University of BRISTOL

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Extended Research Project Presentations

Dtc10 Cohort

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ADVANCED COMPOSITES CENTRE FOR INNOVATION & SCIENCE

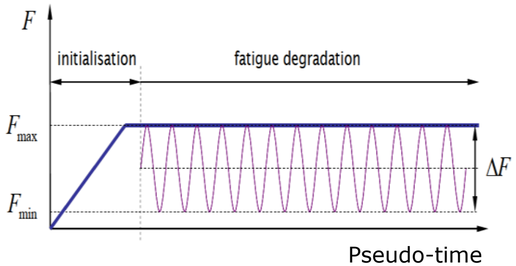
Damage Model for Fatigue Delamination Growth

Jamie Blanchfield

Damage Model for Fatigue Delamination Growth

Numerical Modelling of Fatigue

- Cycle-jump approach
- Damage per time step via a damage model

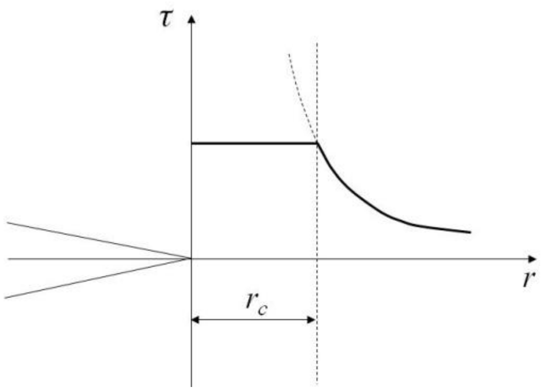


Ref. Kawashita L et al. (2009)

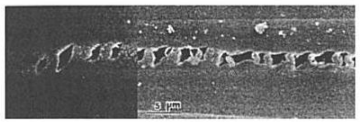
The Damage Model

$$\frac{dD}{dN} = \frac{(1-D)^{-p}}{(p+1)}\left[\frac{\tau_{max}}{\tau_u}\right]^{\frac{b}{(1-R)^{\kappa}}}$$

LEFM and Damage Mechanics

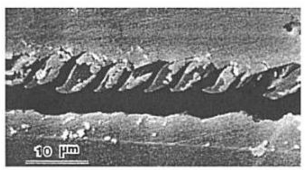


Non-singular stress field



Formation of tension microcracks

Ref. O'Brien TK, 1998

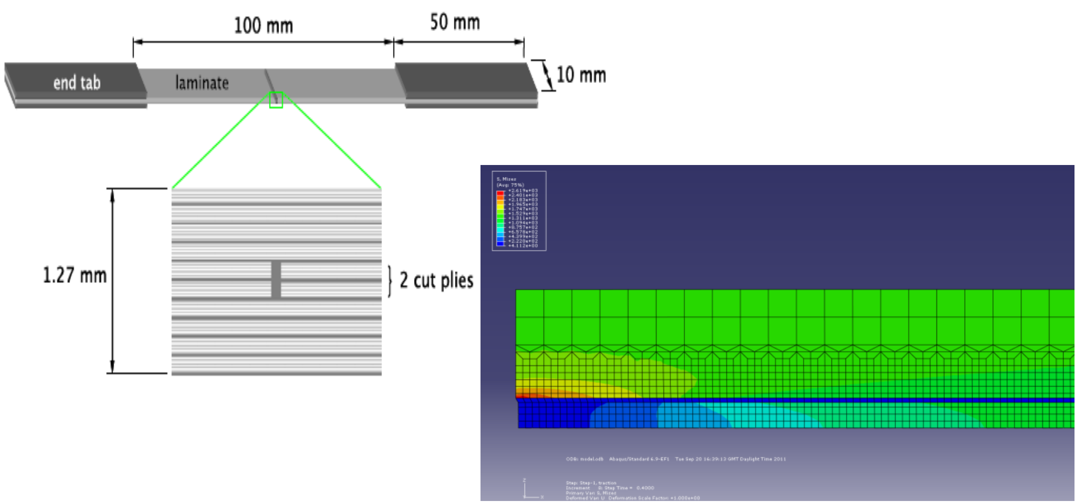


Coalescence of microcracks forming hackles

Numerical Solution

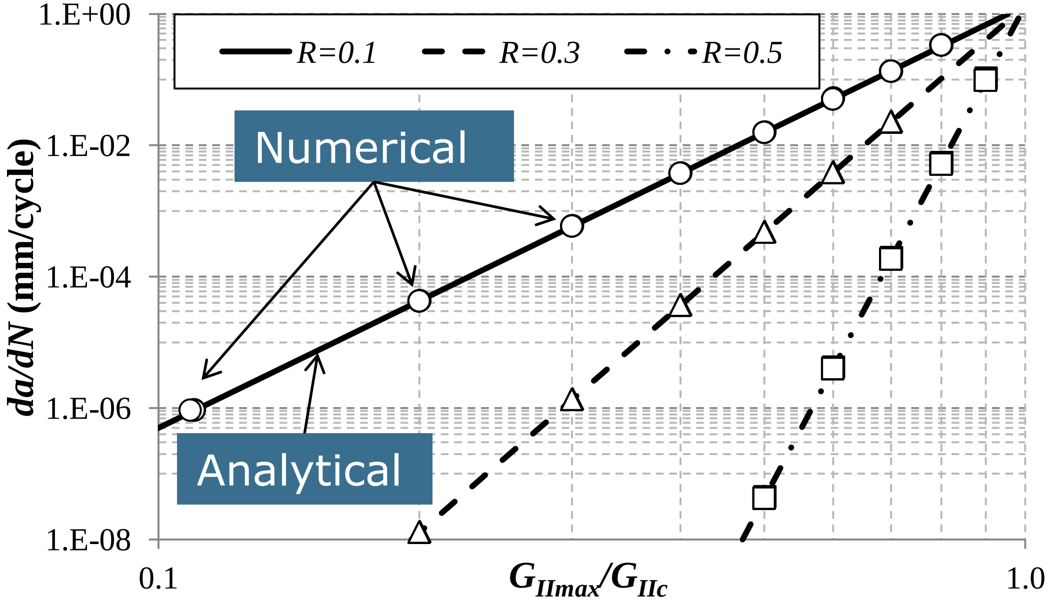
$$N_f = \begin{cases} \left(\dfrac{G_{IIC}}{G_{IImax}}\right)^{\frac{b}{2(1-R)^{\kappa}}} & r \le r_c \\ \left(\dfrac{\tau_u}{\tau_{max}}\right)^{\frac{b}{(1-R)^{\kappa}}} & r > r_c \end{cases}$$

Numerical Implementation



FE Model

- Quarter model of CCP specimen
- Spring elements representing adhesive layer
- Elements deleted when damage = 1
- G_{II} obtained from the VCCT



Future Work

- Generating fatigue initiation data for mode I
- Extension of model to mixed mode conditions
- Commercial FE implementation

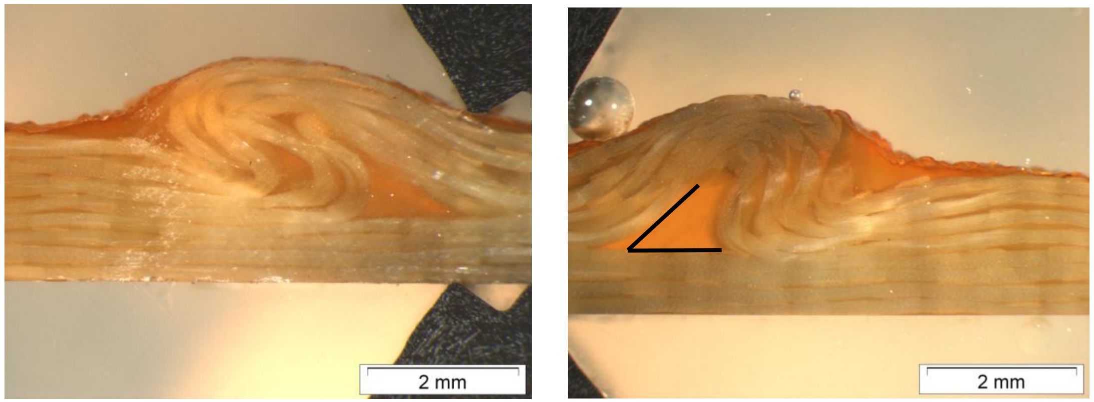
An experimental study of representative wrinkling defects

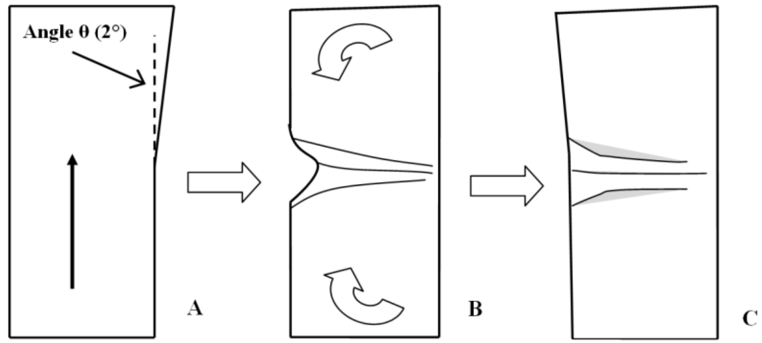
Dominic Bloom

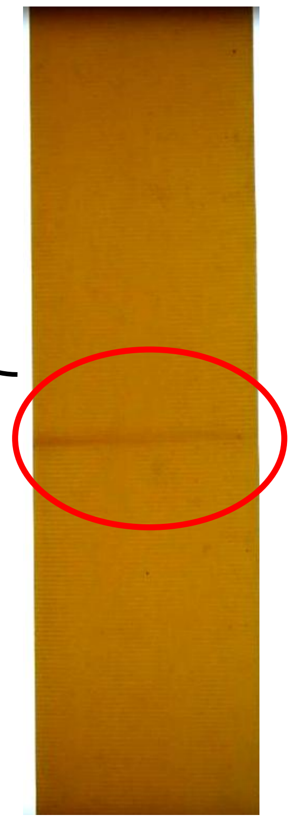
Engineering and Physical Sciences Research Council

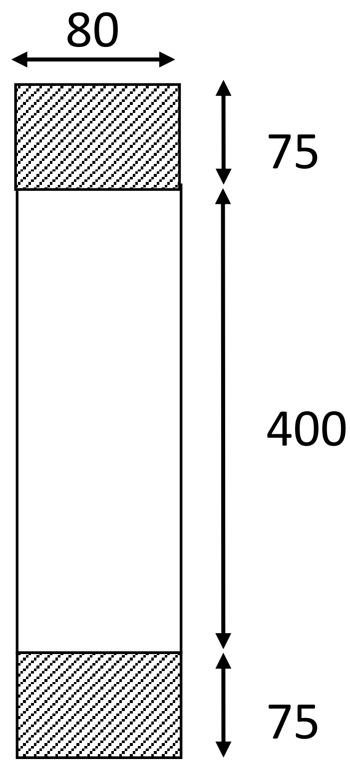
ADVANCED COMPOSITES CENTRE FOR INNOVATION & SCIENCE

- Wrinkling: a common problem





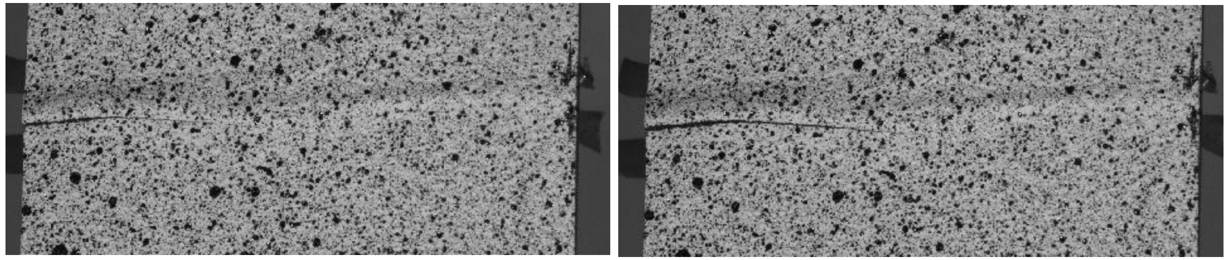


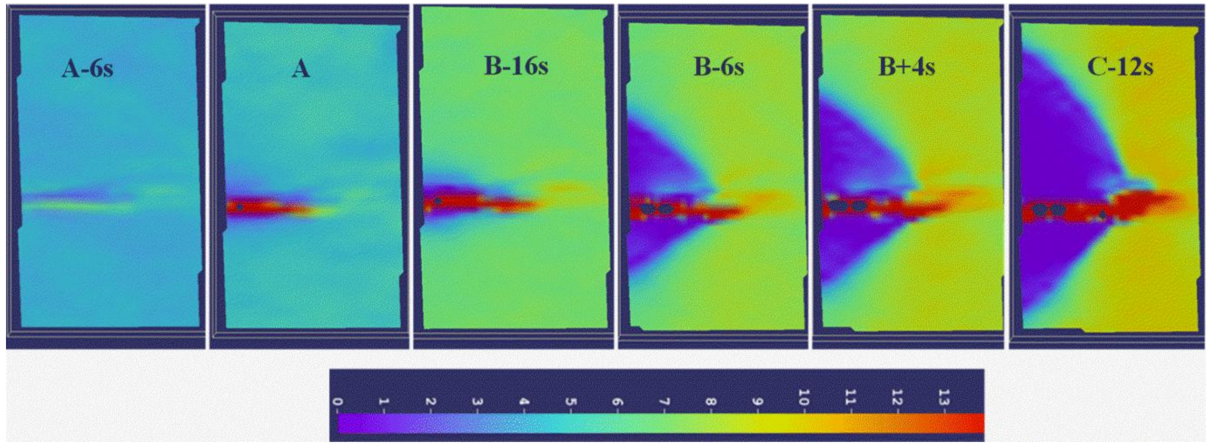


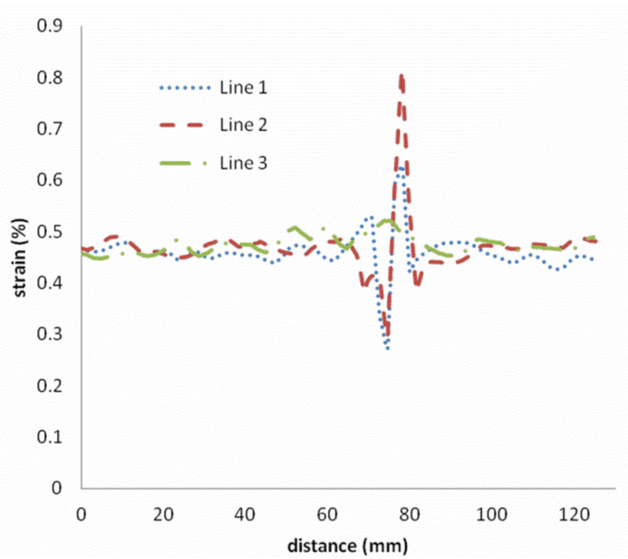
- Formation: Mismatch in area between ply and tool surface
- Can a very localised defect have an effect on overall laminate performance?
- Characterisation

2

- Tensile test
  - Digital Image Correlation
  - Video Gauge
- Crack initiation
- Crack propagation
- Delamination growth
- 40% Knockdown





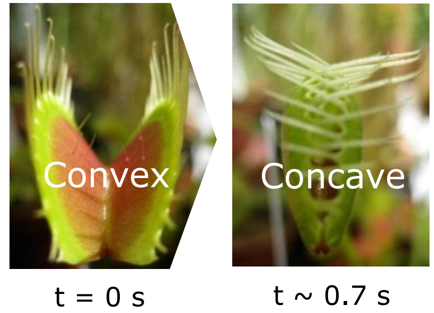


Multistable Orthotropic Shell Structures

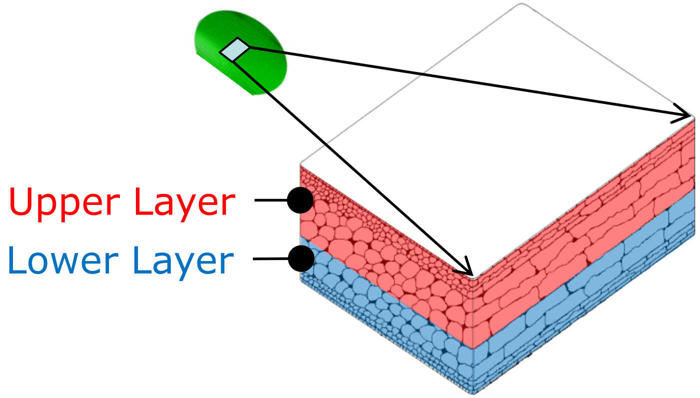
Broderick Coburn

Bistability of the Venus Flytrap

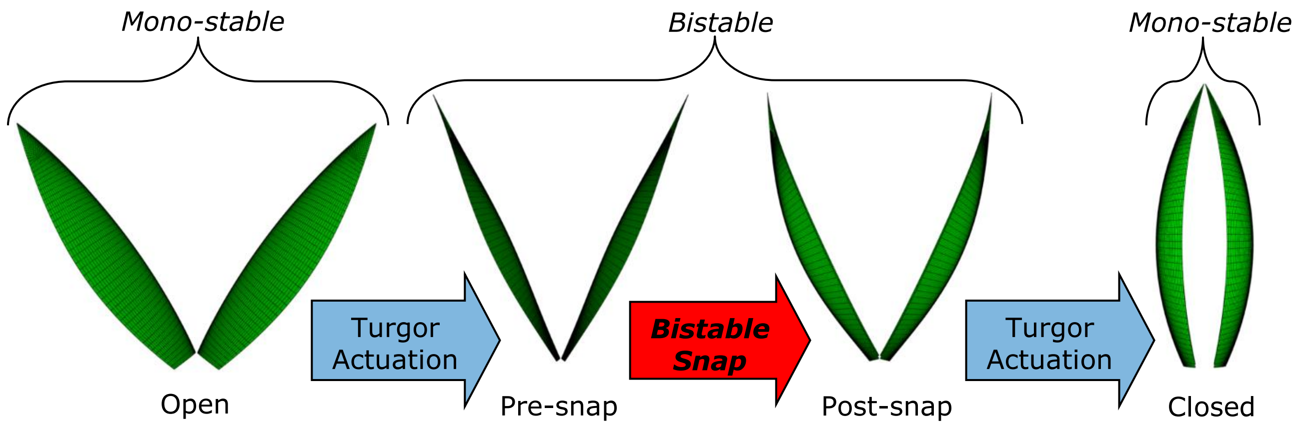
- Snap-buckling instability captures rapid closure.
  - Bistability is due to doubly curved structure and is governed by interplay between bending and stretching energies.
  - Orthotropy is also key.



- Lobe structure and actuation
  - Six orthotropic layers within shell structure.
  - Actuation by differential turgor pressure in hydraulic layers.
    - Consisting of anisotropic pressure vessels.

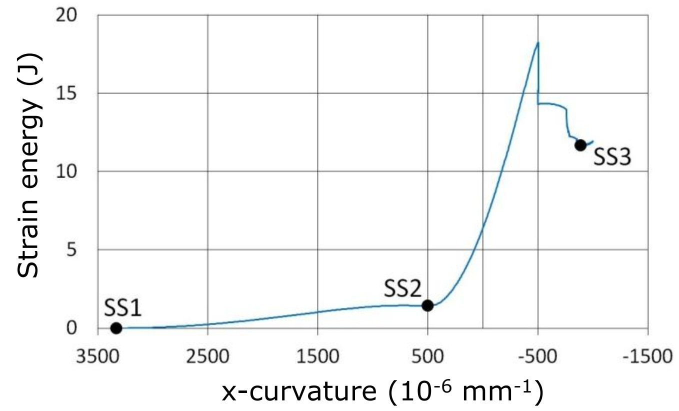


- Momentary bistability
  - Curvature-time results correlate well with flytrap data.
  - Loss of bistabiltiy results in slower capture.

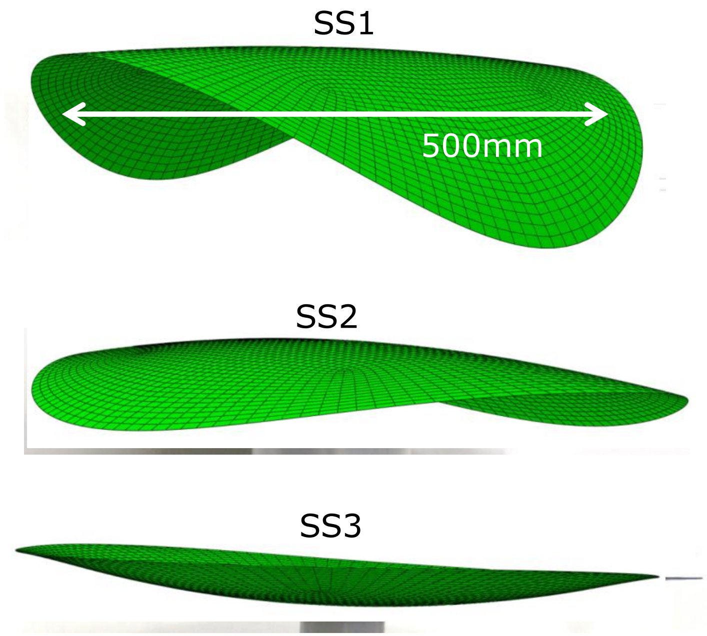


Tristable Shell

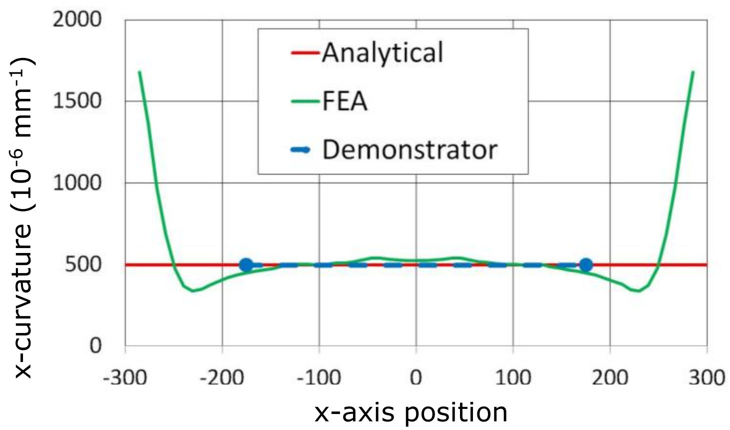
- Analytical Model
  - Multistability due to doubly curved structure.
  - Carbon fibre prepreg layup identified to achieve tristability.
  - Assumptions: constant curvature, negligible bending boundary layer.



- Finite Element
  - Boundary layer length found to be significant » Ø500mm required.
  - SS2 energy minimum very shallow



- Demonstrator
  - Shell tristability shown for the first time.
  - Sensitive to manufacturing imperfections.

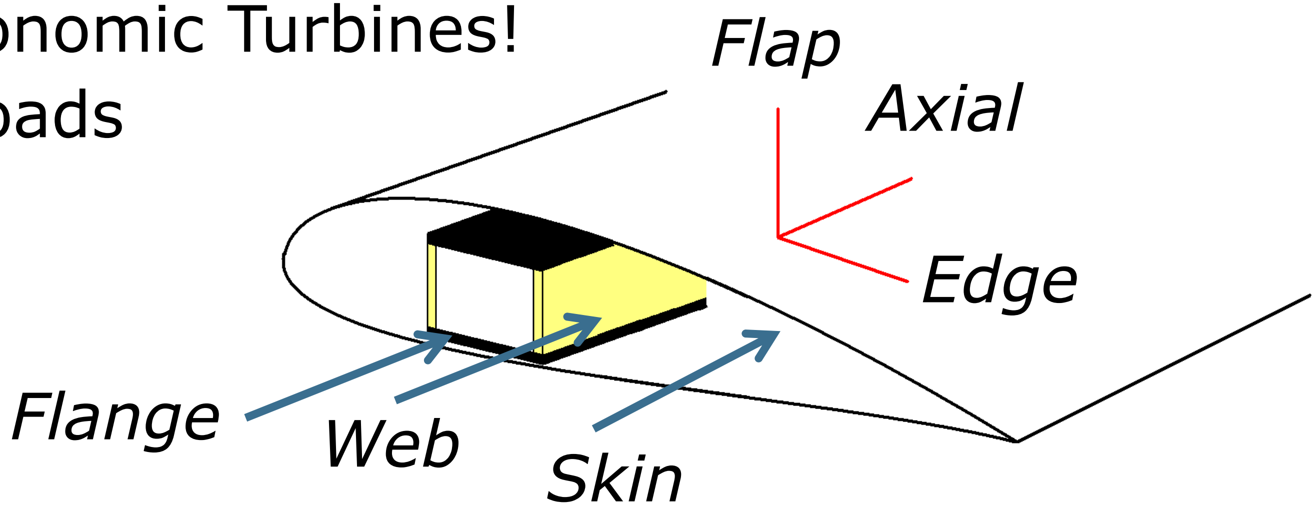


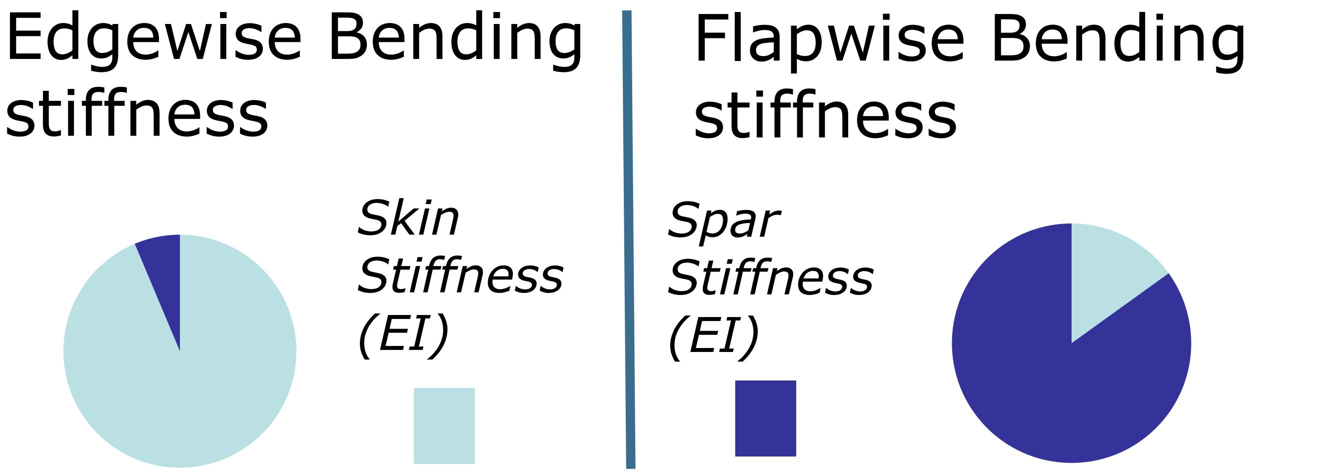
Novel Mid Span Joints

Michael Elkington

NOVEL MID SPAN JOINTS

- Bigger blades = More economic Turbines!
- Too big to transport on roads
- Build them in 2 pieces
- Requires Mid span Joints
- Stress dominated by bending moments

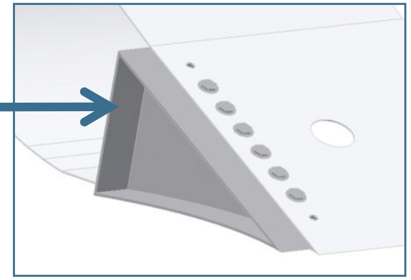


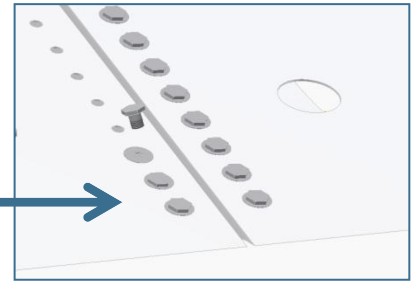


Keep the loads separate across the joint

NOVEL MID SPAN JOINTS

Tapered pre loaded joint, as seen on a bicycle crank.





•Big moments/ Shallow section

=

•Thick
•Highly Anisotropic

Novel Design needed

•Small moments/ Tall section

=

•Thin
•Less Anisotropic

Conventional bolting

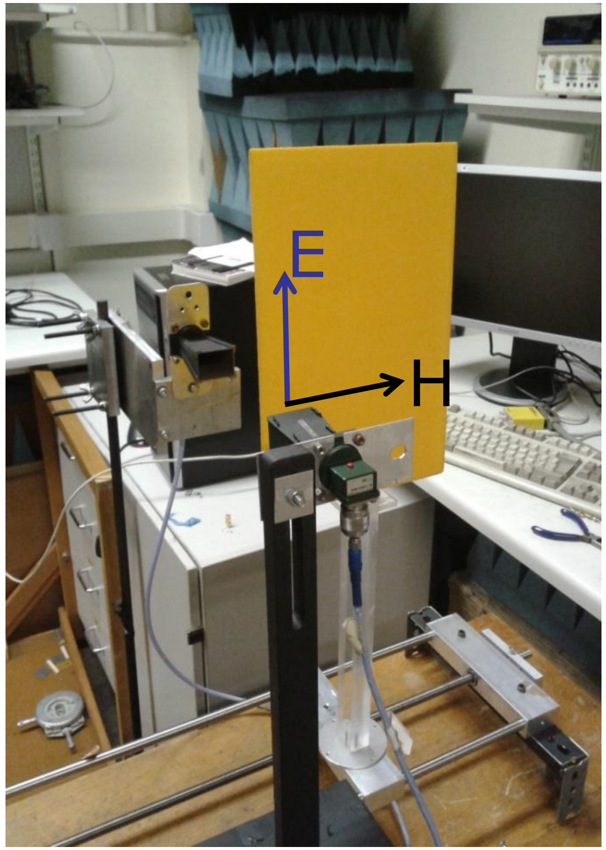
Microwave Attenuation of Ferromagnetic Microwire Composites

Jonathan Fuller

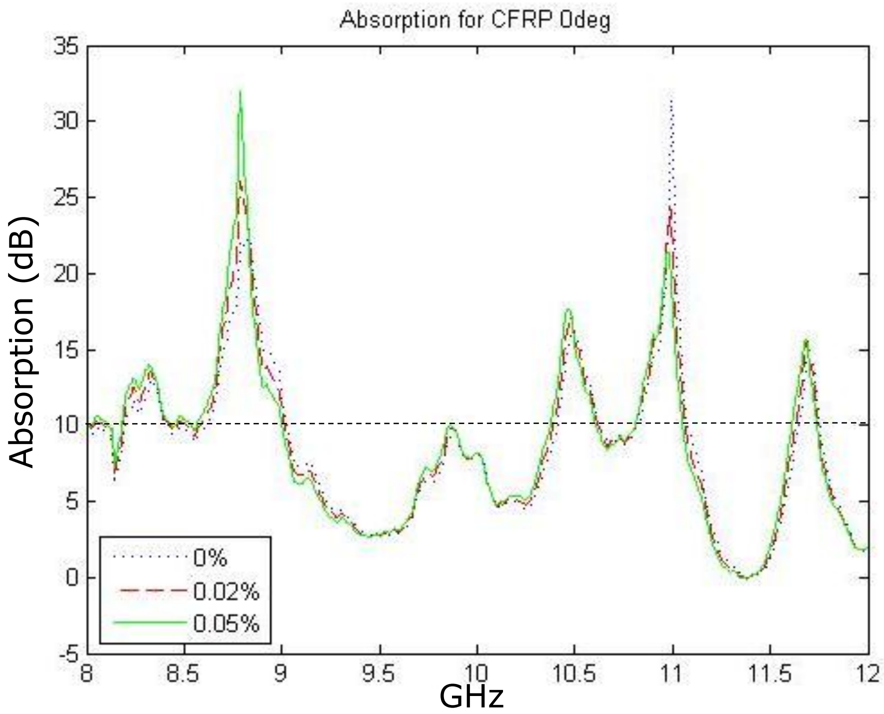
Microwave attenuation of ferromagnetic microwire composites

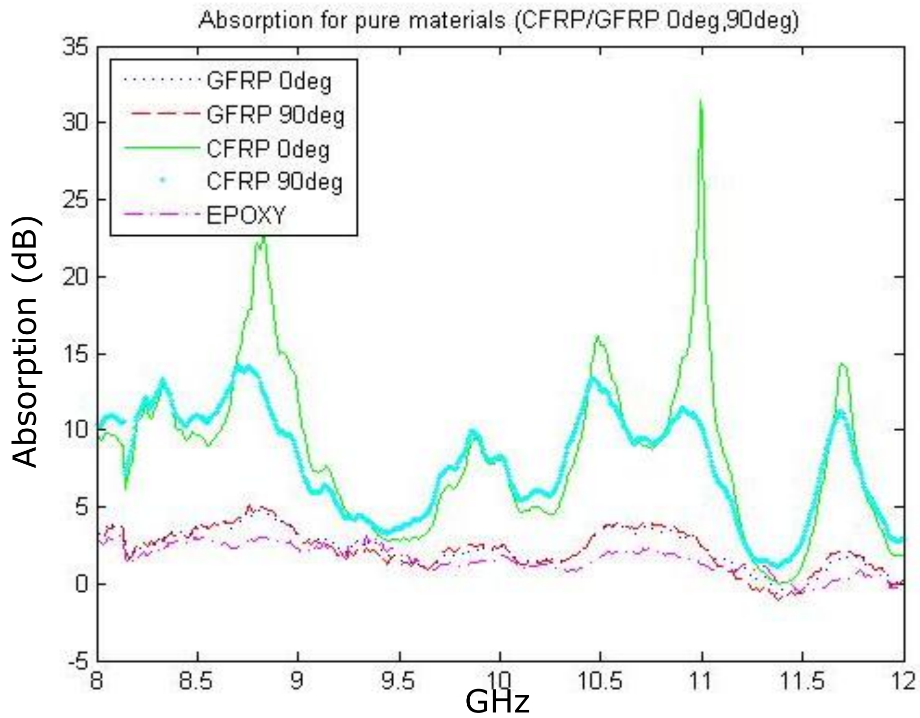
- Aim:
  - *Characterise the microwave responses of different concentrations of ferromagnetic glass-coated microwires in polymer composites, and evaluate the applicability of their integration with structural materials.*

- Experimental
  - 0.02 wt%, 0.05 wt% $Fe_{74}Si_{11}B_{13}C_2$ wires
  - Dispersed in epoxy, UD CFRP and GFRP
  - Vertically polarised X-band horn antennas
  - Two-port scattering parameter measurements
    - **Reflection, S_{11}**
    - **Transmission, S_{21}**
  - Absorption, in dB, defined as:
    - $\mathbf{A = 10*\log_{10}(1 - |S_{21}|^2 - |S_{11}|^2)}$



Microwave attenuation of ferromagnetic microwire composites





Microwire effects

- Absorption in excess of 10 dB
- Shift in matching frequency
  - Increase in dielectric loss

Anisotropic absorbing characteristics

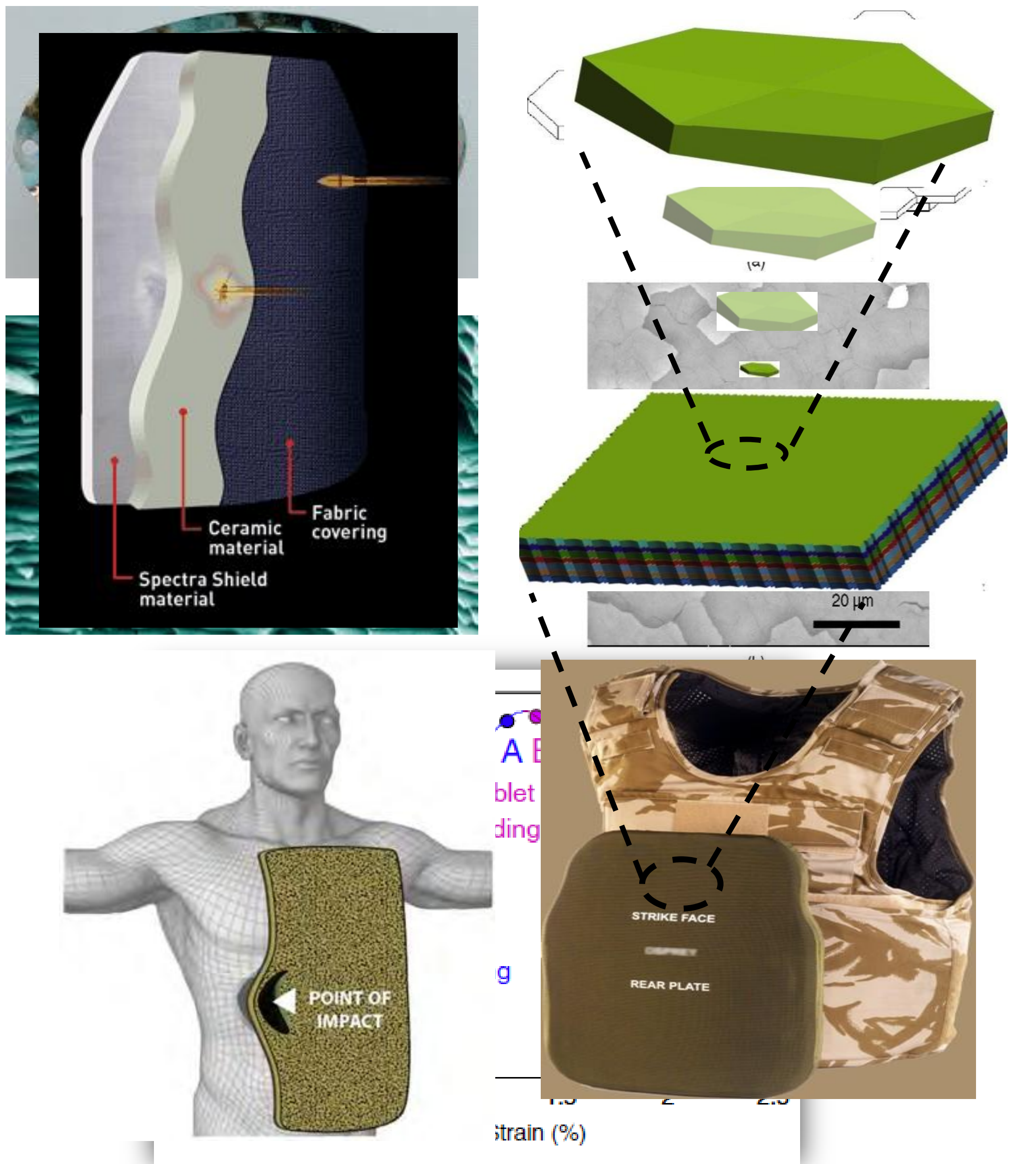
- Fibre direction relative to microwave polarisation affects skin depth, δ
- Parallel to fibres → high conductivity
- Across fibres + matrix → low conductivity

Biologically Inspired Body Armour

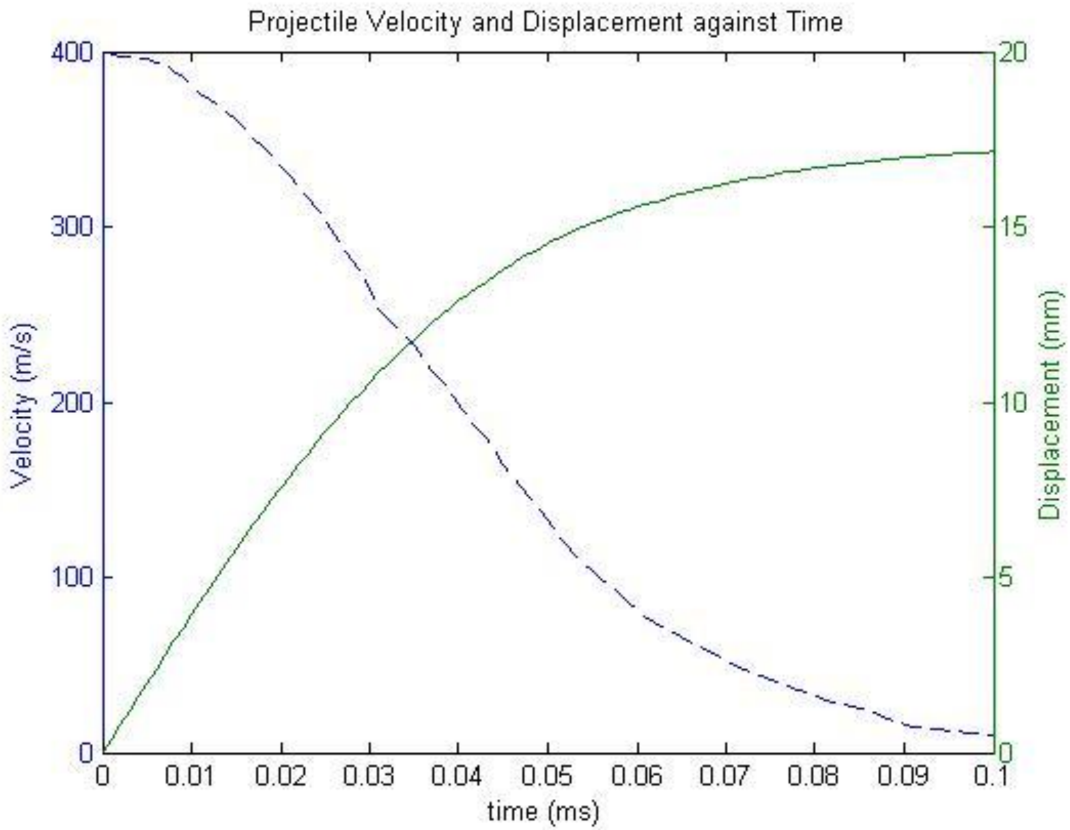
Mark Gilbert

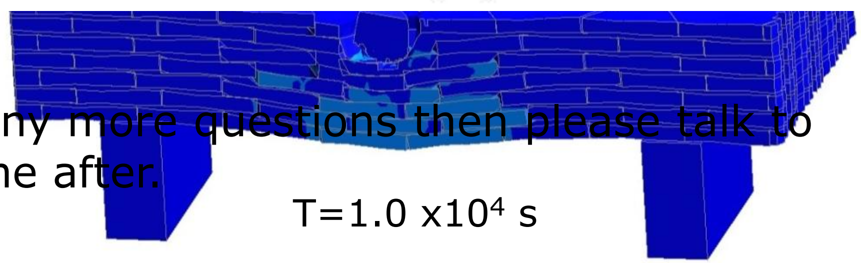
A Novel Ballistic Resistant Armour Based Upon Damage Tolerant Mechanisms In Nacre

- Nacre (red abalone), 95% $CaCO_3$, exhibits a unique damage tolerant mechanism against impact.
  - Brick and mortar layered structure
  - Quasi-hexagonal $CaCO_3$ tiles with variable thickness
  - Chitin crystals in a proteinaceous compliant matrix
- Engineering Synthesis
  - Designed within Msc Patran and impact model analysed within LS Dyna®.
  - Hexagonal tiles with varying thickness creating an interlocking pattern
  - Offset layering forms a brickwork style plate
  - Adhesive interface between layers creates the mortar



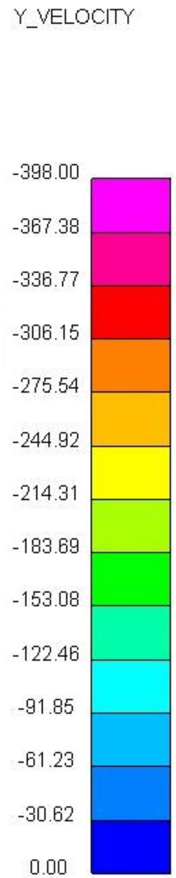
A Novel Ballistic Resistant Armour Based Upon Damage Tolerant Mechanisms In Nacre





Any more questions then please talk to me after.

T=1.0 $\times 10^4$ s



Results

Projectile is based on a 9mm FMJ round with a velocity of 398 m/s, impacted perpendicular to plate surface (21mm thick)

- Offset layers created a delocalisation of the impact energy with platelet interaction seen over the complete layer
- Reduction of the shockwave through adhesive bonded platelet layers
- **Projectile was stopped**.

Simple Numerical Tools for Impact Assessment

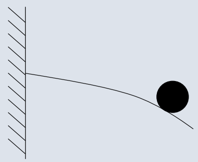
Salah Muflahi

Overview

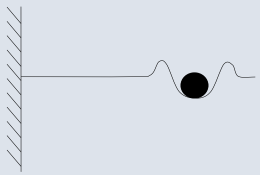
Problem: Being able to accurately model the extent of damage due to impact in a short time-frame using closed-loop analytical methods and simple finite-element tools

Closed-Loop Methods

- Large-mass



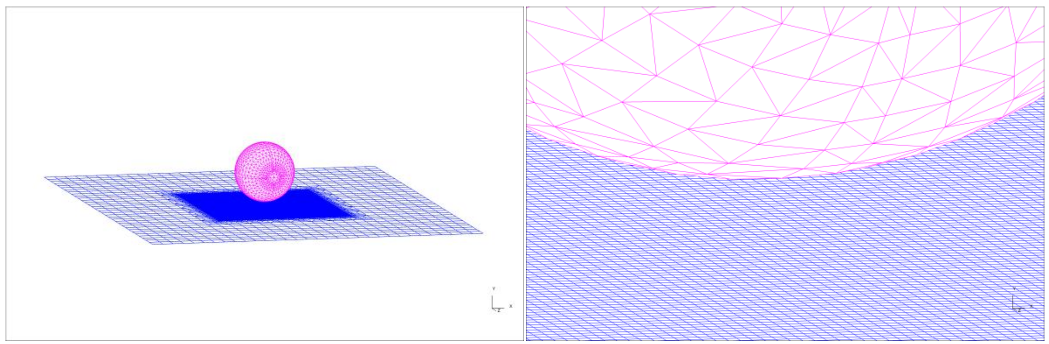
- Small-mass



- Intermediate-mass
  - Superposition of large and small mass responses
- Energy Balance Models describe behaviour at point of impact

Finite Element Methods

- Using MSC Patran and LS-DYNA
- Shell elements to reduce CPU-time
- Cohesive elements to model initiation and propagation of delaminations



Results

Closed-Loop Methods

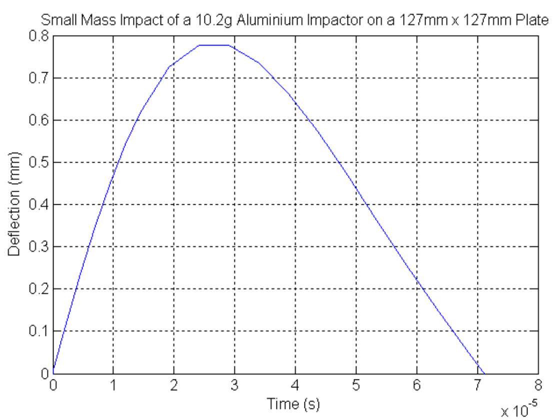
- Assumes Hertzian Contact ($F=K_c\alpha^{3/2}$)
- Non-linear Differential Equations describe deflection at point of impact

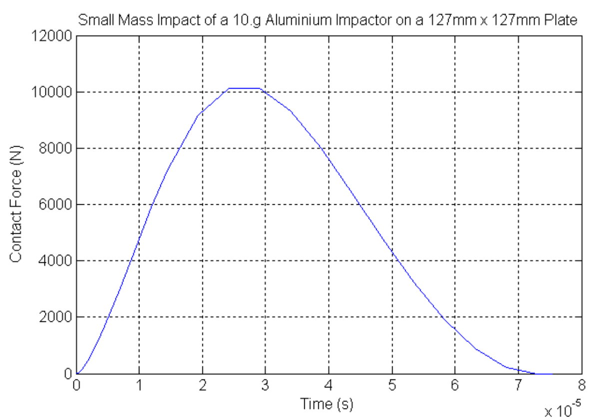
$$\begin{cases} \ddot{\alpha}+\dfrac{3K_c}{16\sqrt{mD^*}}\sqrt{\alpha}\,\dot{\alpha}+\dfrac{K_c}{M_I}\alpha^{3/2}=0 \\ \alpha(0)=0,\ \dot{\alpha}(0)=V \end{cases}$$

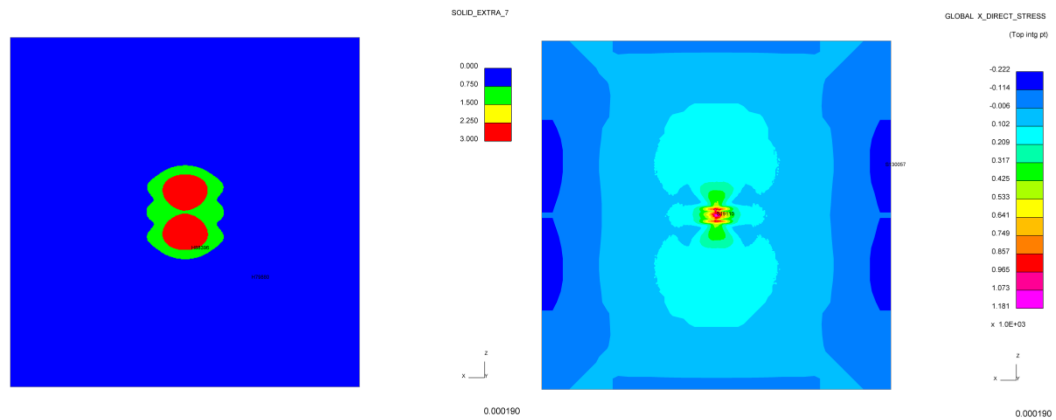
$$\begin{cases} M_I\ddot{x}_1+\delta K_c\left|x_1-x_2\right|^{1.5}=0, \\ M_p\ddot{x}_2+K_{bs}x_2+K_m x_2^3-\delta K_c\left|x_1-x_2\right|^{1.5}=0. \\ x_1(0)=0,\ \dot{x}_1(0)=V,\ x_2(0)=0,\ \dot{x}_2(0)=0 \end{cases}$$

Finite Element Methods

- LS-DYNA in-built load functions used to model soft-body impact
- Single delamination modelled using offset shell elements with a layer of cohesive elements between







Cohesive Zone Model for Delamination and Matrix Cracks Interaction

Maria Francesca Pernice

Cohesive Zone Model for delamination and matrix cracks interaction

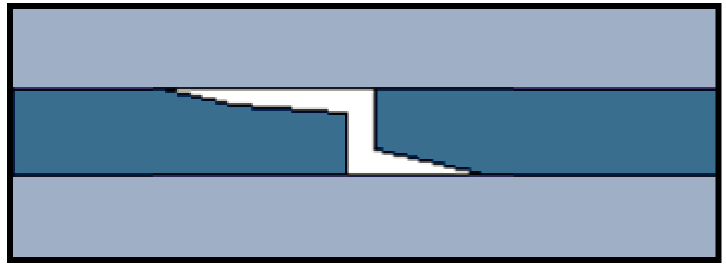
Maria Francesca Pernice

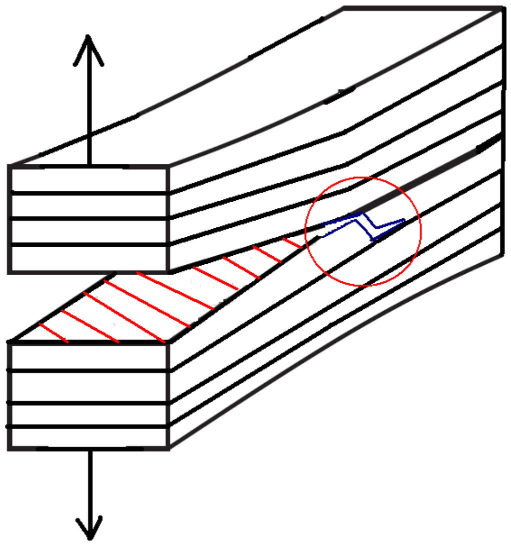
- Finite Element Models
- Experimental tests

- Damage mechanism:
  - Matrix crack inside a ply
  - Delamination at interface
  - Crack "jump"

- Test case:
  - Double Cantilever Beam test
  - Interface between plies with different fibres orientation

Damage interaction



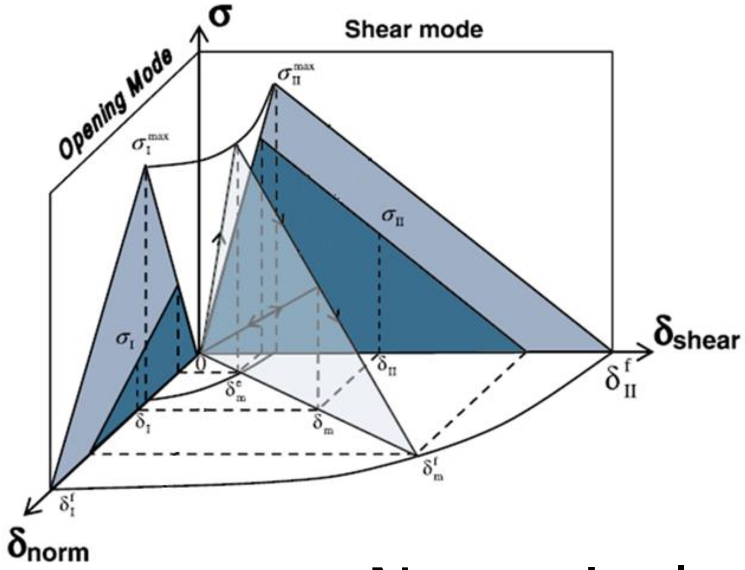


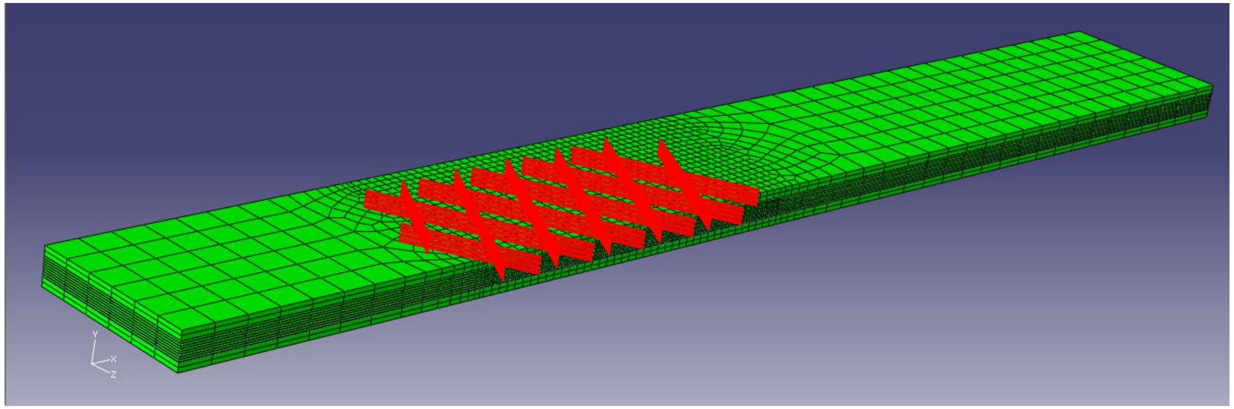
Methods and Results

Cohesive Zone Model →

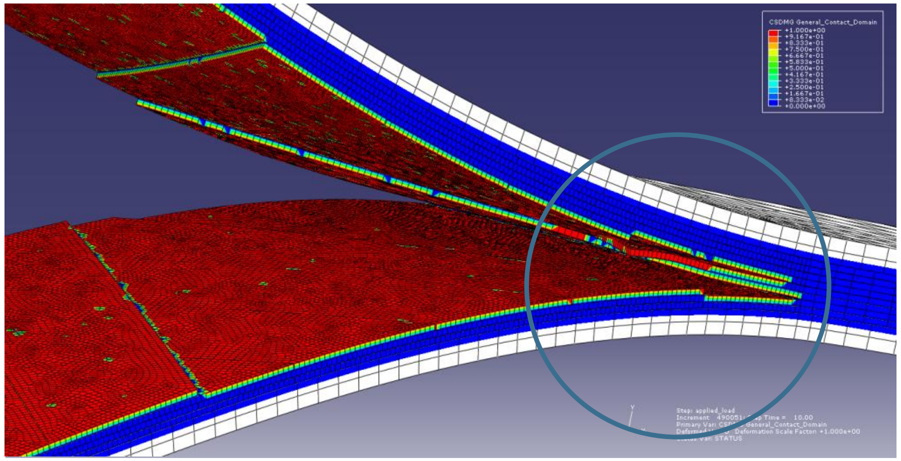
- Cohesive surfaces for **delamination**
- Bands of cohesive elements for **matrix cracks**

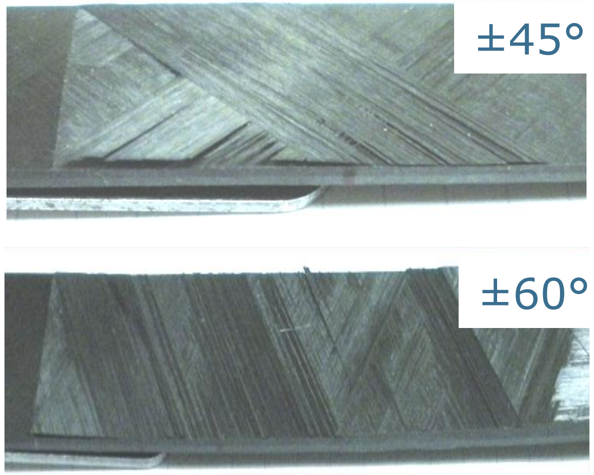
Jiang, Hallett, Green, Wismon. (2007)





Numerical and Experimental Results





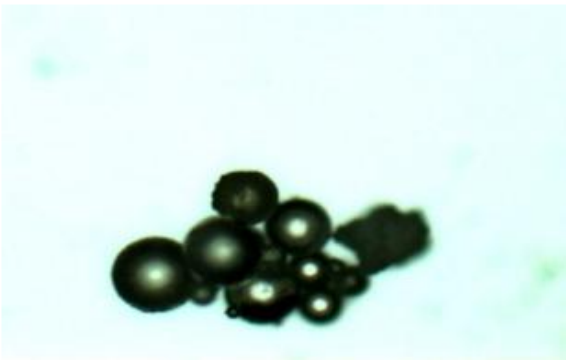
Differential Damage Detection in Composite Materials

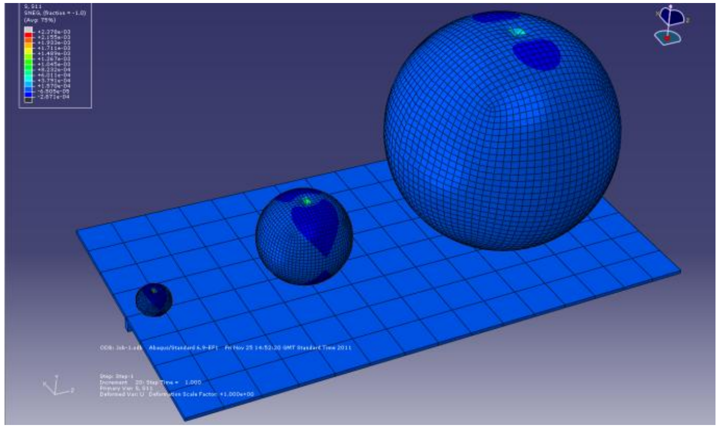
Steven Rae

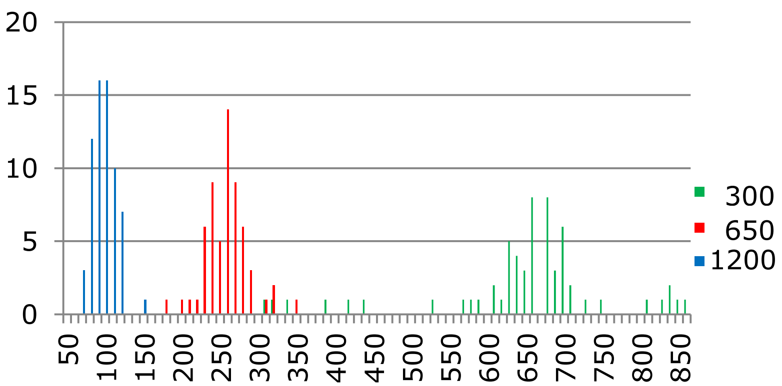
Outline

- Problem
  - BVID – Little surface damage
    - Significant internal damage
  - Detection difficult/time consuming/expensive

- Proposal
  - Microcapsules - varied response to load - pressure required to burst scales with decrease in diameter

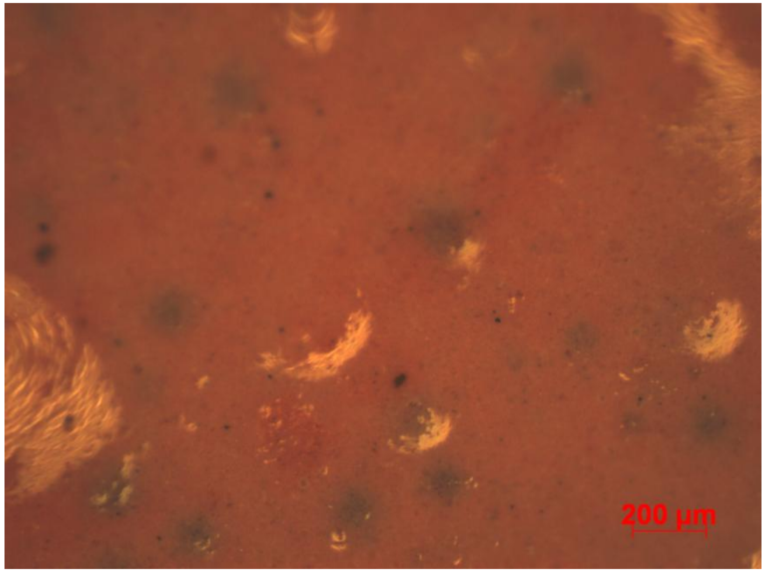


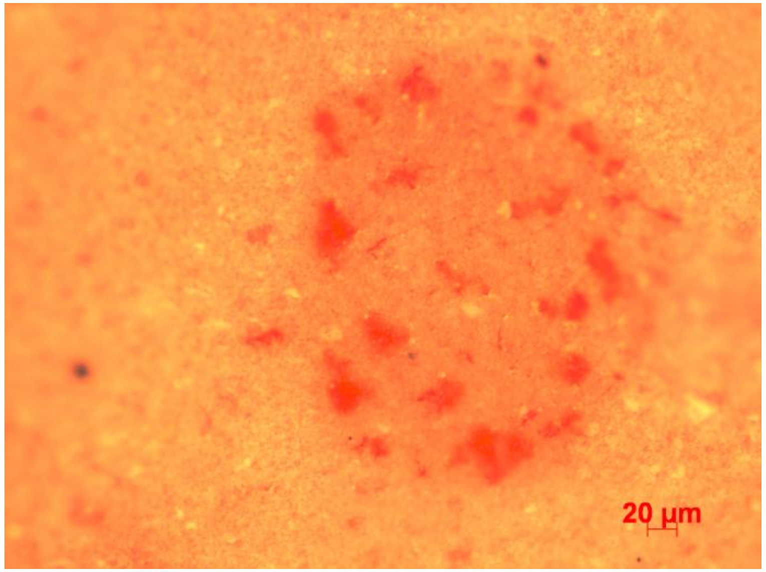




Testing

- Fluorescence
  - Each size range – different fluorescent signature
  - Fluorescence detected – indication of impact severity
- Results
  - Microcapsules embedded into polymer skin
  - Impacted, released dye highlights where impact has occured



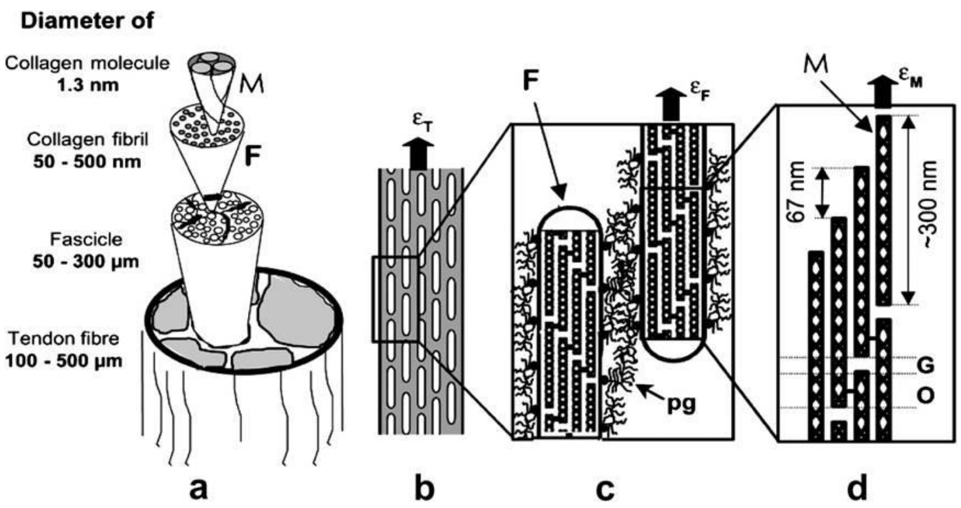


Short Fibre Composites Via Rapid Prototyping Manufacture

Marc Scholz

Theoretical ideas

Fibre architecture



Fratzl / Current Opinion in Colloid and Interface Science 8 (2003) 32–39

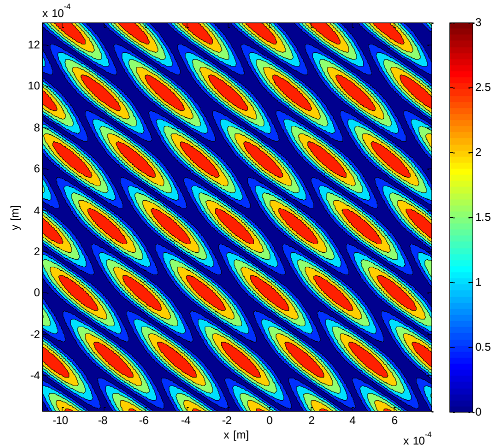
- Hierarchical design features:

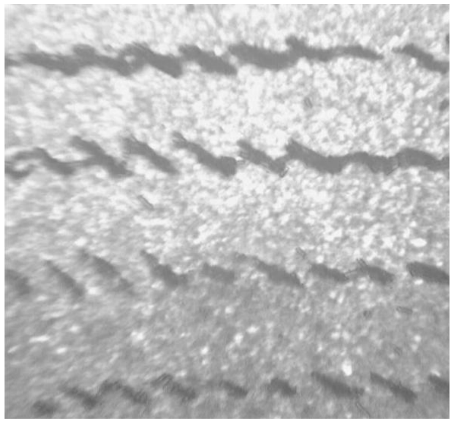
$$\epsilon_{Tendon} > \epsilon_{Fibril} > \epsilon_{Molecule}$$

- Improvements in mechanical performance

Ultrasonic trapping

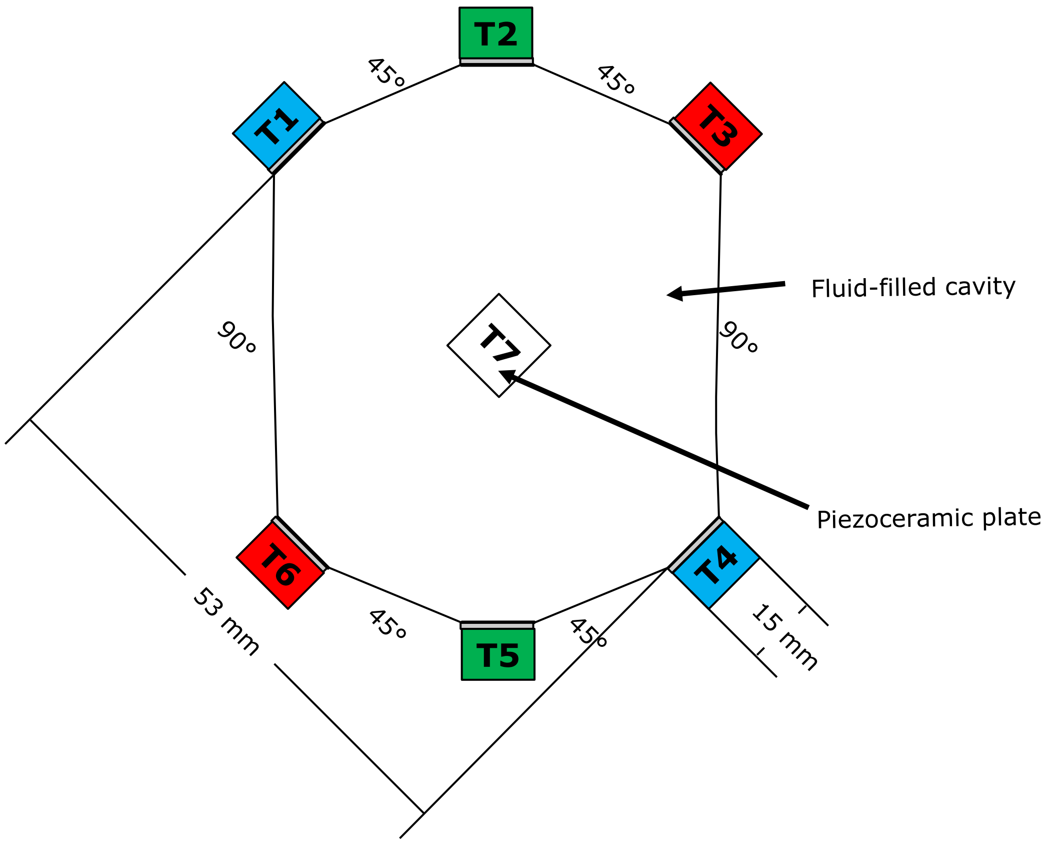
- Traps are formed through ultrasonic standing waves
- Particles accumulate at nodes
- Frequency determines fibre separation
- Patterns form solution to the wave equation





Experimental method

Experimental setup



- Fibres are expected to align along the traps' longitudinal direction

- Self-assembly time depends on viscosity
- Self-assembly capabilities are limited by maximum available trapping force
- Experimental results match theoretical predictions

Composites

Composite samples have already been manufactured on the basis of

- simple fibre architectures
- low viscosity resin systems

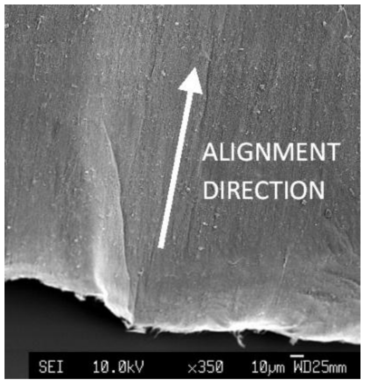
Carbon Nanotube Sheets for Multifunctional Aerospace Composites

James Trevarthen

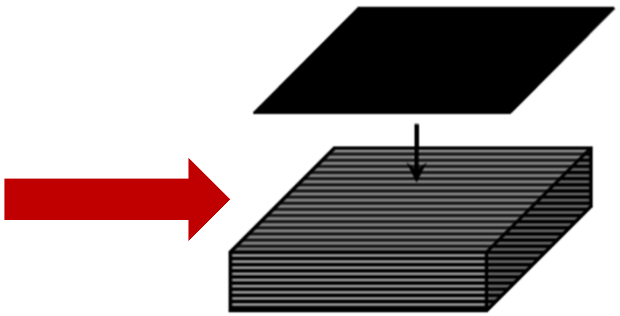
Carbon Nanotube Sheets for Multifunctional Aerospace Composites

1. Aims

- Combine aligned carbon nanotube sheets (CNTS) with composite laminates
- Improve electrical functionality
- Simple, scalable manufacture



SEM of CNTS



Schematic of CNTS coating process

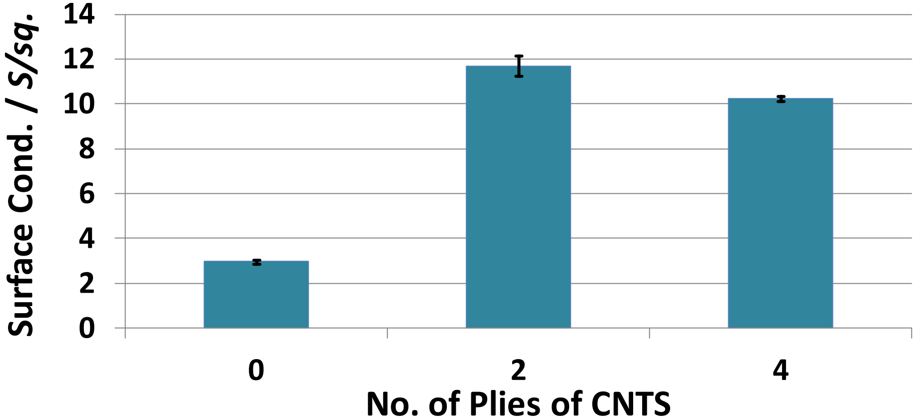
2. Motivation

- CNT: excellent molecular-scale properties
  - Electrical
  - Thermal
  - Mechanical
- Desirable for engineering-scale for aerospace composites
- Progress limited by processing
- CNT sheets and fibres produced at Cambridge
  - Large-scale production
  - Good properties

Carbon Nanotube Sheets for Multifunctional Aerospace Composites

3. Results

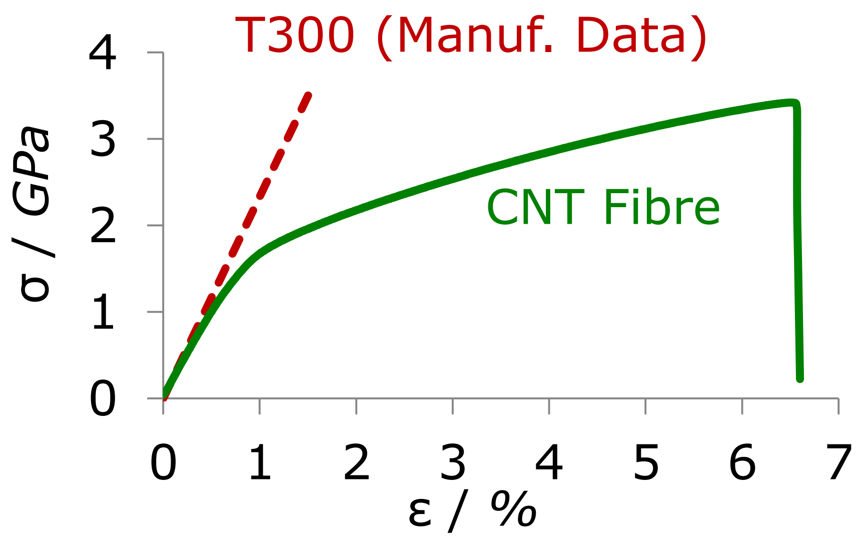
- Surface-coated laminates showed **400% improvement** in surface conductivity
- Charge dissipation, EMI shielding and lightning strike
- Simple, industrial manufacture



Surface conductivity of laminates with varying CNTS coating thicknesses

4. Future Work

- Further explore hybrid composite functionality
- Improve CNT/matrix interface
- Harness ductility of CNT fibres



Stress/Strain Curves of T300 carbon fibre and CNT Fibre

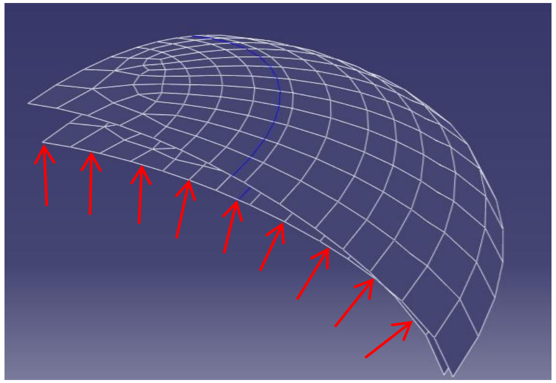
Bend-Free Shells Structures

Simon White

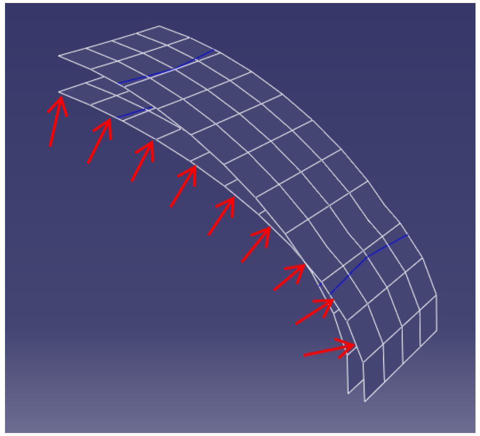
Bend-free shells under internal pressure

S.C. White and P.M. Weaver

Under internal pressure, shells with a variable radius of curvature bend and develop bending moments:



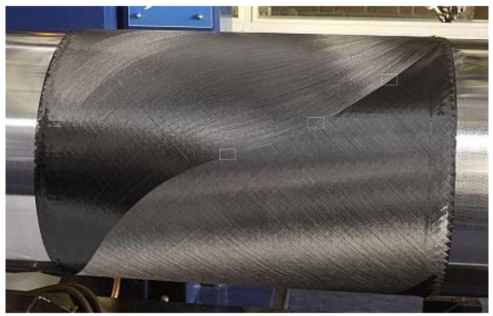
Revolved shell under internal pressure (1/8 model)



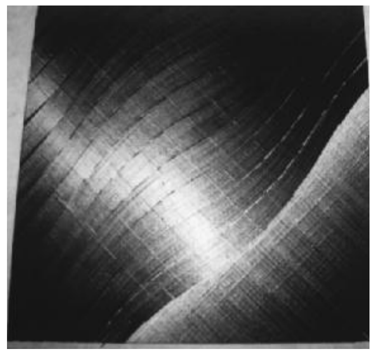
Elliptic cylinder under internal pressure (1/4 model)

Problem:

Is it possible to remove this effect by tailoring the shells properties?



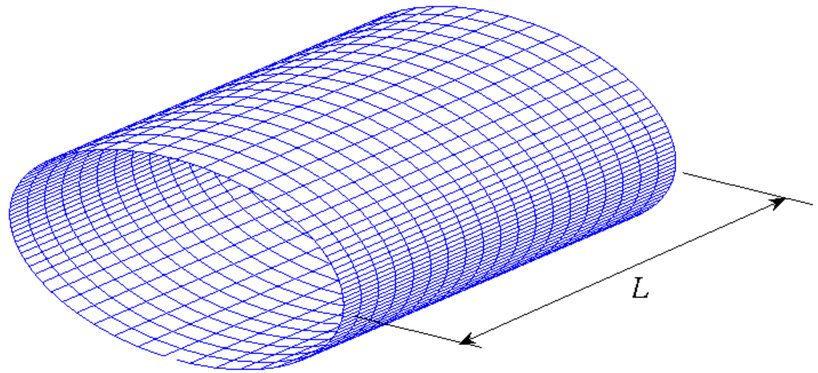
Variable fibre angle cylinder, optimised for bending [Delft]



Variable fibre angle plate, optimised for buckling [Virginia Tech]

Results and Conclusions

• In developable shells, such as the elliptic cylinder, bending moments are not affected by material properties – the problem is **statically determinate.**



• Doubly-curved shells are amenable to the technique.

•The ellipsoid of revolution (spheroid) may be tailored to have no bending moments or bending deformation.