Innovative Multi-Materials Jointing Integrity Engineering

An Overview of the IMAJINE Project: *Monitoring Joint Integrity*

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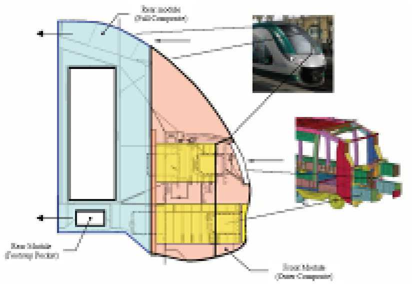
ESR Technology

Introduction

The IMAJINE Project is a TSB Collaborative R&D project aimed at developing structural health monitoring and integrity assessment procedures for adhesive and mechanical joints under the application of static and fatigue loading and environmental exposure.

- 10(+1) Partners
- 7 Work Tasks
- 4 Case Studies
    1. Wind turbine blade
    2. Beam and plate strengthening
    3. Composite pipe repairs
    4. Train body components



www.imajine.co.uk

Objectives

Improve the safety and structural reliability of joints and connections,

Increase structural performance through weight reduction (reduced conservatism in design codes),

Reduce operation and maintenance costs through real-time, remote condition monitoring,

Reduce the occurrence of joint failures,

Increase the use of lightweight structures consisting of both multi-material systems with joints between dissimilar materials and single material systems.

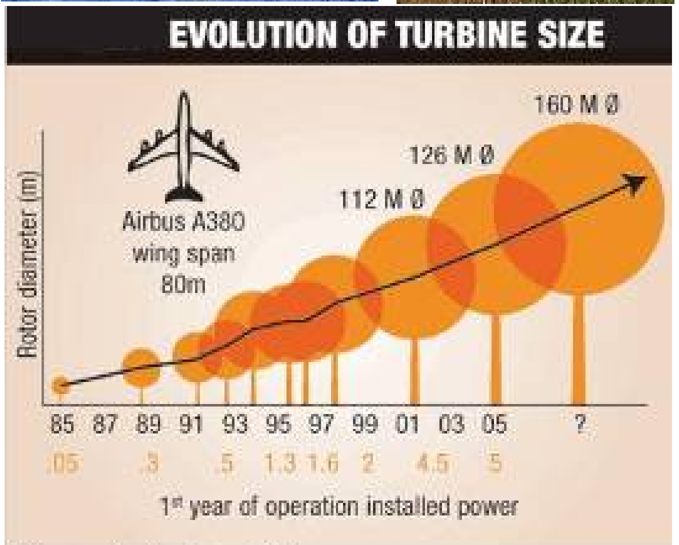
Inspection – which techniques?

Techniques assessed

- Acoustic emission (Amplitude, Energy or Rate)
- Laser shearography (thermal or pressure loading)
- Thermography (Line scan, pulsed)
- Ultrasonics (Manual, Automated, Pulse-Echo, Phased Array)
- X-ray & γ radiography (conventional and digital, CR & DR)
- Microwave Inspection (10 and 24 GHz)
- Mechanical impedance (electronic tappers)
- Others (Optical fibres FBG/CFBG, permanently installed condition sensors
- Crack growth monitoring (Video camera)
- Strain gauges !

Some are commercially available systems

Case Study 1 – Wind turbine blade



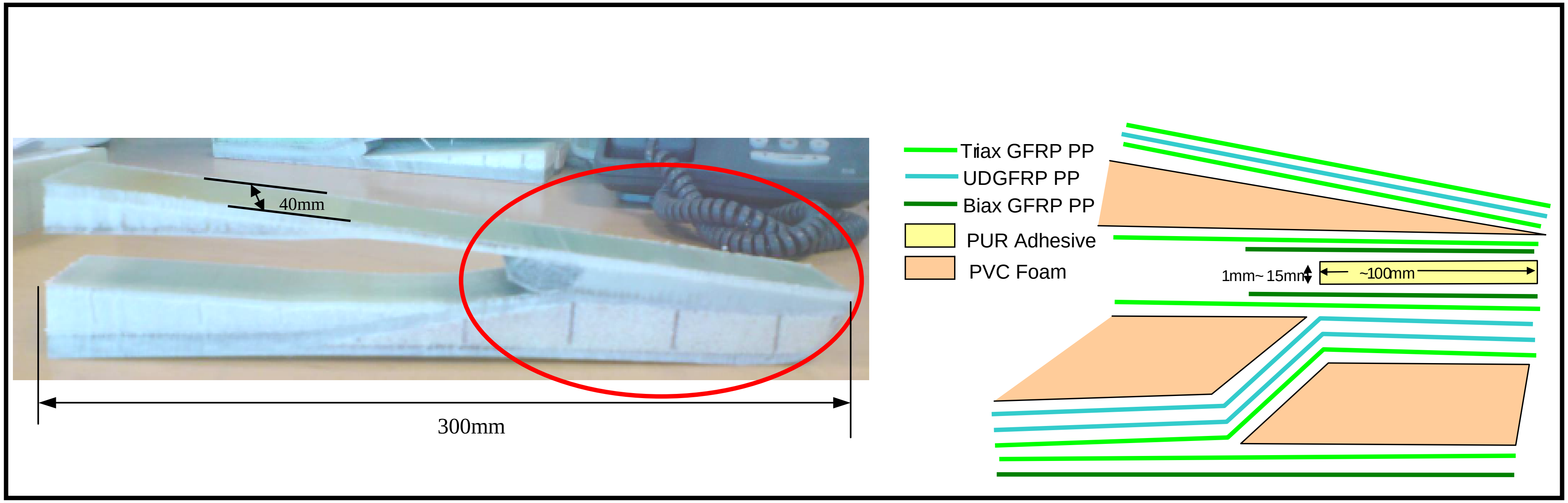
Source: Jos Beurskens, ECN

Failure mode of concern – Interfacial delamination

- Input from Vestas Technology (UK) includes selection of relevant geometry for consideration – trailing edge delamination
- Fracture toughness test specimens – Mode I DCB & Mode II ELS – Back face strain gauge and Chirped FBG fibre optic sensors
- Generic trailing edge joint used in 50 m blade.
- Some commercial sensitivity.
- Several independent inspection projects (e.g. EU funded FP7 – 'WINTUR' & 'INSIGHT' and earlier 'ReNEWiT' & 'UPWIND' projects.
- NPL Reference defect panel was used for inspection trials.

Case Study 1 – Wind turbine blade

Joint detail – geometry, dimensions and lay-up



Vestas have previously used quasi-static mechanical tests to evaluate; (i) the remnant static strength of trailing edge (TE) joint sections from 44 and 49 m length blades and (ii) design improvements of new TE joint constructions.

The objectives of the work undertaken in IMAJINE were to:

(i) evaluate the long-term fatigue performance of the TE joint area,

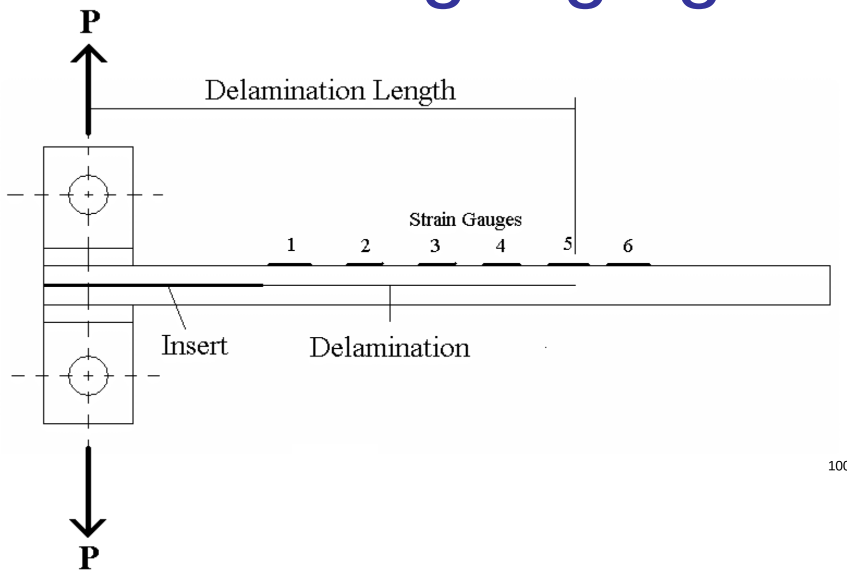
(ii) screen and assess a number of non-destructive evaluation (NDE) techniques and embedded sensor technologies for the detection of delamination/de-bond initiation and propagation.

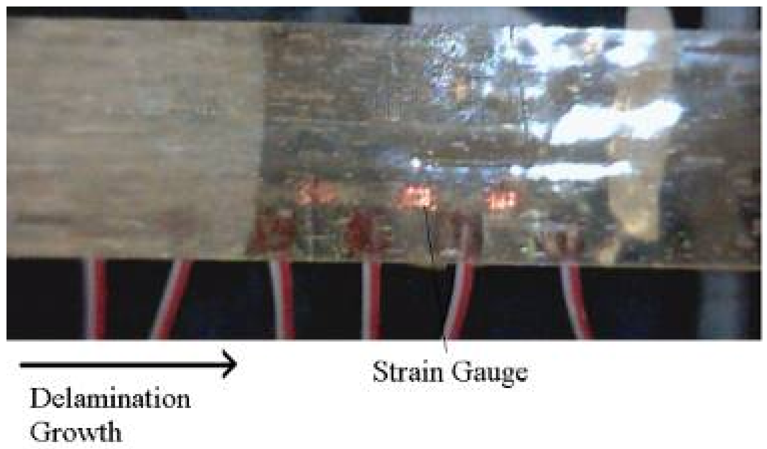
Case Study 1: Wind turbine blade – inspection and monitoring options

Candidate NDE and sensing techniques being looked at are:

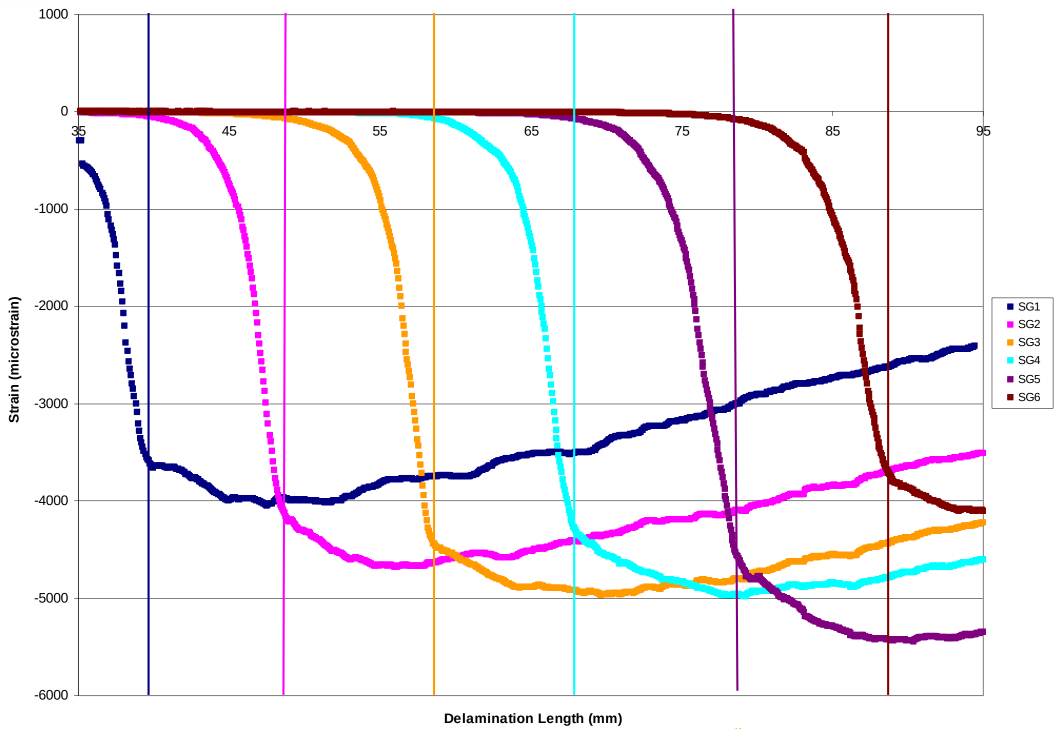
- Back face (+side) strain measurements:
  - strain gauges (as per Prof. A D Crocombe's work, Surrey University)
  - digital image correlation (DIC): full-field and virtual strain gauges (NPL)
- Surface mounted optical fibre FBGs:
  - conventional FBGs (SmartFibres)
  - 'chirped' FBGs (Ogin/Sanderson, Surrey University) - CFBGs
- Acoustic emission – (Physical Acoustics)
- Microwave inspection – Ken Murphy (Exova/ Evisive)
- Pulse & line scan thermography – (NPL & Physical Acoustics)

Strain gauging





- Test uses strain gauges to look at the change in strain as the delamination grows in the DCB specimen
- Six 1mm strain gauges bonded to the surface over a 60mm section
- Delamination length measured using video camera
- Kink in strain response as crack reaches front edge of strain gauge

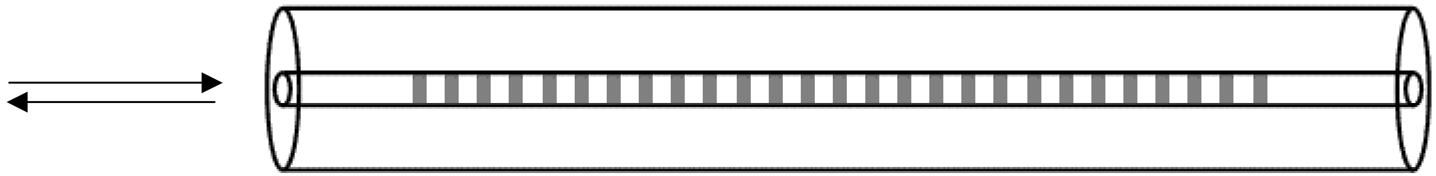


Acknowledgement: Andy Sanderson, Steve Ogin and Andy Crocombe, Surrey University

UNIVERSITY OF SURREY

Detection of de-bonds in Mode I tests using FBGs

- Conventional distributed FBG sensor on an optical fibre

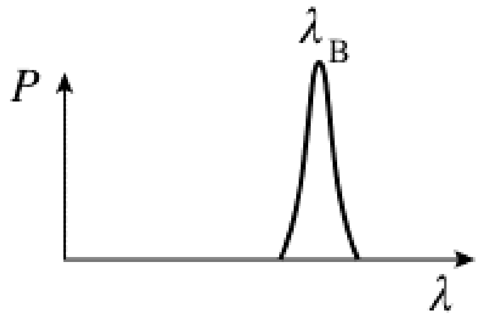


- Sensitive to strain and temperature

$$\lambda_B = 2n\Lambda$$

Refractive index of core

Spatial period of grating



- Commonly used for monitoring strain
- Limited strain data i.e. does not detect position of damage

Detection of de-bonds in Mode I tests using FBGs

Range of grating lengths from Smart Fibres (2, 10 and 15 mm)

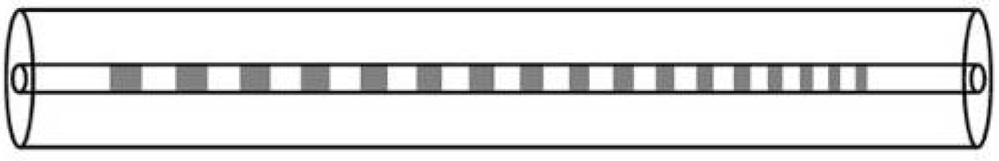
Bonded to top surface of GRP adherends

Reflected signal analysed using Smart Fibres W4 wavelength interrogator

NPL National Physical Laboratory

Detection of de-bonds in Mode I tests using CFBGs

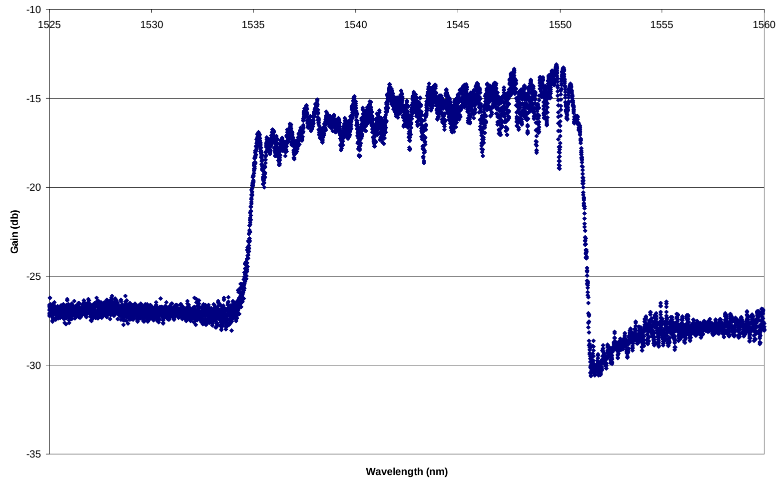
- A CFBG has a linear variation in grating period



- Range of wavelengths corresponds to sensor length

- Range of reflected wavelengths

  – Allows for detection of delamination
  – Allows location of delamination front to be found



Andy Sanderson, Steve Ogin and Andy Crocombe, Surrey University

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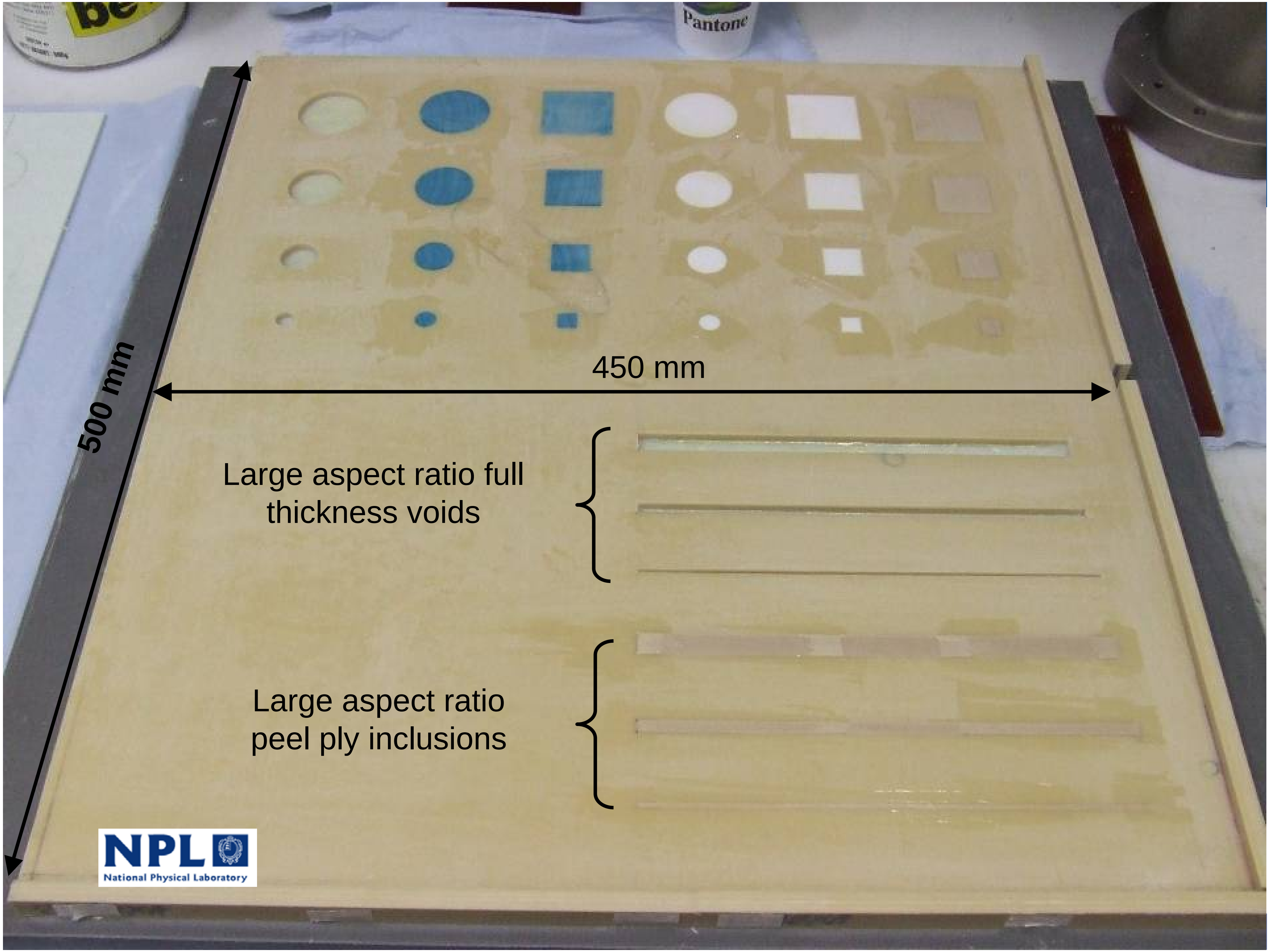


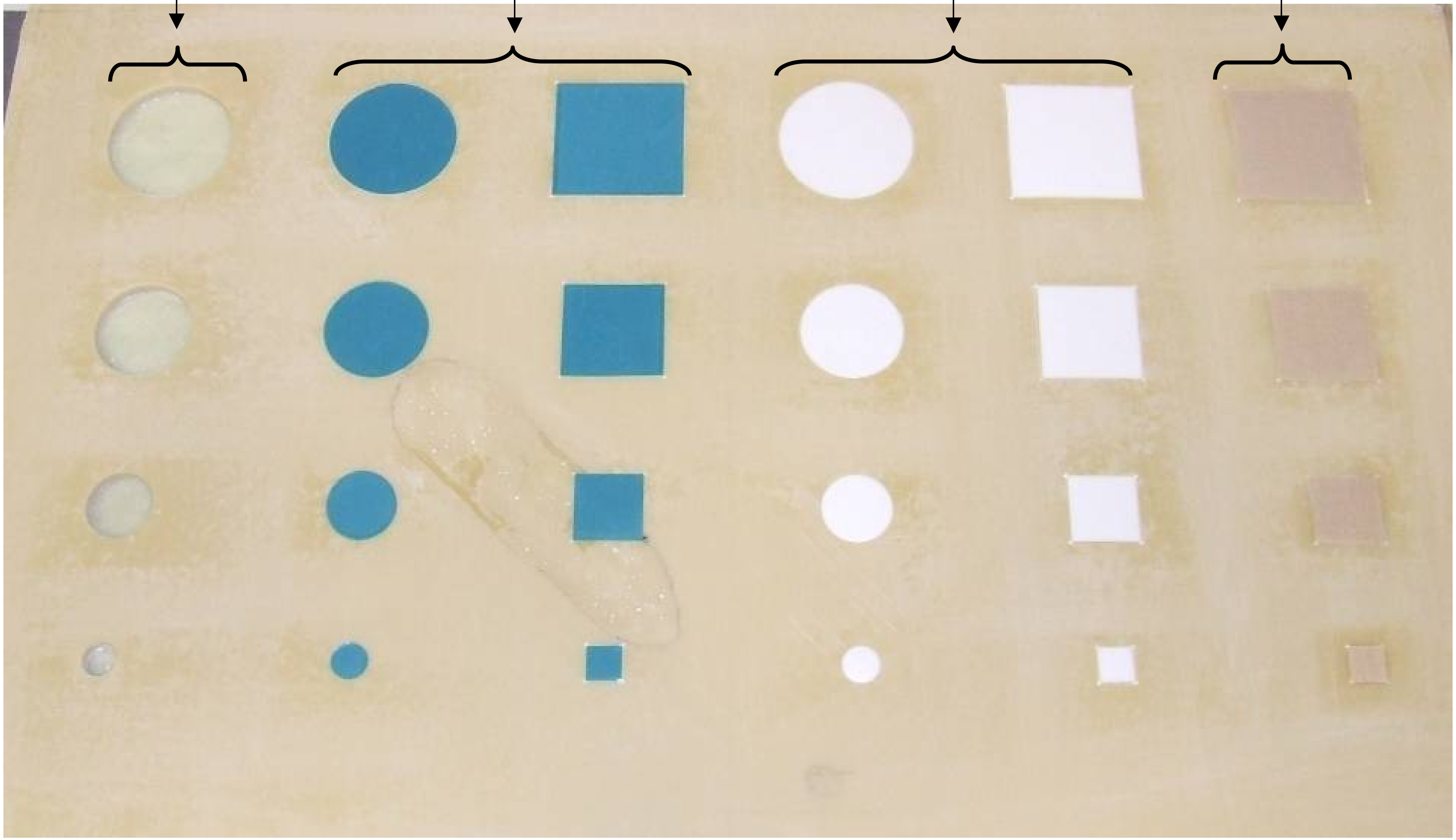
Pantone
450 mm
500 mm
Large aspect ratio full thickness voids
Large aspect ratio peel ply inclusions
NPL
National Physical Laboratory

Circular full thickness voids

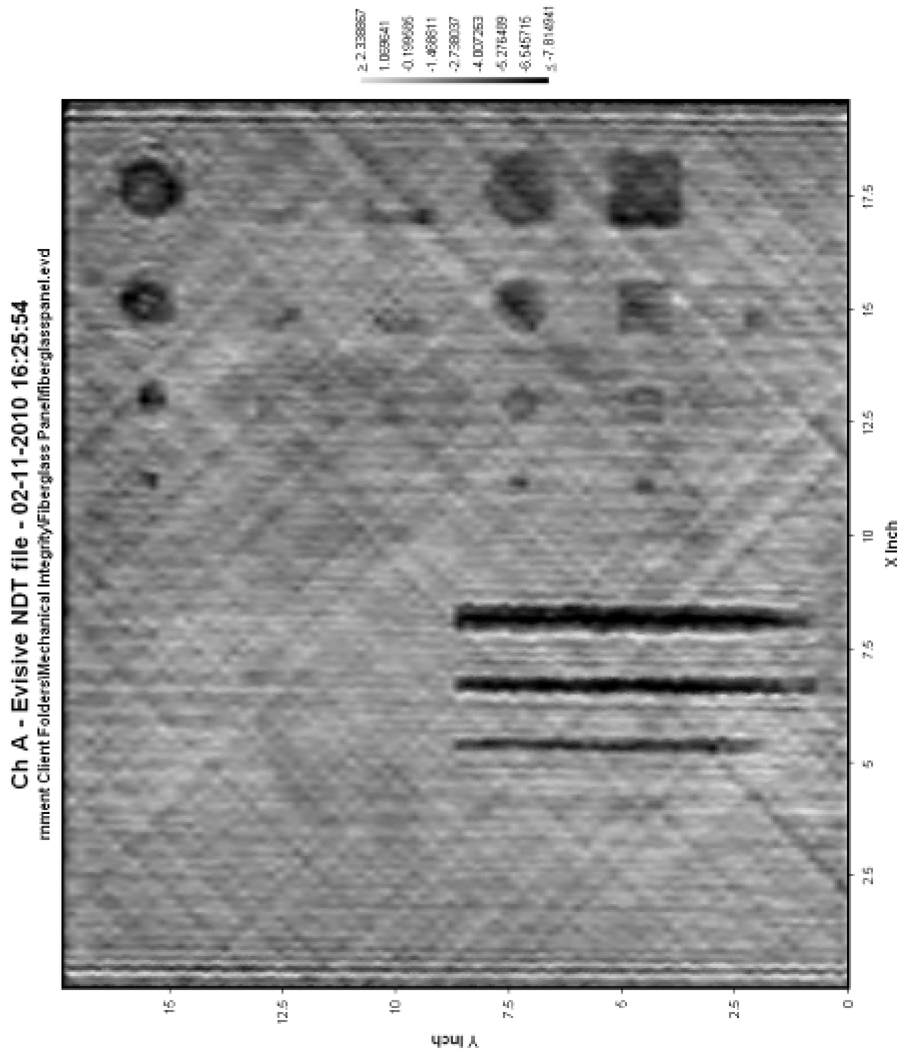
50 mm PTFE film sealed in heat resistant tape

Square and circular 0.5 mm thick PTFE

Square peel ply inclusions



Microwave – Evisive Inc.



Microwave energy passes through the Reference Panel:

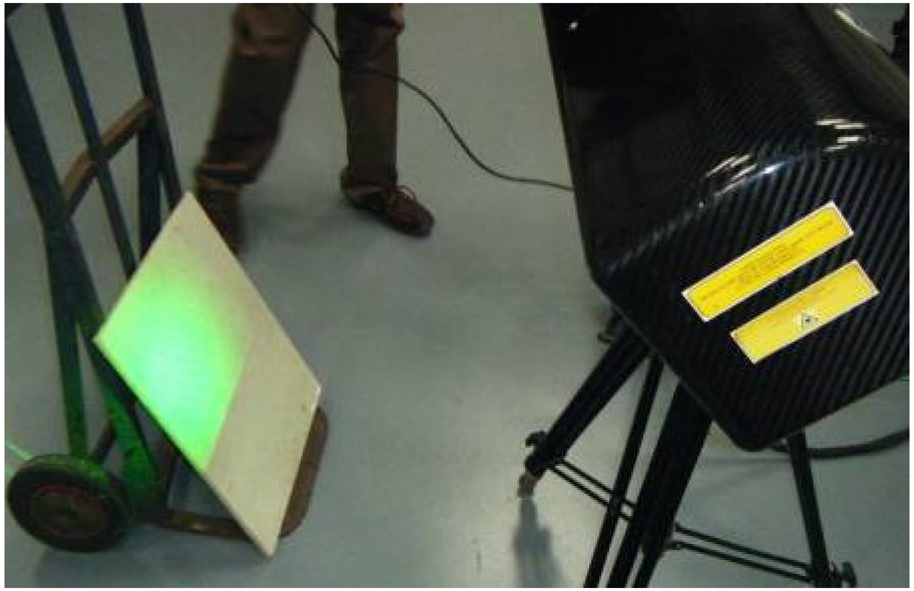
Scans were at 24 GHz, with 5mm Raster step.

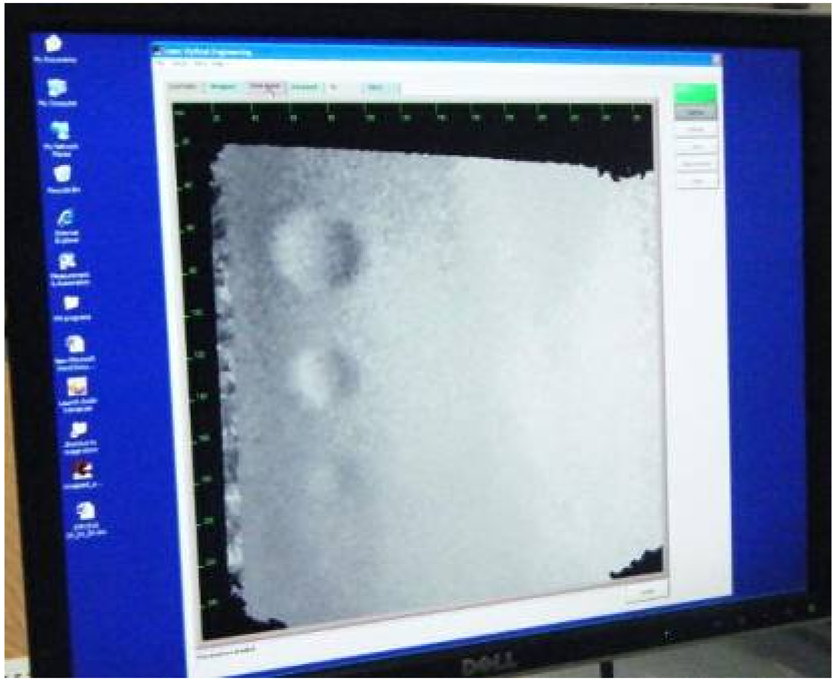
The set-up and scan time was about 30 minutes, limitation being the positioning table.

Void and PTFE sheet inclusions were apparent.

Difficulty in detecting PTFE Pocket and peel ply.

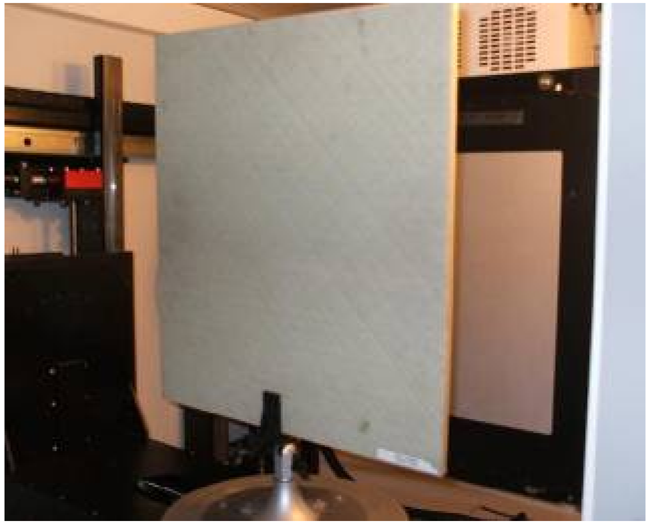
Laser Shearography – Set-up and Result – Laser Optical Engineering Ltd





The Strain Mapper was able to see the largest circular defects using a thermal pulse but the smaller defects were not readily visible. They may become visible if a vacuum pressure hood had been used.

X-Radiography – Nikon Metrology UK (formerly X-Tek Systems Ltd



X-ray source is capable of 225kV and 225W

5µm focal spot reflection target X-ray source

X-Radiography - Nikon Metrology UK

X-ray image of circular void defects – smallest is 10mm.

Some adhesive/ resin in-fill seen around edges of holes.

The PTFE pockets and peel ply inserts were not readily revealed - as anticipated

Case Study 2 – Structural strengthening

Failure mode of concern – Interfacial delamination

- Use of bonded carbon fibre plates.
- Selection of relevant geometry for consideration (not necessarily bridges!)
- Extension of previous work undertaken in DTI ACLAIM Project.
- Determination of the relevant loading regimes and environment
- Test specimen provision
- Testing and inspection plans
- Assessment procedure using artificial defects at the interface.

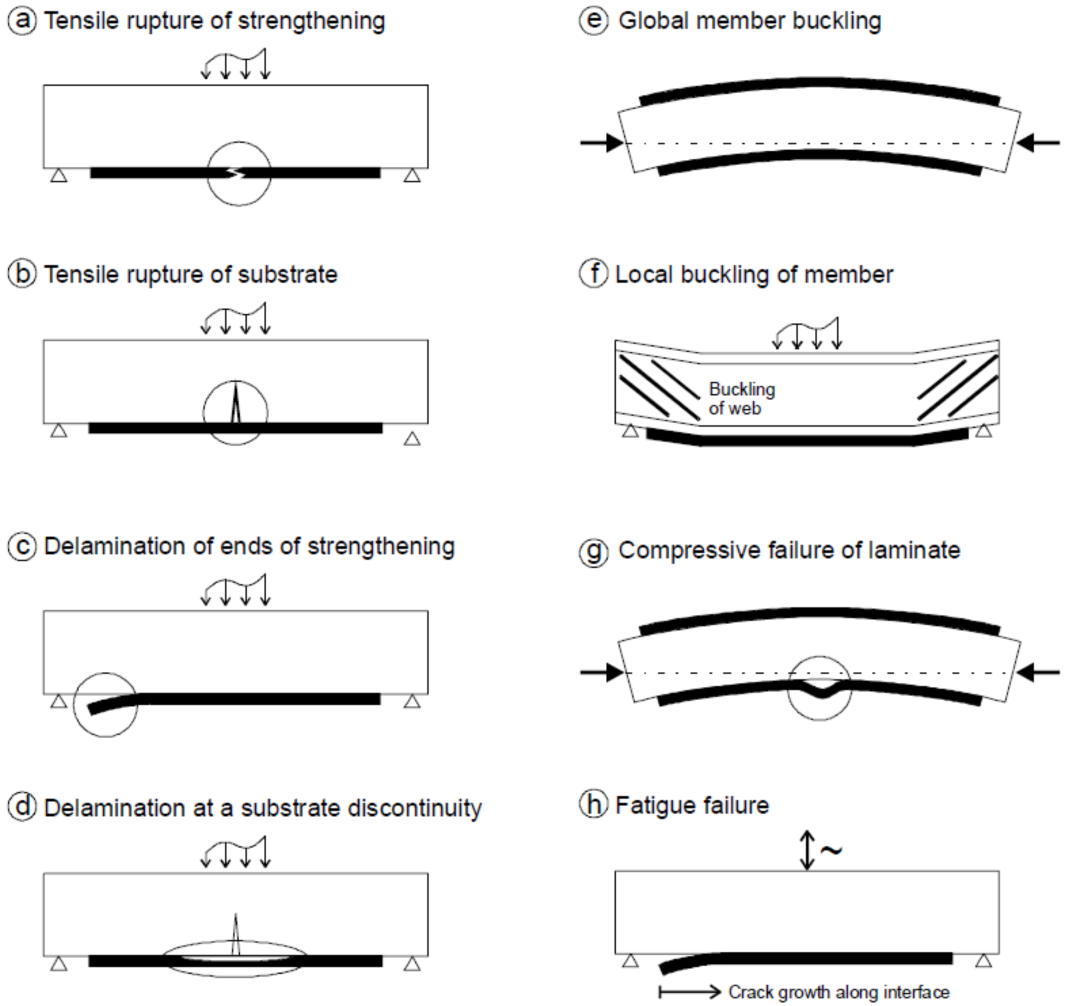
Case Study 2 Beam/Plate Failure Modes

Strengthening metallic structures using externally bonded fibre-reinforced composites

J M C Cadei, T J Stratford, L C Hollaway and W H Duckett

CIRIA C595 Published 2004

ISBN: 978-0-86017-595-7



Case Study 2 Beam/Plate Strengthening

Surrey Uni – Chirped FBG delamination sensor

Figure 1 shows a schematic diagram of the placement of the strain gauge sensors on the sample.

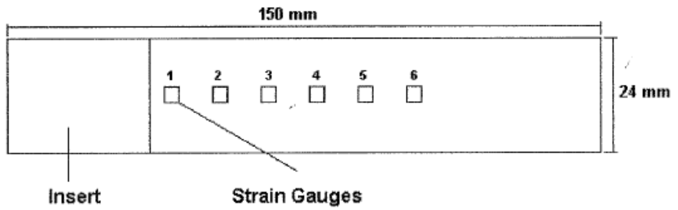


Figure 1 - A diagram of the DCB sample with strain gauges attached

Figure 2 shows the data gathered by the strain gauges with the location of the strain gauges marked by a solid vertical line.

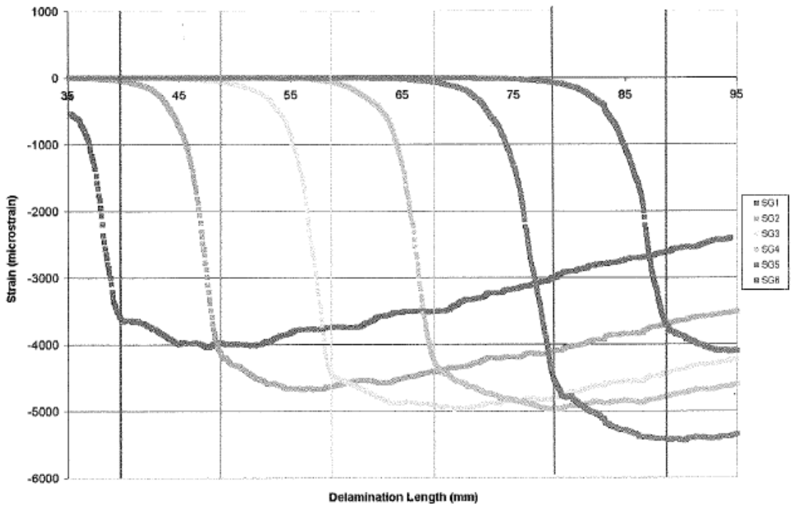


Figure 2 - Strain gauge data for the second Surrey material test

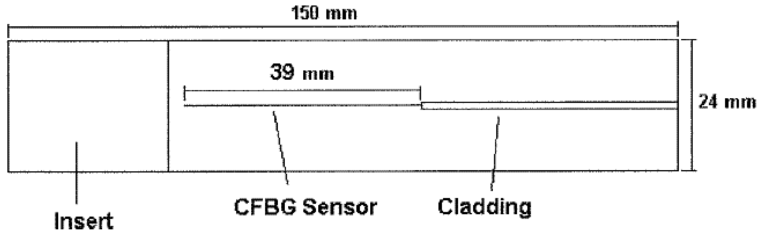


Figure 4 - A diagram of the DCB sample with CFBG attached

1.2x10⁻³ nm/με

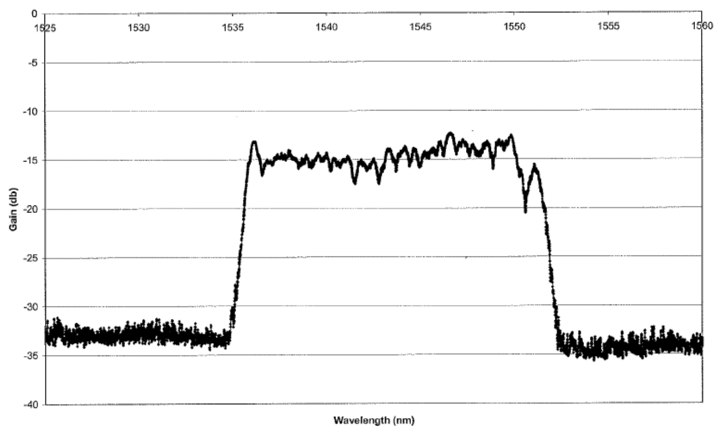


Figure 5 - The reflected spectra of the CFBG prior to testing

Courtesy of Andrew Sanderson & Dr Steve Ogin, University of Surrey

Case Study 2 Beam/Plate Strengthening

1·2x10^{-3} nm/με

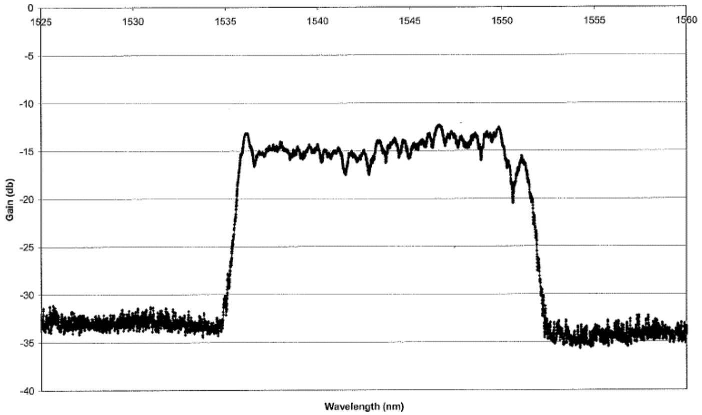


Figure 5 - The reflected spectra of the CFBG prior to testing

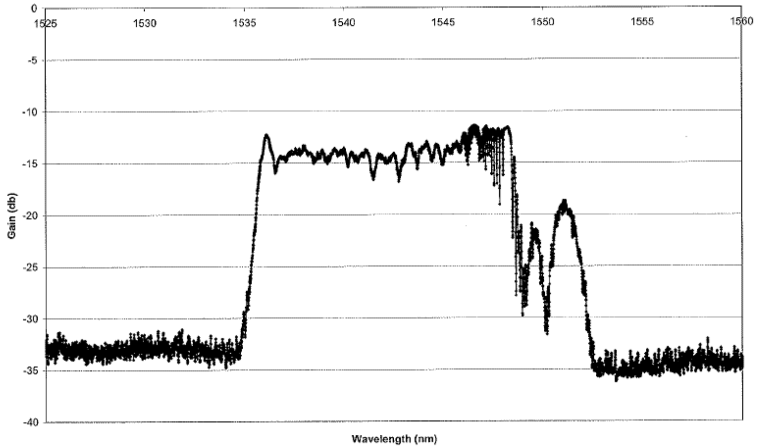


Figure 6 - The reflected spectra when the crack was 44.3 mm long

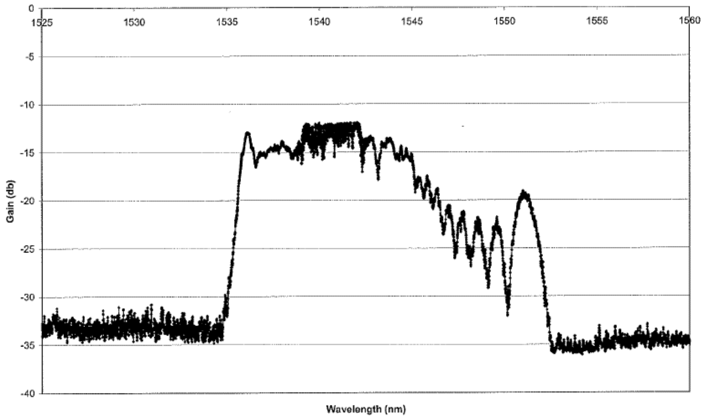


Figure 7 - The reflected spectra when the crack was 62.2 mm long

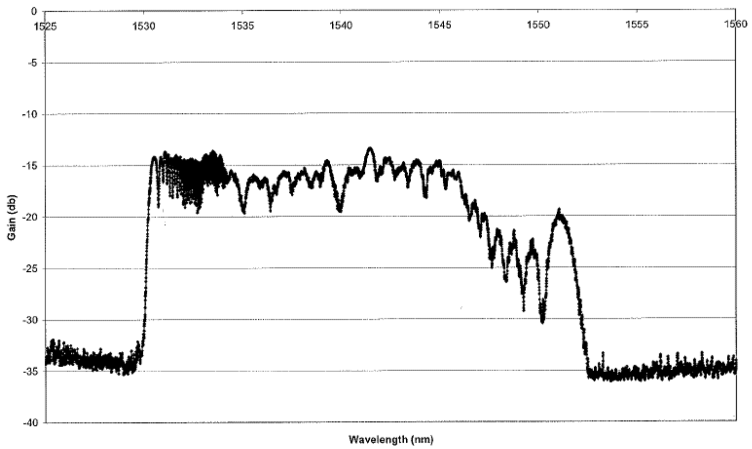


Figure 8 - The reflected spectra when the crack was 85 mm long

Case Study 2 Beam/Plate Strengthening

According to Network Rail *Ref. Brian Bell, ACIC, Edinburgh 2009*

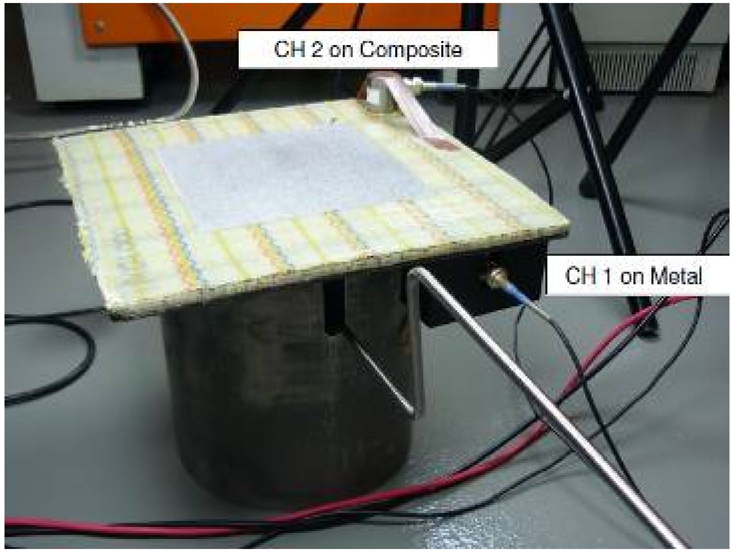
Between 2007 and 2009 the emphasis has moved away from retrospective strengthening of highway bridges, mainly because the majority of bridges needing to be strengthened to accept 40 tonne lorries have been done.

The focus is now on reconstructing the remainder by:

- Replacing time expired bridges with new fully FRP bridges,
- Replacing load bearing timber secondary decking with prefabricated FRP panels on both road and rail carrying bridges
- Constructing new fully FRP station bridges and platforms.

Case Study 3 – Piping repair

Failure mode of concern – Interfacial delamination



- Used in Oil & Gas industries for repair of corroded pipework and pipelines.
- Selection of relevant geometries (including substrates, surface preparation – hand prep, SA2½, primer, etc.) for consideration
- Determination of the relevant loading regimes (static, cyclic) and environment
- ISO/TS 24817 Composite Repairs for pipework

Case Study 3 – Piping repair

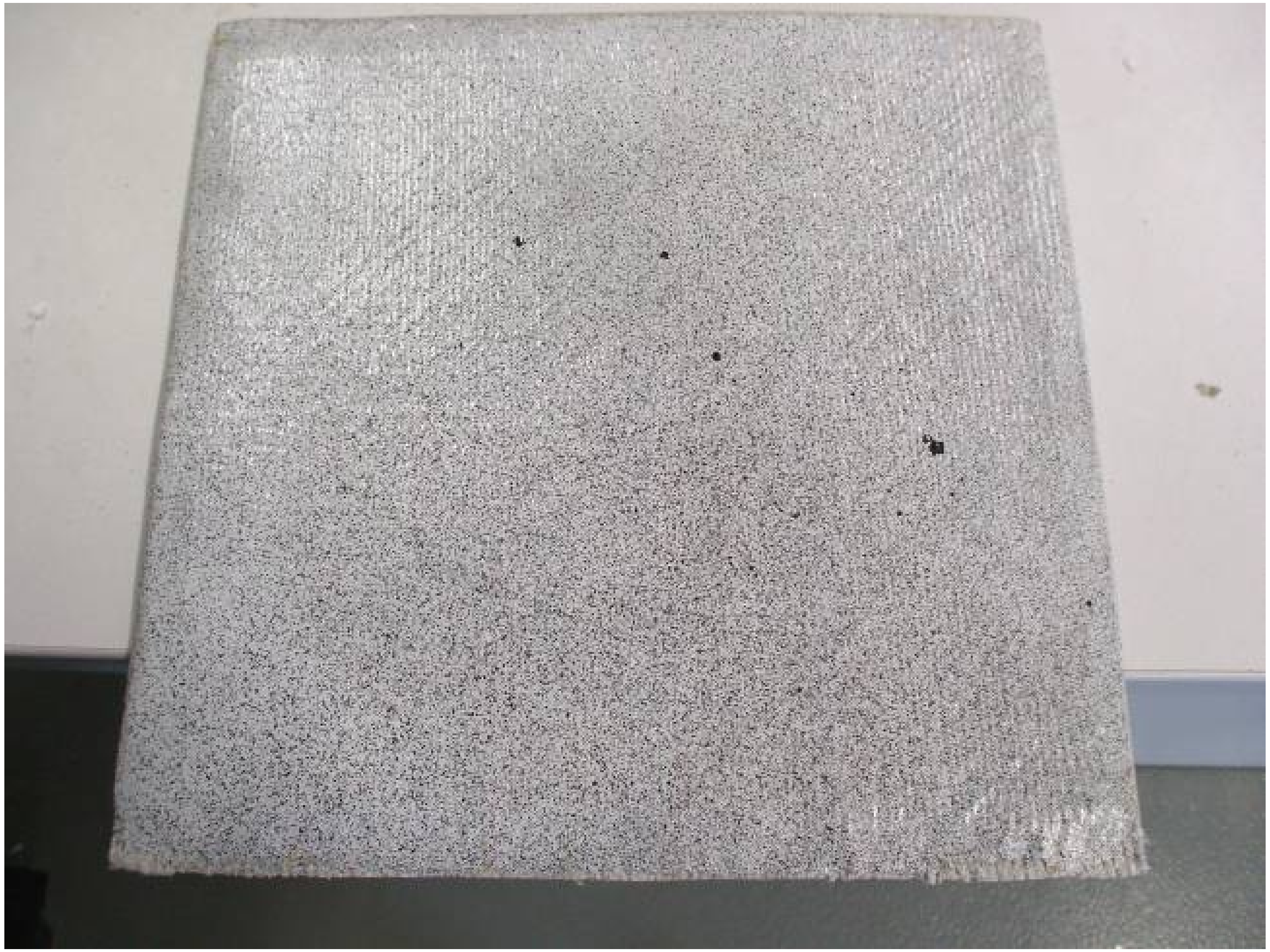
WTR Technowrap system

Multi-axial glass/ epoxy panel bonded to steel plate

3 panels tested

- Hand prep
- No Primer
- With primer

Case Study 3 – Piping repair



Speckle patterned paint coating to produce reference image.

White/ metallic and black spray paint used and air dried for 15 minutes

Case Study 3 – Piping repair

Tested at NPL

Connected to hand pressure pump (Hi-Force) using pressure adapter.

DIC equipment used LAVision DAVIS 7.4 software

www.lavision.de

Case Study 3 – Piping repair

Tested at NPL

Multi-Megapixel CCD cameras

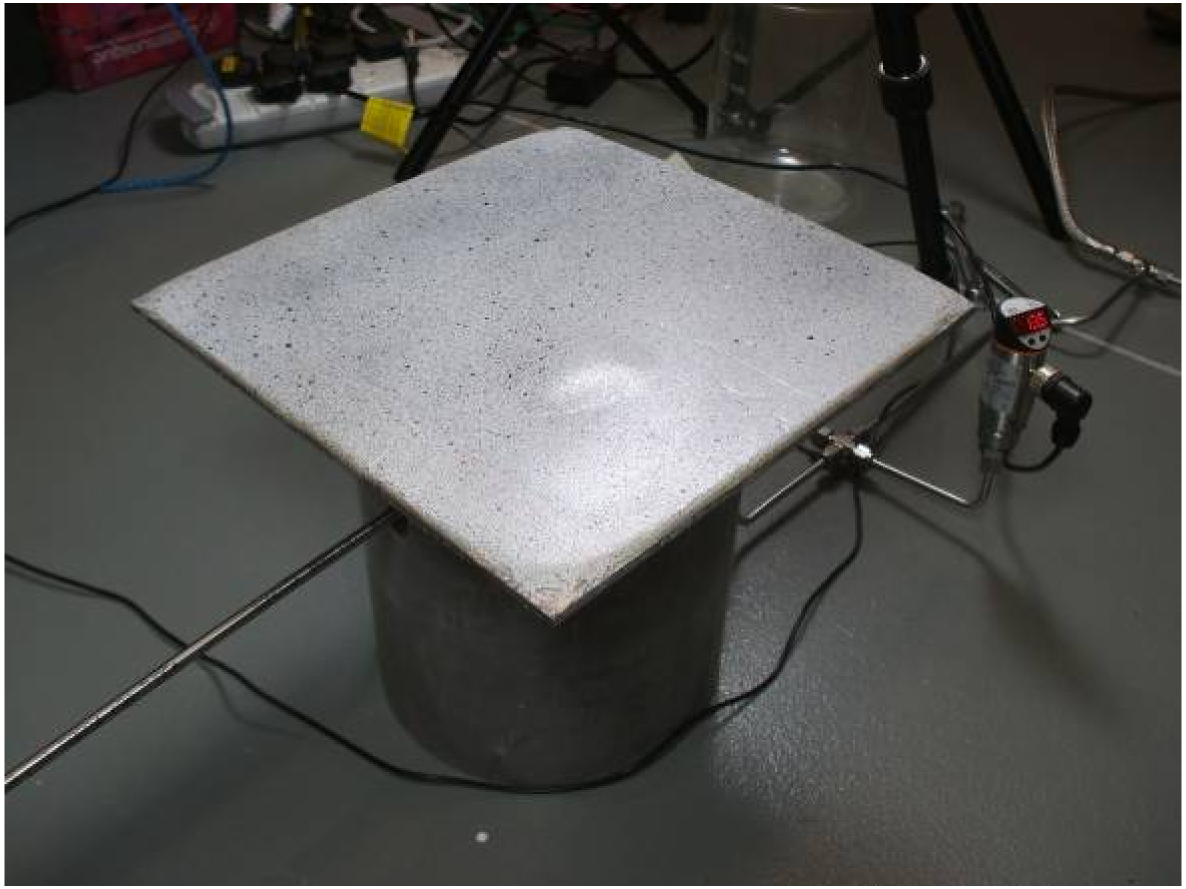
DIC equipment used LAVision DAVIS 7.4 software

StrainMaster

www.lavision.de

NPL National Physical Laboratory

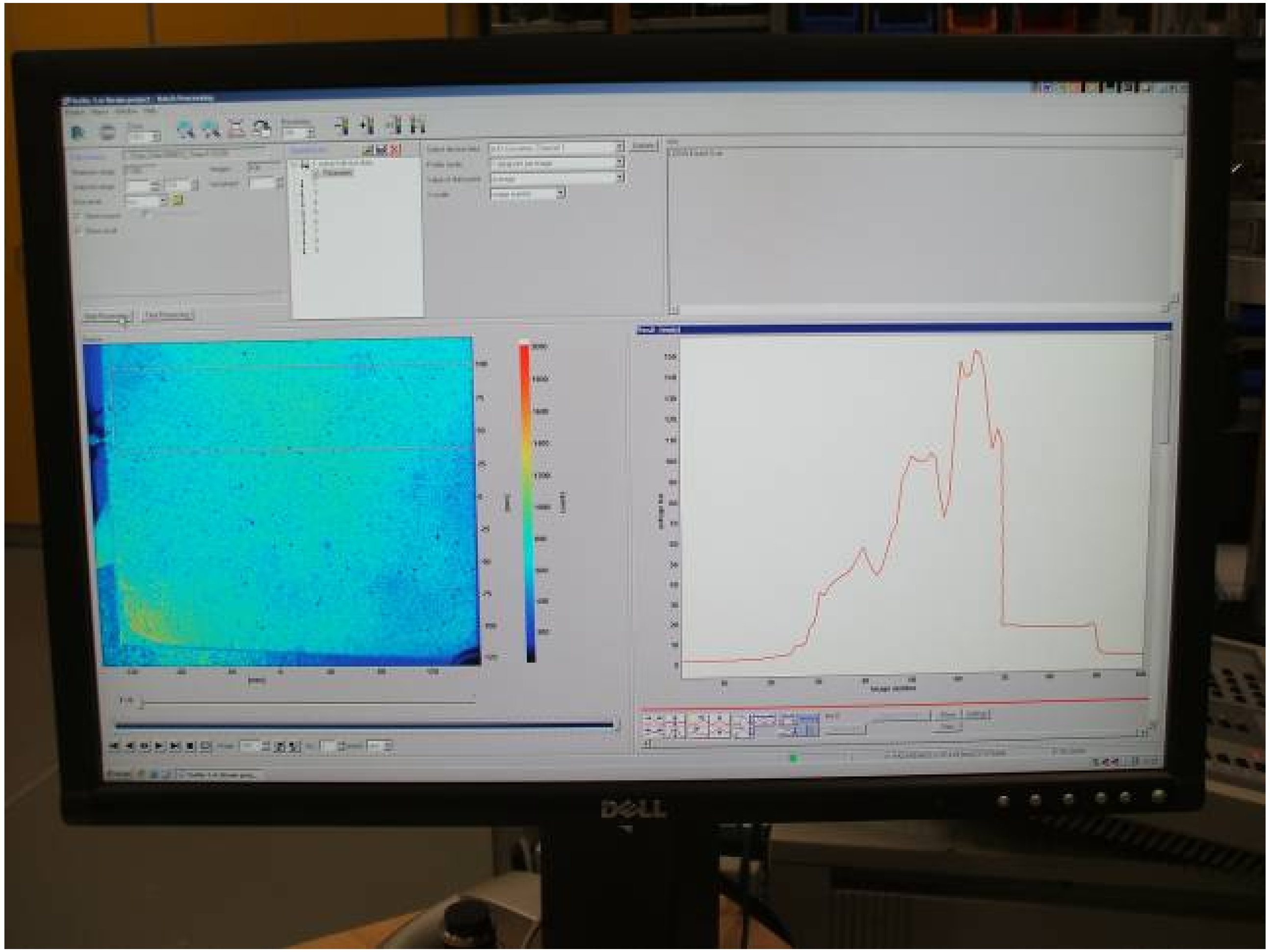
Case Study 3 – Piping repair



Panel #2

Blister formed at 100 bar before weeping at 150 bar.

Case Study 3 – Piping repair



Panel #2

Screen capture of data.

Blister formed at 100 bar before weeping at 150 bar.

Case Study 3 – Piping repair

Report – FT5373 - AE monitoring of plate blow-off tests at NPL for Imagine Project.doc

PHYSICAL ACOUSTICS LIMITED

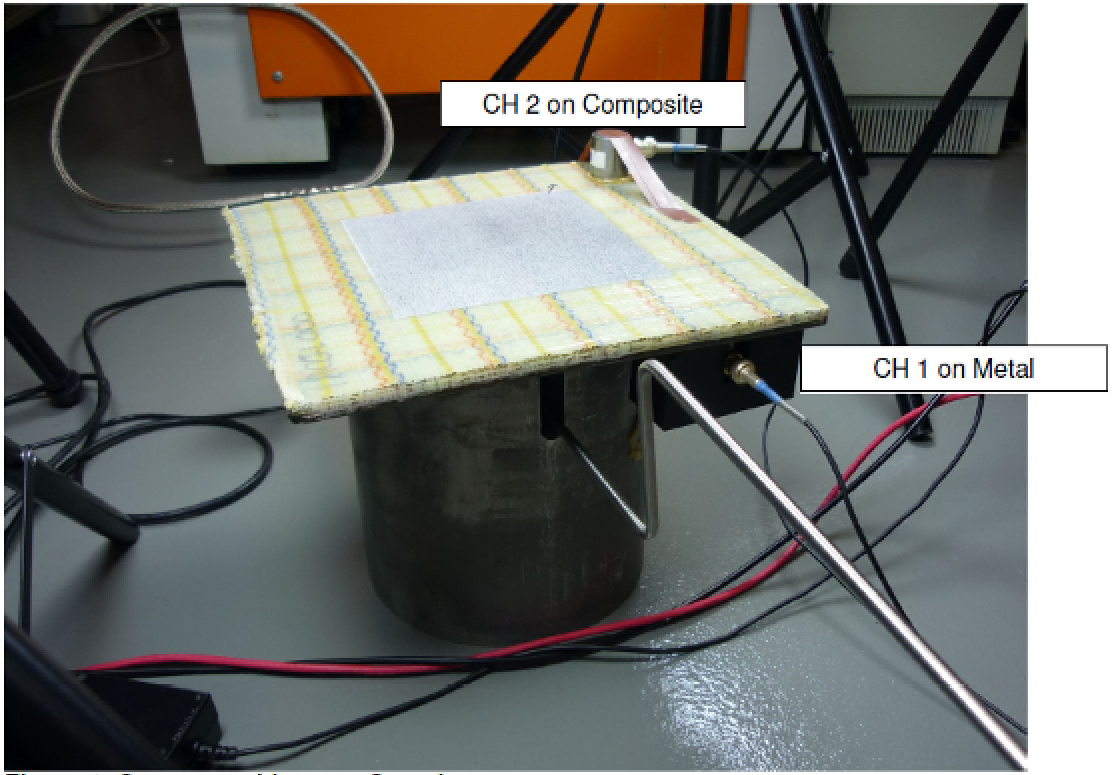


Figure 1: Sensor positions on Samples.

Plate pressure test using DIC and AE sensors mounted

Screen capture of data.

Blister formed at 100 bar before weeping at 150 bar.

More panels are awaiting tests.

Case Study 3 – AE Monitoring

Report – *FT5373 - AE monitoring of plate blow-off tests at NPL for Imagine Project.doc*

PHYSICAL ACOUSTICS LIMITED

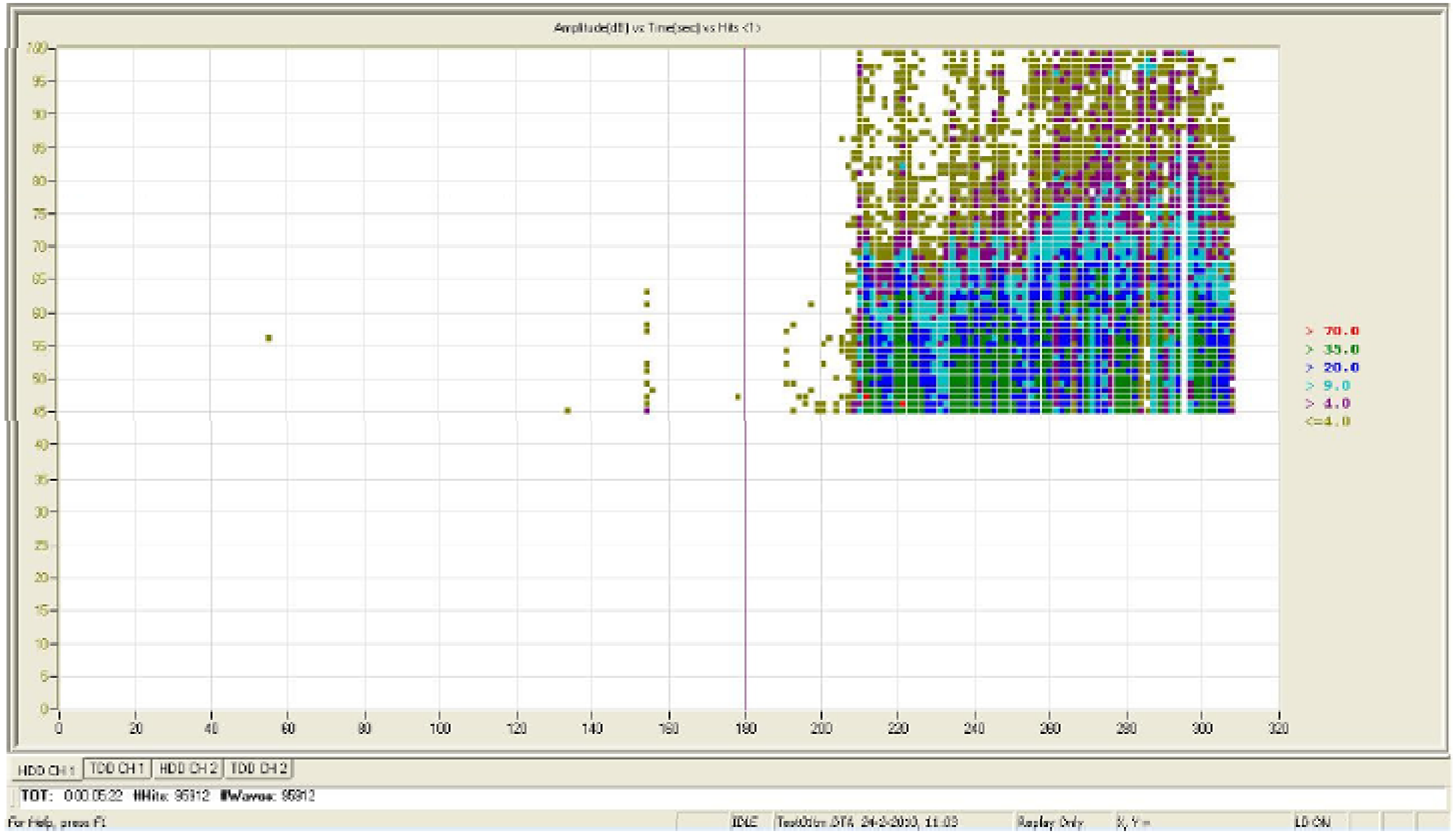
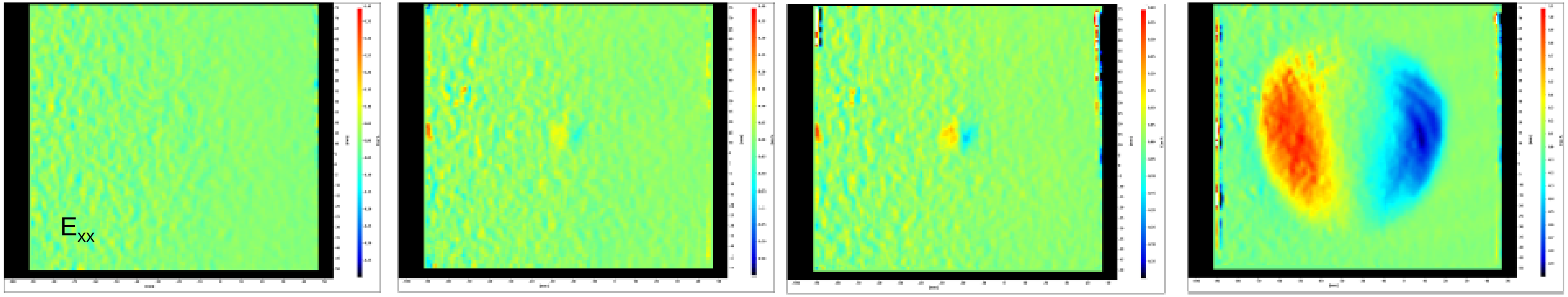
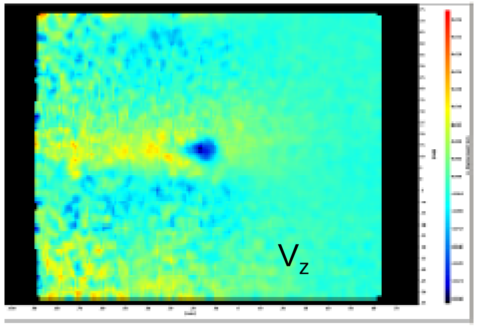


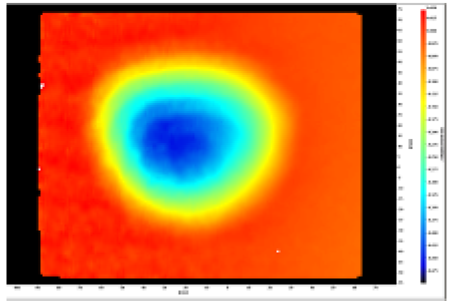
Figure 2: Sample 1 Amplitude results from CH1 (on steel)

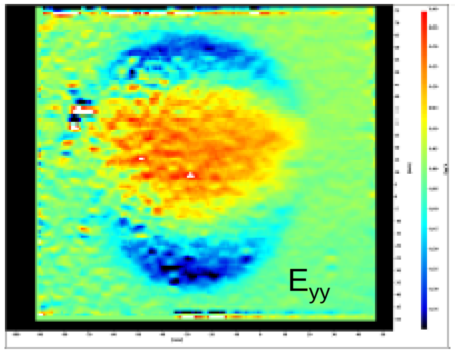
Case Study 3 – Piping repair

DIC Images





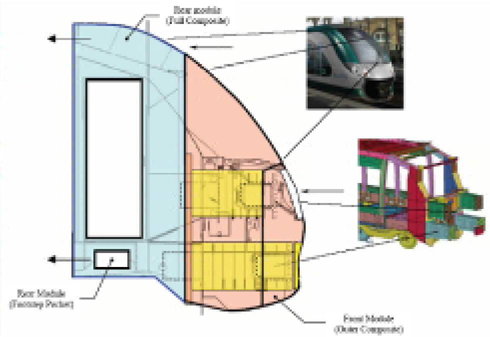


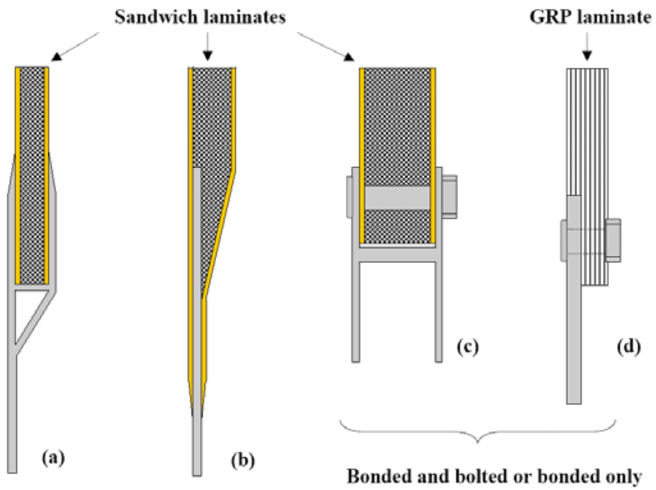


Selected DIC images for E_{xx}, E_{yy} and V_z

Case Study 4 – Rail Cab

- Based on commuter train design. Design includes impact absorbers and anti-climb devices.
- Selection of relevant geometry for consideration, i.e. bolted, flanged, bonded
- Crash absorbing structure.
- How to assess joint integrity in-service.
- Ultrasonic and AE testing during fatigue loading.





Bombardier Spacium 3.06

BOMBARDIER

French National Railways (SNCF) has ordered 372 Bombardier Spacium 3.O6 commuter trains for the Greater Paris/Ile-de-France suburban network. The Spacium 3.O6 commuter train is a swift, flexible vehicle designed to provide maximum seating capacity, superior passenger comfort, improved access and an attractive interior design.

Discussion

- Design guidance and structural integrity assessment is provided in the following documents:

- **Wind turbine blades** – DNV OS-J102 and Germanischer Lloyd guidelines. Based on partial safety factors covering loads, materials and consequences of failure.
- **Beam Strengthening** – Concrete Society TR55 & TR57 and CIRIA C595 based on partial factors varying with fibre type, manufacturing route, modulus of elasticity and time dependent properties.
- **Composite pipe repairs** – Key standards include ISO TS 24817 and ASME PCC-2. Also ISO 14692 (under revision) for GRP pipes
- **Rail cab structural joints** – Appears to be no generally available accepted guides, standards or procedures for design of bolted or bonded joints.

Summary

- The Case Studies represent various jointing configurations used in the energy generation, civil infrastructure and public transport sectors and present significant inspection and monitoring challenges for the future.
- Online monitoring and further in-service experience will enable a better understanding of failure modes and lead to increased confidence in long term joint behaviour.
- This presentation has described the generic joint configurations and materials. It has also mentioned the types of NDT and sensing techniques that could be used for condition monitoring.

Acknowledgements

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- The authors acknowledge all organisations who contributed relevant information and case study material and thank members of the Industrial Partners’ advisory group and the TSB Project Monitor, Ross Hannan.

Thanks for listening

Questions ?

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