EMRP JRP ENG57 – VITCEA

‘Validated inspection techniques for composites in energy applications’

1st VITCEA Workshop
BAM, Unter den Eichen 87, Berlin, Germany

Michael Gower / Maria Lodeiro/Alper Aktas/Richard Shaw
17th February 2015

Content

- Introduction to VITCEA
- Progress to date:
  - Industrial consultation exercise
  - Reference defect artefact (RDAs) designs

BAM
Federal Institute for Materials Research and Testing

PTB

CMI

cea list

NPL
National Physical Laboratory

PARTNERS

EURAMET

Project ENG57: VITCEA

Duration: July 2014 – June 2017

Funding: European Metrology Research Programme (EMRP) – EURAMET / NMS
EMRP Call: Energy 2013

ESR Technology
A Hyder Consulting group company Hyder

ZFL

OLYMPUS Your Vision, Our Future

cen
European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

ISO

DIN

dstl

WALKER TECHNICAL

tfp

SIEMENS

Vestas

RCNDE

LOT QuantumDesign

edevis

NDT

EUROS

Aviation Enterprises Ltd.
Composite & Marine Structures

Technip
take it further.

Exova

zfl
ZENTRUM FÜR FASERVERBUNDE UND LEICHTBAU HALDENSLEBEN
UG (haftungsbeschränkt)

GEVA

VAMAS

EVISIVE
MICROWAVE NDE TECHNOLOGY

EAST-4D
Ideen leicht gebaut

DANTEC DYNAMICS

BLOCK GmbH
Materialprüfungsgesellschaft

TodsCompositeSolutions
AGC AEROSPACE & DEFENSE

University of BRISTOL

The Need

- Improved efficiency and increased lifetime of energy applications is offered through full exploitation of the excellent mechanical properties, low weight, fatigue and corrosion resistance of fibre reinforced plastic (FRP) composites
- Increased confidence in the use of FRPs requires development of a non-destructive inspection (NDI) infrastructure to improve detection, identification and sizing of defects
- Requirement for a range of validated inspection techniques with contrasting and complementary detection capabilities to cover diverse range of FRP materials and energy applications
- Urgent requirement for standards specific to FRP composite inspection (3-5 years)

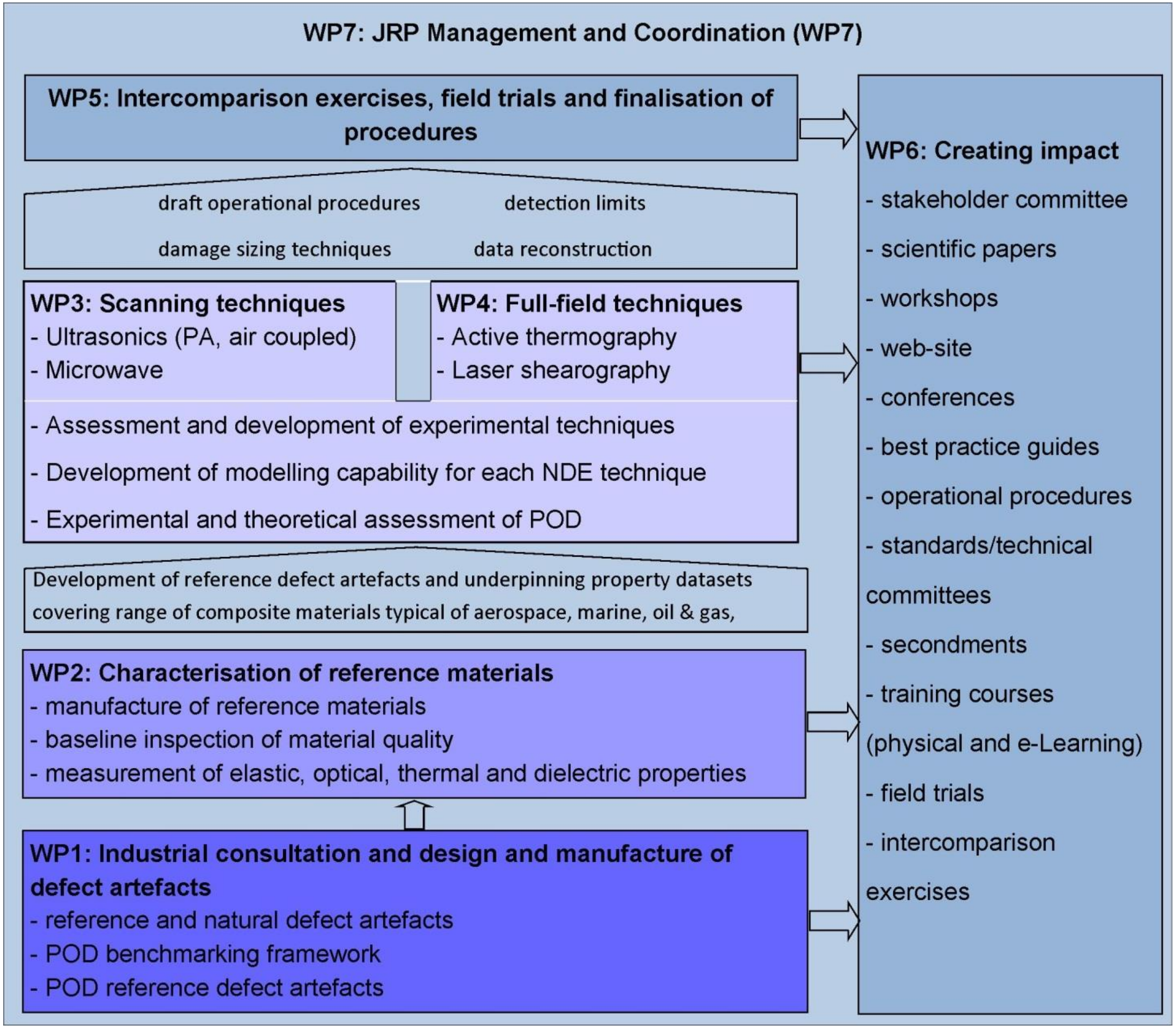
Current state-of-the-art

- Inspection standards specific to composites exist (e.g. ASTM) but limited to aerospace applications and grades of material
- Commonly used NDI techniques limited to visual inspection, tap testing, ultrasonic C-scan and X-radiography - not suitable for inspection of complex FRP structures or for application in service
- Microwave, active thermography, laser shearography and phased array/air-coupled ultrasonics show significant potential but require further development – currently insufficient knowledge of sensitivity and reliability
- Absence of standard reference defect artefacts (RDAs) for assessing NDI methods, equipment and sizing calibration for FRP materials
- Detection capability defined by probability of detection (POD) studies incurring high cost due to time and labour intensive assessments of large numbers of defects in relevant samples

Objectives

- Design and manufacture of defect artefacts representative of materials and defects found in renewable energy, oil & gas and transport sectors
- Develop operational procedures for microwave, active thermography, laser shearography, and phased array/air coupled ultrasonic techniques
- Metrology objectives:
- i. Develop techniques for sizing defects and establish limits of detection
- ii. Compare merits of NDI techniques using an objective experimental probability of detection (POD) framework
- iii. Advance state of the art modelling based on physical principles to improve understanding of performance of NDI techniques
- Assess potential of theoretical POD using simulations for NDI techniques
- Validation and refinement of operational procedures via intercomparison exercises and field trials

VITCEA Project Structure



WP7: JRP Management and Coordination (WP7)

WP5: Intercomparison exercises, field trials and finalisation of procedures

draft operational procedures

detection limits

damage sizing techniques

data reconstruction

WP3: Scanning techniques
- Ultrasonics (PA, air coupled)
- Microwave

WP4: Full-field techniques
- Active thermography
- Laser shearography

- Assessment and development of experimental techniques
- Development of modelling capability for each NDE technique
- Experimental and theoretical assessment of POD

Development of reference defect artefacts and underpinning property datasets covering range of composite materials typical of aerospace, marine, oil & gas,

WP2: Characterisation of reference materials
- manufacture of reference materials
- baseline inspection of material quality
- measurement of elastic, optical, thermal and dielectric properties

WP1: Industrial consultation and design and manufacture of defect artefacts
- reference and natural defect artefacts
- POD benchmarking framework
- POD reference defect artefacts

WP6: Creating impact
- stakeholder committee
- scientific papers
- workshops
- web-site
- conferences
- best practice guides
- operational procedures
- standards/technical committees
- secondments
- training courses (physical and e-Learning)
- field trials
- intercomparison exercises

NDE Techniques

Scanning techniques:

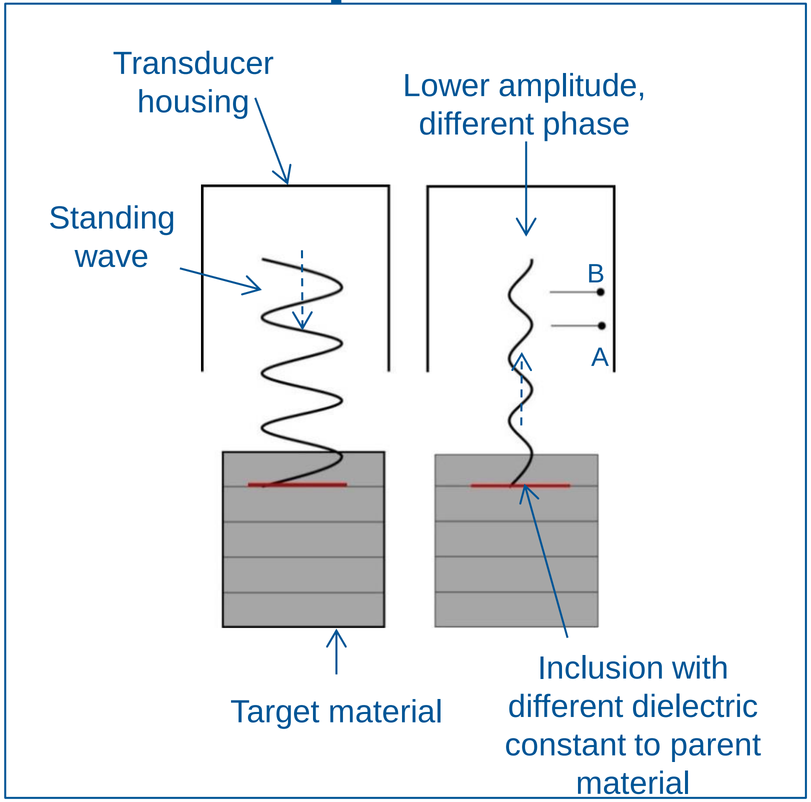
- Ultrasonics: phased array and air-coupled – BAM/CEA
- Microwave inspection: NPL

Full-field techniques:

- Active thermography: BAM/NPL
- Laser shearography: NPL

Principle of microwave inspection

- NPL's equipment is the Evisive microwave scan system
- 10 and 24 GHz probes
- 750 mm x 750 mm scanning area
- 24 GHz probe used for all scans
- Probe in contact with surface of panels – no coupling used or required



Transducer housing

Lower amplitude, different phase

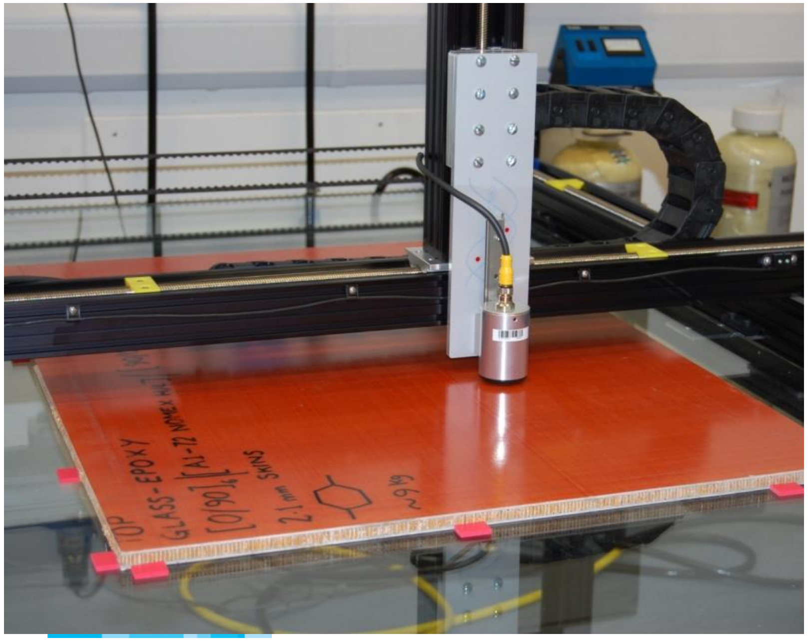
Standing wave

B

A

Target material

Inclusion with different dielectric constant to parent material

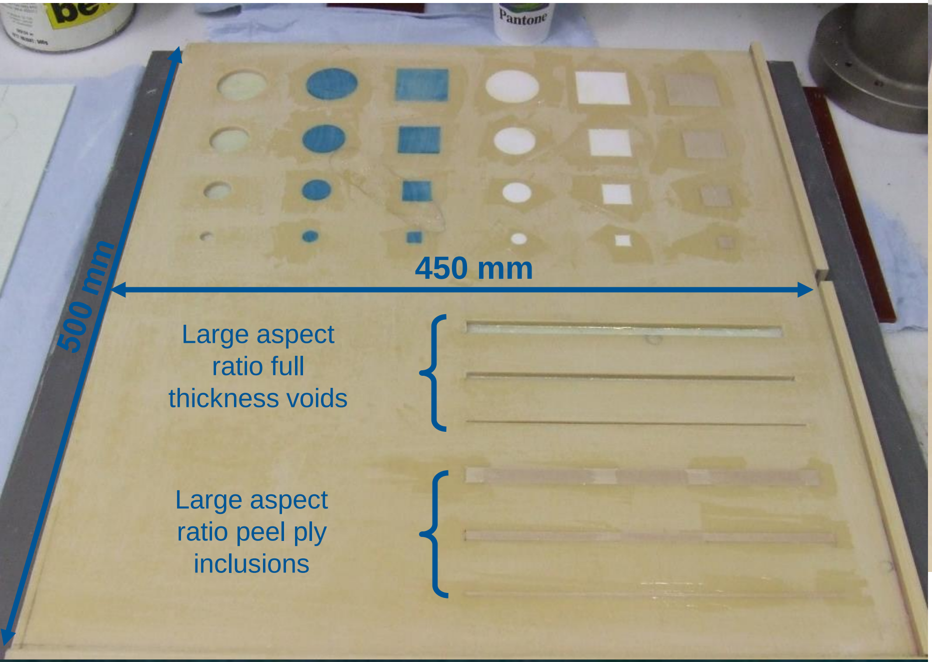


- Microwaves projected passed two sensor diodes (A and B) – record baseline voltage
- Penetrate test piece and at each interface for which there is a change in the dielectric constant energy is reflected
- Reflected energy is combined with transmitted signal and interference pattern is converted to a voltage by sensor diodes

Microwave inspection

- Microwave technique is based on measuring changes in dielectric properties of material
- Can be used on composites containing conductive components but whose construction makes them overall non-conductors or bulk dielectrics
- Adaptation of microwave oven technology - frequency range 10-50 GHz
- Microwaves transmitted to sample via
    - microwave horn
    - directly placing waveguide on sample
- Waveguide contains a power detector enabling power variations due to material quality or defects to be detected
- Increasingly used in defence and offshore composite applications due to its ability to inspect thick or poorer quality materials – larger defects in thick sections and low integrity GFRP
- For poor quality materials, high porosity of material attenuates ultrasound - microwaves are less effected
- Higher wavelengths of microwaves tend to give poorer resolution than for ultrasonics
- Main application is for detecting delaminations, de-bonds and impact damage

GFRP/PUR reference defect panel



Large aspect ratio full thickness voids

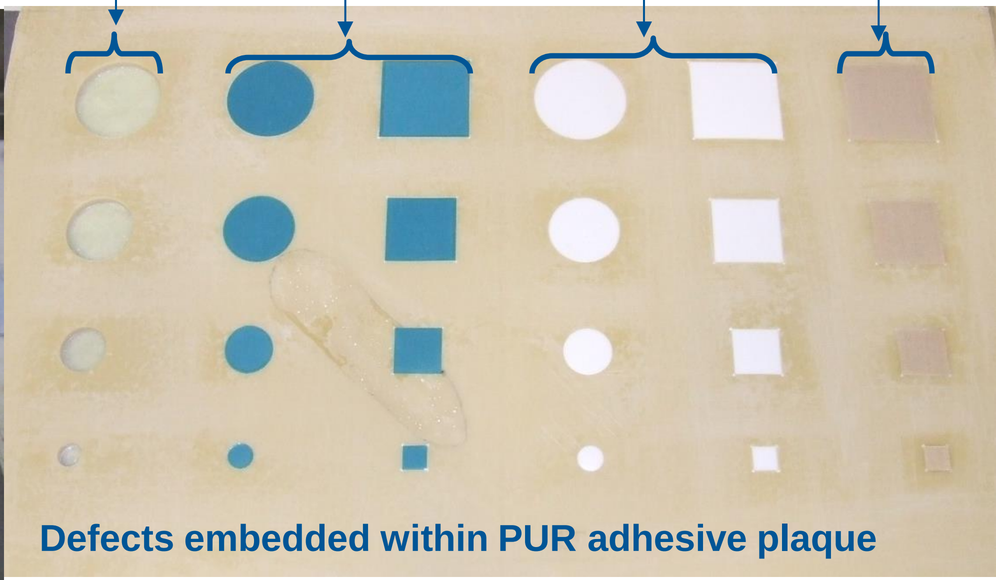
Large aspect ratio peel ply inclusions

Circular full thickness voids

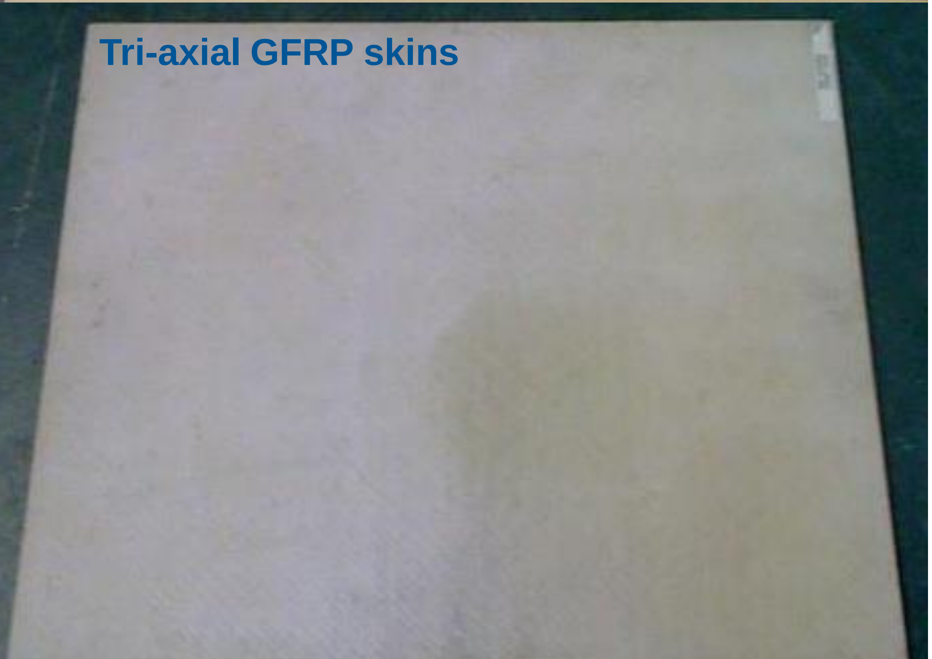
50 μm PTFE film sealed in heat resistant tape

Square and circular 0.5 mm thick PTFE

Square peel ply inclusions (0.02 mm thick)



Defects embedded within PUR adhesive plaque



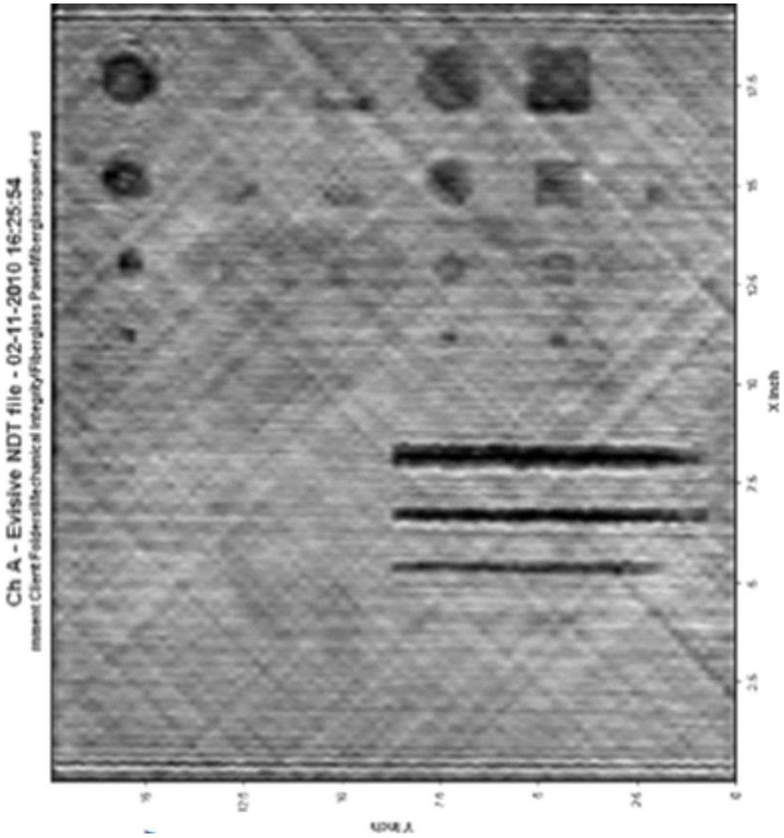
Tri-axial GFRP skins

3.5 mm thick GFRP skins

5 mm thick PUR adhesive core

Microwave - GFRP/PUR reference panel

- GFRP/PUR reference defect panel scanned using Evisive Inc system
- Able to detect:
  - voids
  - 0.5 mm thick PTFE sheet inclusions
  - peel ply
  - some unintentional defects
- Barely able to detect:
  - 50 μm PTFE film sealed in heat tape
- Also able to detect fibre direction
- Much better results than ultrasonic C-scan as microwave technique not susceptible to attenuation of poor quality GFRP material



Microwave

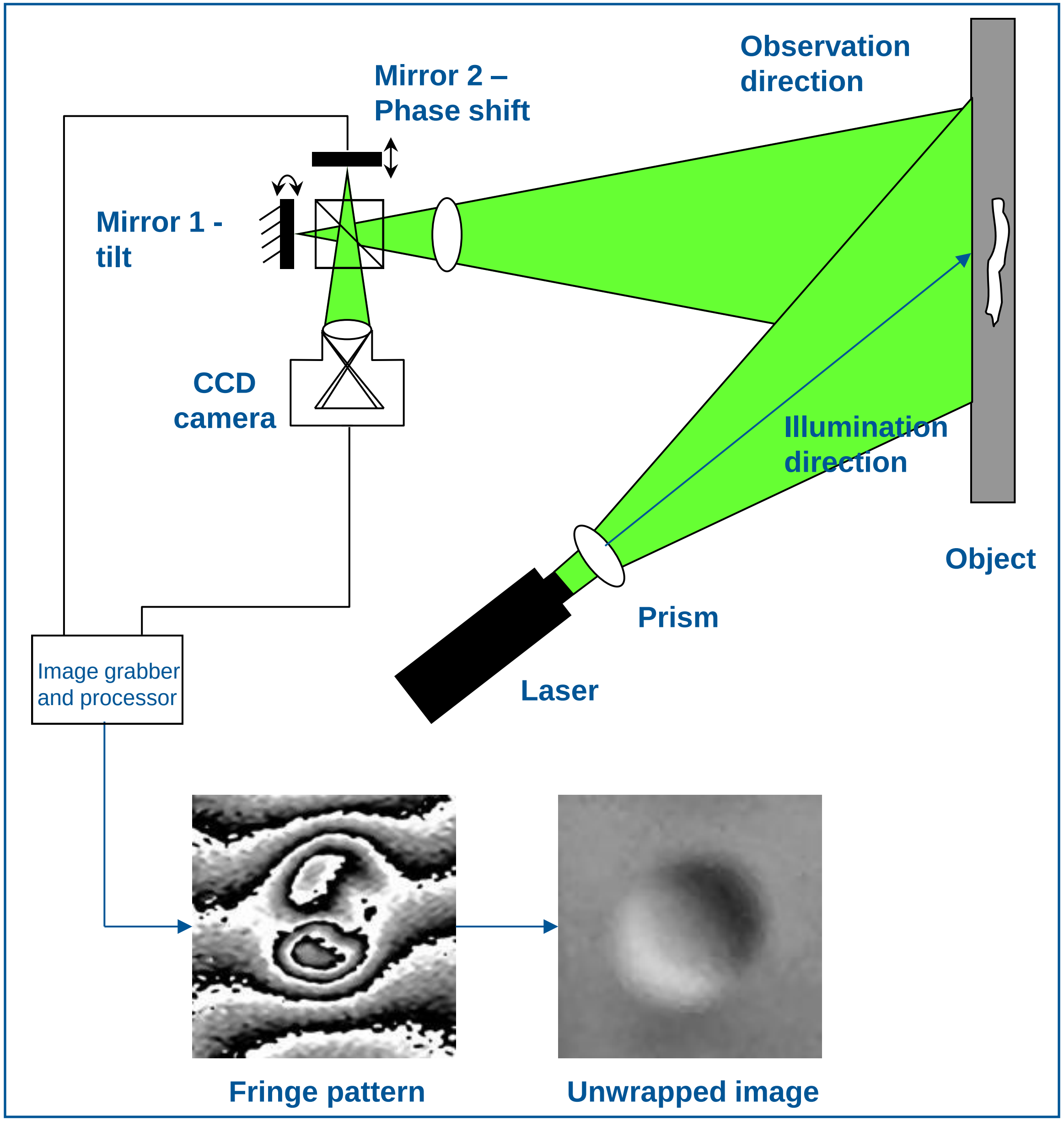
Advantages	Limitations
• can be used for detecting defects in lower grade/ quality materials (GFRP) • good depth penetration – suitable for thick structures • good for near-side, core and far-side defect detection in sandwich structures	• poor resolution due to high wavelengths • potentially limited to GFRP – subject of further research

Suitable for detecting:

- delamination
- de-bonds
- impact damage
- skin/core de-bonds
- sandwich core cracking
- inclusions (depending on dielectric constant of material e.g. water or oil)
- cracks
- voids

Laser shearography

- Non-contact technique that presents a visual qualitative map of the strain field of the surface of the structure due to an applied stress
- Uses coherent, monochromatic laser light to generate speckle patterns
- CCD grabs sheared speckle image under one stress state
- Stress state changed and second speckle image recorded
- Image subtraction produces strain fringe pattern
- Tightly packed fringes indicate higher rate of change of strain



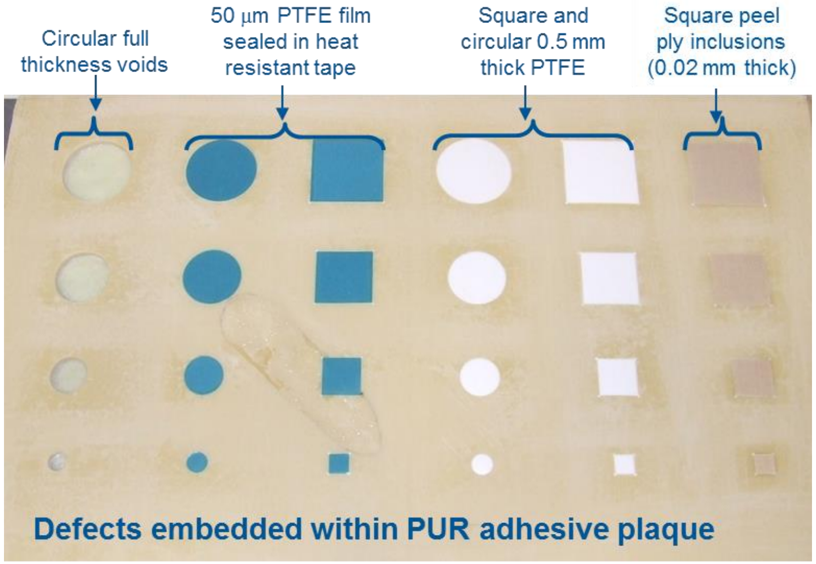
Inspection of GFRP/PUR reference defect panel (wind turbine blade RDA)

- Wind turbine blade RDA inspected using Q-800 Dantec Dynamics laser shearography system

- Computer controlled lamps used as a heat source to introduce thermal strain

- Successfully used to detect:
  - ✓ full through-thickness voids in adhesive
  - ✓ 0.5 mm thick PTFE sheet inclusions
  - ✓ peel ply
  - ✓ some unintentional defects!

- Not able to detect:
  - 50 µm PTFE film sealed in heat tape



Defects embedded within PUR adhesive plaque

Laser shearography

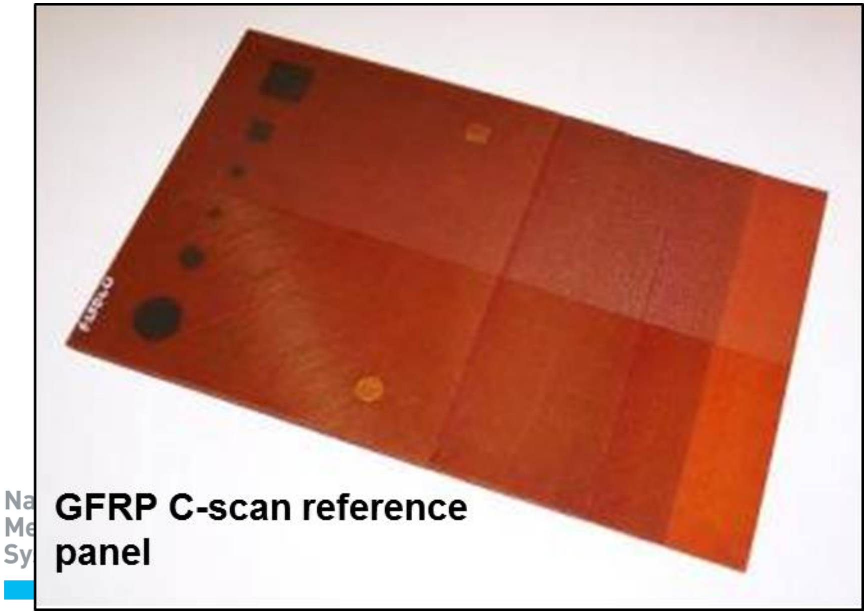
Advantages	Limitations
• quick (~30 frames/second for whole field measurements) • non-contact - no coupling required • full-field measurements (large area) • sensitive to a variety of defects • range of methods for stressing component (thermal, vacuum, mechanical etc.) • sensitive to changes in bond strength	• component needs to be stressed • not suited for applications where there is a lot of vibration • requires specialist evaluation • measured defect size inversely proportional to depth

Suitable for detecting:

- delaminations
- de-bonds
- un-bonded regions
- voids
- inclusions
- impact damage/BVID
- erosion
- fibre wrinkling

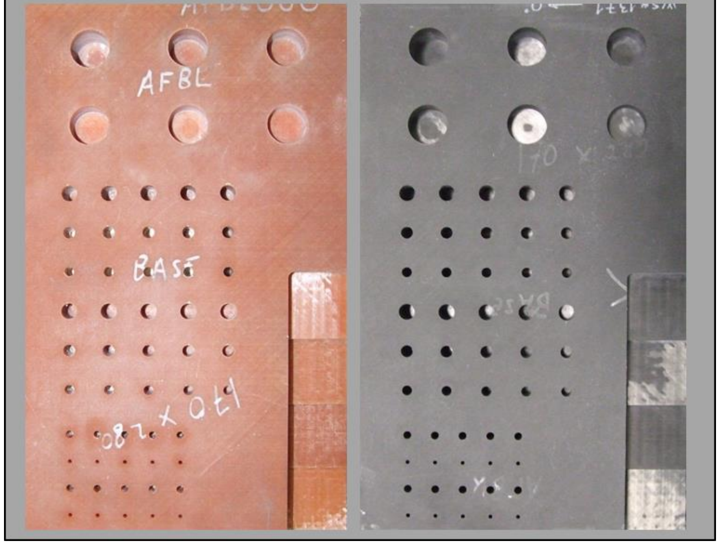
WP1: Industrial consultation for design and manufacture of defect artefacts

- Consultation with industry to determine a collection of defect artefacts that will be sourced, designed, manufactured and inspected that are representative of the defects, materials, processing routes and structural elements that are of concern to a range of renewable energy, oil and gas, and transport applications in which FRPs are used
- Design and manufacture of reference defect artefacts (RDAs) in which the defect sizes and locations are well defined and controlled



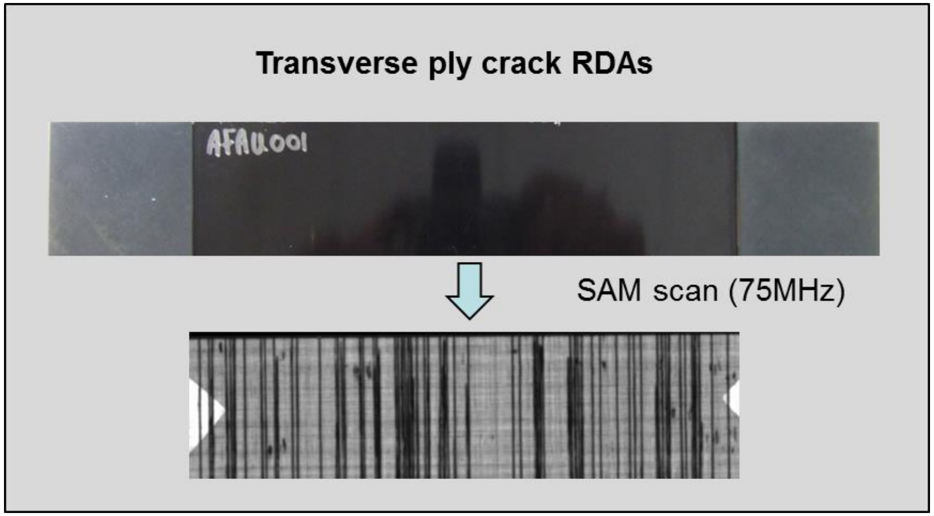
GFRP C-scan reference panel

GFRP and CFRP back-face drilled hole RDAs

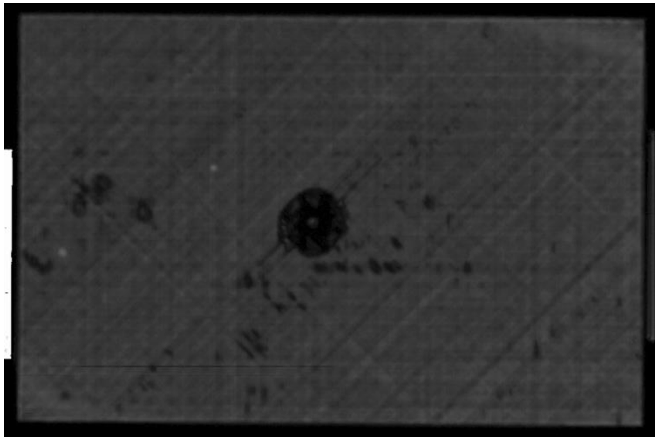


WP1: Industrial consultation for design and manufacture of defect artefacts

- Consultation with industry to determine a collection of defect artefacts that will be sourced, designed, manufactured and inspected that are representative of the defects, materials, processing routes and structural elements that are of concern to a range of renewable energy, oil and gas, and transport applications in which FRPs are used
- Design and manufacture of reference defect artefacts (RDAs) in which the defect sizes and locations are well defined and controlled
- Design and manufacture natural defect artefacts (NDAs) with defects produced via controlled processing techniques and/or loading mechanisms (fatigue, impact)



5J impact damage panel – SAM scan



WP1: Industrial consultation for design and manufacture of defect artefacts

- RDAs and NDAs will be used to assess each NDE technique’s robustness for accurately and consistently detecting a range of defects
- A two stage approach has been adopted:

1. At the simplest level of inspection:
    - RDAs/NDAs using well characterised material systems containing defects that are routinely required to be inspected and positioned in accessible locations
    - used to develop the baseline NDE operational procedures

2. More complex inspection scenarios:
    - inherent nature of the material (e.g. stitched fabrics, NCF)
    - type of defect (e.g. kissing de-bonds, fibre deviations)
    - location (e.g. back face skin-to-core de-bonds within a sandwich construction)

- Survey completed and now designing RDAs and NDAs together with BAM to reflect issues of concern to industry………………………………………..

Industrial survey

Survey sent out to a wide range of organisations – 26 responses covering the following sectors:

- Oil & Gas
- Transport
- Renewable Energy (wind and wave)
- Aerospace
- Marine
- Automotive
- Regulatory
- Academic

Industrial survey results

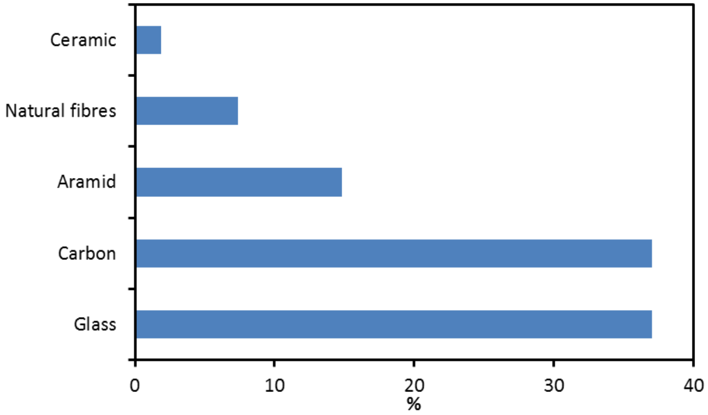
Inspection Methods:

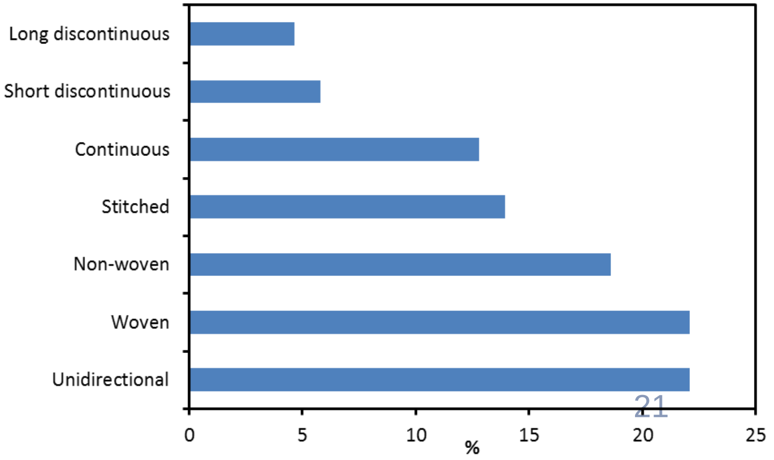
- Ultrasonic
- X-ray
- Thermography
- Shearography
- Tap test
- Eddy current
- Microwave
- Acoustic Emission

Purpose of NDT:

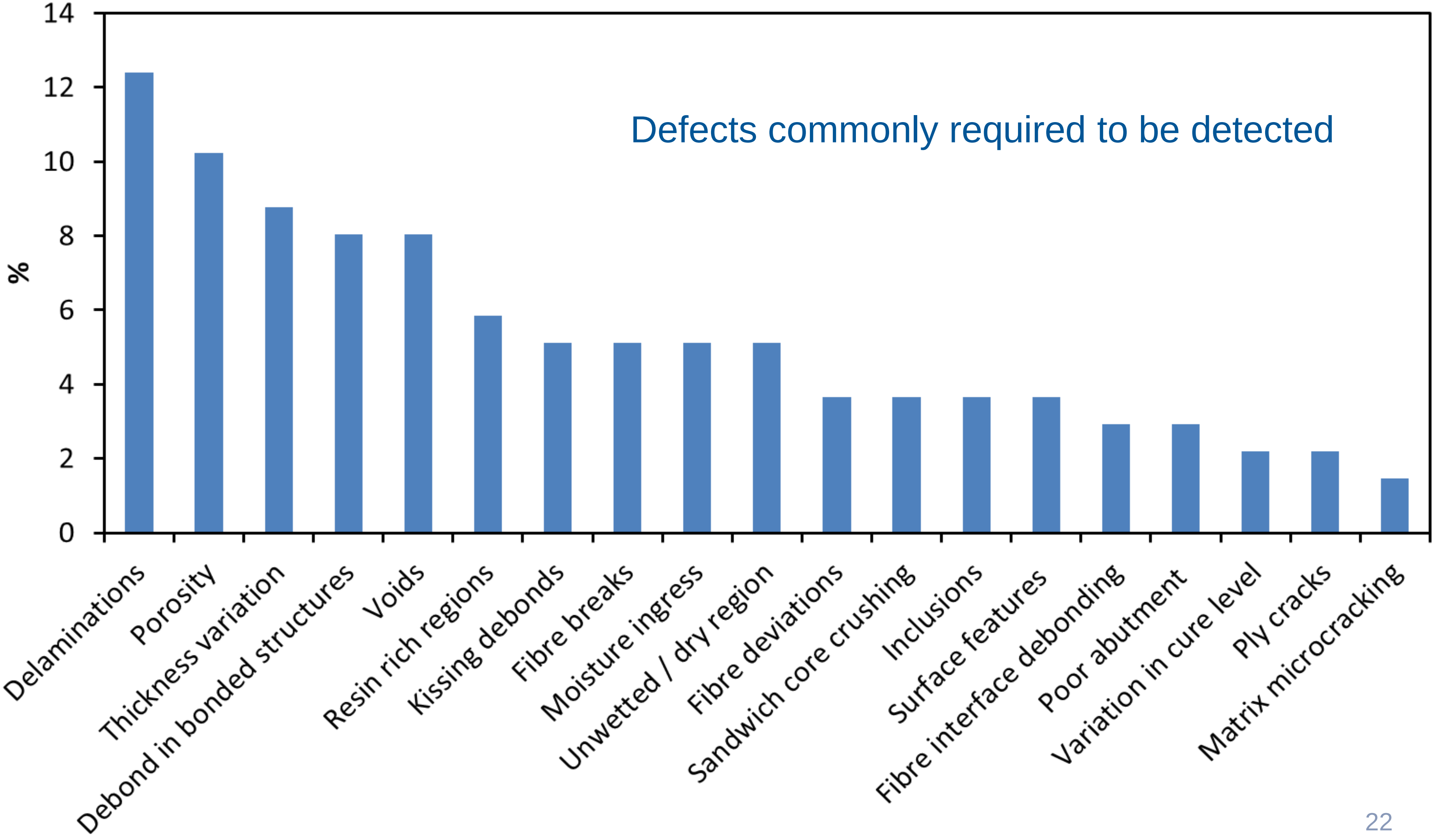
- Defect detection
- Sizing
- Depth location
- Detection of moisture
- Failure

Fibre types and formats:

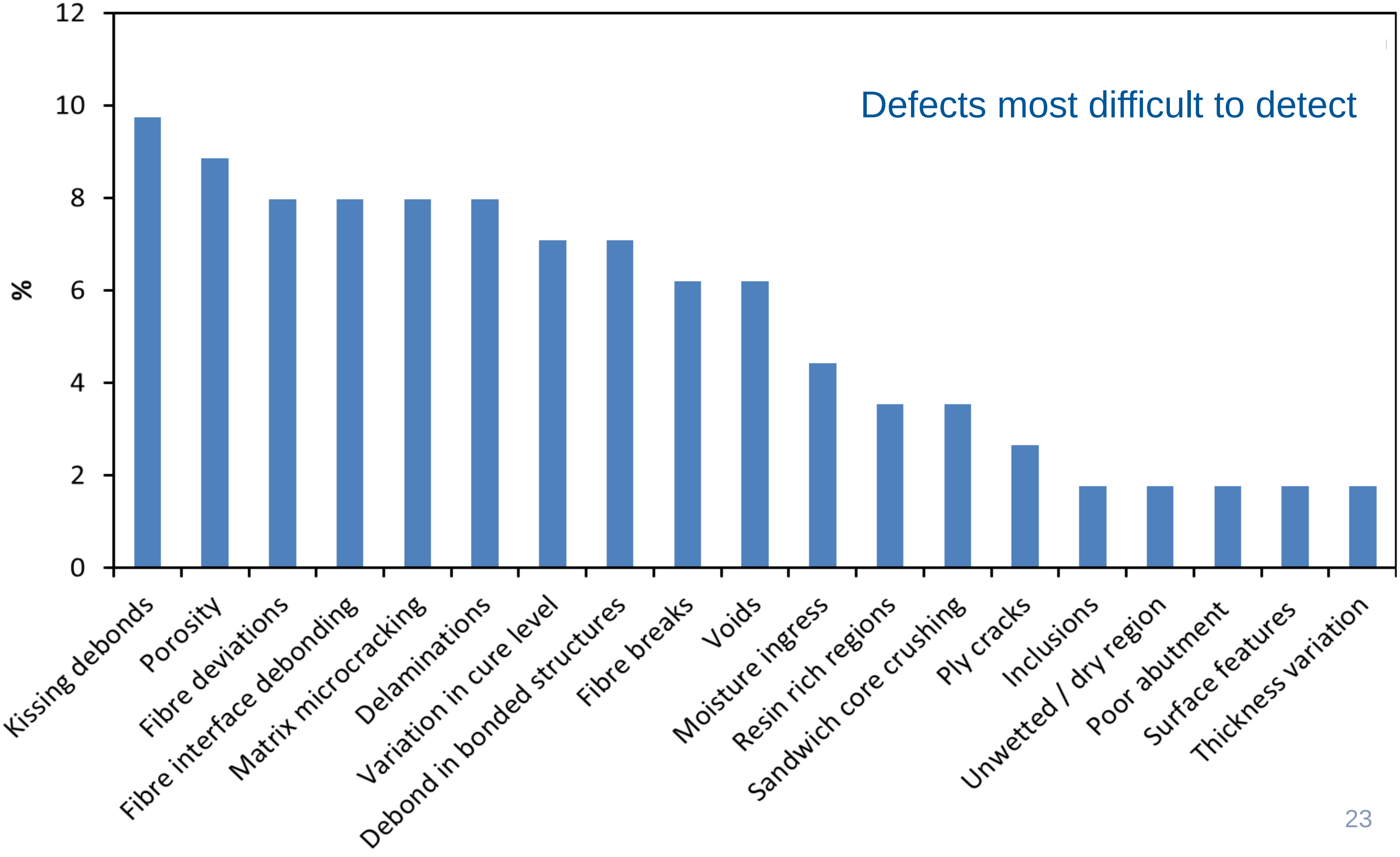




Industrial survey results


Defects commonly required to be detected

Industrial survey results



Defects most difficult to detect

Prioritisation of defects for study in VITCEA

Defect Type	Difficult (%)	Common (%)	Normalised (%)
Delamination	8	12	**10**
Porosity	9	10	**9**
Kissing debond	10	5	**7**
Debond in bonded structures	7	8	**7**
Voids	6	8	**7**
Fibre deviations	8	4	**6**
Fibre interface debonding	8	3	5
Fibre breaks	6	5	5
Resin rich regions	4	6	5
Thickness variation	2	9	5
Matrix microcracking	8	1	4
Variation in cure level	7	2	4
Sandwich core crushing	4	4	4
Moisture ingress	4	5	4
Inclusions	2	4	3
Surface features	2	4	3
Unwetted/dry region	2	5	3
Ply cracks	3	2	2
Poor abutment	2	3	2

Reference Defect Artefact (RDA) designs

Geometries

- Flat laminates
  - Monolithic (single and stepped thickness)
  - secondary bonded
- Curved monolithic laminates
- Sandwich construction
  - Glass FRP skins
  - PVC foam core
- Pipe section + simulated over-wrap repair

Materials (process methods)

- 1 x unidirectional carbon fibre-reinforced epoxy pre-impregnated tape (autoclave or oven cure)
- 2 x unidirectional glass fibre-reinforced epoxy pre-impregnated tapes (autoclave or oven cure)
- Quadraxial glass fabric infused with epoxy resin (oven cure)
- Unidirectional glass fibre-reinforced PA12 (thermoplastic – hot press or autoclaved)

Sectors

- Renewable (wind)
- Lightweight transport (marine/automotive)
- Oil and gas
- Generic sector

Defects

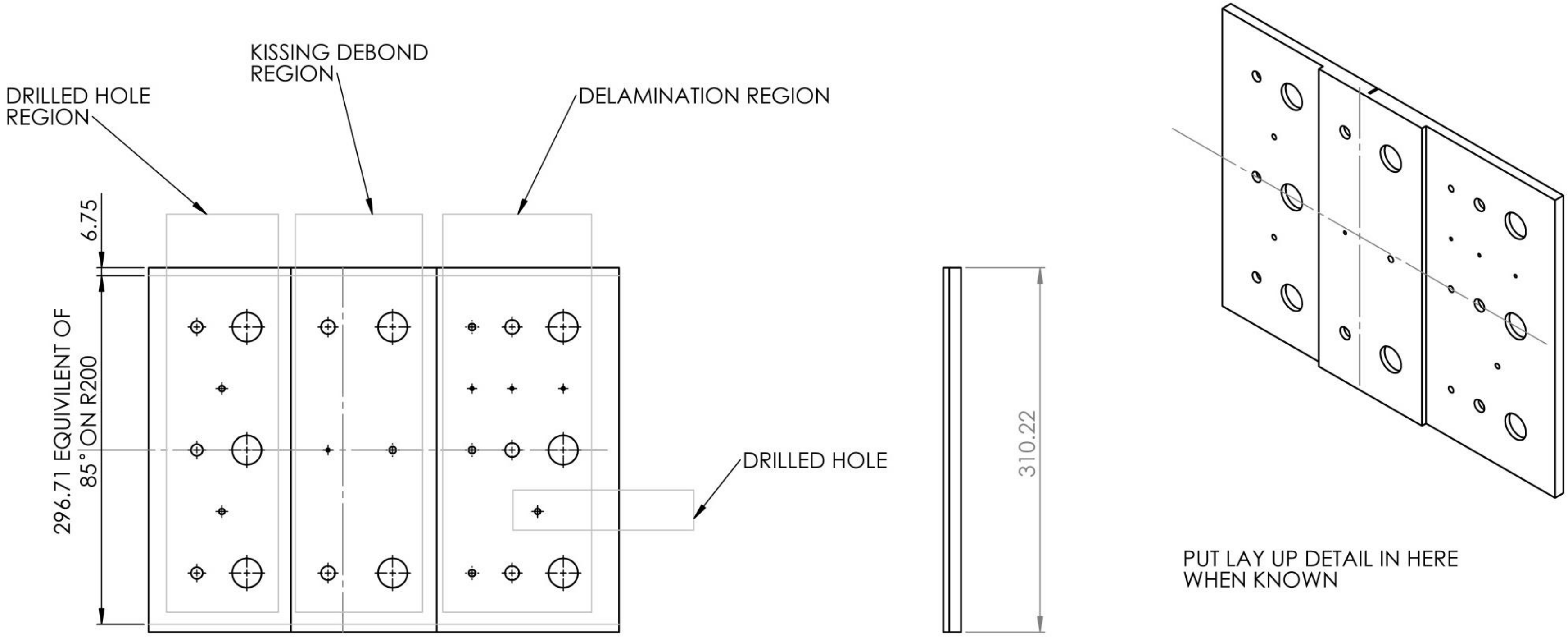
- Artificial delaminations
- Kissing bonds
- Fibre misalignment
- Voids/porosity
- Wall thinning
- Sandwich core damage

Oil & gas pipe repair

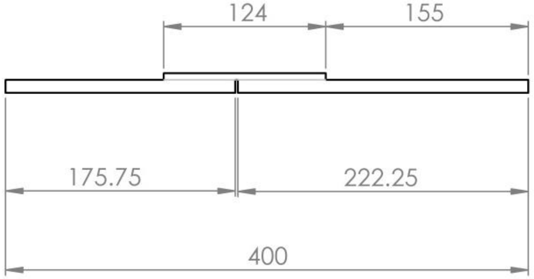
- Composite over-wrap repairs used in the oil and gas industry
  - repair of corroded pipe-work and pipelines
  - applied to pipe systems that are leaking, i.e. a through pipe wall defect, usually caused by excessive internal corrosion
- Repair materials
  - multi-axial fabrics: glass, carbon, aramid fibres
  - resins (matrix): epoxy, polyester, vinyl ester, polyurethane (good chemical resistance to hydrocarbons (e.g. alkanes, cyclo-alkanes),
  - adhesives: epoxy, methacrylates, laminate resin systems
- Hand applied either using wet lay-up systems or prefabricated rolls of composite reinforcement bonded together on-site and allowed to cure

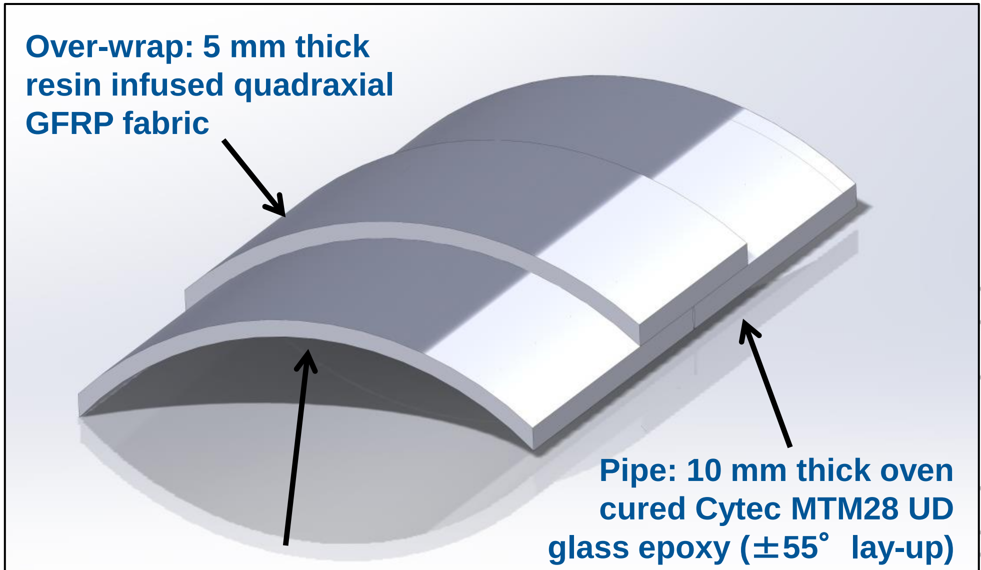
Courtesy: Walker Technical Resources

Oil & gas pipe repair (RDA-4)



Radius	200
Degree	Flattened
360	1256.637
15	52.35988
30	104.7198
88.87	310.2148



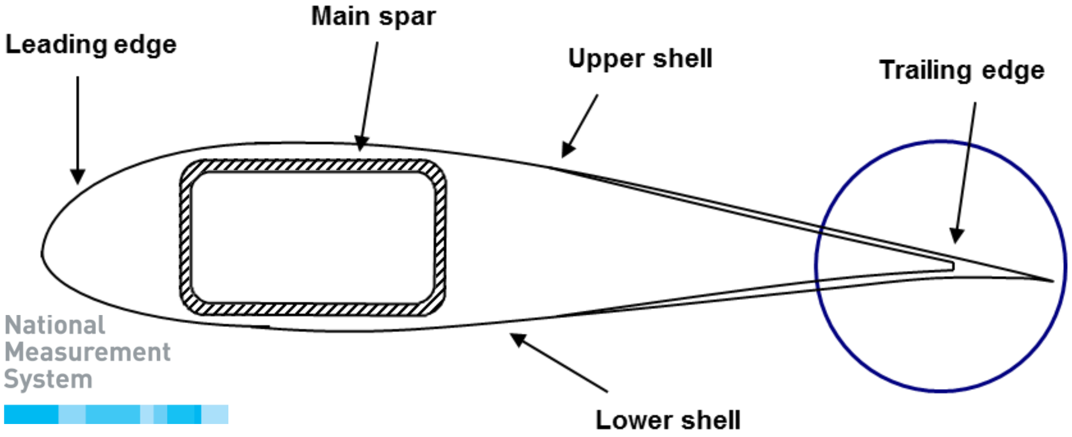


Over-wrap: 5 mm thick resin infused quadraxial GFRP fabric

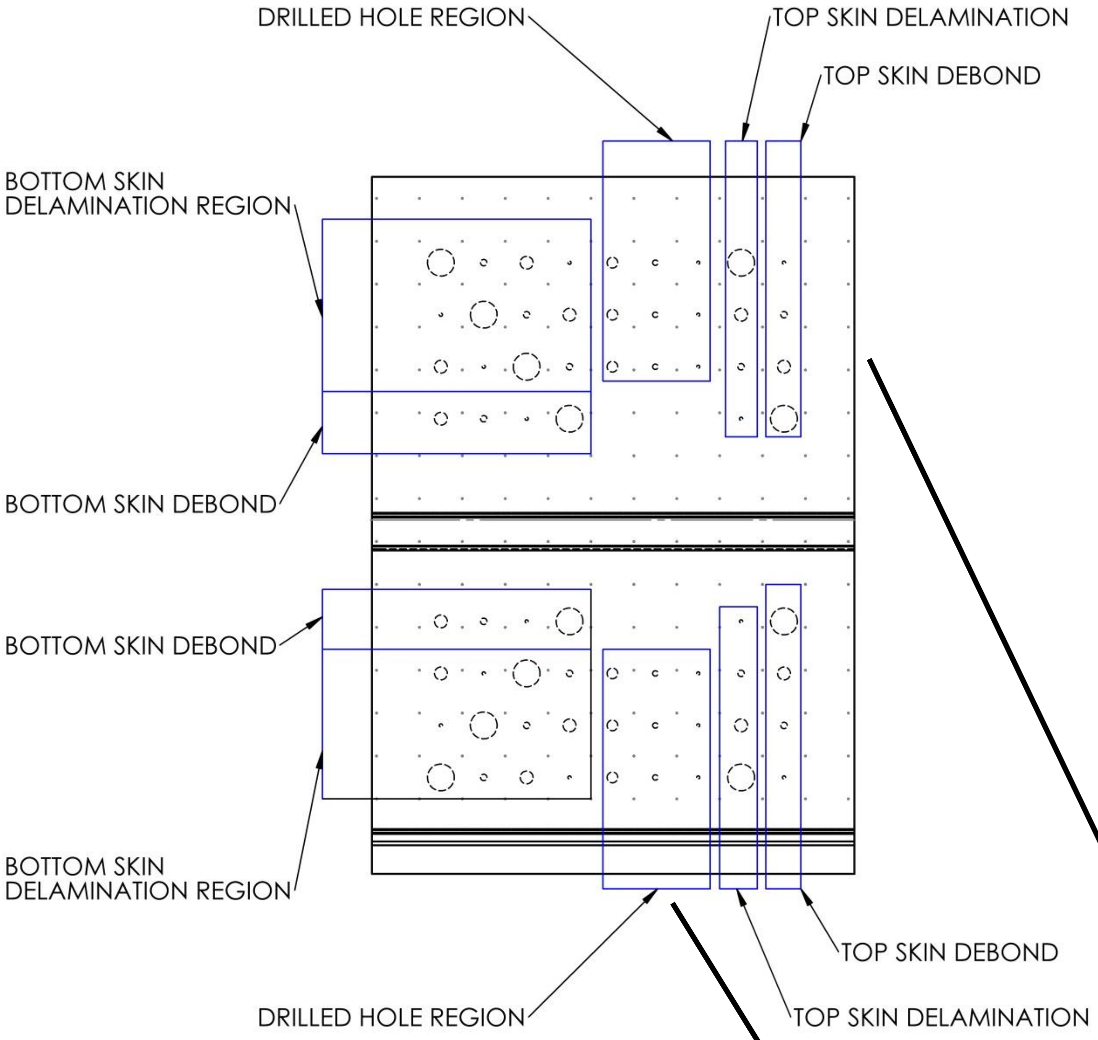
Pipe: 10 mm thick oven cured Cytec MTM28 UD glass epoxy (±55° lay-up)

Renewable energy (wind)

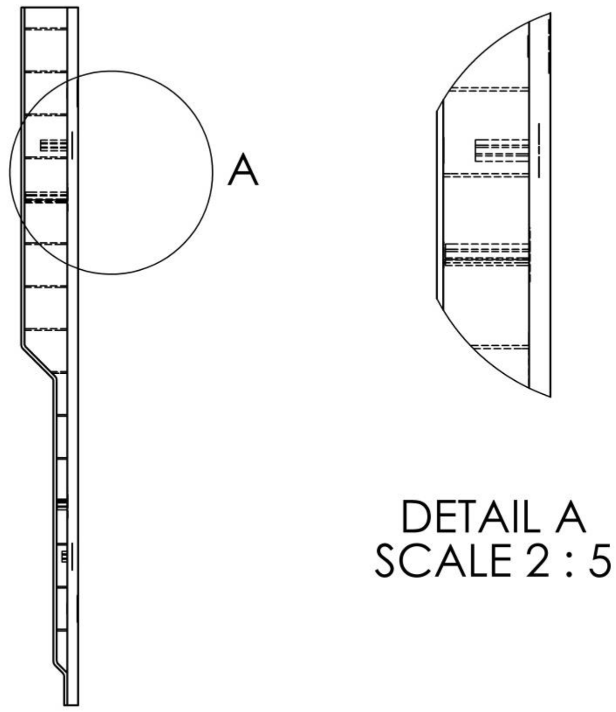
- RDA design proposed is representative of relatively slender construction typical of trailing edge regions of turbine blades
- Complex multi-material structures comprising skins, core, thick adhesive bond lines
- Skin materials
  - Unidirectional and/or multi-axial glass fabrics
  - Process: pre-impregnated tapes, resin infused dry fabric
  - Resins: typically epoxy, vinyl ester
- Foam core: PVC
- Can feature thick polyurethane adhesive bond-lines

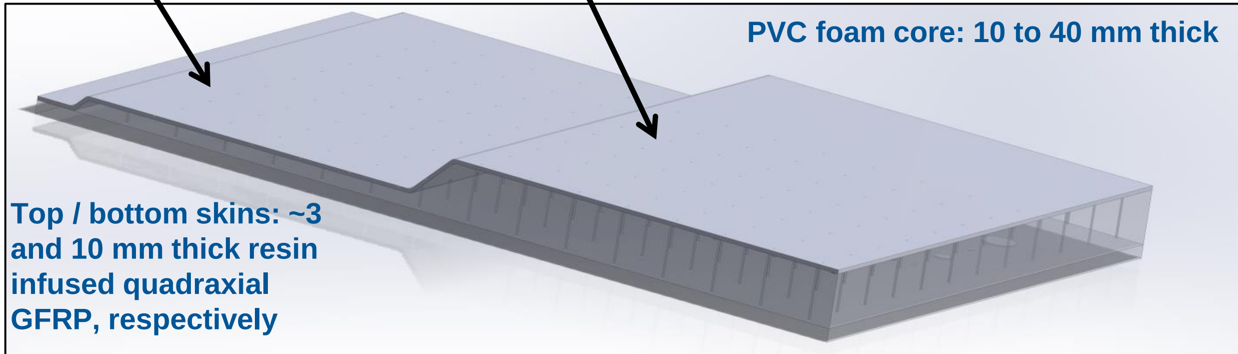


Renewable energy (wind)/marine (RDA-3)



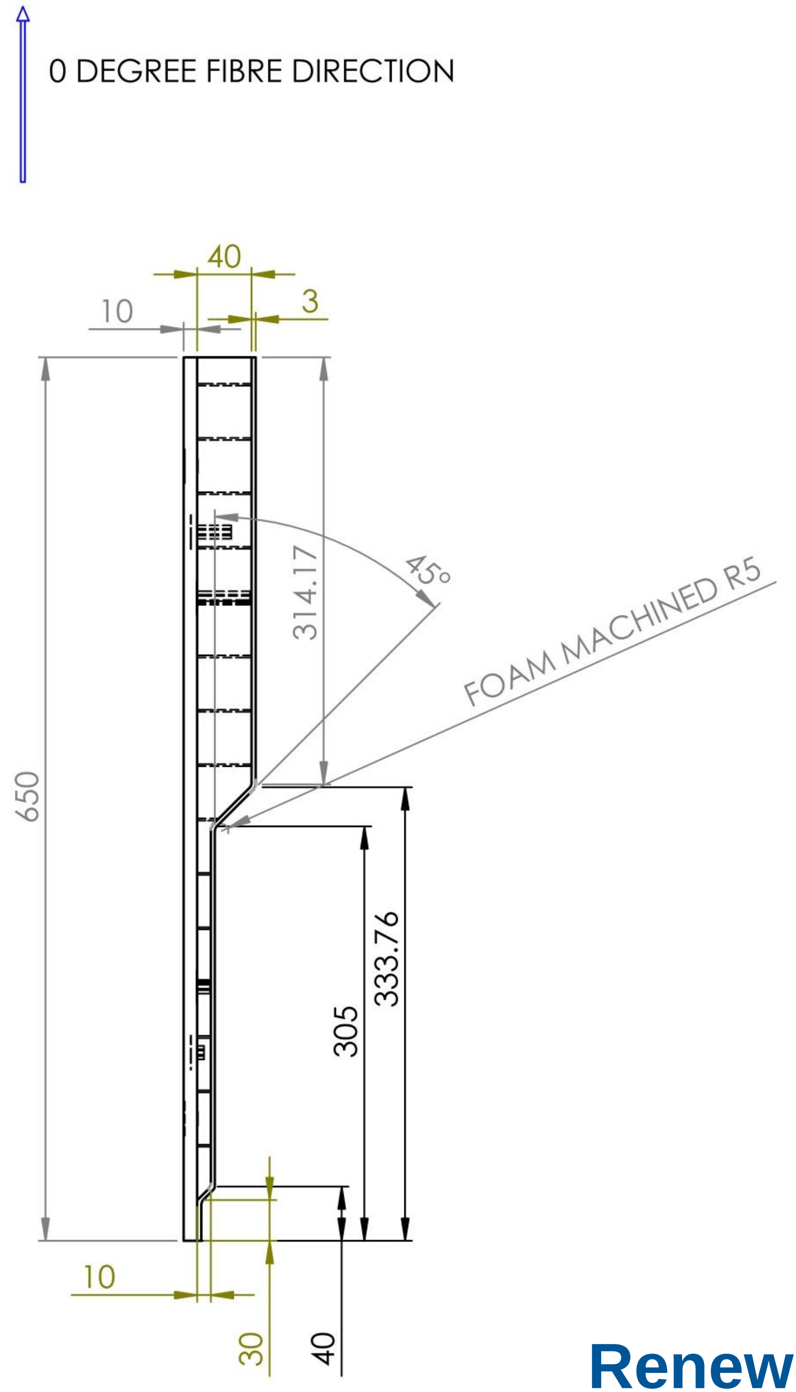
Drilled holes in core representing core damage

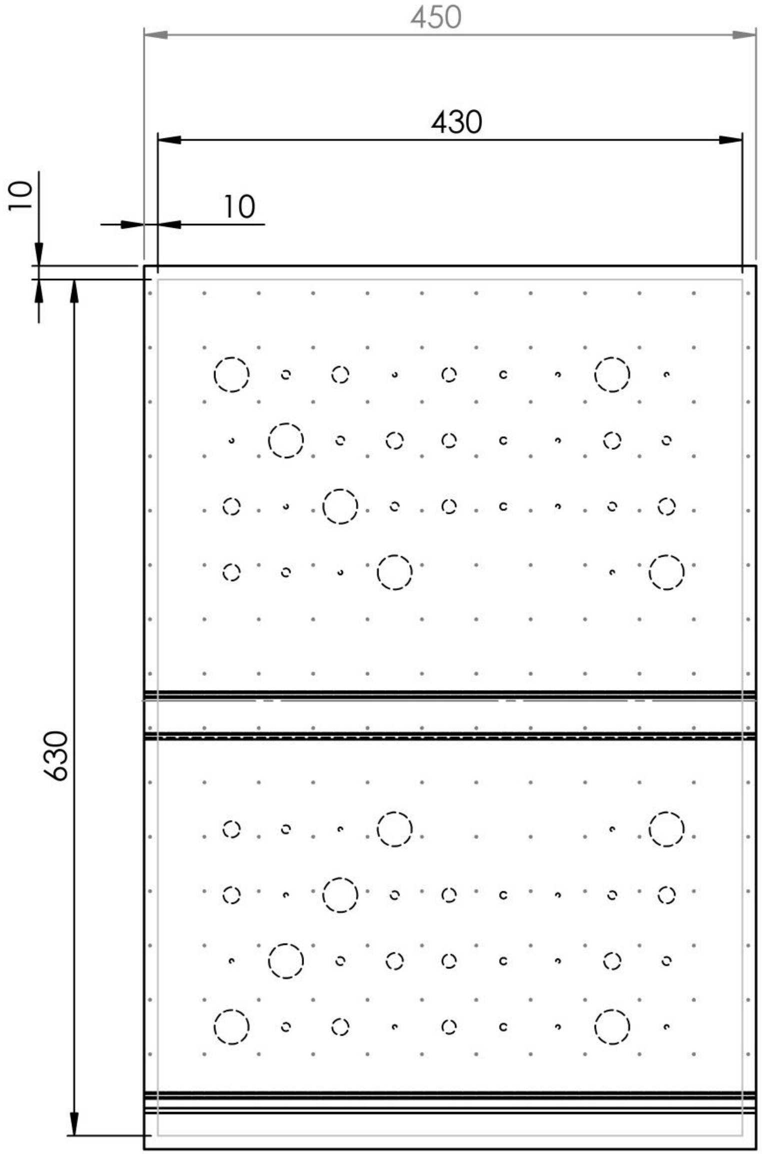




PVC foam core: 10 to 40 mm thick

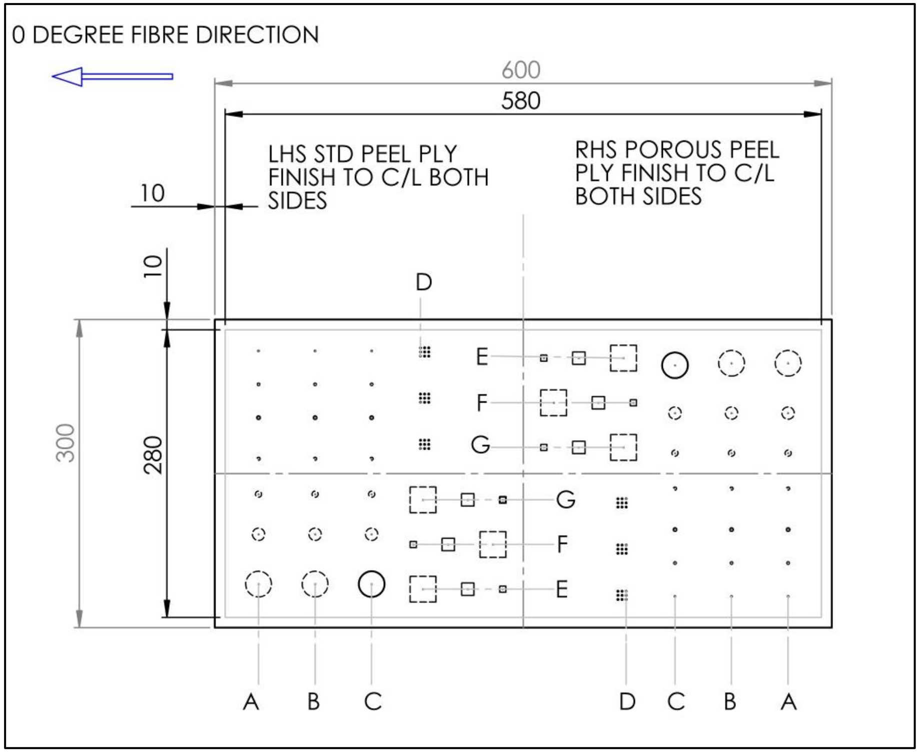
Top / bottom skins: ~3 and 10 mm thick resin infused quadraxial GFRP, respectively

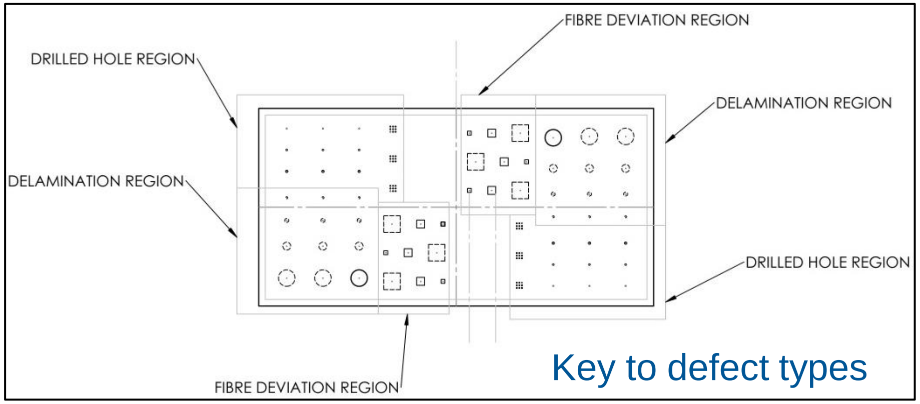




Renewable energy (wind)/marine (RDA-3)

Flat laminate – CFRP pre-preg (RDA-1a) (generic sector)





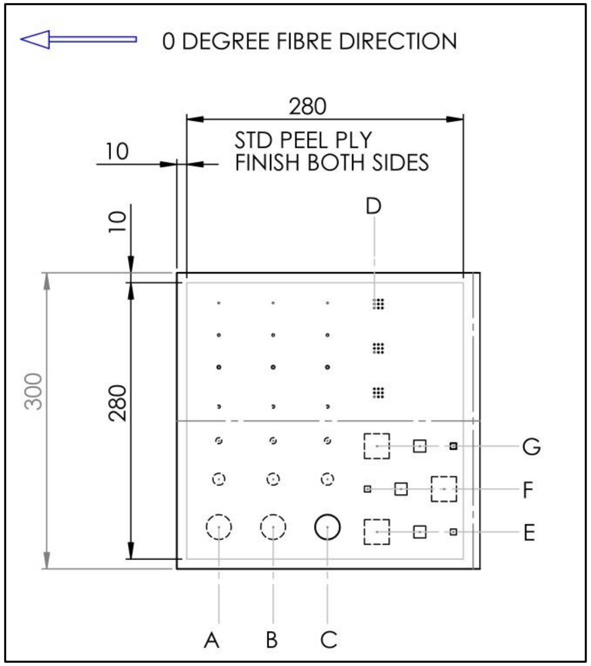
Key to defect types

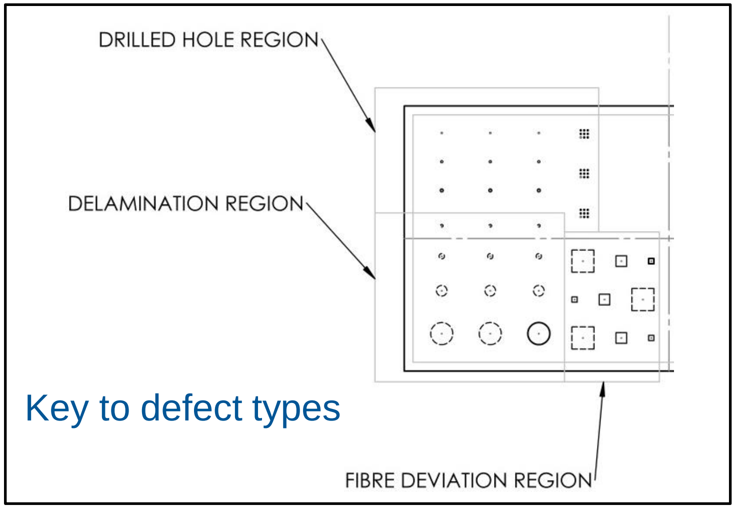
Construction:

- SE84 carbon fibre epoxy UD pre-preg
- 16 ply UD lay-up (~4 mm thick)
- Autoclave processed
- Matt and gloss surface finishes

Defect type	Sizes	Locations
Delamination	∅3, 6, 12 & 25 mm	- near front face - mid-thickness - near back face
Fibre deviation	- 6, 12 and 25 mm sq - 15° misalignment	- near front face - mid-thickness - near back face
Drilled holes (void and porosity)	- ∅1, 2, & 3 mm individ - 3 x 3 arrays of ∅1 mm	- near front face - mid-thickness - near back face

Flat laminate – GFRP pre-preg (RDA-2a) (generic sector)





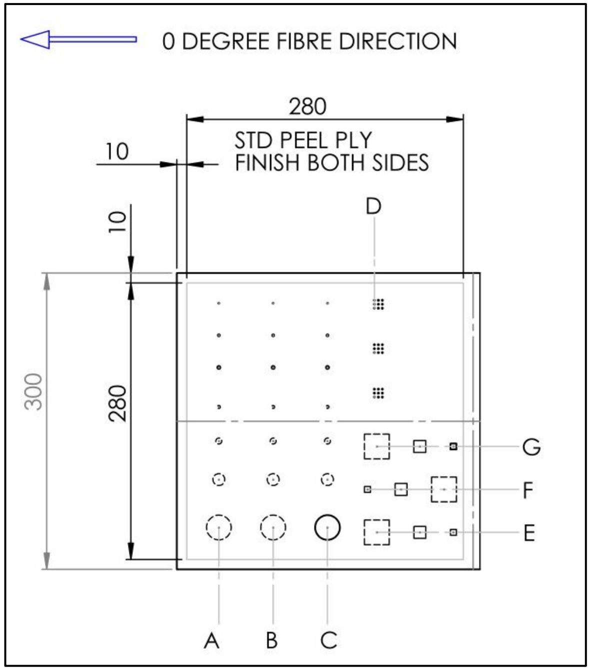
Key to defect types

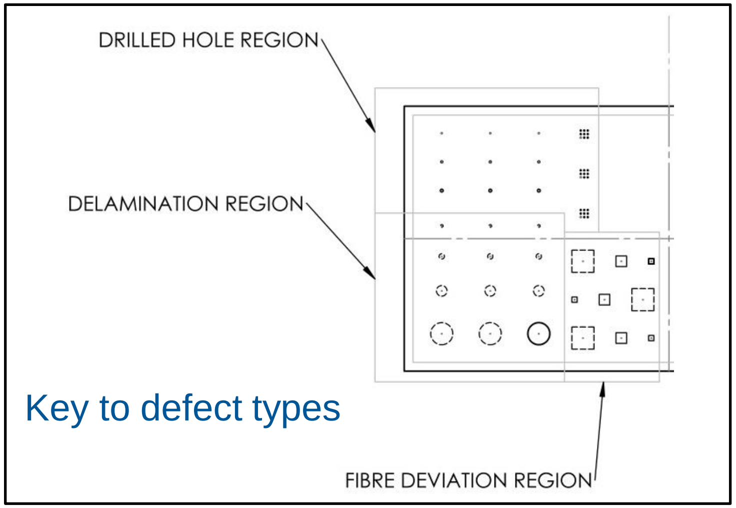
Construction:

- 913 glass fibre epoxy UD pre-preg
- Cross-ply $[0/90]_{10s}$ lay-up (~5 mm thick)
- Autoclave processed
- Gloss surface finish only

Defect type	Sizes	Locations
Delamination	∅3, 6, 12 & 25 mm	- near front face - mid-thickness - near back face
Fibre deviation	- 6, 12 and 25 mm sq - 15° misalignment	- near front face - mid-thickness - near back face
Drilled holes (void and porosity)	- ∅1, 2, & 3 mm individ - 3 x 3 arrays of ∅1 mm	- near front face - mid-thickness - near back face

Flat laminate – UD glass fibre thermoplastic (RDA-5) (automotive)





Key to defect types

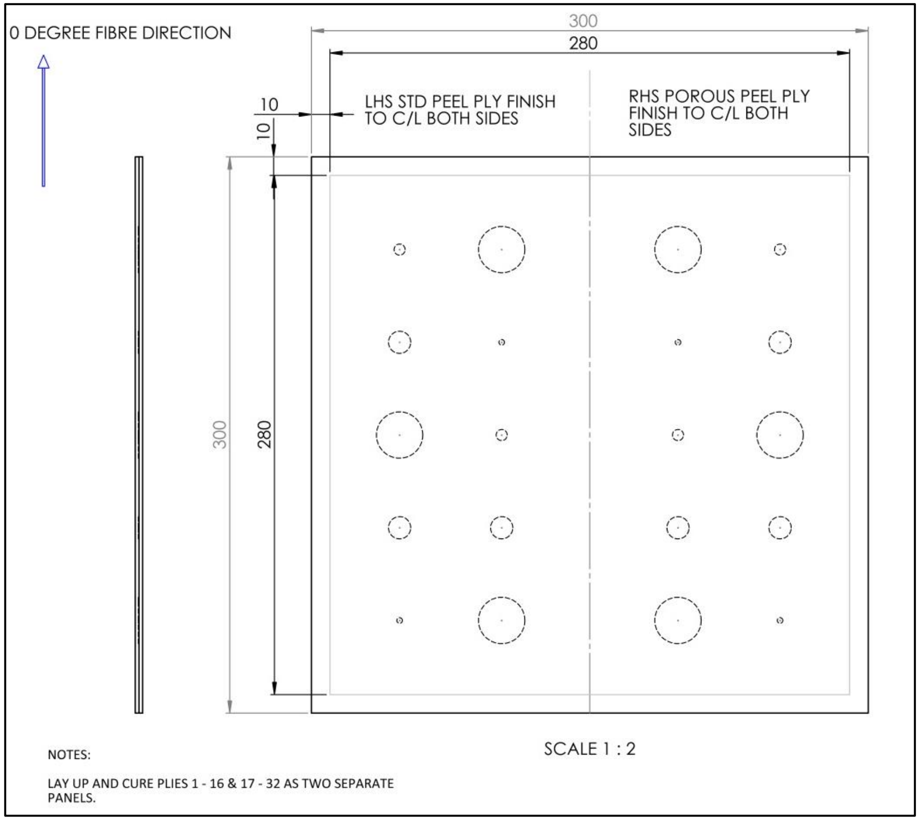
Construction:

- Polyamide 12 unidirectional glass fibre tape
- 16 ply UD lay-up (~4 mm thick)
- Autoclave or hot press processed (220-240C)

N.B. materials used for construction of artificial delaminations should be rated to 260C

Defect type	Sizes	Locations
Delamination	∅3, 6, 12 & 25 mm	- near front face - mid-thickness - near back face
Fibre deviation	- 6, 12 and 25 mm sq - 15° misalignment	- near front face - mid-thickness - near back face
Drilled holes (void and porosity)	- ∅1, 2, & 3 mm individ - 3 x 3 arrays of ∅1 mm	- near front face - mid-thickness - near back face

Flat laminate: CFRP/GFRP pre-preg (RDA-1b & 2b) (kissing bond)



NOTES:

LAY UP AND CURE PLIES 1 - 16 & 17 - 32 AS TWO SEPARATE PANELS.

Defect type	Sizes	Locations
Kissing bond	∅3, 6, 12 & 25 mm	~mid-thickness between bond-line and laminate

RDA-1b material:

- SE84 carbon fibre epoxy UD pre-preg
- 2 off pre-cured 8 ply (2 mm) UD laminates

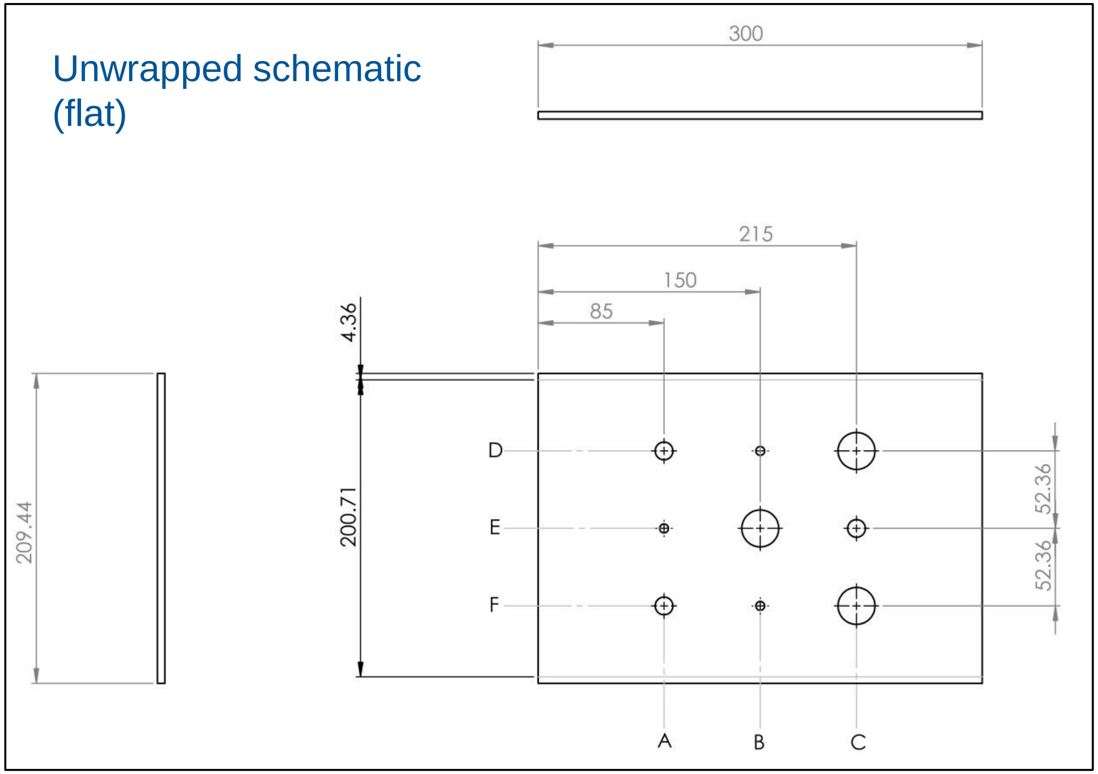
RDA-2b material:

- 913 glass fibre epoxy UD pre-preg
- 2 off pre-cured 16 ply (2 mm) cross-ply $[0/90]_{4s}$ laminates

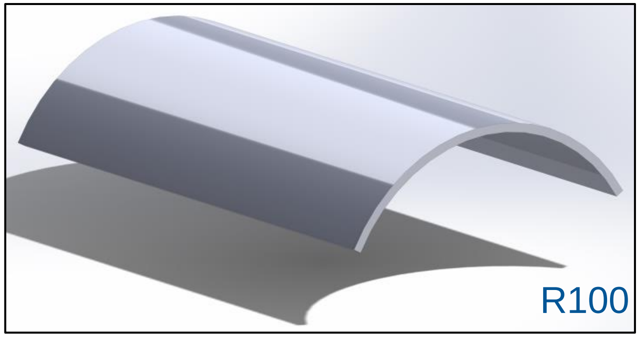
Construction:

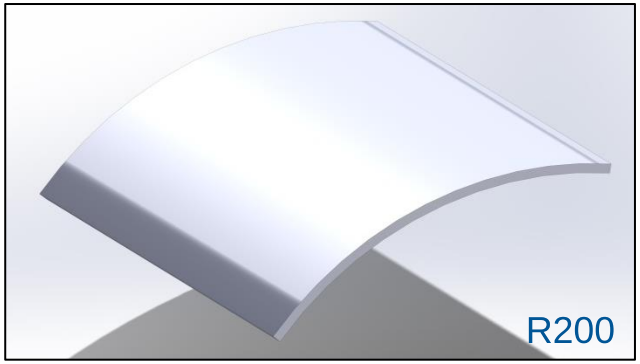
- Surface preparation for kissing bonds applied to one laminate only
- Laminates bonded together using Cytec FM300K film adhesive (autoclaved)
- Matt and gloss surface finishes

Curved monolithic laminates – CFRP pre-preg (RDA-6a & 6b) (delaminations)



Unwrapped schematic (flat)



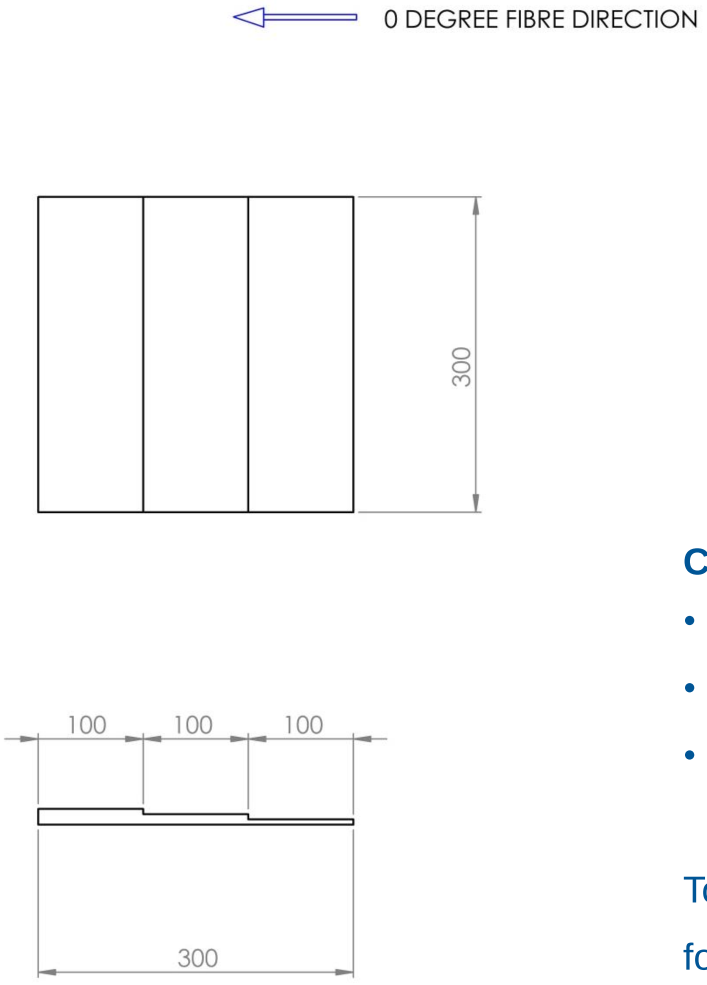


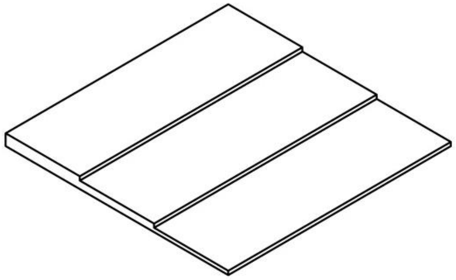
Defect type	Sizes	Locations
Delamination	∅6, 12 & 25 mm	- near front face - mid-thickness - near back face

Construction:

- SE84 carbon fibre epoxy UD pre-preg
- Cross-ply lay-up $[0/90]_{4s}$ (~5 mm thick)
- Autoclave processed

Stepped thickness laminate – CFRP pre-preg (RDA-6c) (no defects)





Construction:

- SE84 carbon fibre epoxy UD pre-preg
- Cross-ply lay-up giving regions of 5, 10 and 15 mm thickness
- Autoclave processed (120C)

To be used for attenuation measurements of ultrasound required for simulation purposes

Next steps

- All materials have now been sourced and RDA designs finalised
- Trials underway to optimise methods for producing fibre misalignment and kissing bond defects
- Manufacture of RDAs now started
- BAM and NPL to finalise designs for NDAs using the same material types used for RDAs
- Characterisation of elastic, dielectric, thermal and optical properties within WP2
- Properties used for optimisation of experimental application of each technique plus modelling

National Measurement System

The National Measurement System delivers world-class measurement science & technology through these organisations

National Measurement Office

NPL National Physical Laboratory

LGC Setting standards in analytical science

nel technology for life

The National Measurement System is the UK's national infrastructure of measurement Laboratories, which deliver world-class measurement science and technology through four National Measurement Institutes (NMIs): LGC, NPL the National Physical Laboratory, TUV NEL The former National Engineering Laboratory, and the National Measurement Office (NMO).