MANCHESTER
1824
The University of Manchester

northwest
composites
centre

Technique Validation for SHM

Dr. Matthieu Gresil

Wednesday 10th February 2016

Outline

- Introduction
- Distributed optical fibre sensors
- Piezoelectric sensors - Acoustic emission
- Concluding remarks and Challenges

Structural health monitoring: definition

- "Structural health monitoring **assesses** the state of structural health and, through appropriate **data processing** and interpretation, may **predict the remaining life** of the structure." [Giurgiutiu]

- A system of classification for damage-identification methods defines **four levels** [Rytter, 2003]:

  - Level 1: **detect** the existence of damage
  - Level 2: **detect** and **locate** damage
  - Level 3: **detect**, **locate**, and **quantify** damage
  - Level 4: **estimate** remaining service **life** (prognosis)
  - …
  - Level N: Self-healing

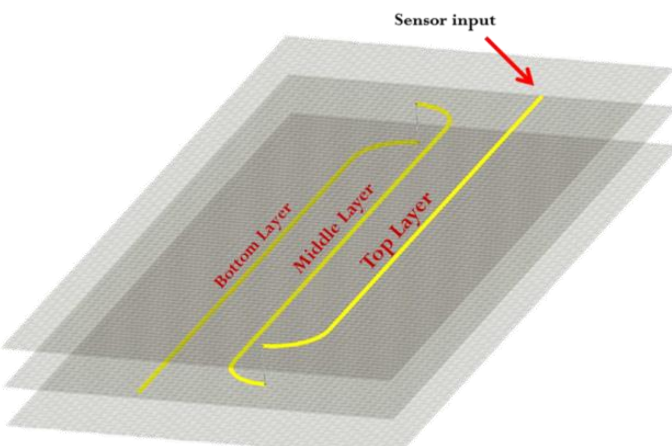
Lay-up

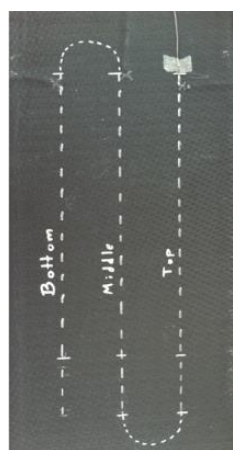
Standard telecom fibre; diam.125 μm

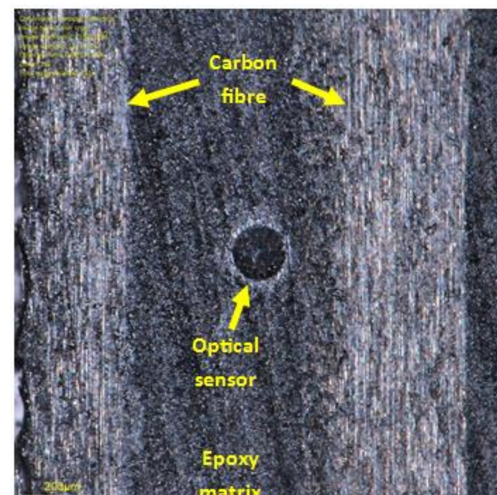
Carbon fibres 5–10 μm

6 layers carbon fibre

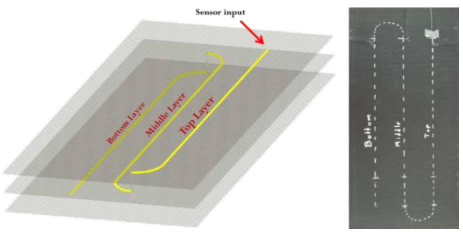
3 sensing regions

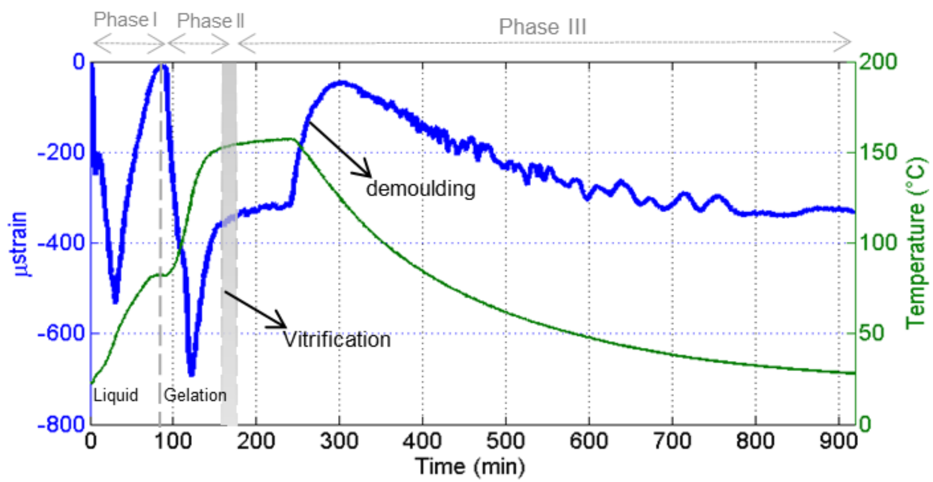




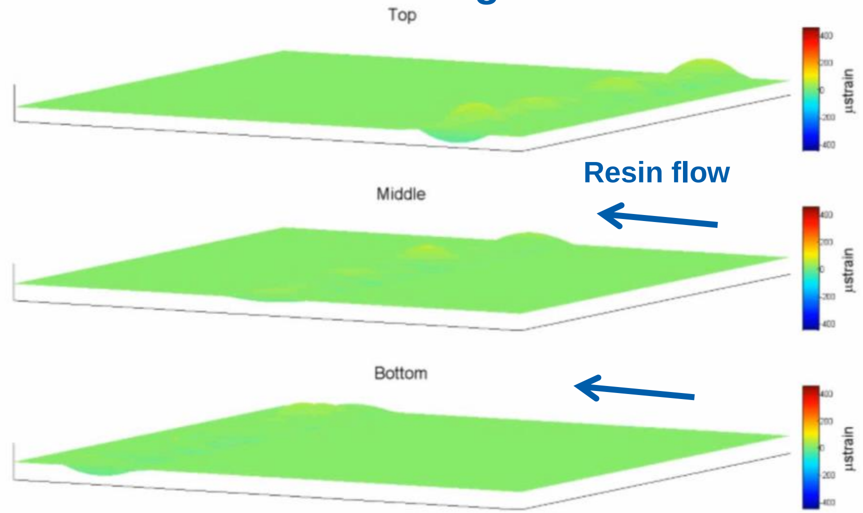


Infusion - curing - residual strain

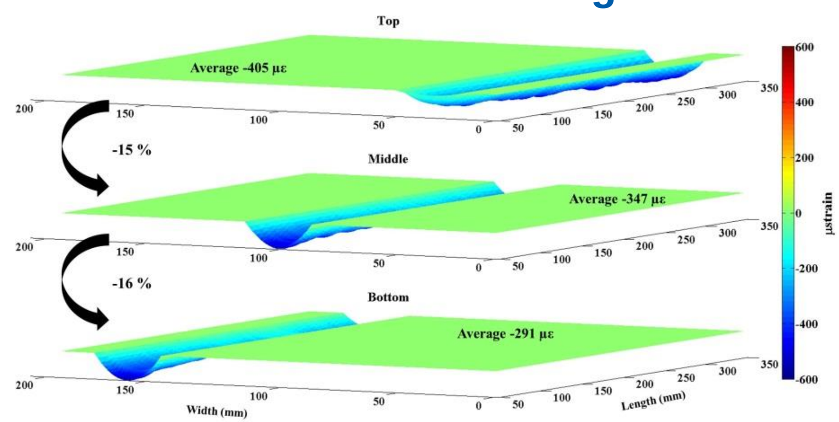




Strain distribution during the infusion

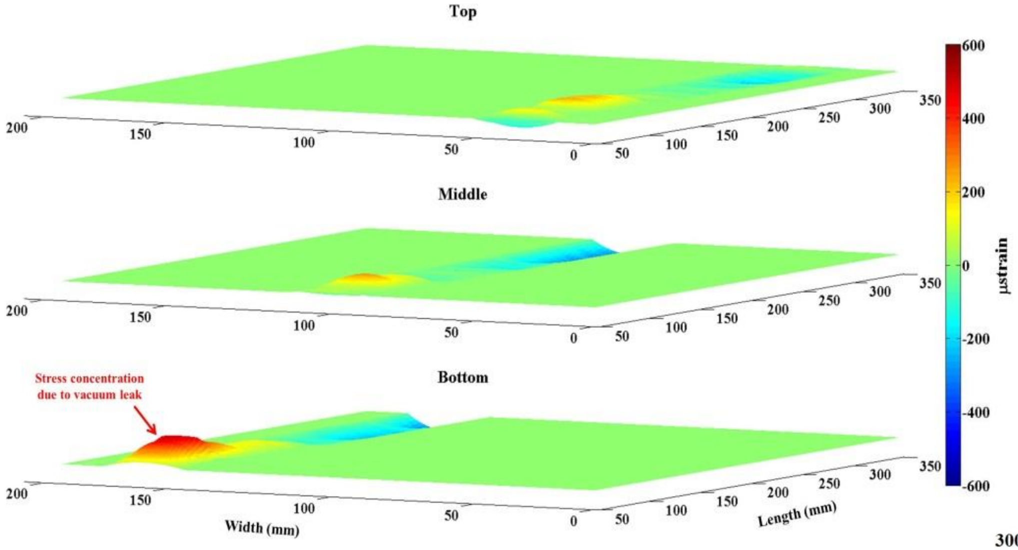


Distribution of the residual strain after the manufacturing

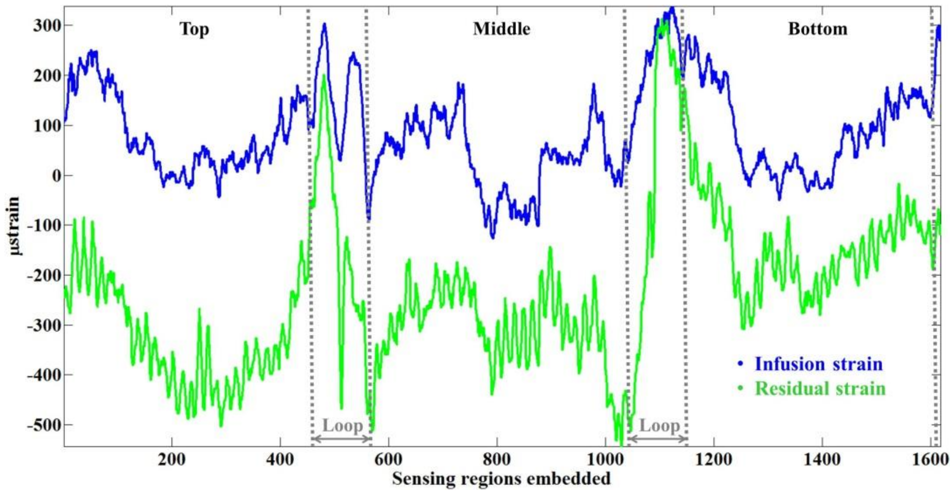


"Defect" detection
Infusion vs. residual strain

"Defect" detection



Infusion strain versus residual strain



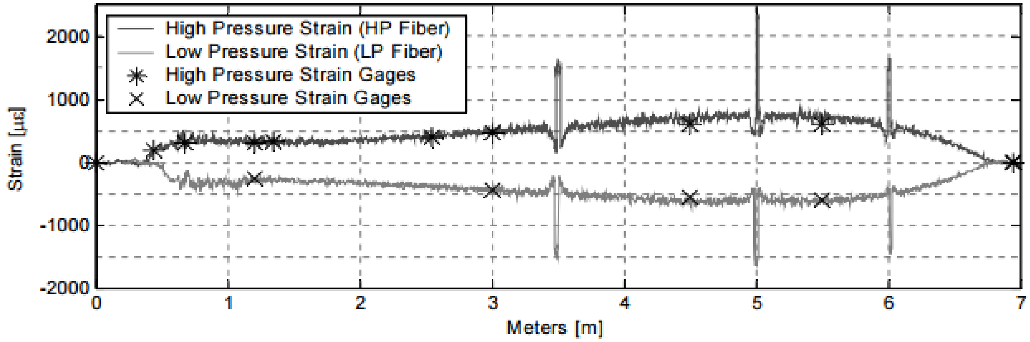
[D. Martinez Sánchez, M. Gresil, and C. Soutis, *Composites Science and Technology*, Accepted, 2015]

MANCHESTER 1824

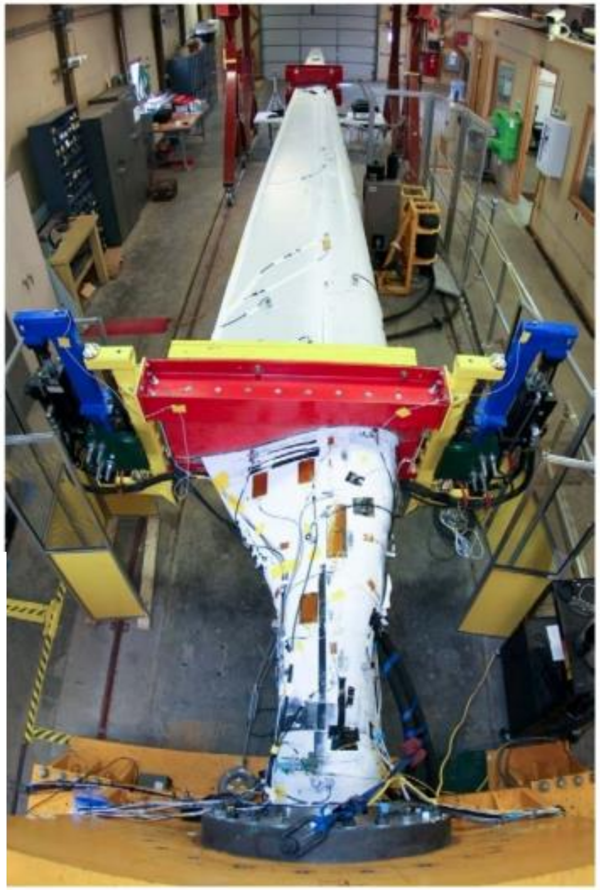
Implementation

northwest composites centre

Oil and gas



Wind turbine test

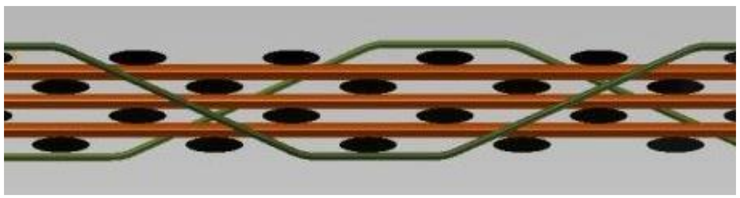


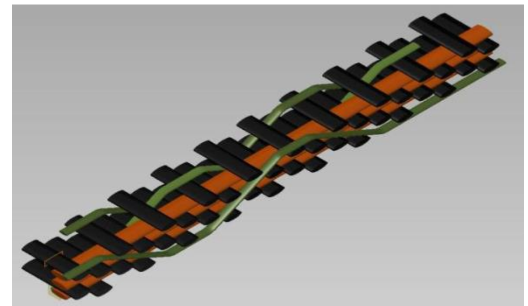
Pedrazzani et al., 2012

ACOUSTIC EMISSION

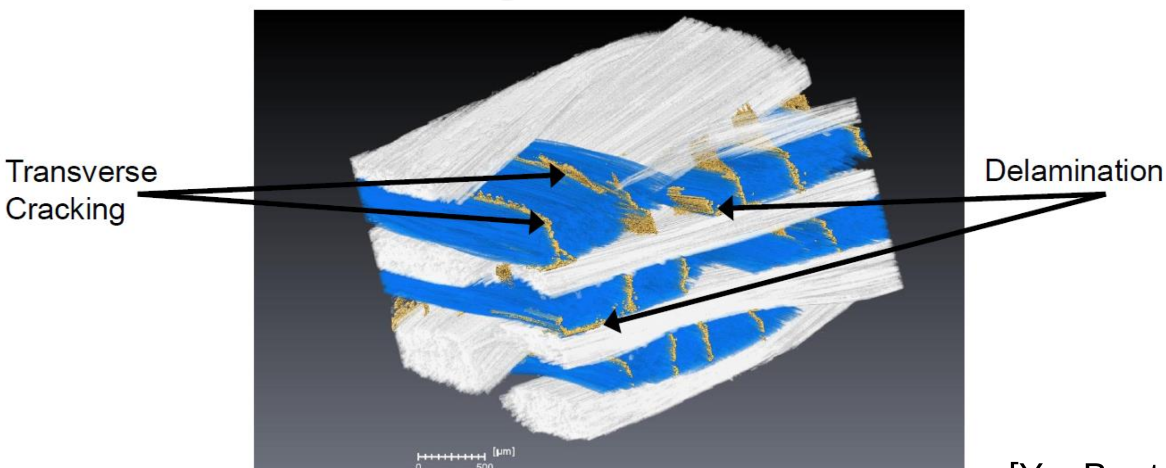
Damage mechanisms

3D woven fabric - Angle Interlock/through-thickness binding



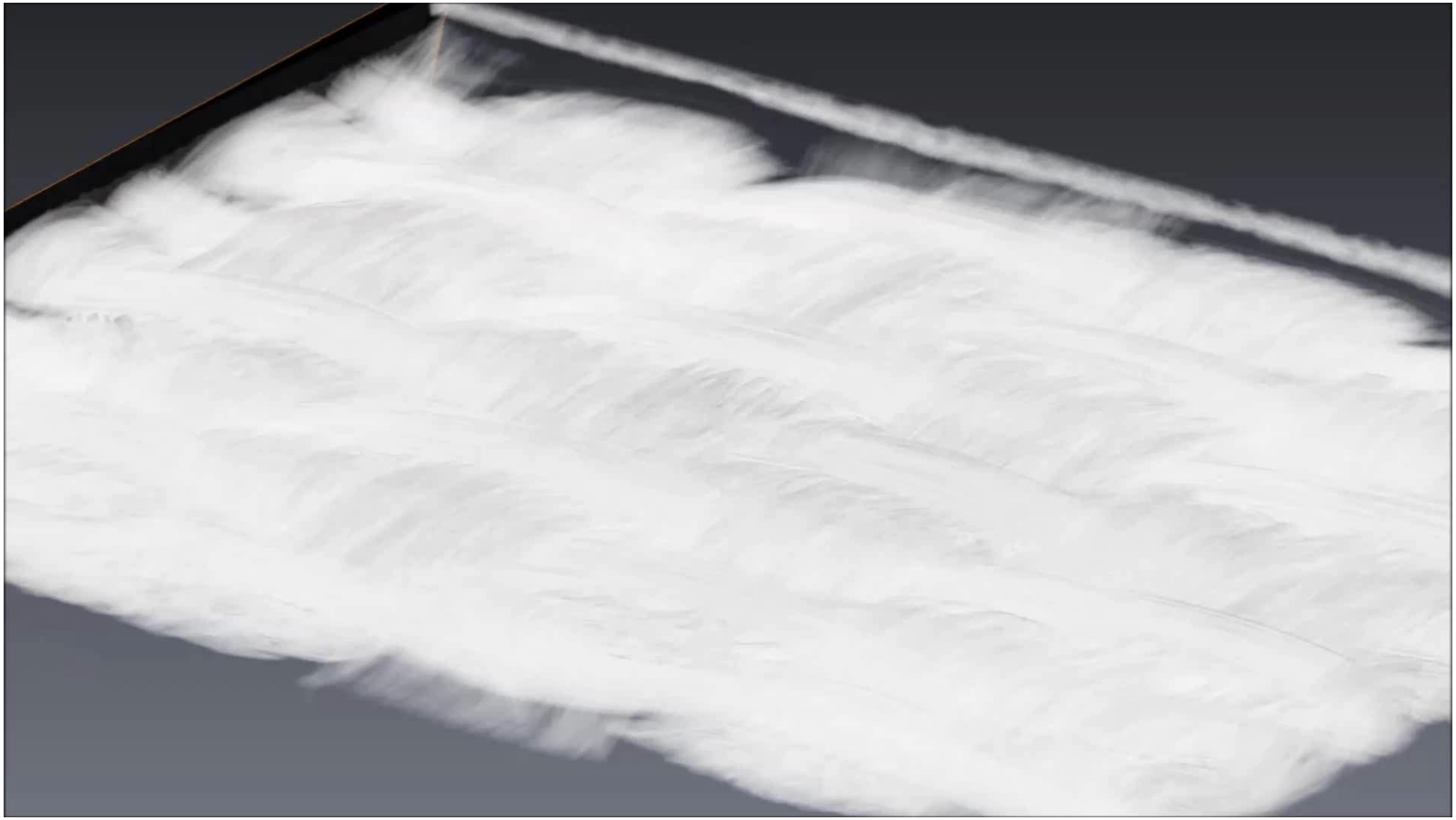


- Damage mechanism in uniaxial loading
  - Transverse cracking ⟶ Delamination



[Yu, B. et al., 2015]

Damage mechanisms – Video X-Ray CT



[Yu, B. et al., 2015]

Passive system : Acoustic emission Literature review

Amplitude distribution according to the damage mechanisms in composite materials

Ref.	Matrix cracking	Interface decohesion (fibre/matrix)	Fibre/matrix friction and fibres pull-out	Fibres breakage
Wadim, 1978	**30**-45 dB	45-55 dB	--	>55 dB
Komai et al, 1991	<70 dB	<60 dB	--	--
Chen et al., 1992	60-**80 dB**	70-90 dB	--	--
Barre et al., 1994	40-55 dB	60-65 dB	65-85 dB	85-95 dB
Ceysson et al., 1996	50 dB	--	--	--
Kim et al., 1997	40-70 dB	--	--	60-100 dB
Gong et al., 1998	33-45 dB	50-68 dB	69-86 dB	87-100 dB
Kotsikos et al. 1999	40-55 dB	--	>80 dB	--
Godin et al., 2005	35-**80 dB**	50-80 dB	70-100 dB	--
Liu et al. 2012	40-60 dB	50-70 dB	80-100 dB	80-100 dB
Masmoudi et al., 2014	40-78 dB	72-100 dB	--	95-100 dB
Li et al., 2014	35-55 dB	55-100 dB	--	35-80 dB

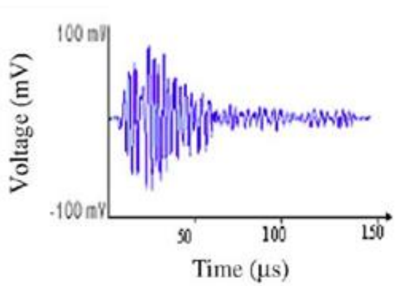
Frequency distribution according to the damage mechanisms in composite materials

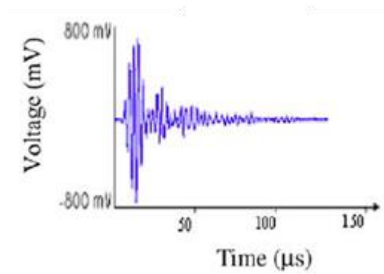
Ref.	Matrix cracking	Interface decohesion (fibre/matrix)	Fibre/matrix friction and fibres pull-out	Fibres breakage
Russel et al., 1977	50-150 kHz	--	--	140-180 kHz
Susuki et al., 1987	30-150 kHz	30-100 kHz	180-290 kHz	300-400 kHz
Susuki et al., 1991	80-130 kHz	--	250-410 kHz	250-410 kHz
Komai et al., 1991	~ **300 kHz**	--	300 kHz	>500 kHz
De Groot et al., 1995	50-180 kHz	220-300 kHz	180-220 kHz	>300 kHz
Ramirez-Jimenez et al., 2004	90-110 kHz	--	200-300 kHz	> 420 kHz
Jong, 2006	200-**600 kHz**	200-350 kHz	0.7-1.1 MHz	>1.5 MHz
Bossiba et al., 2008	~ 140 kHz	~300 kHz	--	~ 405 kHz
Gutkin et al., 2011	**<50 kHz**	200-300 kHz	500-600 kHz	400-500 kHz
Li et al. 2014	50-80 kHz	50-150 kHz	--	150-500 kHz

AE - Literature review

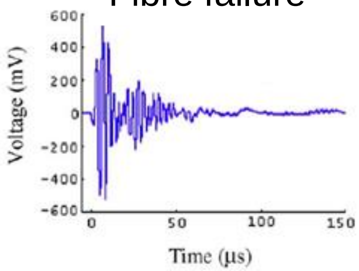
Typical waveforms collected during tensile tests on composite

Matrix cracking

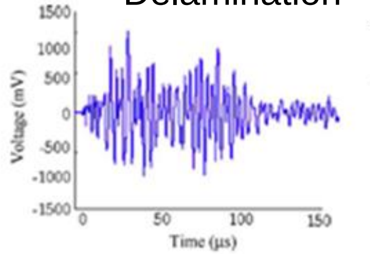




Fibre failure

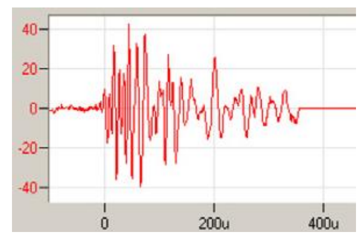


Delamination

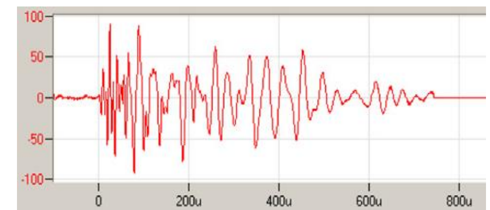


[Godin et al., 2005]

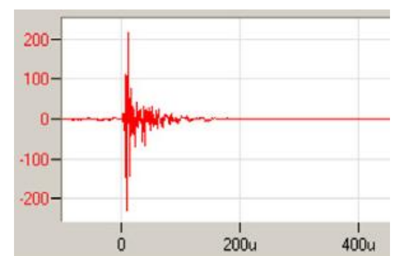
Matrix cracking



Interface debonding



Fibre failure



[Masmoudi et al., 2014]

Angle Interlock Cracking Simulation

- For composite materials, the strain energy density can be calculated as function of the applied strain/ stress.
- The strain energy density components can be calculated as

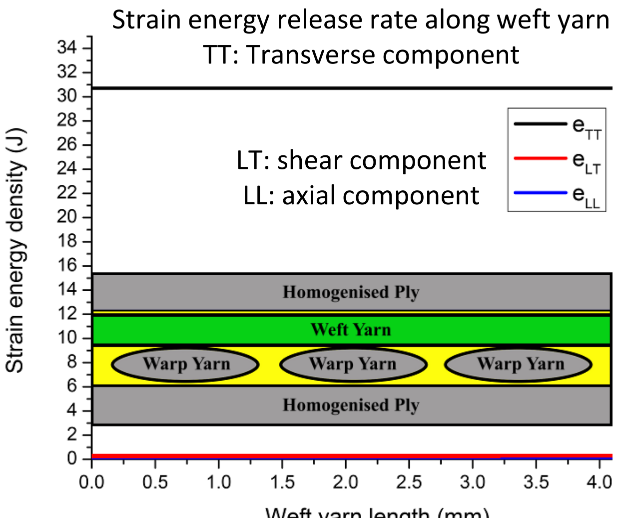
$$e_{ij} = \frac{1}{2V}\int_{v} \frac{\sigma_{ij}^{2}}{E_{ij}}$$

V is the volume of the (ply/yarn/laminate) determined as the cross-sectional area multiplied by the thickness

σ_{ij} is the ij component of stress

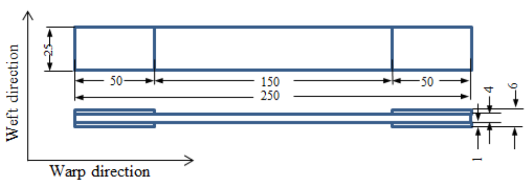
E_{ij} is the corresponding Young modulus ($i=j$) or shear modulus ($i \neq j$).

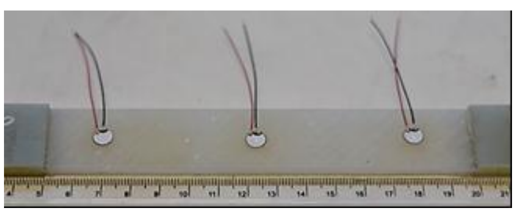
- To determine which constituent part will crack, the strain energy density components are calculated for a unit cell when applying 1% strain along the warp direction.
- Measuring the strain energy density along the weft yarn.

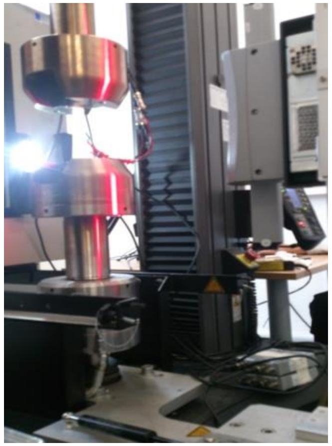


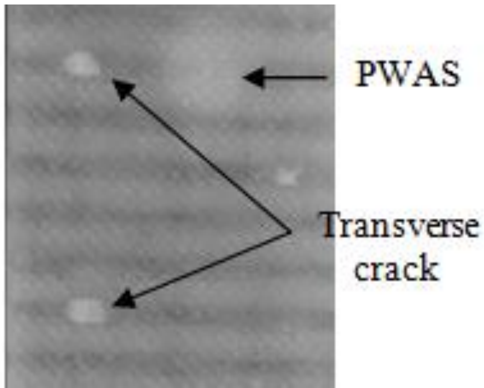
AE Experiments

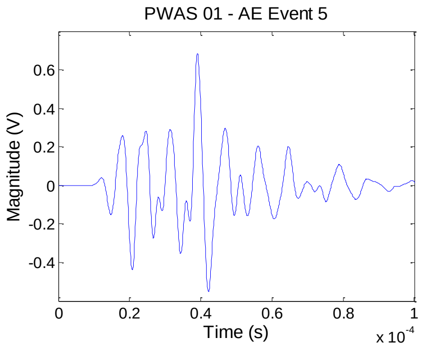
To develop only transverse cracks, the specimen was loaded up to 20% of its ultimate strength

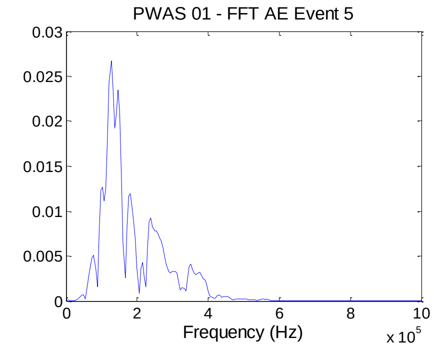


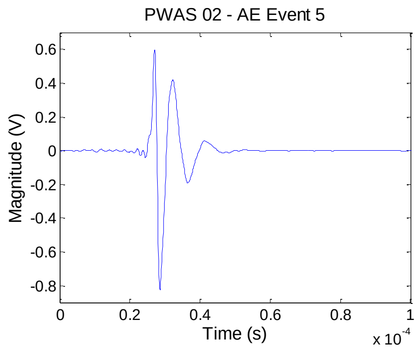


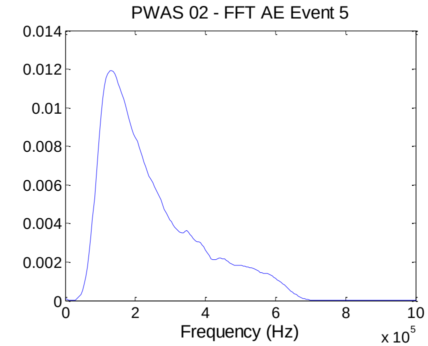


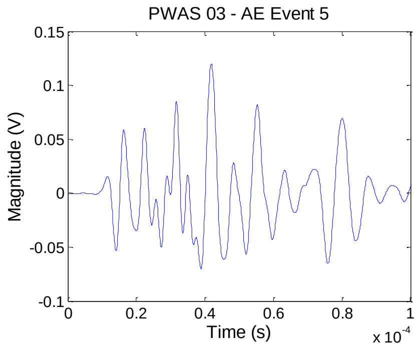


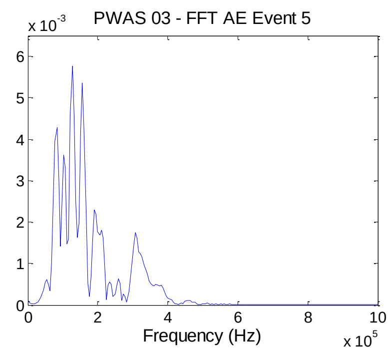




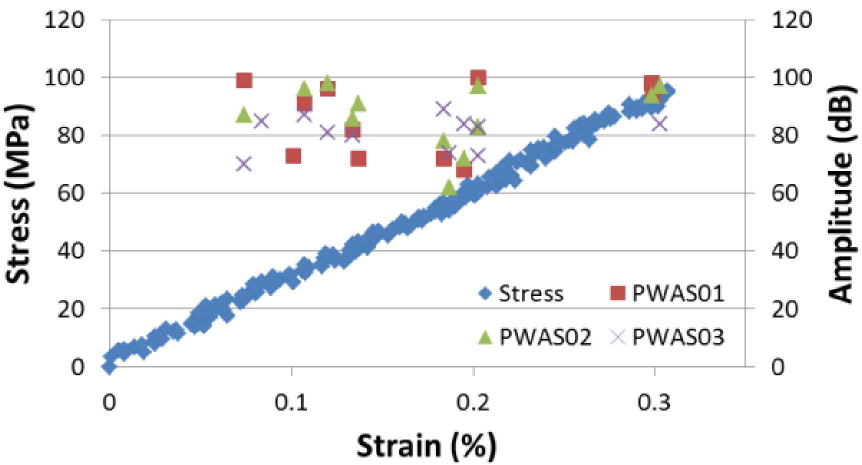


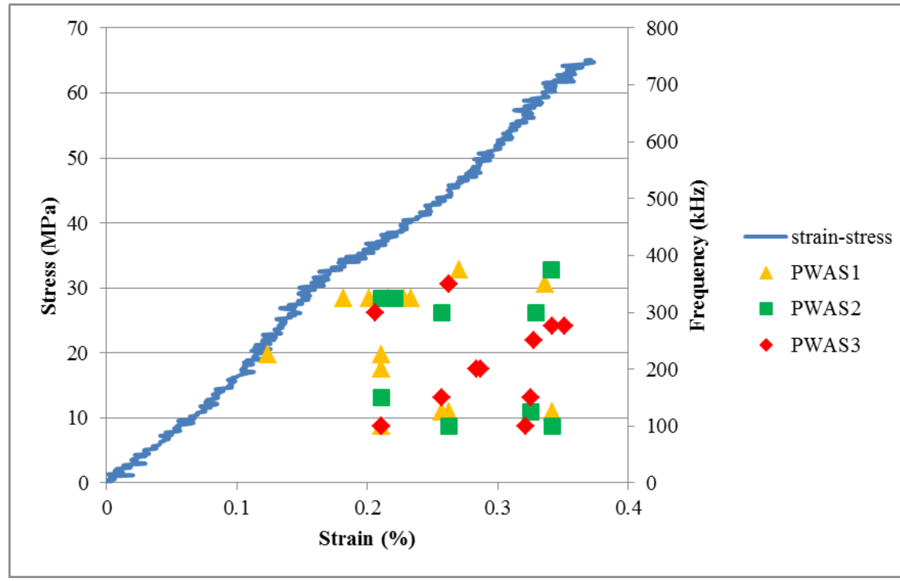






AE Experiments – Results

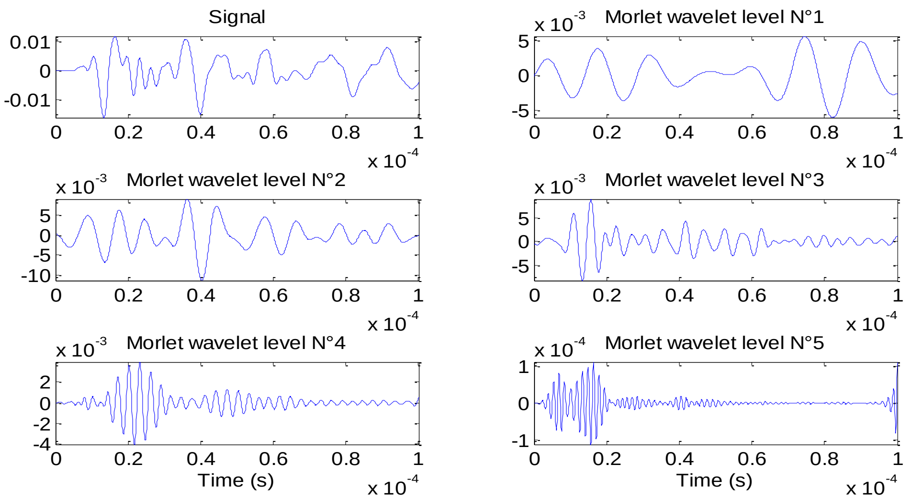




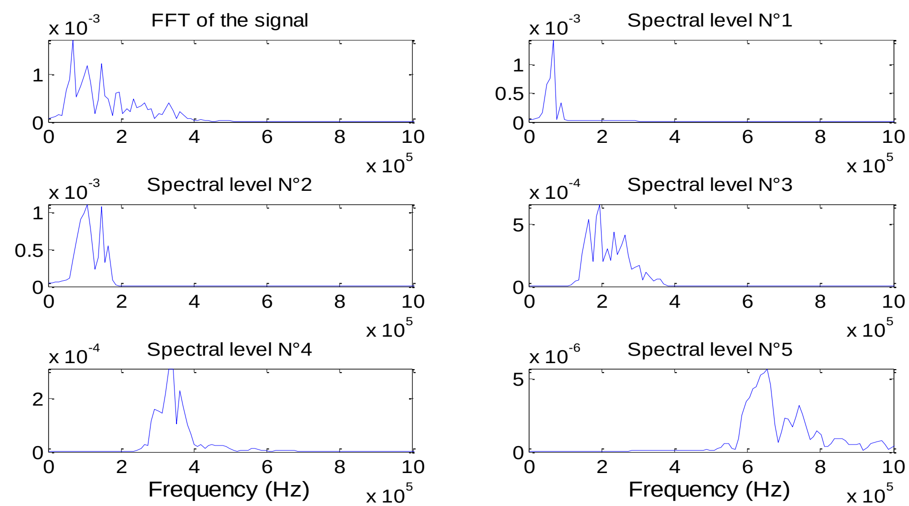
AE event component	Transverse crack
Amplitude	60-100 dB
Frequency	100-400 kHz

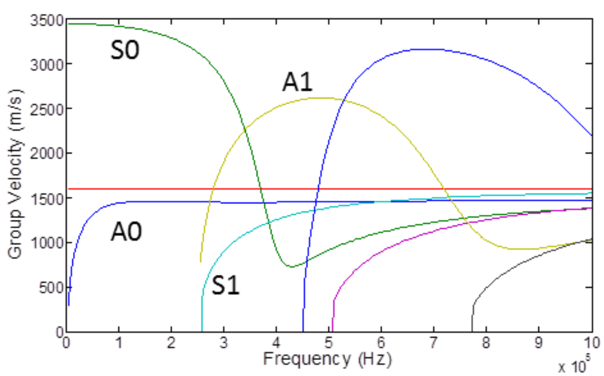
Waveform processing

Discrete Wavelet Transform (DWT)



FFT of the DWT



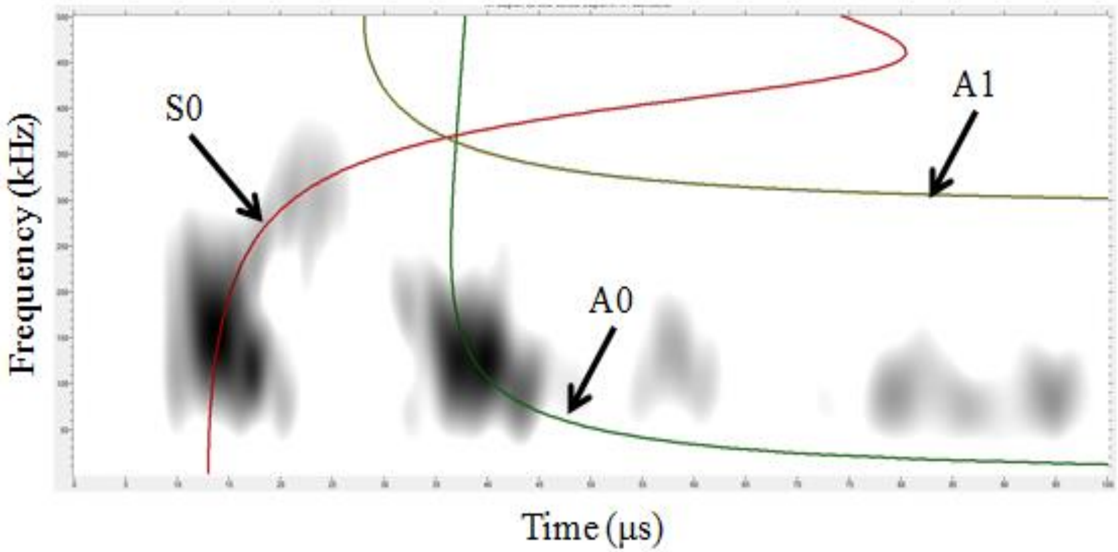


Level 1, 2 and 3 (68, 120 and 200 kHz): Two modes exist S0 and A0.

Level 4 (340 kHz) : Four modes exist S0, S1, A0, and A1.

Level 5 (650 kHz) : Six modes exist S0, S1, S2, A0, A1, and A2 .

Waveform processing

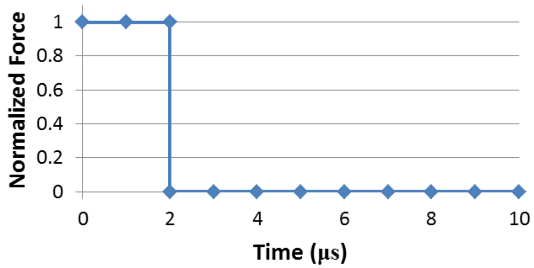


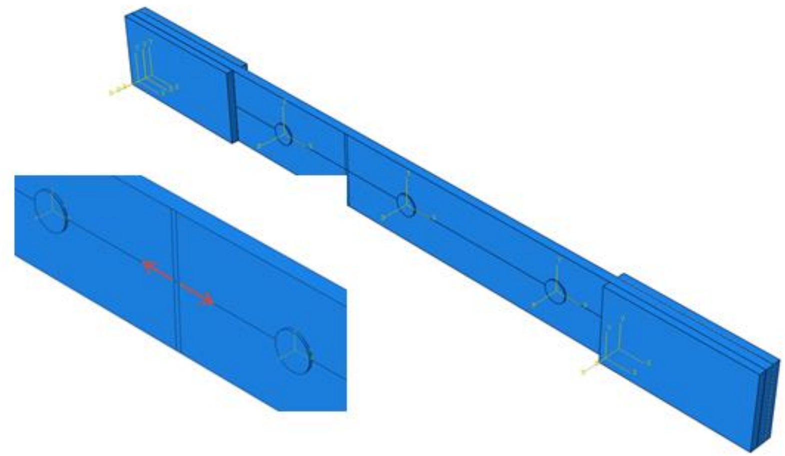
However, Surgeon and Wevers (1999) mentioned that matrix cracks will generate AE waves which contain a predominant extensional mode (i.e. S0 mode).

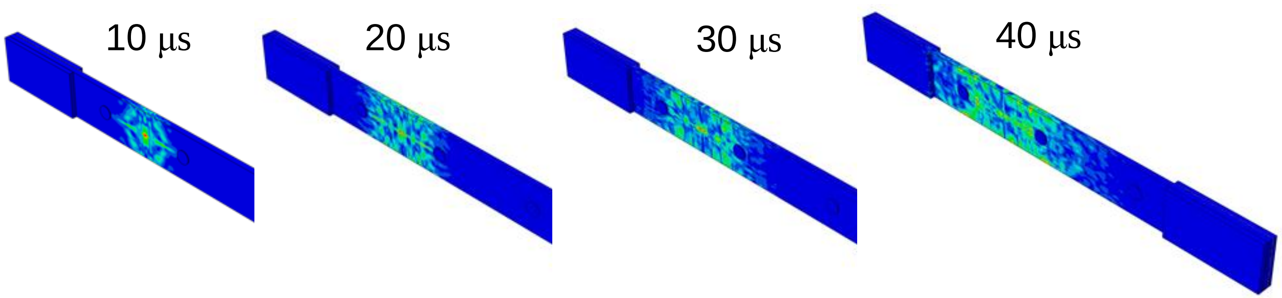
It might be explained by the symmetry of the transverse crack which is maybe not the case in our experiments.

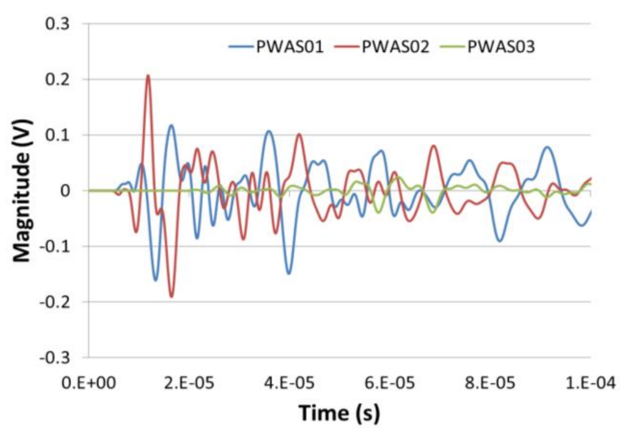
AE simulation

Transverse crack is simulated by 2 points forces







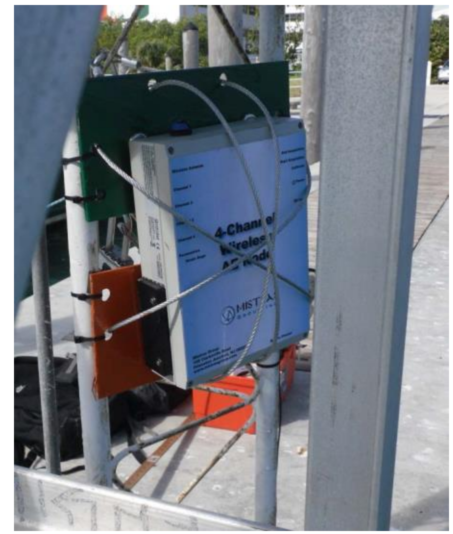


MANCHESTER 1824

Implementation - Bridges

northwest composites centre

- "Self-powered Sensor Network for Bridge Health Prognosis", sponsored by NIST through is TIP program



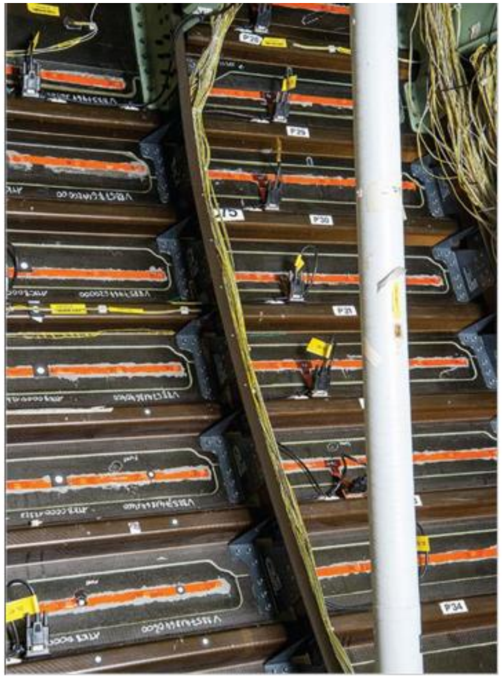
UNIVERSITY OF MIAMI

Virginia Tech

UNIVERSITY OF SOUTH CAROLINA

MISTRAS GROUP, INC.

Implementation - Aerospace



In-service testing – smart layer sensors for impact detection on A350 CFRP door surround panel
Source: Airbus

SHM technique	In-service monitoring of certification tests	Flying on aircraft
Acoustic emission	- B777 horizontal stabilizer full scale fatigue and ultimate load tests - A380 full-scale fatigue test	
acousto-ultrasonics	- Bombardier Learjet 85 flight test monitor impact damage to composite vertical stabiliser	
Fibre Bragg grating	- A350 horizontal tail plane structure & flight testing	

Concluding remarks and Challenges

- Multi-disciplinary research

- **Many challenges** - quantify damage; estimate remaining service life (prognosis)-automation

- Implementation in real structure and environment

≠

The University of Manchester

northwest composites centre

Thank you for your attention

Dr. Matthieu Gresil

matthieu.gresil@manchester.ac.uk

http://www.mub.eps.manchester.ac.uk/i-composites-lab/home/