Non-Destructive Inspection of Thick-Walled Composites (PPT)

Anisimov, A.; Groves, R.M.; Fazzi, L.; Tao, N.; Elenbass, Marce; Huizinga, Jon; Troost, Peter; Wevers, Davy

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Development Center for Maintenance of Composites

Non-Destructive Inspection of Thick-Walled Composites

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Development Center for Maintenance of Composites

Dutch initiative of innovative companies and knowledge institutes combine and develop knowledge and experience in inspection, production, repair and maintenance of composites.

Founded by

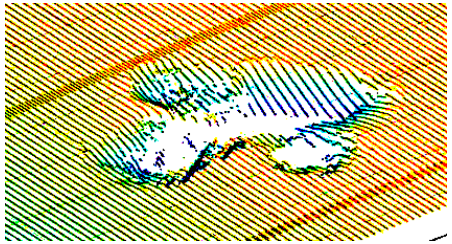
Partners

Research & Innovation

Development Center for Maintenance of Composites

<u>Research & Innovation program Focusing on:</u>

1. Hybrid structures maintenance & corrosion prevention
2. Quality improvement through Automation
   - Spider robot
   - Laser Ablation/Waterblast scarfing
   - Automation of NDI
3. More efficient NDI through data Fusion



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AeroNDT. Who are we?

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Transport

Energy

Cultural Heritage

Paolo Rossini "La Crucifixión con Santa María Magdalena"

Aerospace NDT Laboratory

Objective

Research and innovation of instrumentation and algorithms for characterisation of materials and structures

Vision

To develop the next generation of advanced optical and ultrasonic sensors and sensor systems which can measure more accurately, faster and with better resolution

Who are we?

- Established in 2008 in the Faculty of Aerospace Engineering at TU Delft
- 20+ researchers and project students developing instrumentation, algorithms and applications
- Interdisciplinary and international research team

Capabilities

- Advanced research in optics and ultrasonics
- Custom measurement solutions
- Pre-industrial prototyping
- Development of control and data processing algorithms
- Experimental design
- Data fusion and visualisation
- Prototypes environmental testing

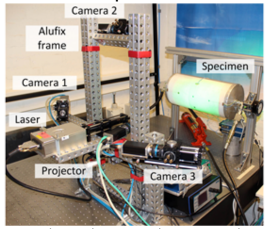
Main Current Projects

- ❑ H2020 EXTREME Project
- ❑ DTP Bonded Repair Project
- ❑ World Class Composites Solutions (WCCS)
- ❑ Dutch Aerospace TAPAS2 Project
- ❑ Dutch NICAS Gilt Leather and Rembrandt Projects
- ❑ Dutch NWO Climate4Wood Project

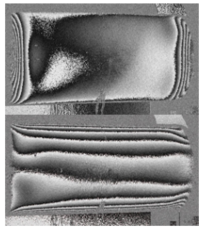
Optical Metrology

Research of optical measuring techniques for experimental mechanics and non-destructive testing:

- ❑ Shearography
  - Non-destructive testing and defect detection
  - Strain characterisation
  - Vibration characterisation (full-field)
- ❑ Fringe projection and structured light
  - 3D shape measurement
- ❑ Line scan and point shape sensors
  - Shape measurement and fusion with strain data



3D shape shearography setup with structured light projector

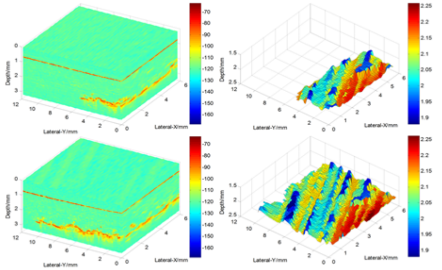


X- and Y-shear phase maps during inner pressure loading

Fibre Optic Sensing

Research of fibre optics sensors and applications:

- ❑ Optical Coherence Tomography (OCT)
  - 3D materials characterisation
  - Coating thickness measurement
- ❑ Fibre Bragg Gratings (FBGs)
  - Strain and temperature sensors
- ❑ Structural Health Monitoring (SHM)
  - SHM in manufacturing, operation and service
  - Distributed sensor networks

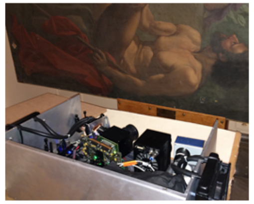


OCT measurement of crack propagation in a glass fibre composite plate

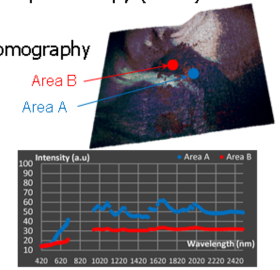
Spectral Imaging

Research of multi and hyperspectral imaging systems:

- ❑ Spectral imaging: VIS, NIR and SWIR
  - Imaging spectrographs and tunable filters
- ❑ Spectral processing
  - Principal Component Analysis (PCA)
- ❑ Fibre Optic Reflectance Spectroscopy (FORS)
- ❑ Terahertz imaging
  - LWIR/microwave tomography



SYDDARTA prototype in use

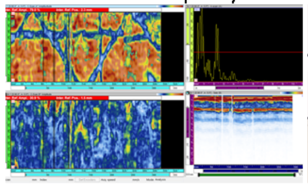


Relative (areas A and B) VIS and IR reflection spectrum

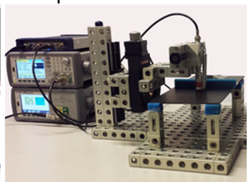
Ultrasonics

Research of ultrasonics and guided waves:

- ❑ Lamb wave ultrasonics
  - NDT/SHM of composite plates
  - Time-reversal Lamb waves
  - Air-coupled ultrasonics
- ❑ C-scan ultrasonics: including data fusion from different sources (e.g. C-scan + shape)
- ❑ Phase-array ultrasonics
  - Multi-frequency ultrasonic inspection



C-scan of a carbon plate with complex structure



Setup for air-coupled ultrasonics flaw detection

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Thick composites

DAMEN

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https://www.seanews.com.tr/damen-ramses-project-reaches-significant-milestone/187217/

https://magazine.damen.com/editors-choice/composite-materials-for-the-next-generation-of-ship-owners/

Fieldlab Zephyros, project: AIRTuB Automatic Inspection & Repair of Turbine Blades

https://www.worldclassmaintenance.com/sub-project/airtub-automatische-inspectie-reparatie-van-turbinebladen/

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Non-Destructive Inspection of Thick-Walled Composites

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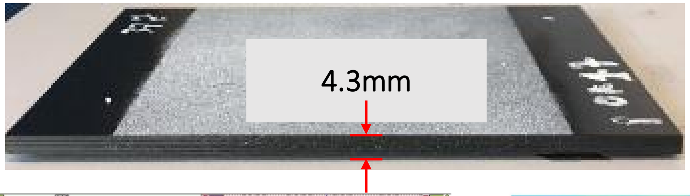
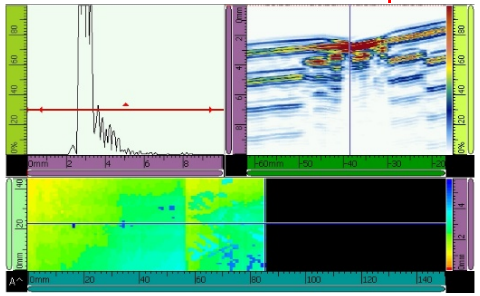
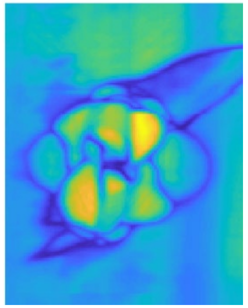
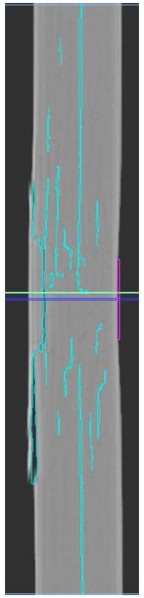
Aerospace CFRP laminate

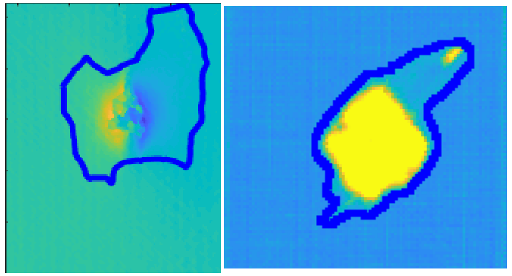




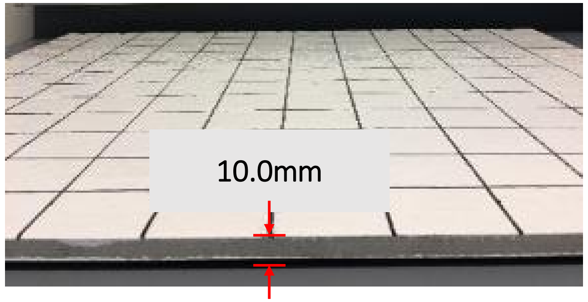


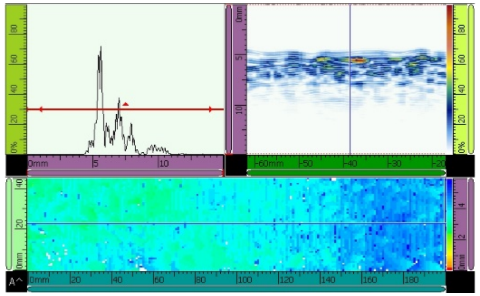


Ultrasonic @ 5 MHz



Thick marine GFRP laminate





Ultrasonic @ 5 MHz

Thick marine GFRP sandwich

Anisimov, A. G., Serikova, M. G., Tao, N., Anand, C., Esrail, F., Kassapoglou, C., & Groves, R. M.Multimodal nondestructive inspection of impact damages in composite laminates: a case study to assess the damage volume (Conference Presentation). In *Multimodal Sensing: Technologies and Applications* (Vol. 11059, p. 110590W). International Society for Optics and Photonics. (2019, July)

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Marine issues

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Extreme events

- Impact
- Blast

Aggressive environments

- Temperature cycling
- Saltwater immersion
- Moisture absorption
- Ultraviolet radiation

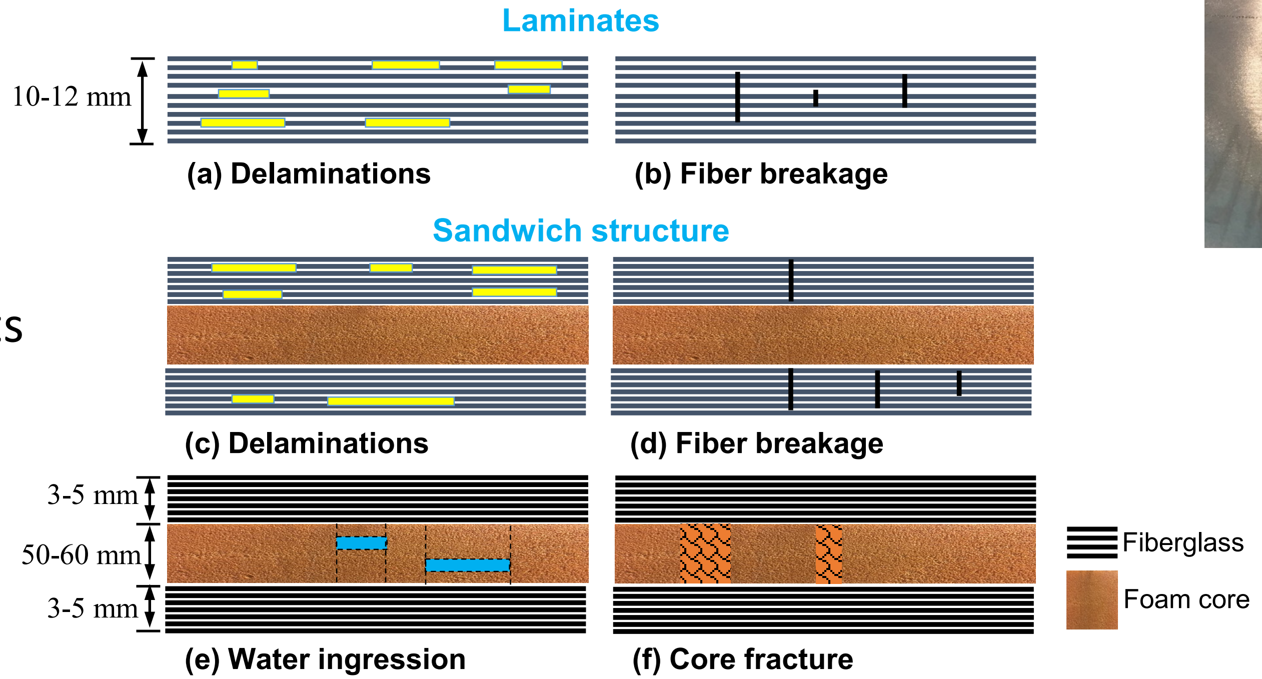

Illustration of common defects in marine composites (Source: Damen)

Fatigue fracture of PMI 51 S foam core

SSC-463INSPECTION TECHNQIUES FOR MARINE COMPOSITE CONSTRUCTION AND NDE

Fig. 3.3 Damage zones on the laminated composite sandwich panel after underwater blast loading (Wei et al., 2013a).

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Literature / past

	Defect	Technique	Composite
Manufacturing	Fibre bunching, waviness	Ultrasonics Radiography Microwave	Monolithic laminate
	Layup irregularities, ply orientation	Ultrasonics Eddy-current	CFRP only
	Fibre volume fraction	Ultrasonics Microwave Eddy-current	CFRP only
	Voids/porosity	Ultrasonics Radiography Thermography	
	Foreign inclusions	Microwave Radiography Ultrasonics	GFRP only
	Bondline integrity	Radiography Ultrasonics	
In-service	Delamination	Thermography Optical interferometry Ultrasonics Thermography Optical interferometry	Near-surface Near-surface Near-surface Near-surface
	Fibre breakage	Acoustic emission	
	Skin-to-core disbonding	Optical interferometry Thermography Resonance	Sandwich structure
	Core crush	Ultrasonics Radiography Thermography	Sandwich structure
	Water presence	Microwave Radiography Thermography Capacitive imaging	Honeycomb sandwich
	Global strain state	Vibration analysis Strain sensing	
	Surface-breaking cracks	Most techniques	

	Defect	Laser Shearography	Ultrasonic Inspection	Infrared Thermography	Digital Tap Hammer
Delamination	Min. Size Detected	2 inches	2 inches	3 inches	3 inches
	Max. Depth Detected	1- 2 plies	1 ply	2 – 3 plies	2 – 3 plies
	Overall Effectiveness	good esp. for kissing bonds	can't detect kissing bonds	can't detect kissing bonds	can't detect kissing bonds
Water Ingress	Min. Size Detected	2 inches	4 inches	2 inches	4 inches
	Max. Depth Detected	skin/core interface	skin/core interface	skin/core interface	skin/core interface
	Overall Effectiveness	good	use higher frequency transducer	very good	fair
Impact Damage	Min. Size Detected	1 inch	2 inches	1 inch	3 inches
	Max. Depth Detected	skin/core interface	1- 2 plies	skin/core interface	skin/core interface
	Overall Effectiveness	very good	good	good	only edge delaminations found
Void	Min. Size Detected	2 inches	2 inches	1 inch	defect not detected
	Max. Depth Detected	¼ inch	½ inch	¾ inch	
	Overall Effectiveness	fair with thick laminates	good for uniform laminates	very good	not effective
System limitations:		Requires good reflective surface – not good with matt finish black parts or clear gel coat; not good with thick or highly curved parts	Requires good calibration sample and uniform laminate; small probe area	Known good laminate required for baseline data; defect must produce a thermal gradient	Only effective with larger defects
Equipment cost:		≈ $100,000	≈ $40,000	≈ $10,000	≈ $1,500

Defects	Visual	Ultrasonics		Thermography		Laser Shearogrphy	
		A-Scan	C-Scan	Steady	Pulsed	Vacuum	Heat
Adhesive bond failure	0	A	A	B	A	A	B
Air bubble	C	C	C	C	B	C	B
Blister	A	C	C	C	B	C	C
Core crushing	C	B	B	B	A	B	C
Core shear failure	0	C	C	B	A	A	B
Crazing	A	0	0	C	C	C	C
Delaminations	C	B	A	C	B	A	B
Fiber failure	C	B	B	0	C	A	A
Kissing bond	0	B	A	B	A	A	B
Local impact damage	B	C	B	B	B	A	B
Matrix cracking	A	C	B	C	C	B	C
Moisture ingress	C	C	B	A	A	B	A
Ply waviness	B	0	0	0	C	C	C
Pit (or pinhole)	A	0	C	0	0	0	C
Porosity	B	0	C	C	B	0	C
Resin rich area	0	C	B	B	A	0	C
Resin starved area	0	C	B	B	A	0	C
Skin-to-core disbond	0	C	B	B	A	A	B
Surface cracking	A	0	0	C	C	C	C
Thermal damage	B	C	B	B	B	C	B
Voids	C	C	B	C	B	C	C

- To identify techniques capable of:
  - Reliable defect detection
  - High automation capabilities

Ibrahim, M. E. "Nondestructive testing and structural health monitoring of marine composite structures." *Marine Applications of Advanced Fibre-Reinforced Composites*. Woodhead Publishing, 2016. 147-183.

INSPECTION TECHNQIUES FOR MARINE COMPOSITE CONSTRUCTION AND NDE 2012
http://www.shipstructure.org/pdf/463.pdf

SSC Project 1464 Test Panel Program
http://www.shipstructure.org/pdf/463.pdf

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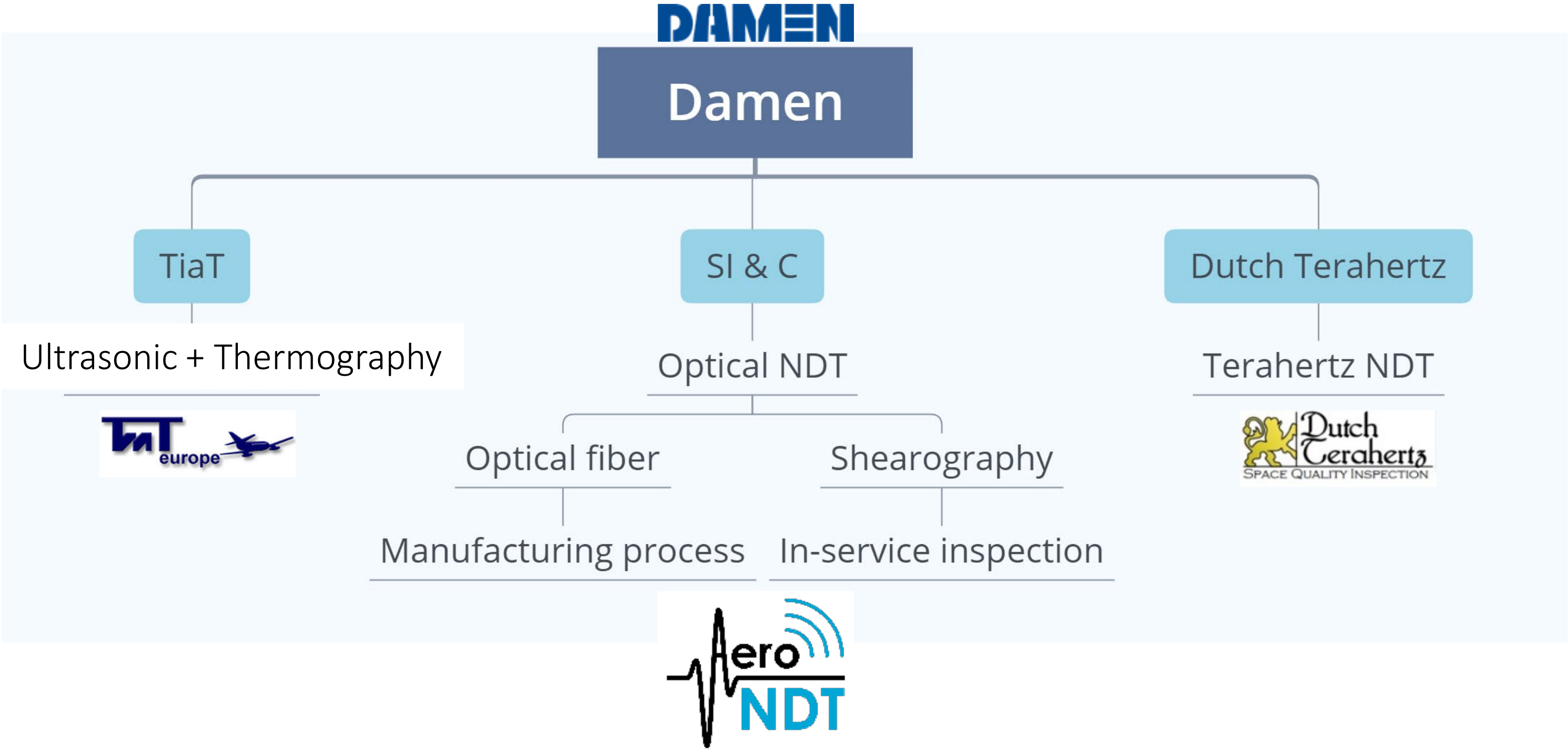

Op Zuid: Work Package 4

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Fibre Bragg Grating (FBG)

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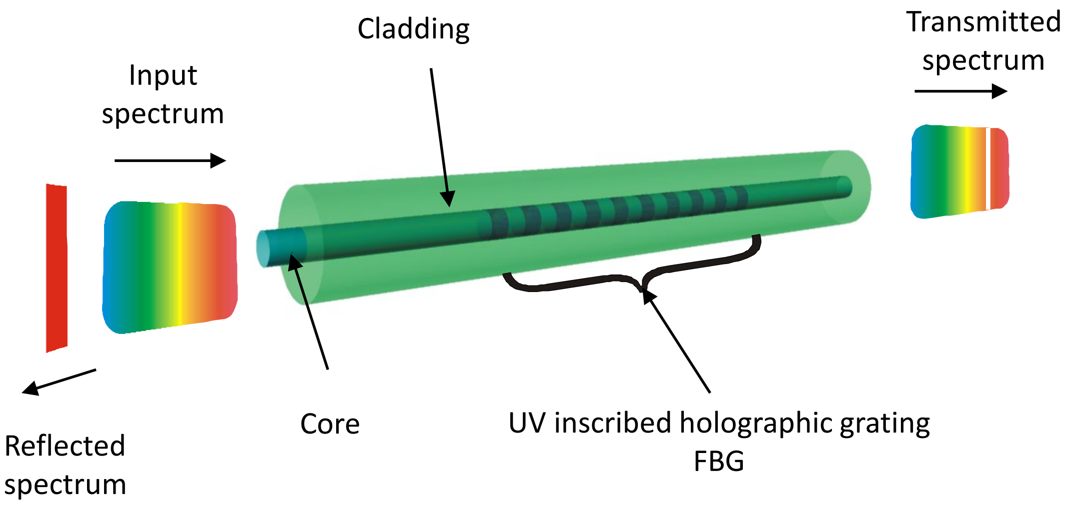
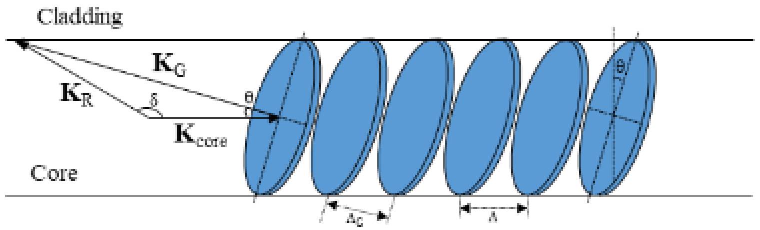
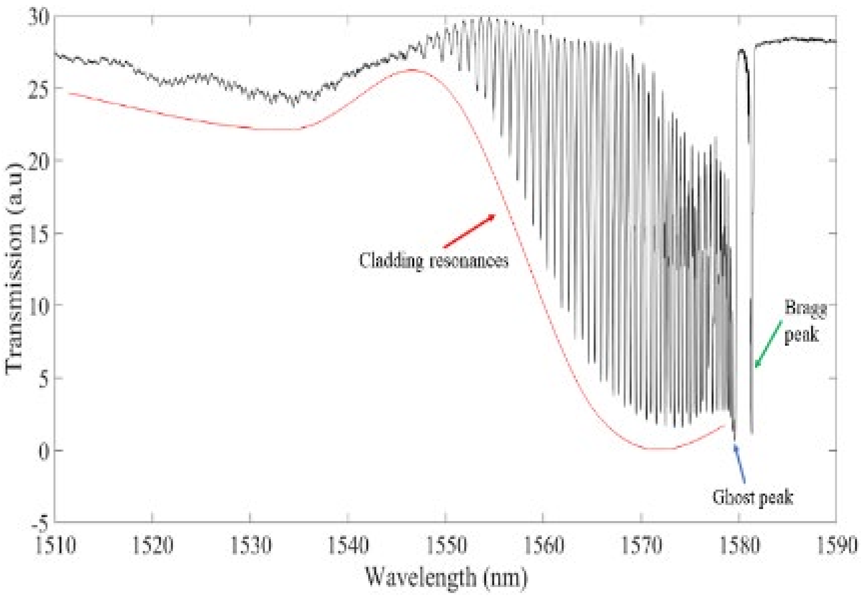
- Each FBG sensor reflects narrow wavelength spectrum
- Wavelength shifts due to strain change



- Tilted Fibre Bragg grating (TFBG)





- Temperature and strain – Bragg resonance peak
- Temperature and strain – Ghost resonance peak
- External refractive index – area of the cladding resonances peaks envelope

L. Fazzi, R.M. Groves "Demodulation of a tilted fibre Bragg grating transmission signal using α-shape modified Delaunay triangulation“ Measurement 166 (2020): 108197

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Tilted Fibre Bragg Grating (TFBG): experiments

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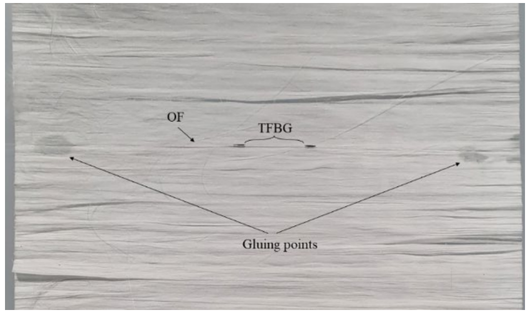

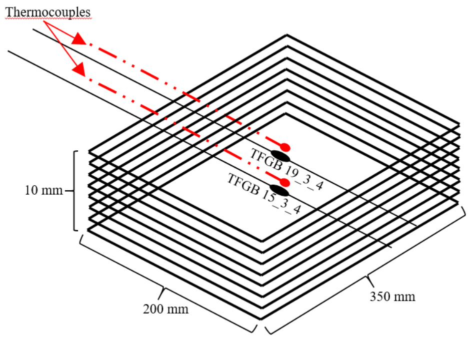

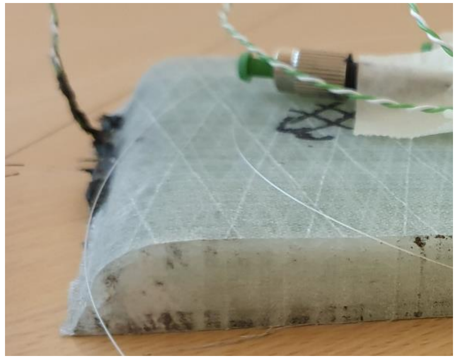

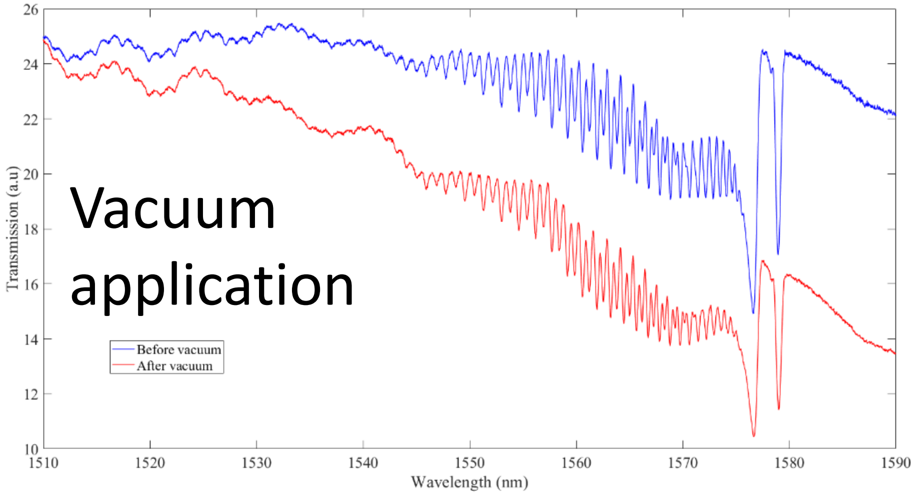

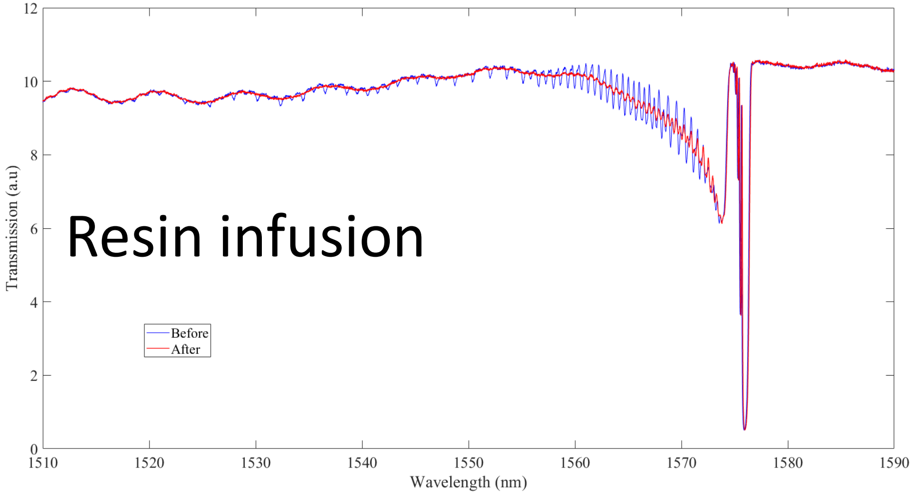

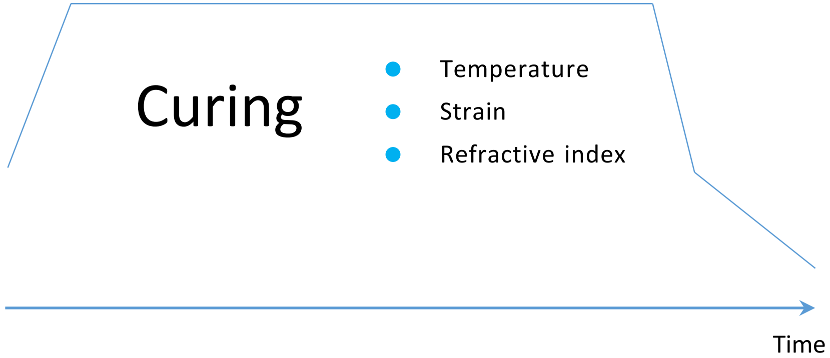

L. Fazzi, R.M. Groves "Demodulation of a tilted fibre Bragg grating transmission signal using α-shape modified Delaunay triangulation“ Measurement 166 (2020): 108197

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Phase 1. Test specimens

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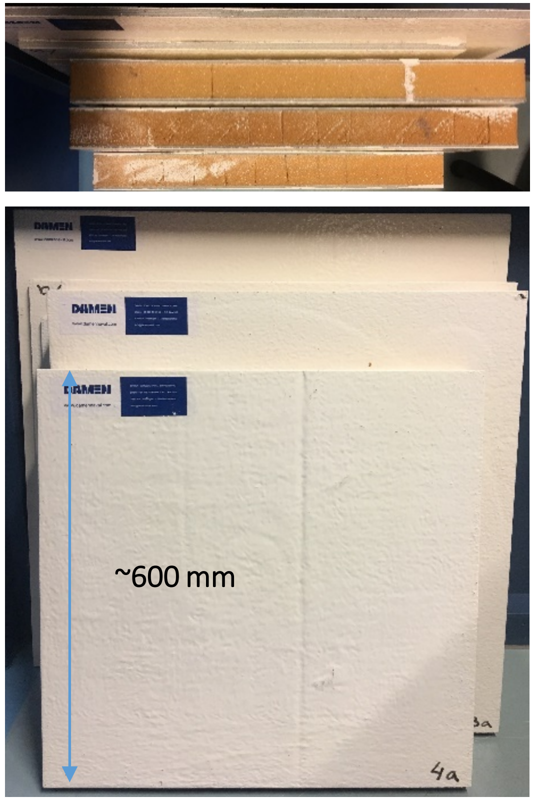

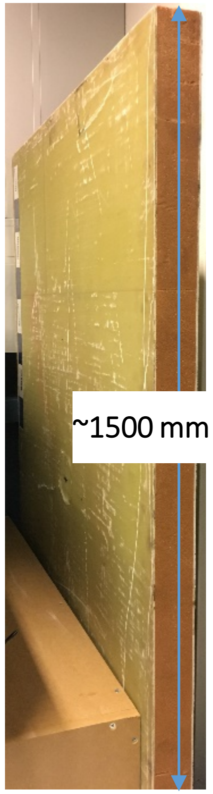

Panel	Type	Dimensions	Defects
1B	Sandwich	658*650*60	Delaminations
3	Sandwich	654*649*60	Water ingression + core fracture
4	Sandwich	571*562*60	Fiber breakage
7B	Laminate	654*644*13	Delaminations
7C	Laminate	609*608*10	Delaminations
8C	Laminate	600*600*10	Fiber breakage
9B	Laminate	769*762*12	Intact

- Bond-tester — TiaT
- IR Thermography — Tiat
- Lock-in Thermography — Tiat
- **Shearography** — **TU Delft**
- Terahertz Imaging — DTIS
- Pulse-echo Ultrasonics — TiaT
- **Phased array ultrasonics** — **TiaT**

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Shearography: speckle pattern shearing interferometry

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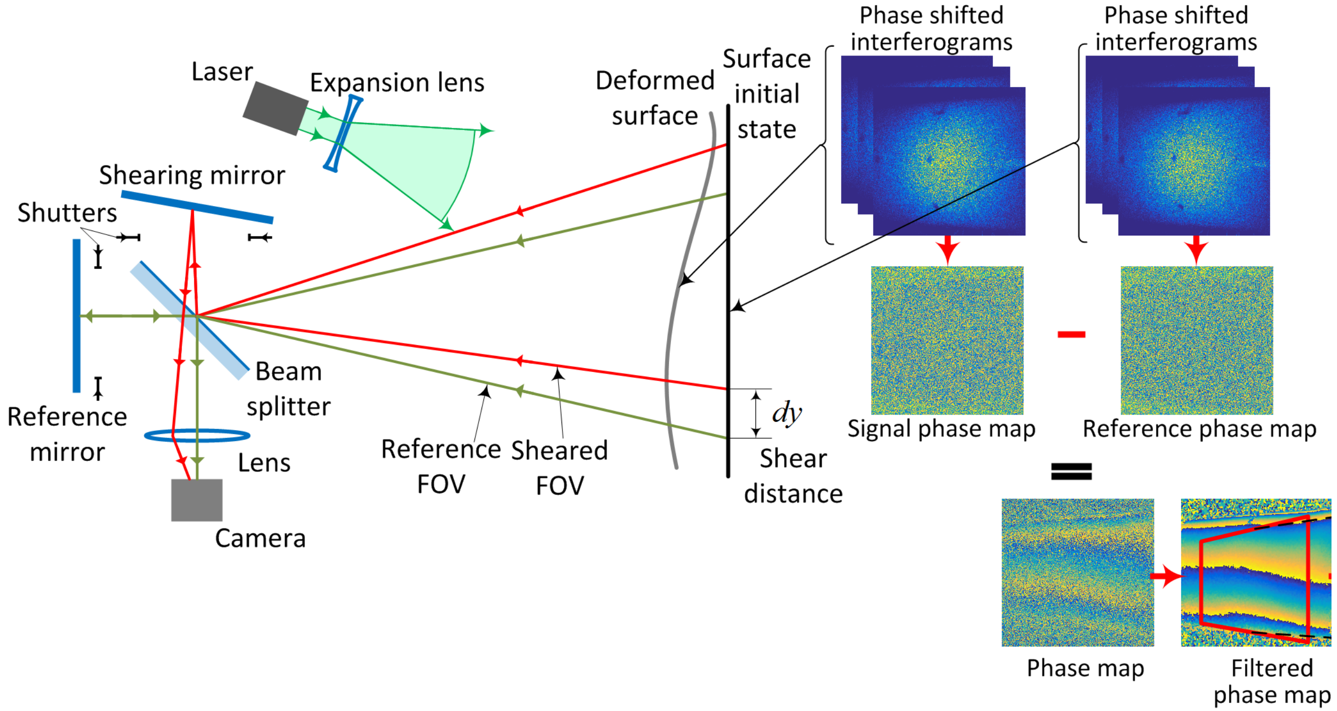
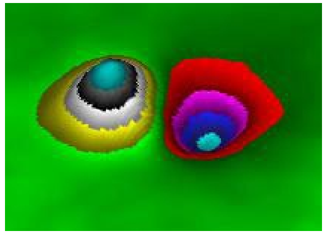


- Shearography directly measures the surface displacement gradients

- Shape (interferometry)



- Gradient (shearography)

Andrei G. Anisimov, Mariya G. Serikova, and Roger M. Groves, "3D shape shearography technique for surface strain measurement of free-form objects," Appl. Opt. 58, 498-508 (2019)`

Some of the commercial shearography systems that are available on the market; the Q-800 from Dantec Dynamics (*a*), the Steinbichler ISIS mobile 3000 (*b*), the Optonor SNT 4045 (*c*) and the SE3-NDT from ISI-sys (*d*).

Francis, D., Tatam, R.P., Groves, R.M., "Shearography technology and applications: a review," Meas. Sci. Technol. 21, 102001, 29 (2010).

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Shearography: speckle pattern shearing interferometry

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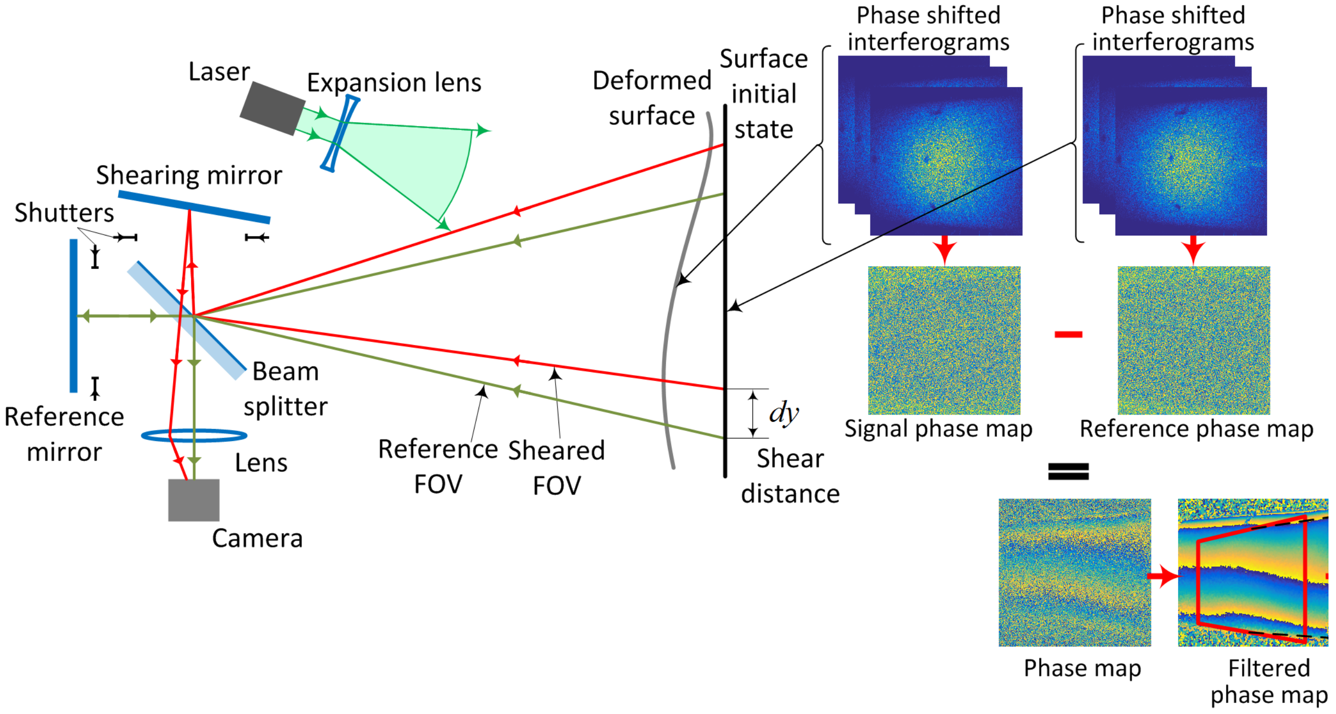
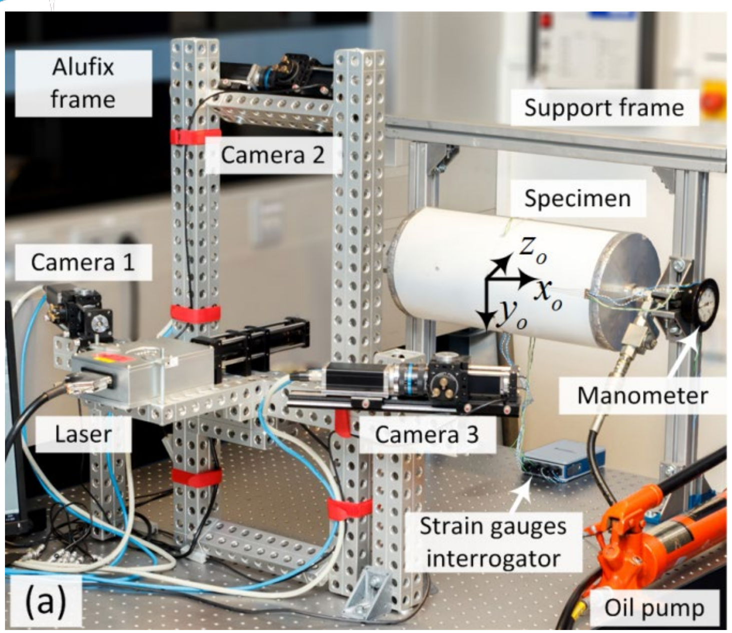
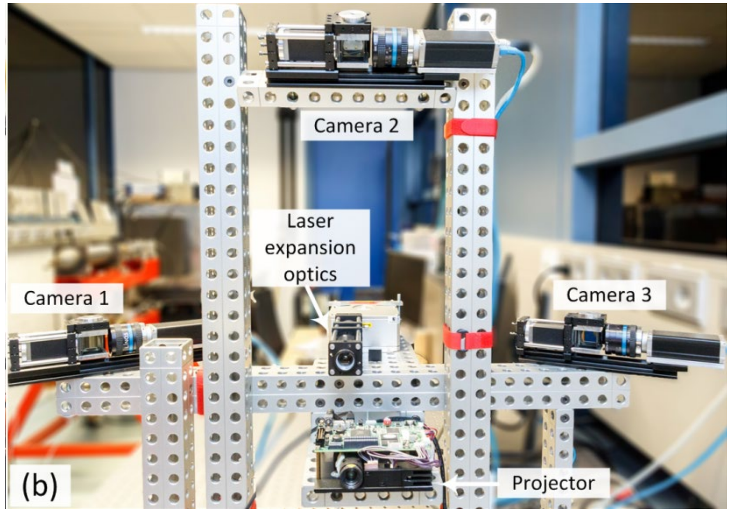
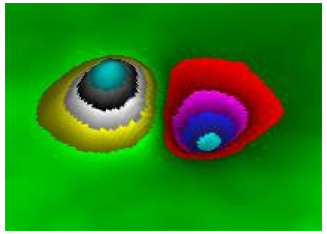






- Shearography directly measures the surface displacement gradients

- Shape (interferometry)



- Gradient (shearography)

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Andrei G. Anisimov, Mariya G. Serikova, and Roger M. Groves, "3D shape shearography technique for surface strain measurement of free-form objects," Appl. Opt. 58, 498-508 (2019)`

Panel 7C: laminate with Teflon inserts

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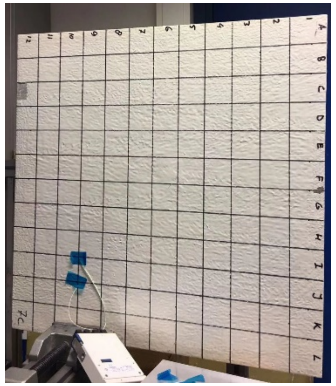
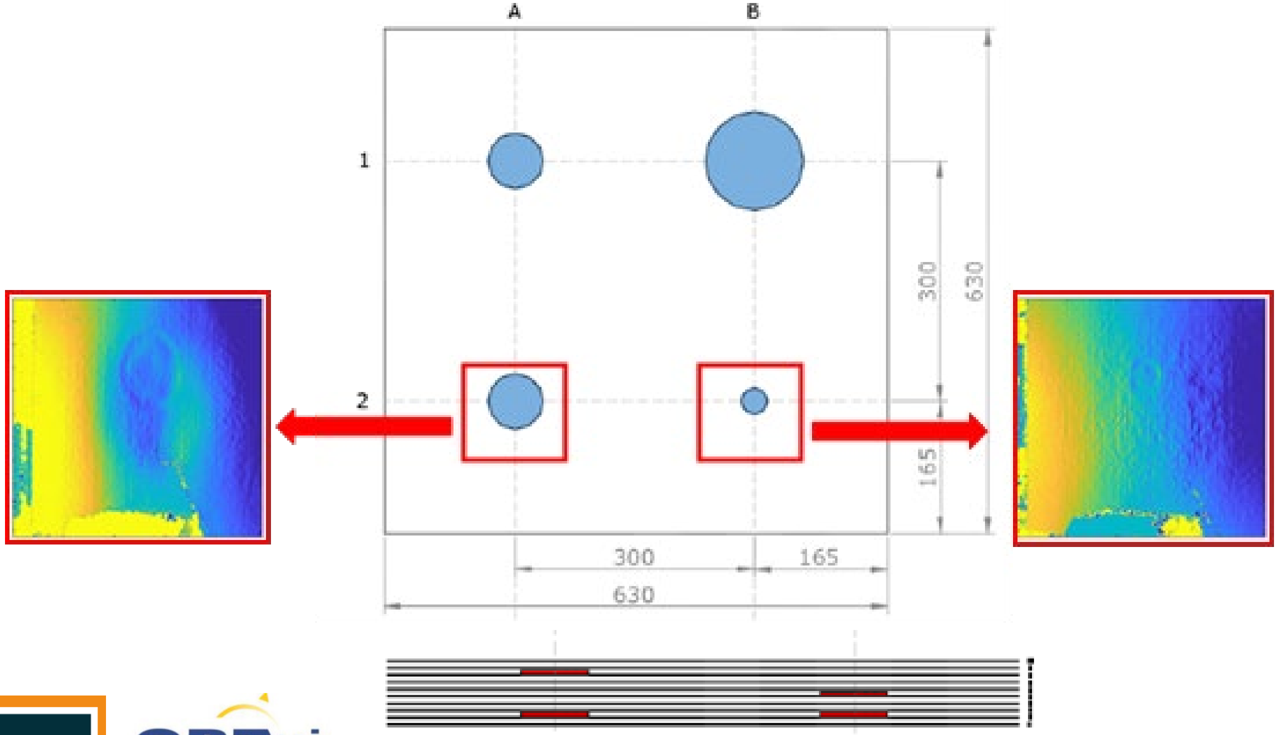
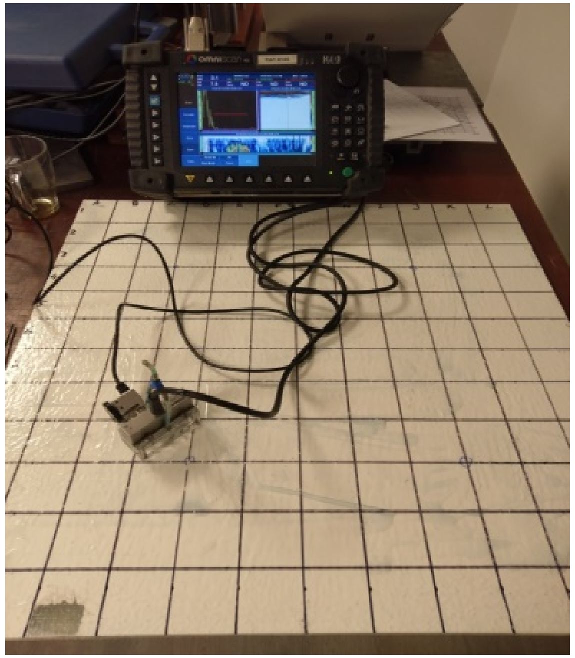


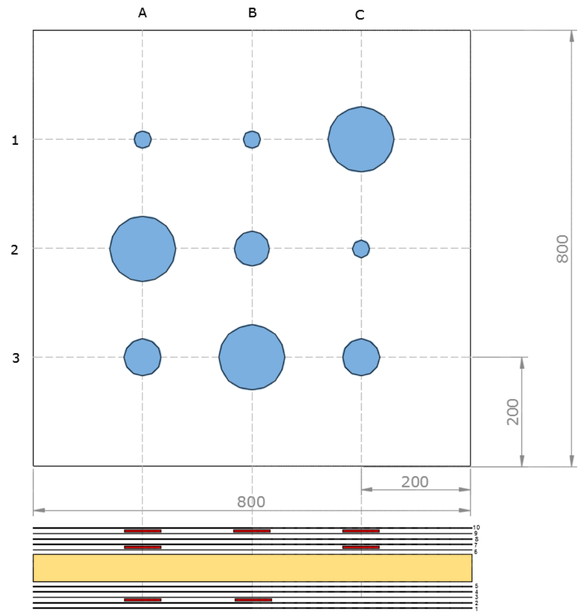


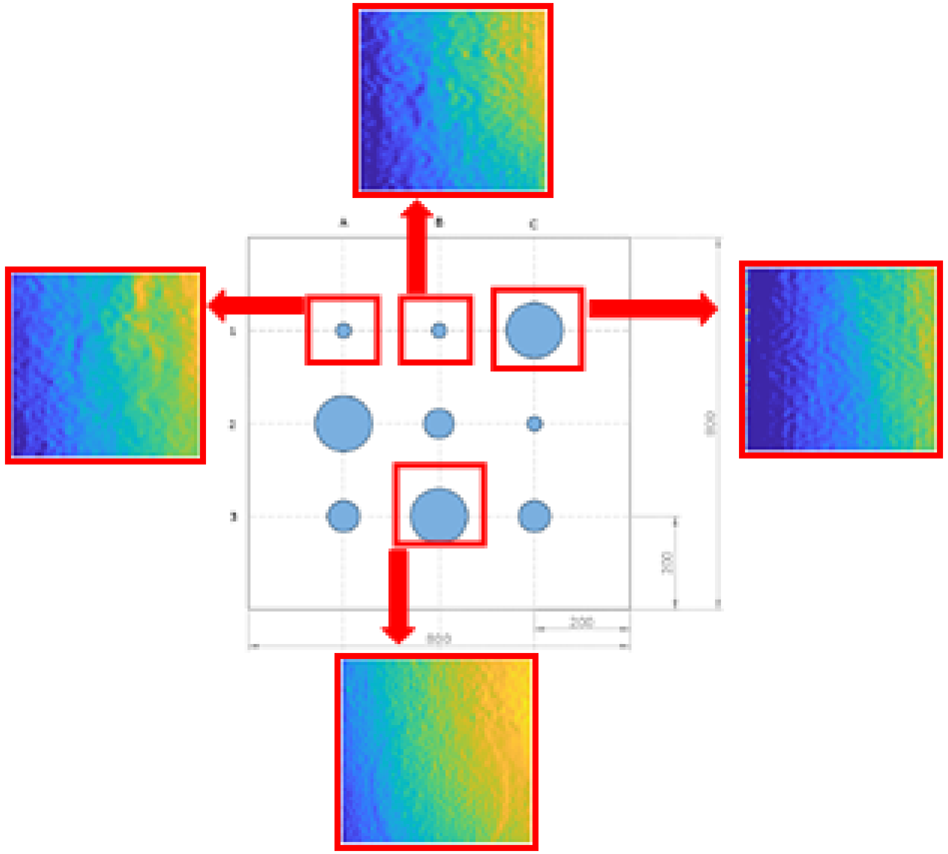
Shearography: top layers



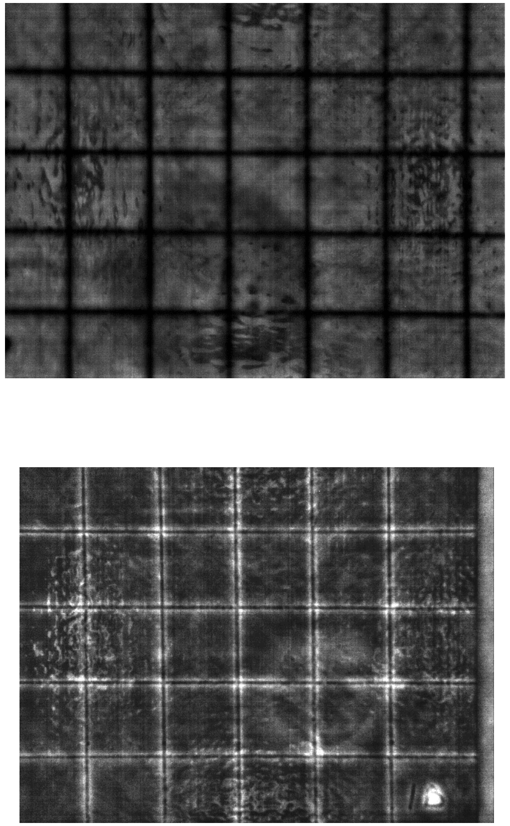
Phased array ultrasonics. Results depend on frequency

Panel 1B: foam core with Teflon inserts





Shearography: top skin-core



Lock-in thermography: top skin-core

Panel 3: water ingression + core fracture

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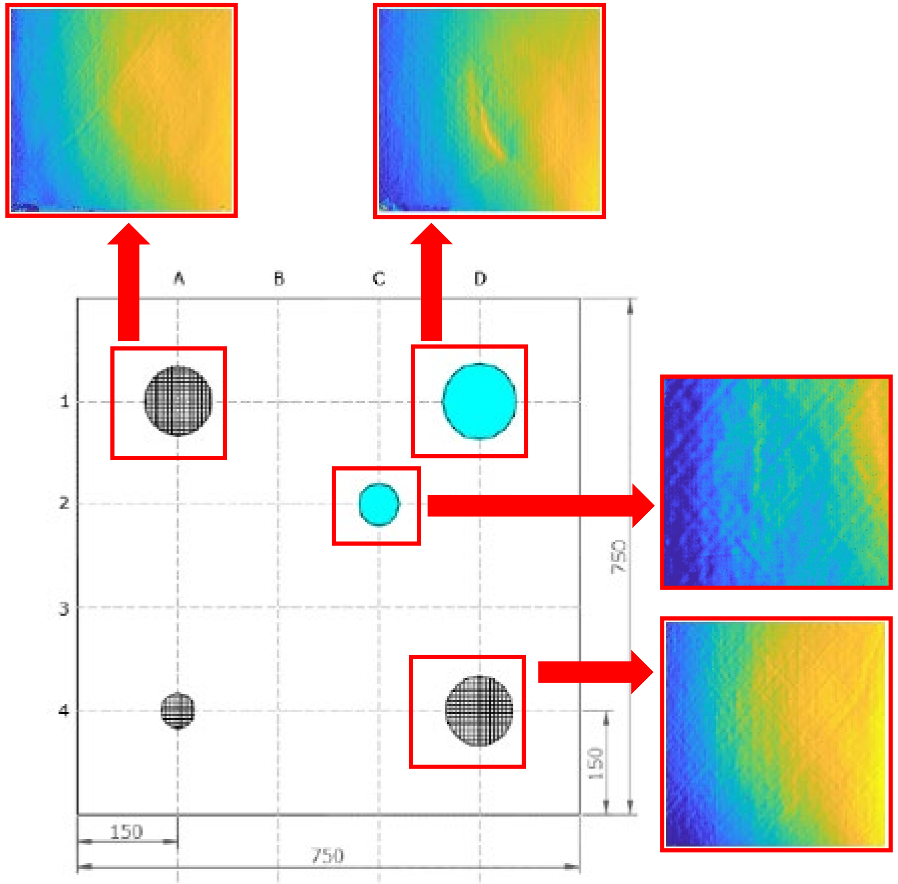
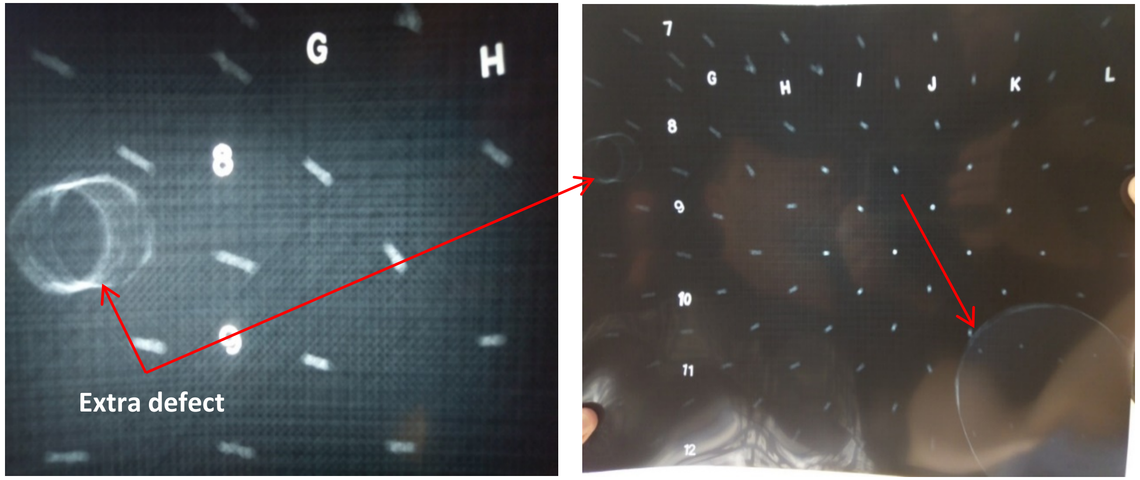
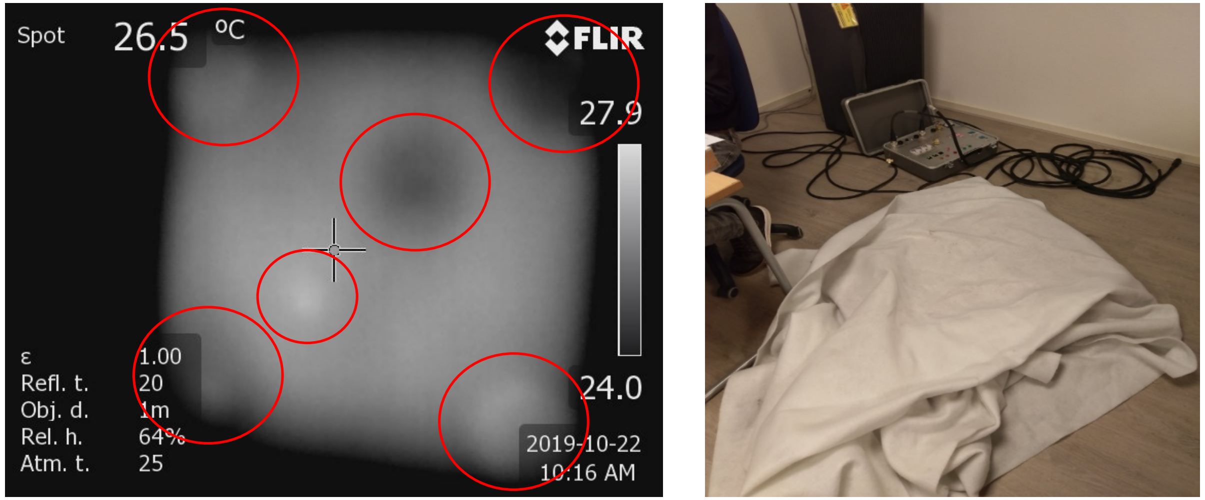


Shearography: almost all found



Radiography: all found



Thermography: all found

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Phase 2. How to improve?

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Material on ongoing research is not publically available yet.

Contact us for details

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Main results

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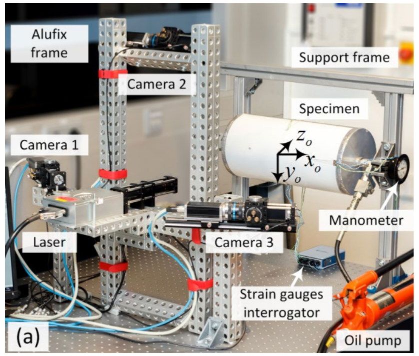
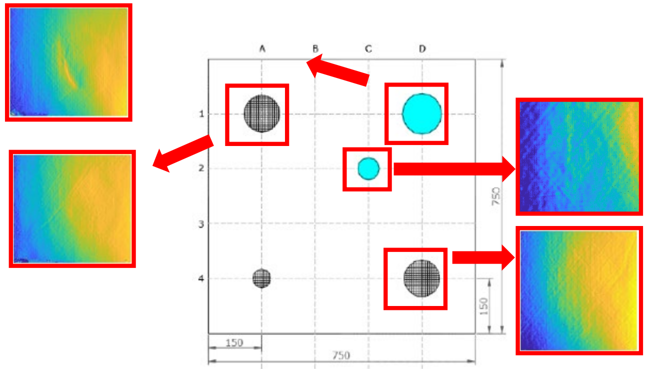
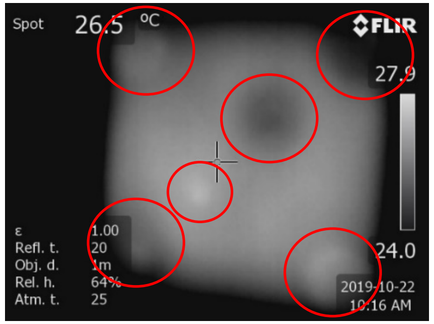
- Thick composites are challenging
  - Adaptation of NDT techniques
  - Automatic scanning = possible
  - Automatic defect detection = challenging



- Defects detection
  - Skin and shallow (<15 mm) – shearography (up to 25 mm in solids)
  - Deeper (<50-70) – low frequency phased array ultrasonics





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This project is part of EFRO-project PROJ-00730 - DCMC

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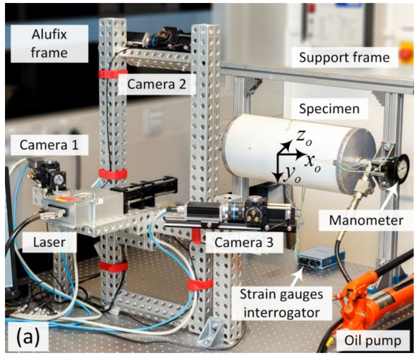
Non-Destructive Inspection of Thick-Walled Composites

This project is part of EFRO-project PROJ-00730 - DCMC



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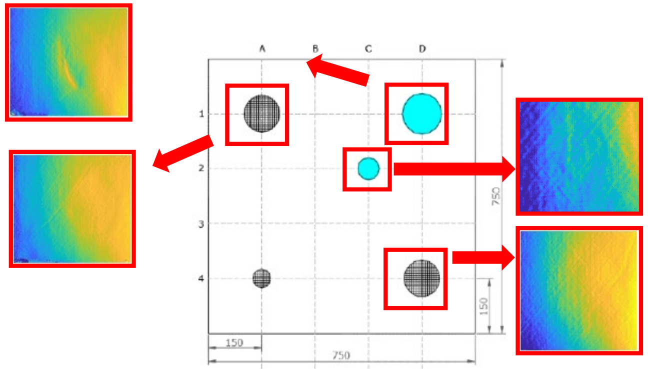

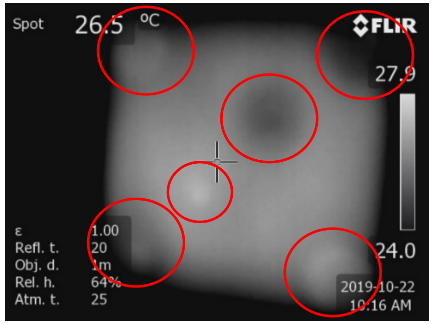

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