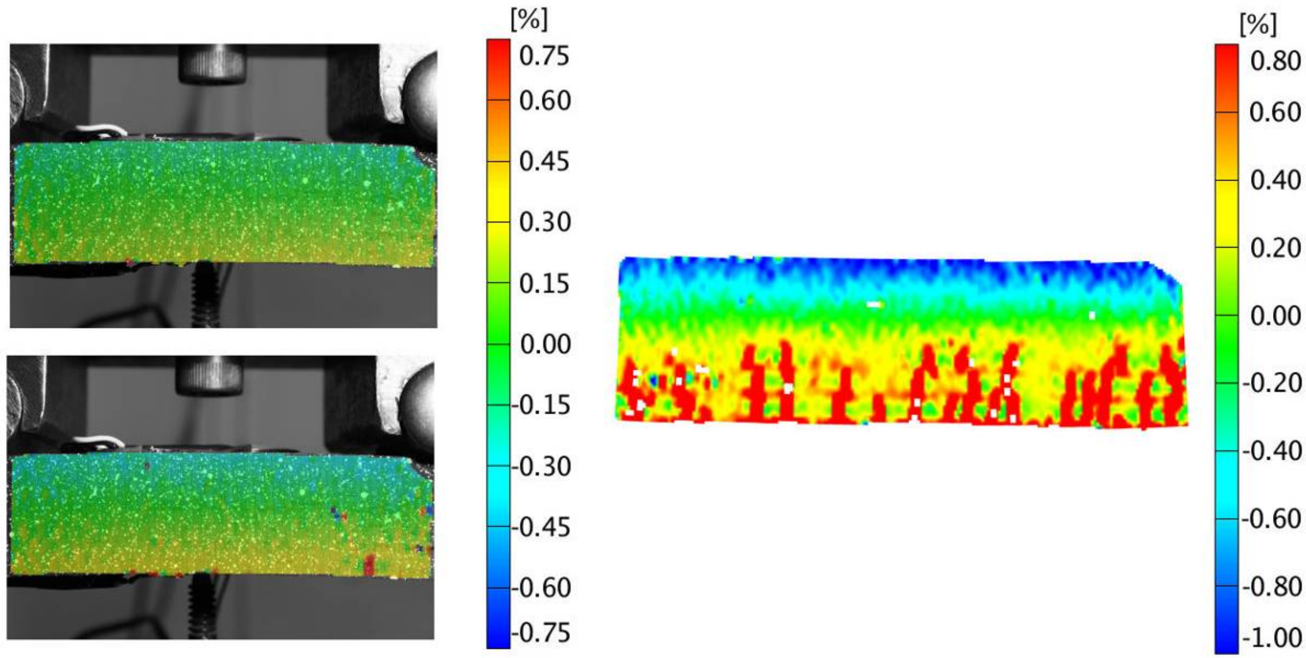


Bending strain (horizontal) plots

Imperial College London

e·on UK

Flange Panel Results

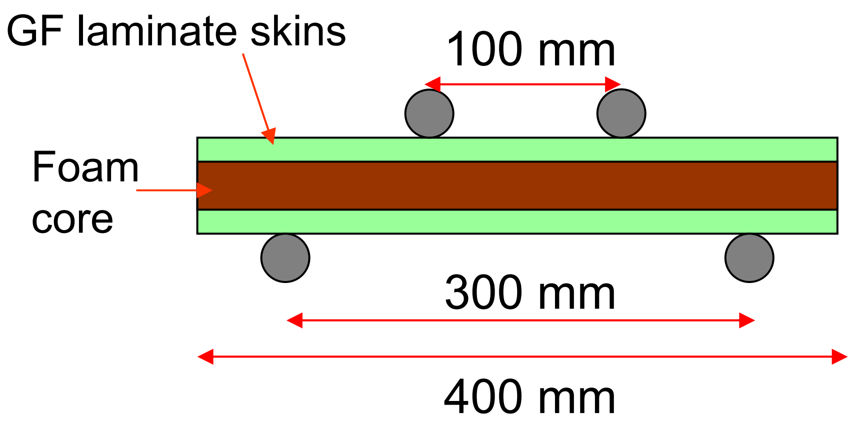


- Surface cracks evident as regions of high strain
- Cracks propagate upwards through layers

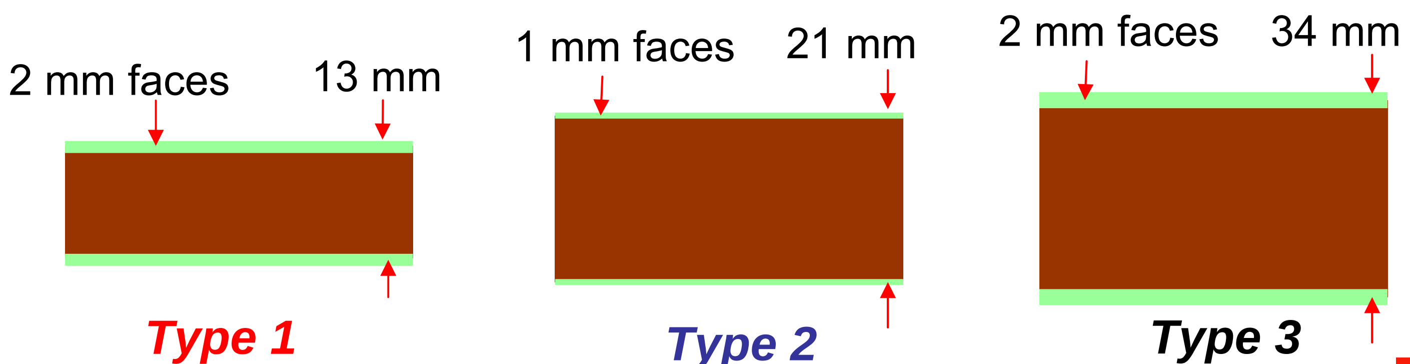
Imperial College London

e·on UK

Sandwich Panel Experiments



- Loading compliant with ASTM C393-00
- Material extracted from real web
- Three different cross-sections tested



Three Cross-Sections

Imperial College London

e·on UK

Sandwich Panel Results

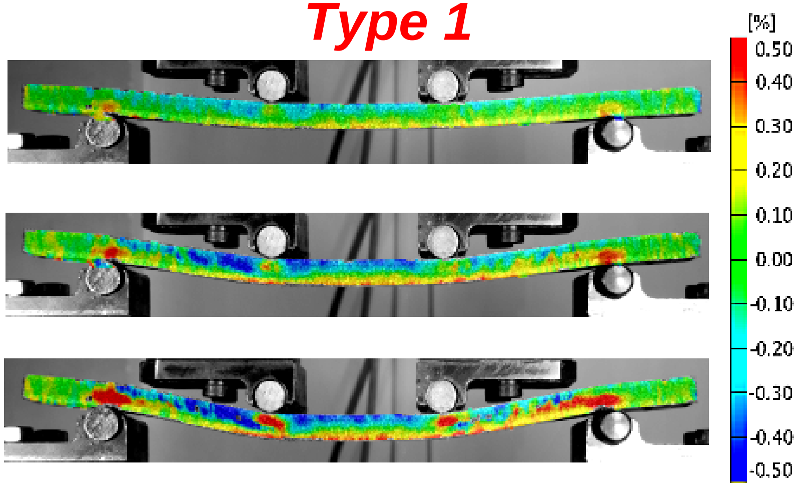
Bending Strain

Type 1

5 mm

10 mm

16 mm

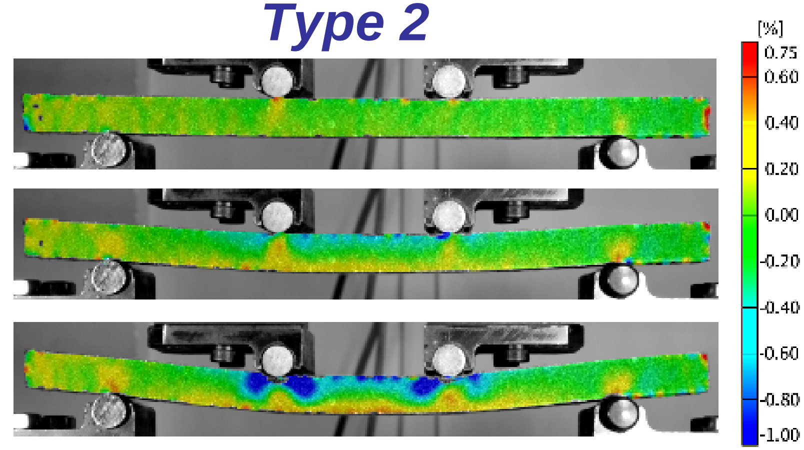


Type 2

5 mm

10 mm

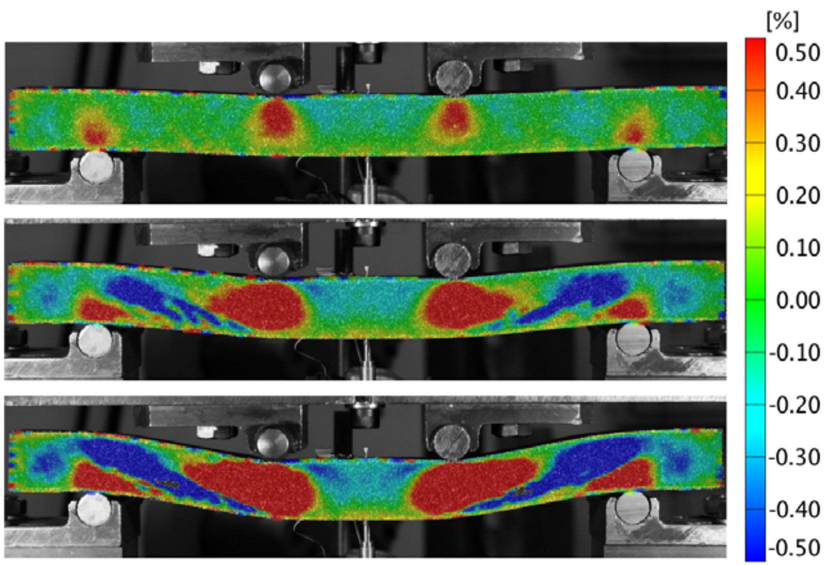
16 mm



5 mm

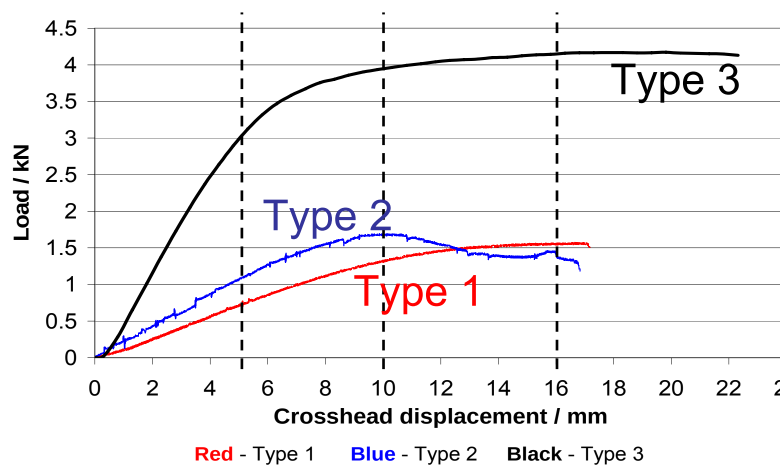
10 mm

16 mm



Type 3

Bending strain



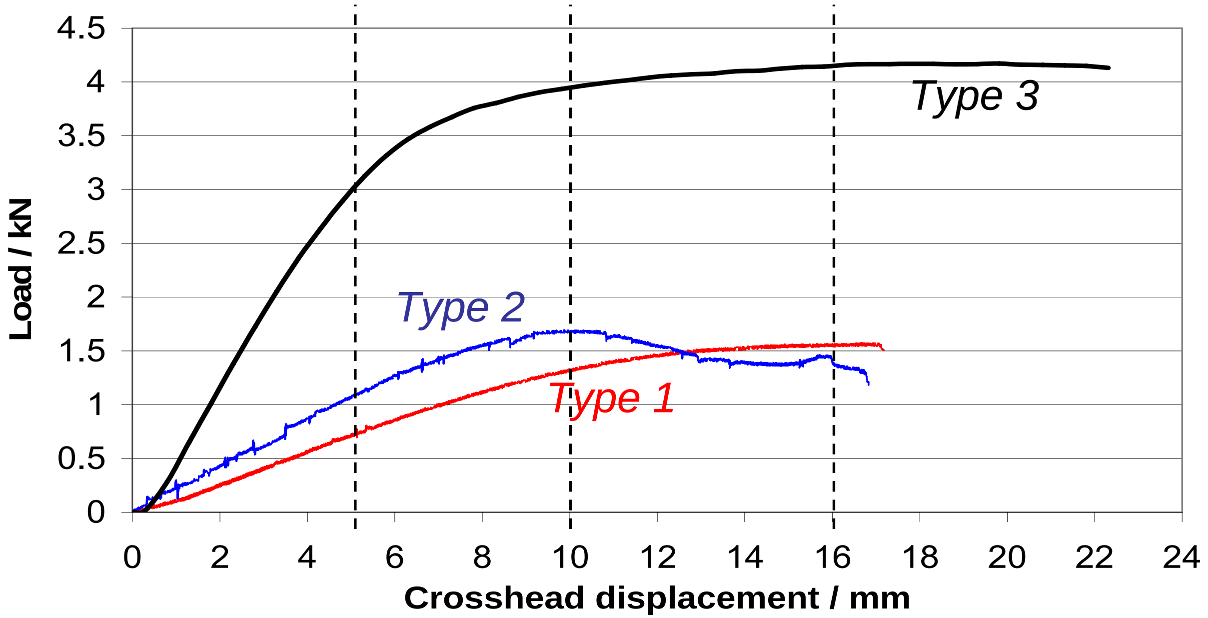
Imperial College London

e·on UK

Sandwich Panel Results

Load Displacement Graphs

- *Type 3* and *Type 2* have higher second moment of area and increased bend resistance
- *Type 2* exhibits drop in load after peak due to indentation
- *Type 1* and *Type 3* exhibit plateau as core fails by shear



Red - Type 1 **Blue** - Type 2 **Black** - Type 3

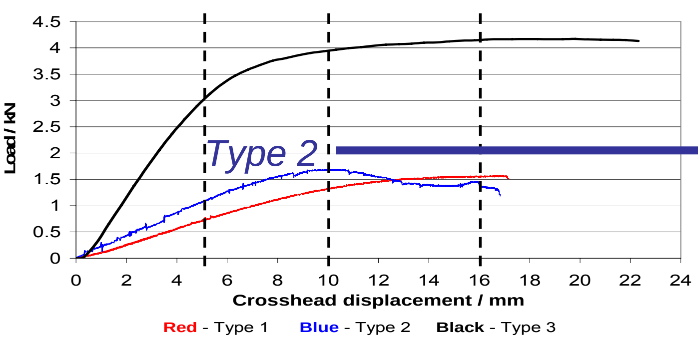
Imperial College London

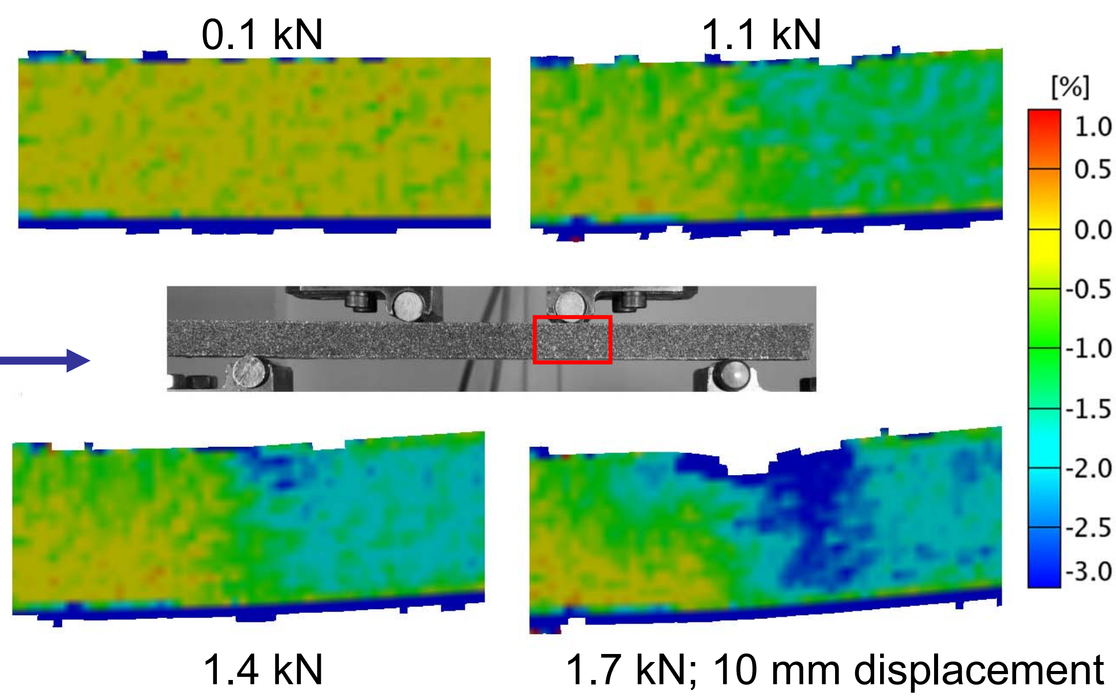
e·on UK

Sandwich Panel Results

Indentation Failure in *Type 2*

- DIC plot shows the through thickness strain
- Compression failure of foam core beneath roller
- Critical strain for PVC foam crushing is ca. 2%





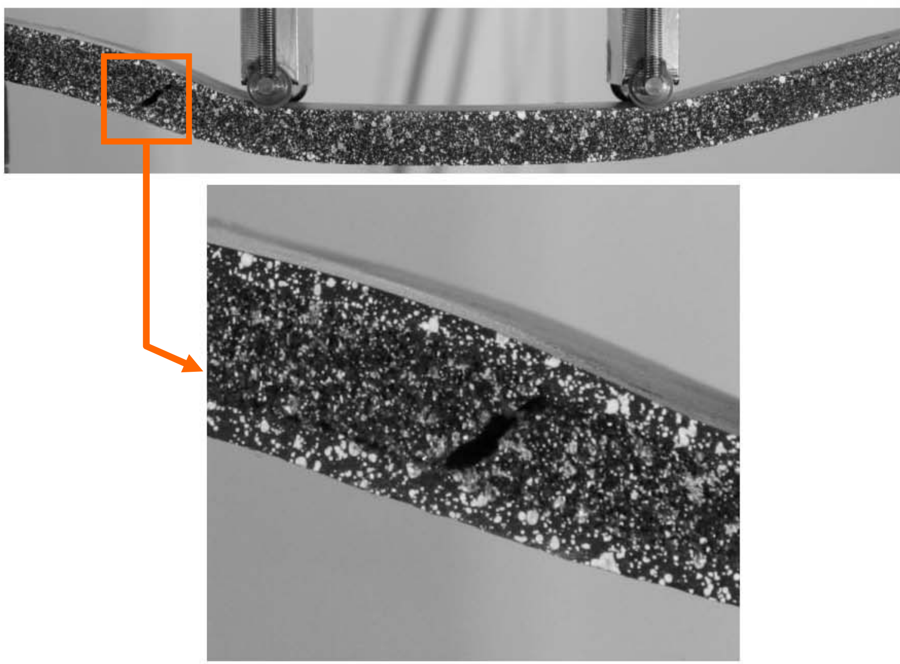
Through-thickness strain

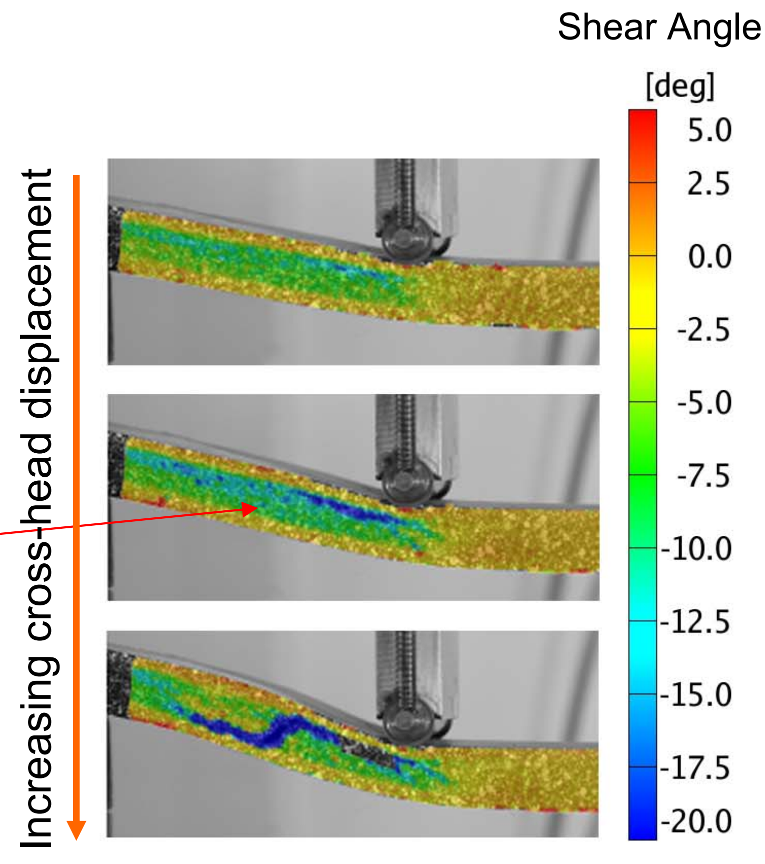
Imperial College London

e·on UK

Sandwich Panel Testing

Shear failure of core in *Type 1*

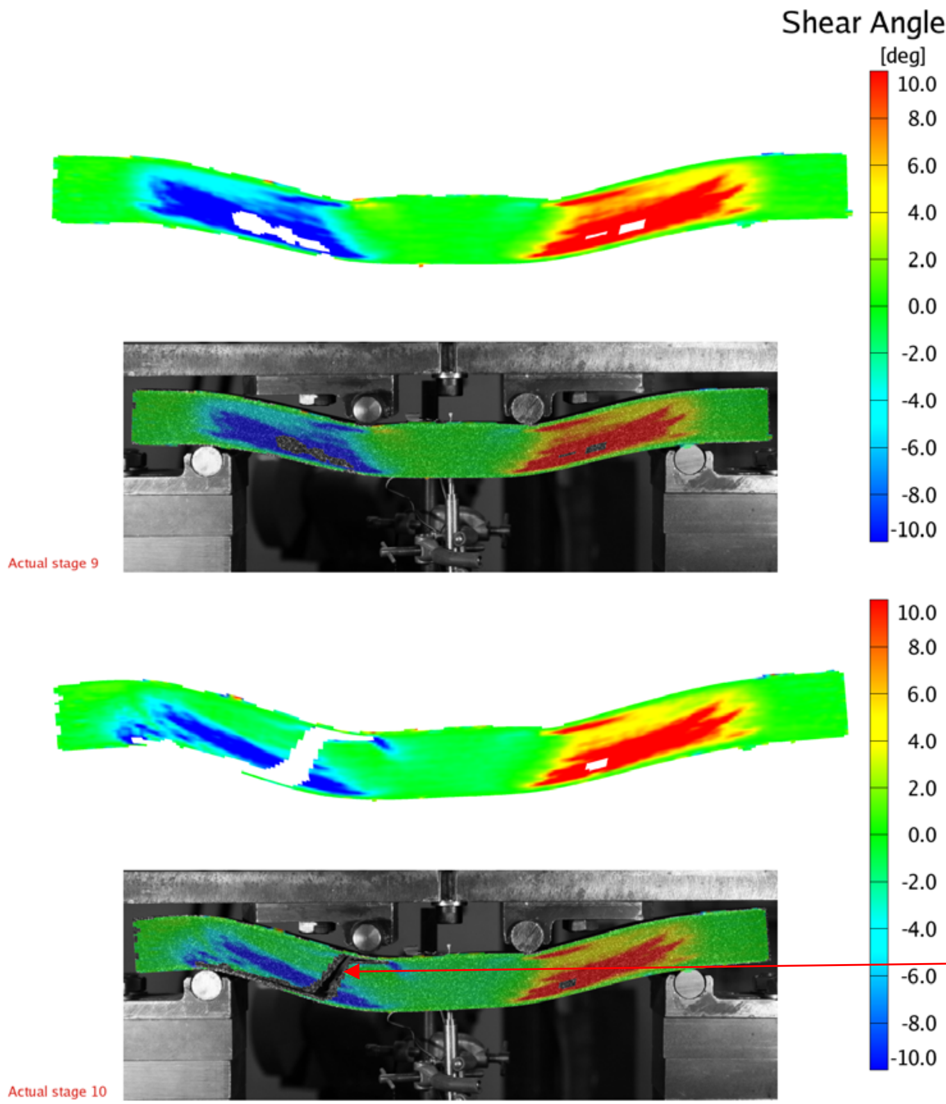




Build up of shear in adhesive identified followed by debonding of skin/core and core shear failure

Sandwich Panel Testing

Shear failure of core in *Type 3*



Increasing cross-head displacement

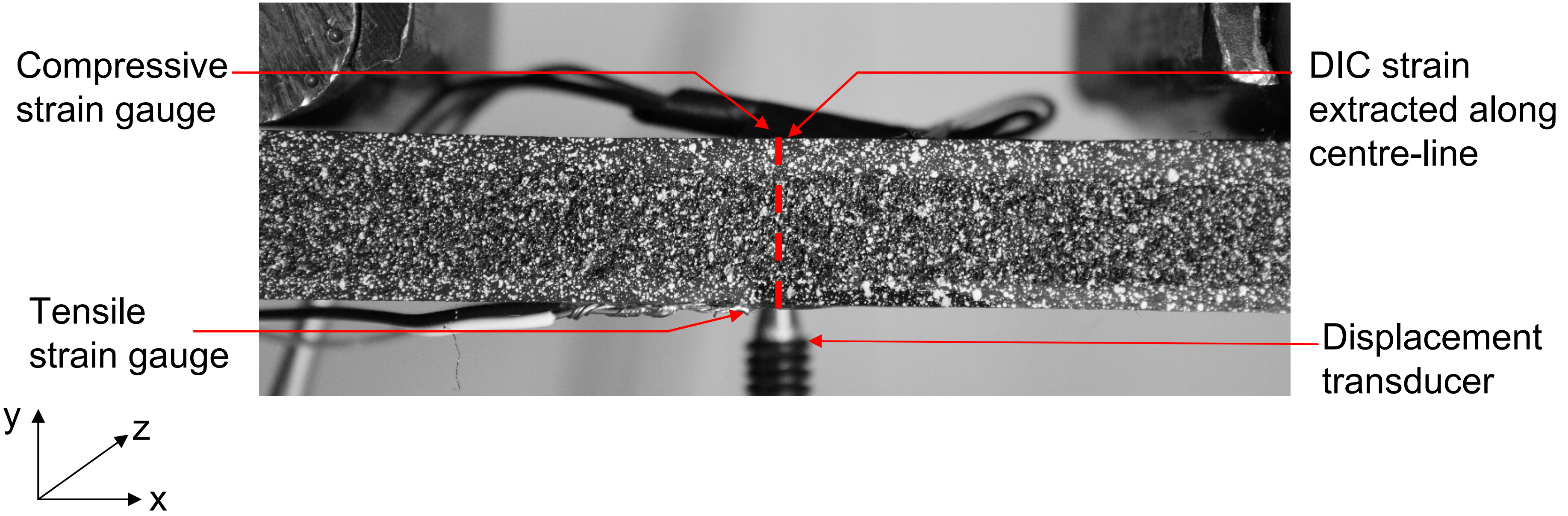
Debonding of skin/core and core shear failure

Imperial College London

e·on UK

Sandwich Panel Results

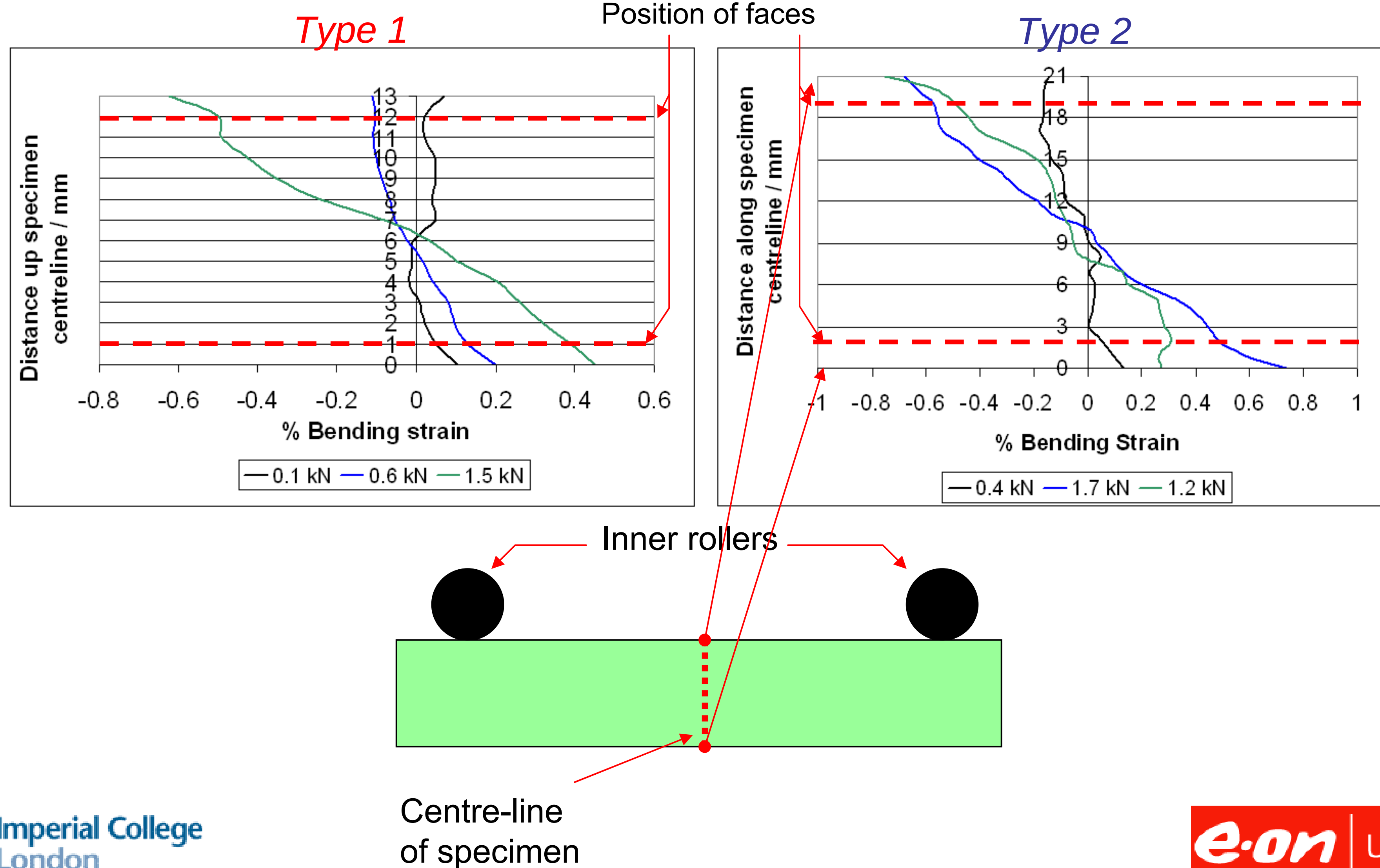
Comparison to Standard Metrology



- Use of strain gauge and displacement transducer
- Experiments on *Flange*, *Type 1* and *Type 2* panel specimens
- 4-point loading geometry
- Comparison against DIC values along centre-line (red dashed line)

Sandwich Panel Results

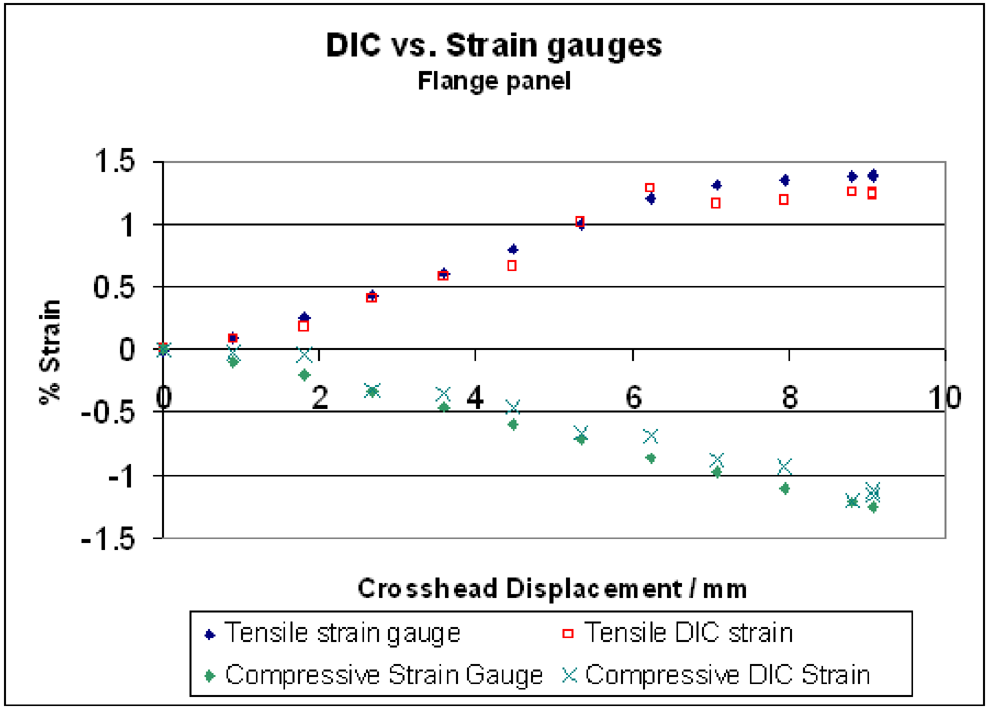
Comparison to Standard Metrology



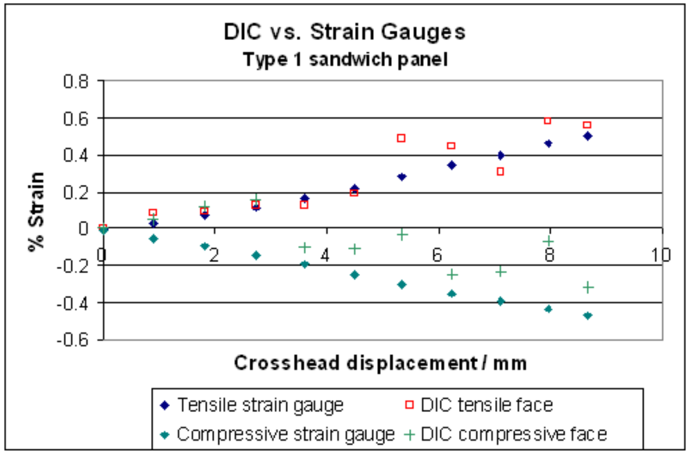
Sandwich Panel Results

Comparison to Standard Metrology

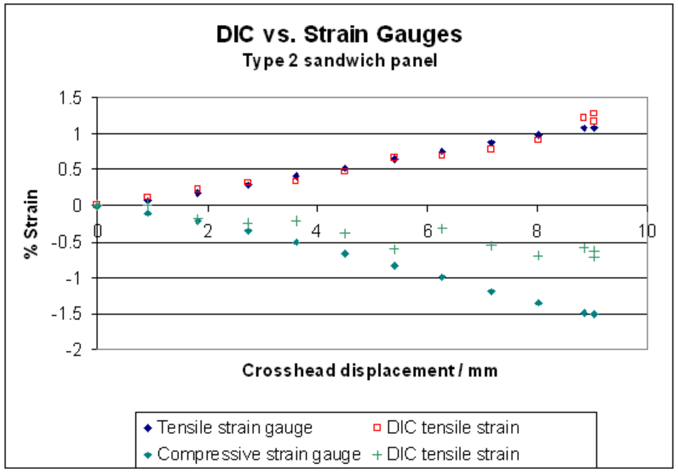
Comparison of DIC and strain gauge data



Flange panel



Type 1 sandwich panel



Type 2 sandwich panel

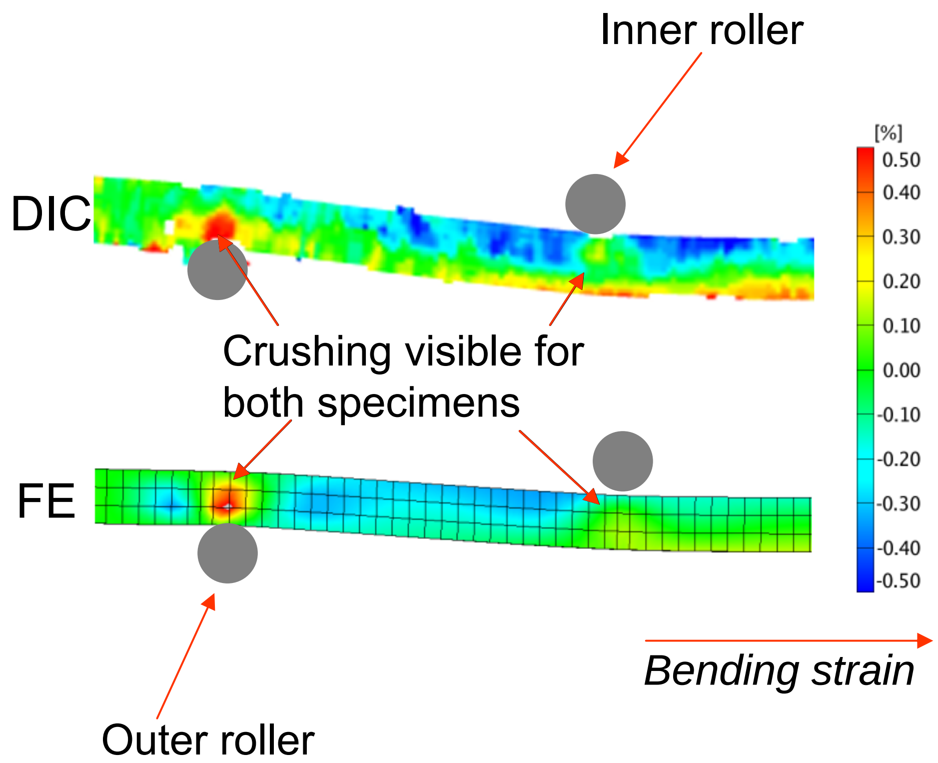
Imperial College London

e·on UK

Sandwich Panel Results

Comparison to FE Model

- Similarities:
  - Crushing
  - Indentation
  - Contact Mechanics
- Discrepancies:
  - FE model stiffer than experiments
- Reasons:
  - 2D vs. 3D
  - Model needs redesigning
- Some good general agreement



Imperial College London

Collaboration with Risø - DTU

Box-Section Testing

1. DIC for strain/displacement mapping of edge profile
2. Acoustic Emission to detect onset of failure
3. Different geometries of box-section

Summary

- DIC able to identify failure modes and causes
- Good agreement between FE and DIC
- Future work:
  - Improve FE model (*inc. damage modelling*)
  - Model to fracture
  - DIC on faces
  - Correlate DIC, AE and FE results for box-section
  - Apply DIC and AE to full-scale box beam test
- Beneficial for manufacture and maintenance

Thank you for listening
Questions

Strain mapping of composite sandwich structures for wind turbine applications

John Dear *e-mail: j.dear@imperial.ac.uk*

Amit Puri *e-mail: amit.puri01@imperial.ac.uk*

Andy Morris *e-mail: Andy.P.Morris@eon-uk.com*

Find Jensen *e-mail*: *find.moelholt.jensen@risoe.dk*

Imperial College London

e·on | UK