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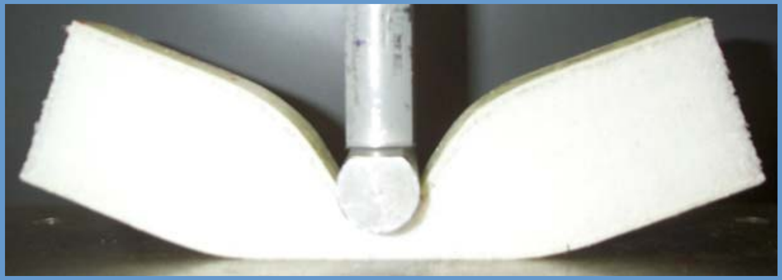
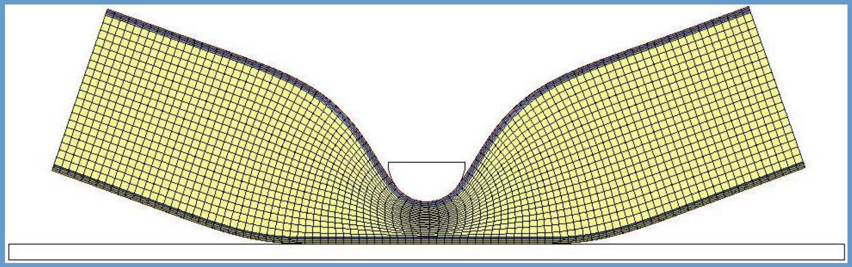
SIMULATING THE IMPACT RESPONSE AND FAILURE IN THERMOPLASTIC COMPOSITE SANDWICH STRUCTURES WITH ANISOTROPIC FOAM CORES





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BSSM
Core Materials and Sandwich Structures
University of Liverpool, 2nd April 2008

Outline

- Introduction
  - Thermoplastic Composites – Automotive Applications
  - Thermoplastic Composite Sandwich Structures
- Objective
- Materials and manufacture
- Composite skin material model
- Polymer foam core model
- TPC sandwich structure
  - Indentation simulation
  - 3-point bending simulation
- Conclusions

“Simulating the Impact Response and Failure in Thermoplastic Composite Sandwich Structures with Anisotropic Foam Cores”

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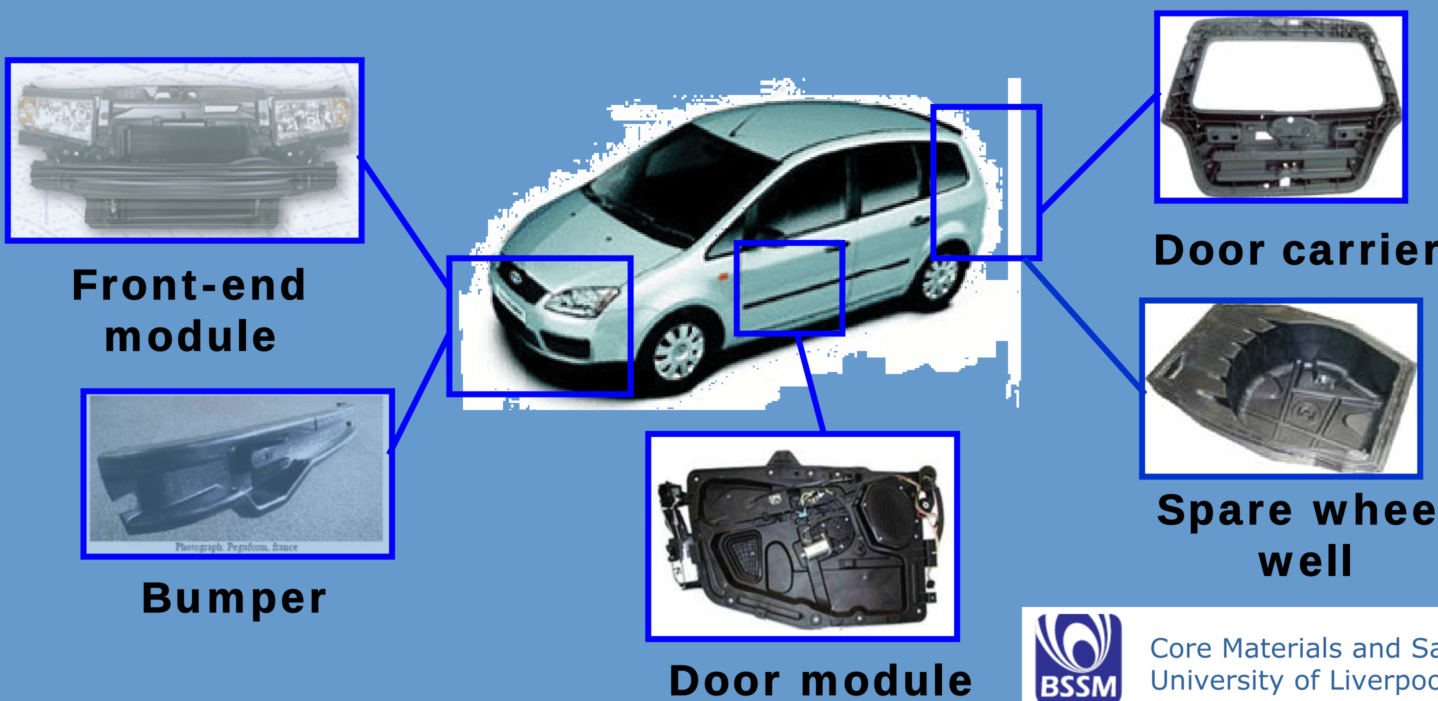
Thermoplastic Composites (TPCs) - Automotive Applications

Vehicles of the future must be lighter, eco-friendly, SAFER

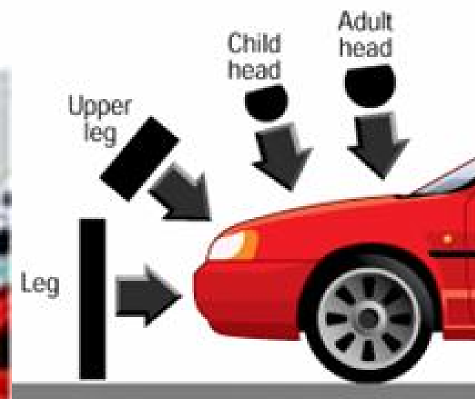
- There is now an increased interest in thermoplastic composites for vehicle bumper and frontal structures for improved crashworthiness and pedestrian protection
- The use of these materials in the automotive industry has remained limited due in part to the lack of design capability regarding their crash response



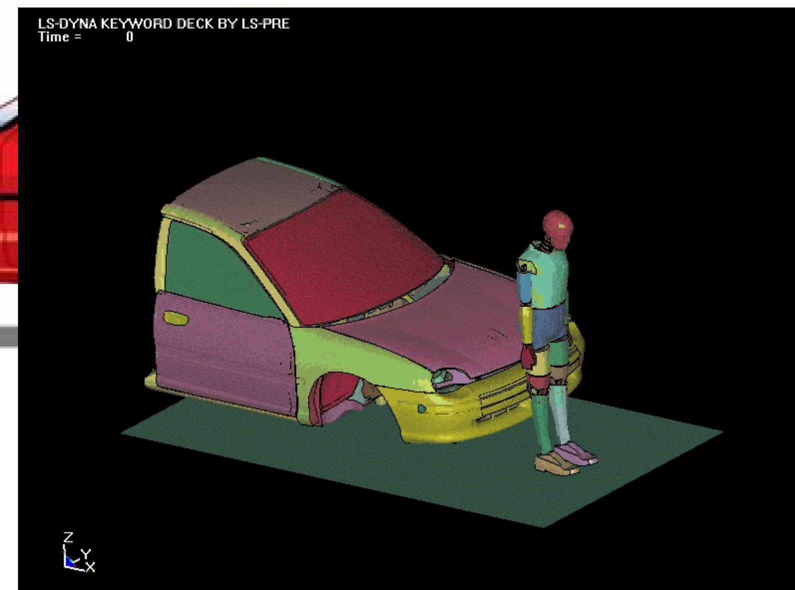
TPC Sandwich Structures for Pedestrian Protection ?

- Automotive manufacturers are faced with more stringent pedestrian safety legislation introduced by the European Commission (EC)

Testing with dummies

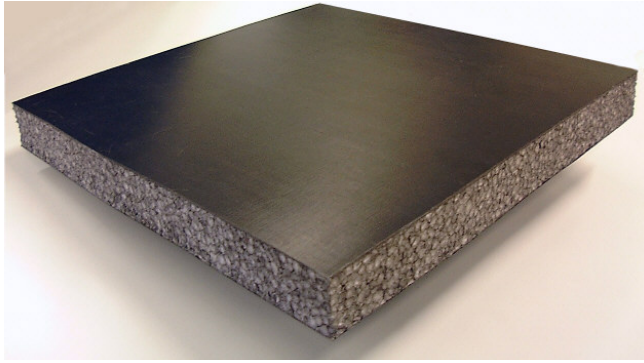


Impactor Testing



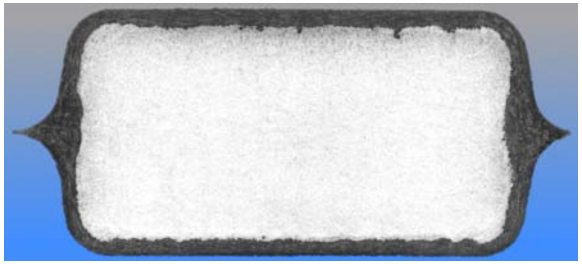
Finite Element analysis of pedestrian impact

Thermoplastic Composite (TPC) Sandwich Structures



Plytron® - PP Zote foam

Twintex® – Syntactic PP Foam Rail Bracket



GMT – EPP Foam Bumper

- **Volume manufacture**
- **Recyclability**
- **Impact resistance**
- **Durability**

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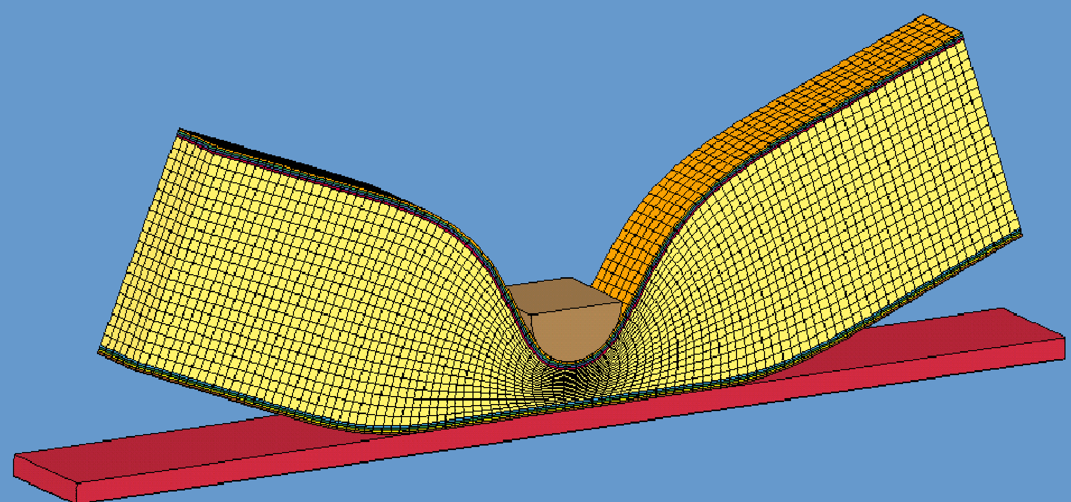
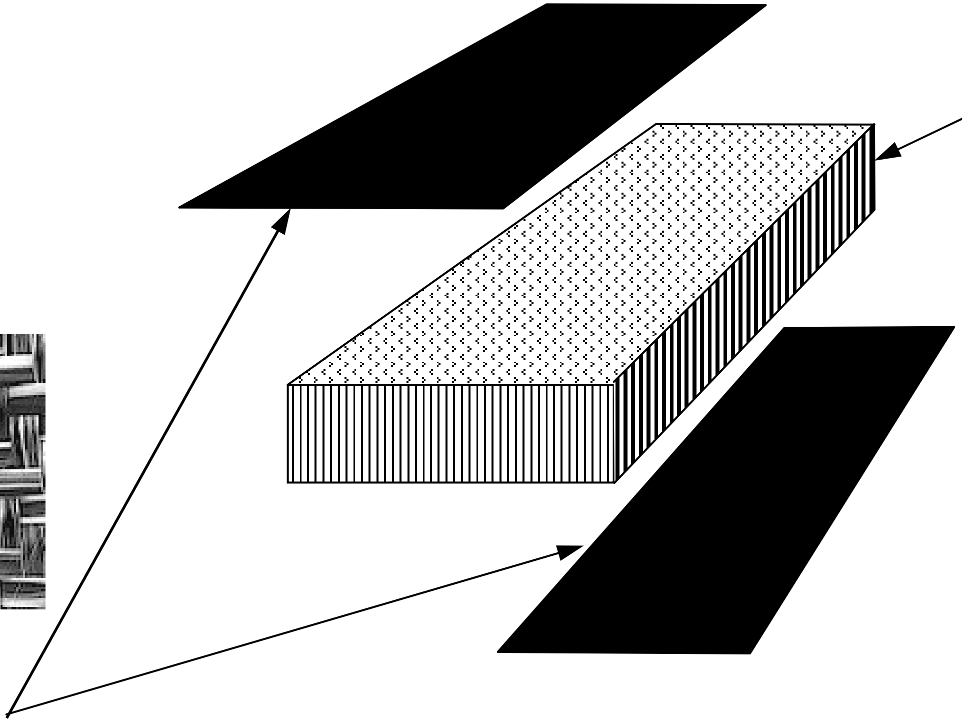
Objective

- To develop a predictive computational modelling capability for predicting the elastic and failure response of thermoplastic composites sandwich structures under impact/crash conditions



Materials and Sandwich Geometry

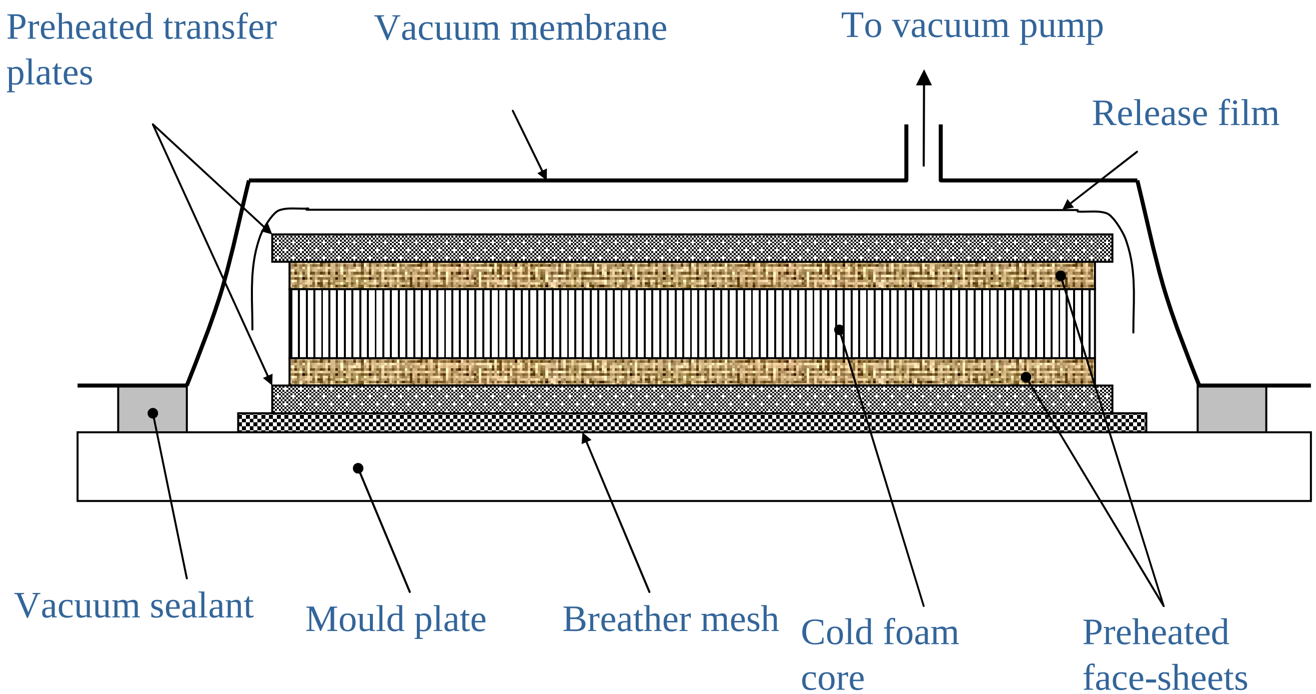


CORE
Strandfoam® 64 PP
(25 mm thick)

Plaque Dimensions
800 mm x70 mm
projected area

SKINS
Twintex 2:2, 0-90, balanced weave
Glass/PP commingled fabric
(1 to 3 mm thick)

Non-isothermal Vacuum Moulding



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Non-isothermal Vacuum Moulding

Heated Stack

Vacuum Applied

Moulding Complete

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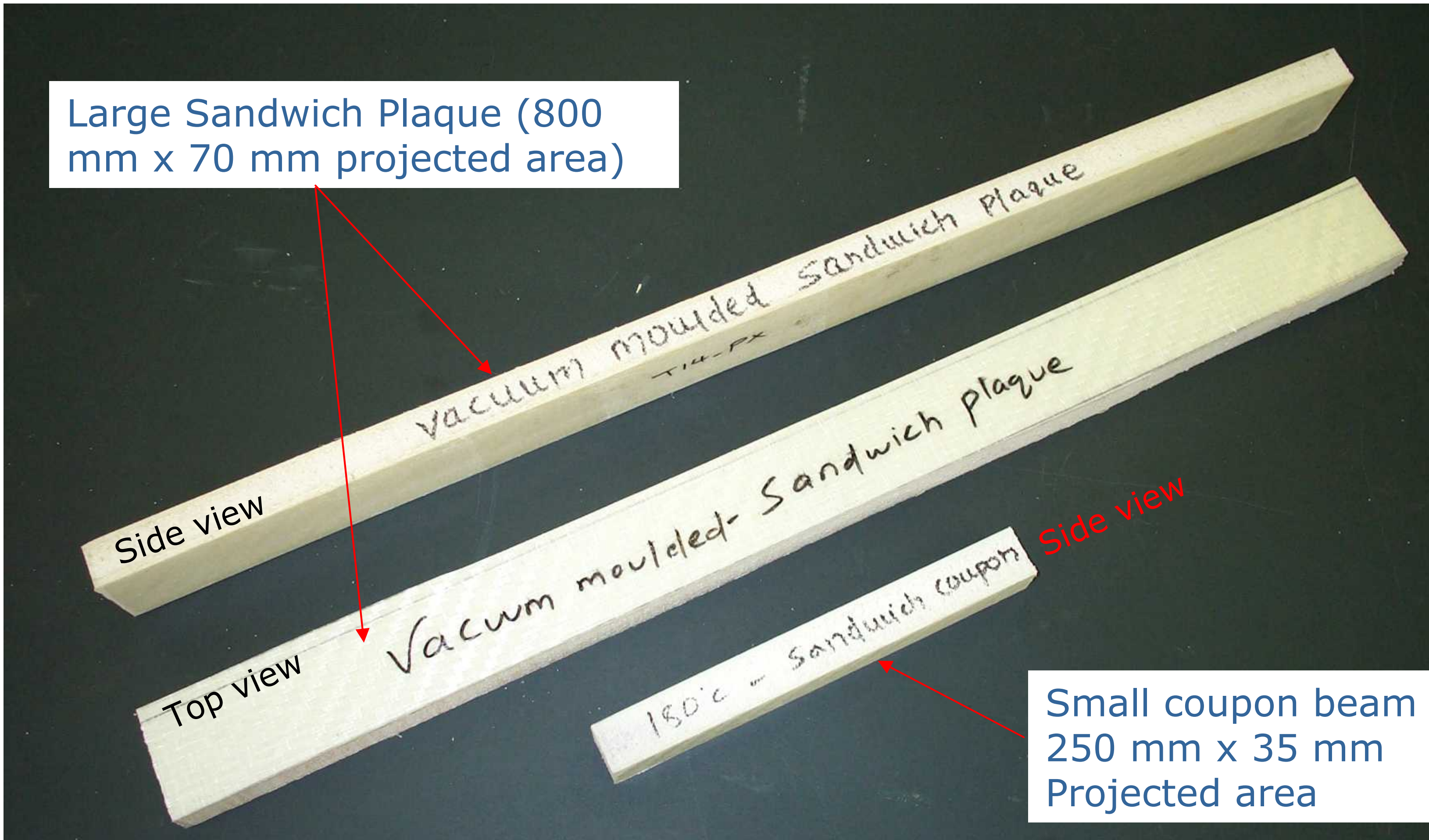
Moulded Beams



"Simulating the Impact Response and Failure in Thermoplastic Composite Sandwich Structures with Anisotropic Foam Cores"
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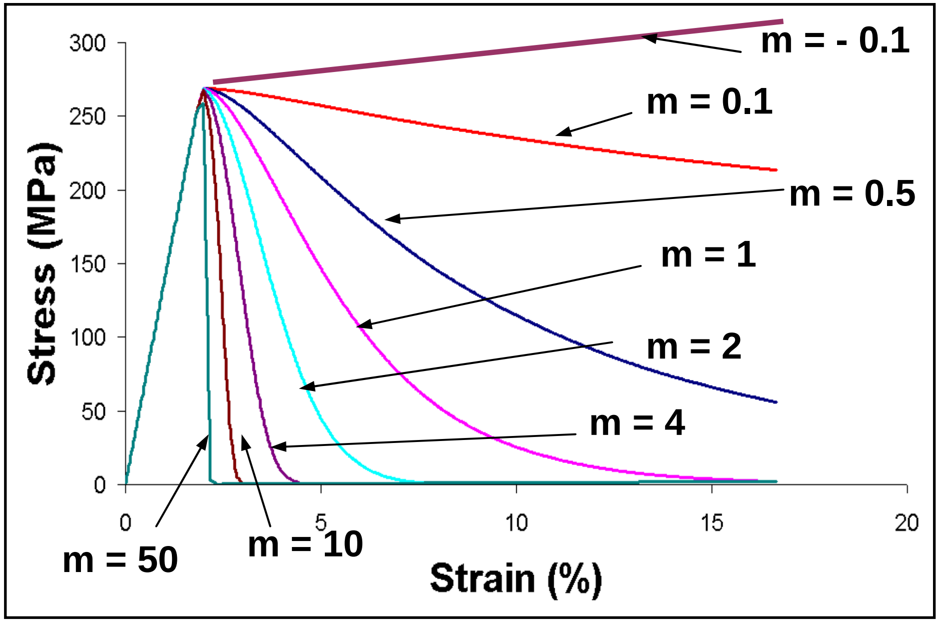
Composite Skin Material Model

- The advanced **LS-DYNA® MAT 162** composite material model is used to model the thermoplastic composite skin.
- MAT 162 is based on continuum damage mechanics – 3D elements
- Orthotropic elastic stiffness and strength properties
- Failure criteria (damage initiation) based on different failure mechanisms e.g. in-plane fibre damage, fibre crush damage, matrix and delamination damage
- A set of damage variables, $\mathbf{m_i}$ model the post-elastic damage progression
- Element elimination
- Strain rate variables for scaling elastic and strength properties



$$E_i' = (1-\omega_i)E_i$$

$$\omega_i = 1 - \exp\left(\frac{-r_i^{m_i}}{m_i}\right),$$

$$r_i \geq 0 \quad i = 1,\ldots,4$$

<u>Damage Variables</u>
m1 – fibre (x-direction)
m2 – fibre (y-direction)
m3 – fibre crush/shear
m4 – matrix and delamination

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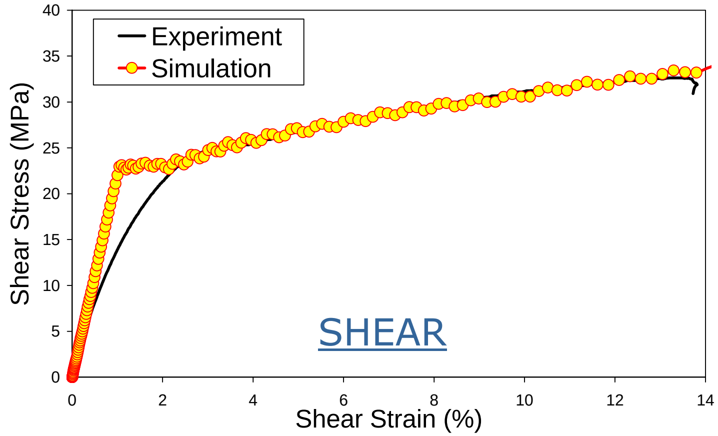
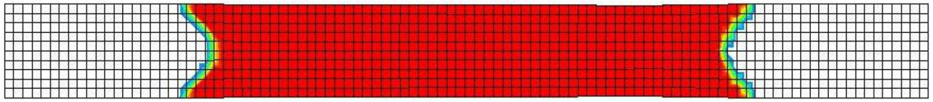
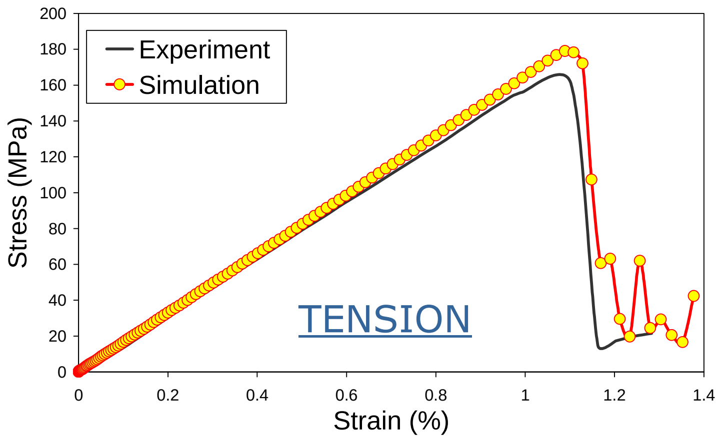
Composite Skin - Quasi-static Material Calibration

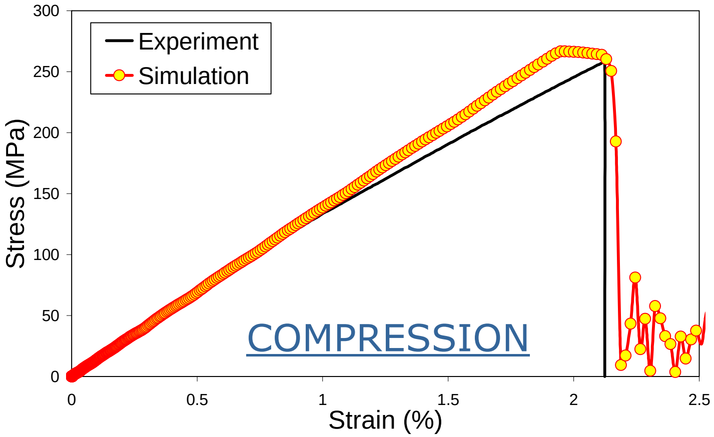


Post test shear specimen



Predicted matrix damage





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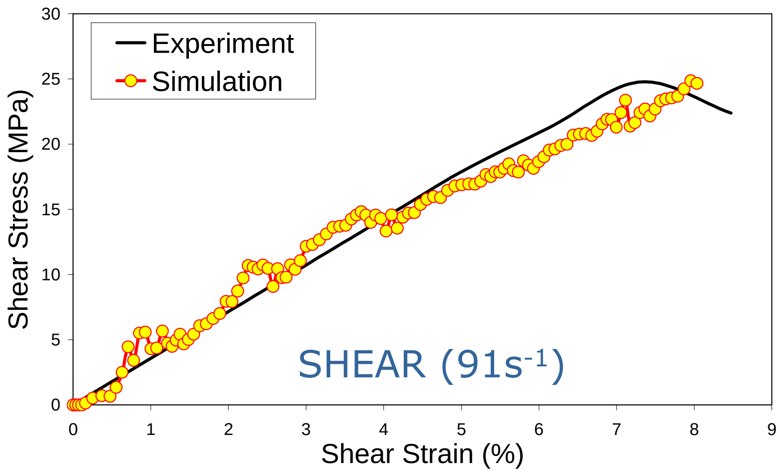
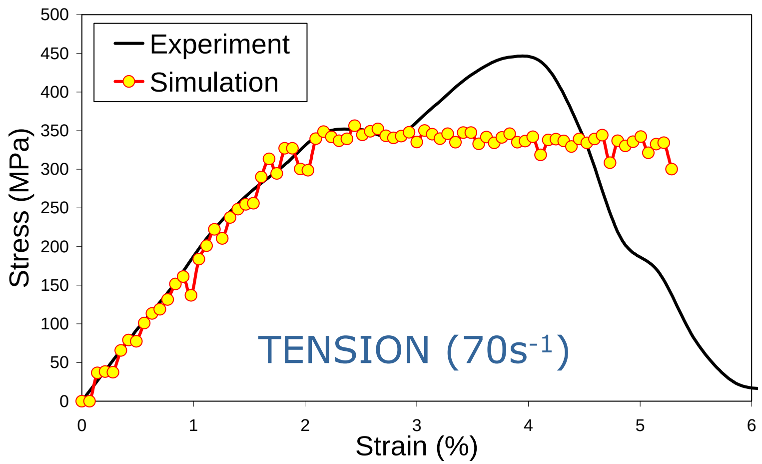
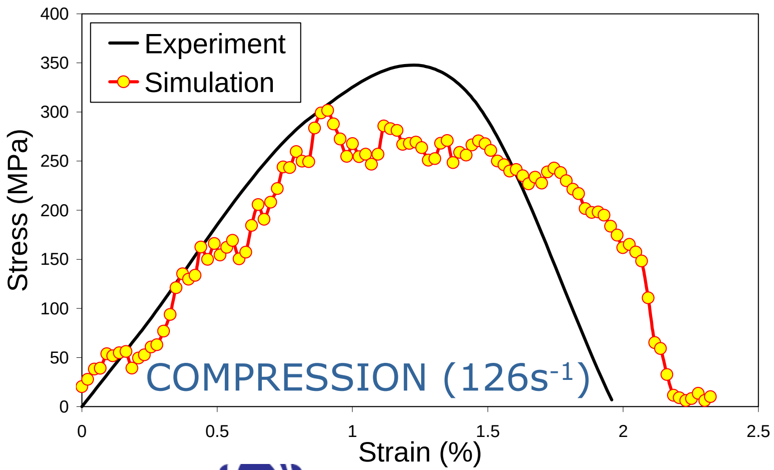
Composite Skin - Dynamic Material Calibration



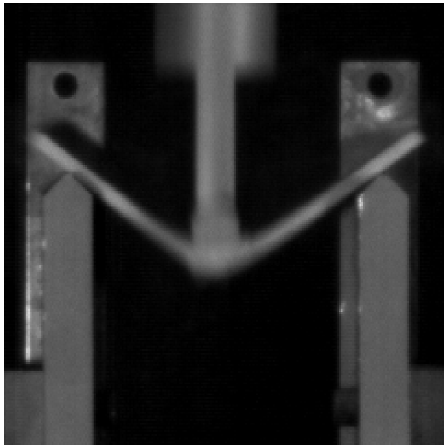
- Instrumented Falling Weight impact tests
- Specially constructed tension/ shear and compression jigs

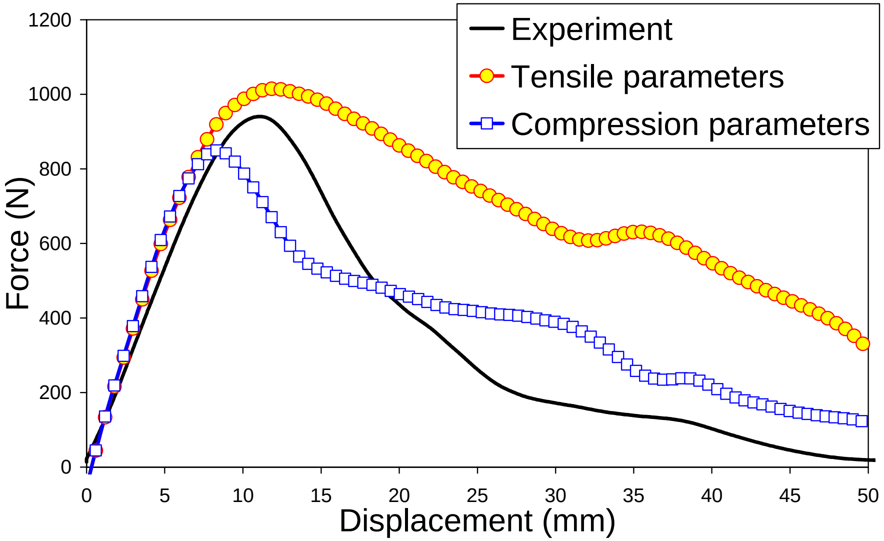


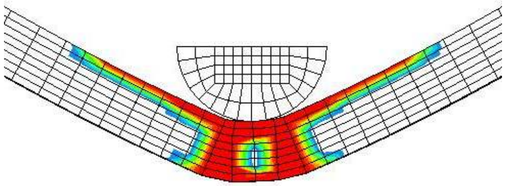


Composite Skin – 3-Point Bending Validation (Dynamic)

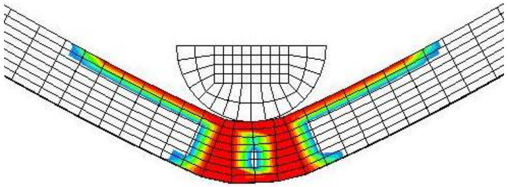
- Dynamic impact
- 163 Joules, 5 m/s
- 80 mm span, 4 mm thick
- 10 mm diameter cylindrical impactor



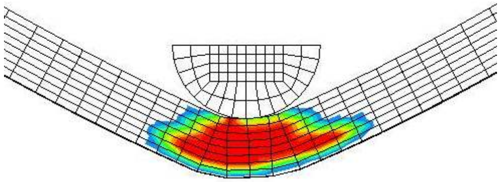




Matrix damage

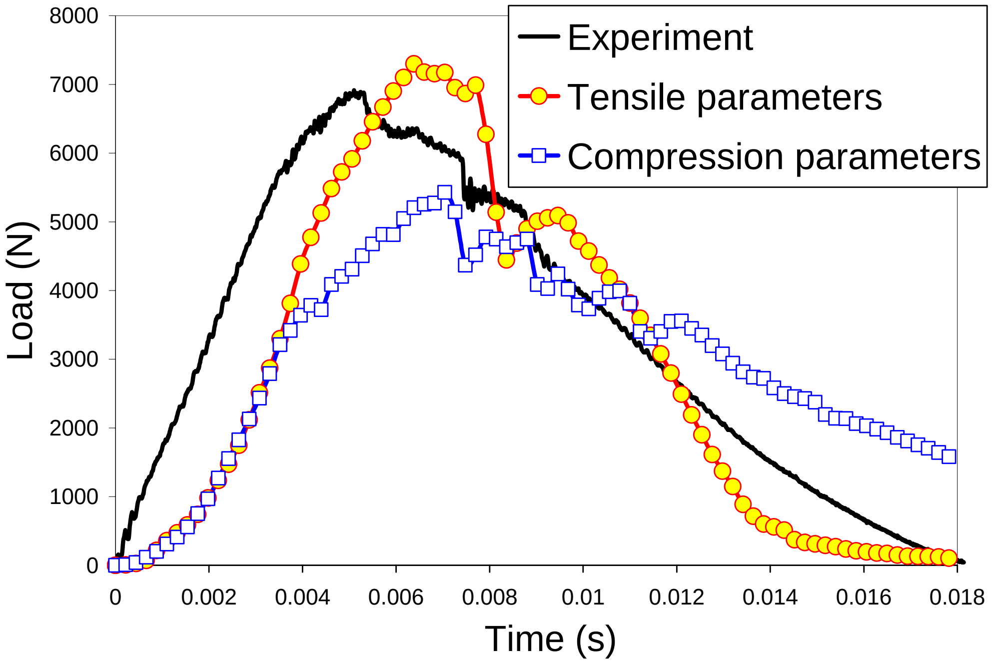


Fibre damage

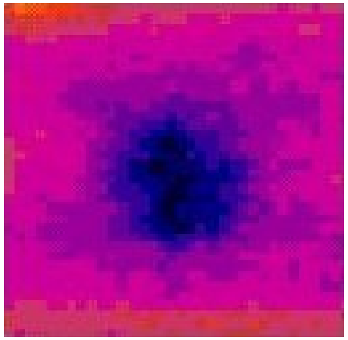


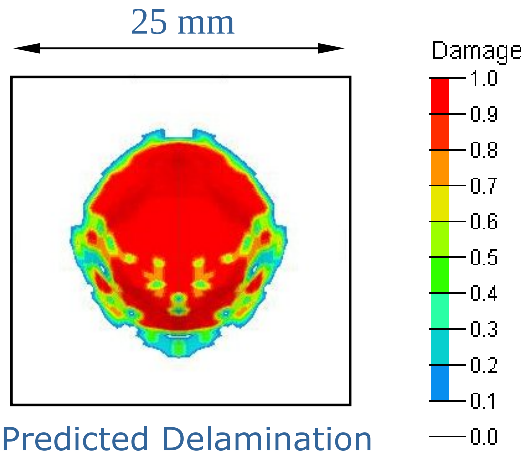
Delamination

Composite Skin – Penetrating Dart Validation (Dynamic)



Experimental Thermograph





Predicted Delamination

- 35J Falling dart impact
- 40 mm diameter Twintex® Plate, 4 mm thick
- 12.7 mm diameter hemispherical impactor

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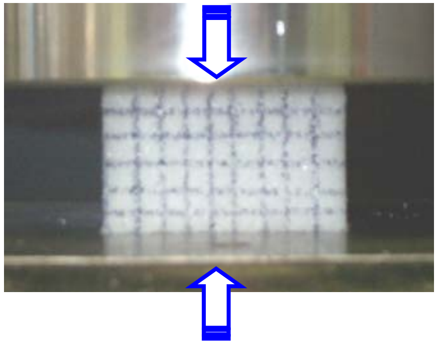
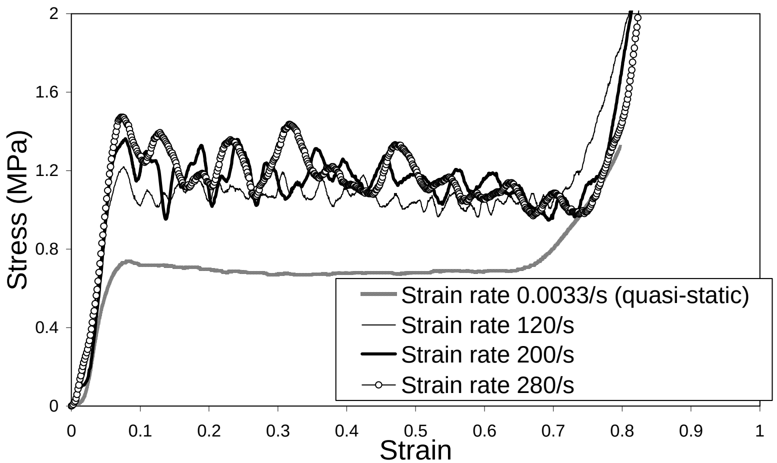
Foam Core Material Model

- The **LS-DYNA® MAT 142** transversely isotropic material model is used for the core
- Elastic-plastic response
- ‘Tsai-Wu’ failure criterion to define yield surface
- ‘Maximum principal strain’ brittle failure criterion $\varepsilon_1 > \varepsilon_p$ (bending only)
- Element elimination

Materials Characterisation (Compression)





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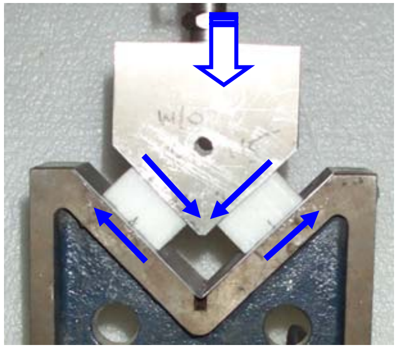
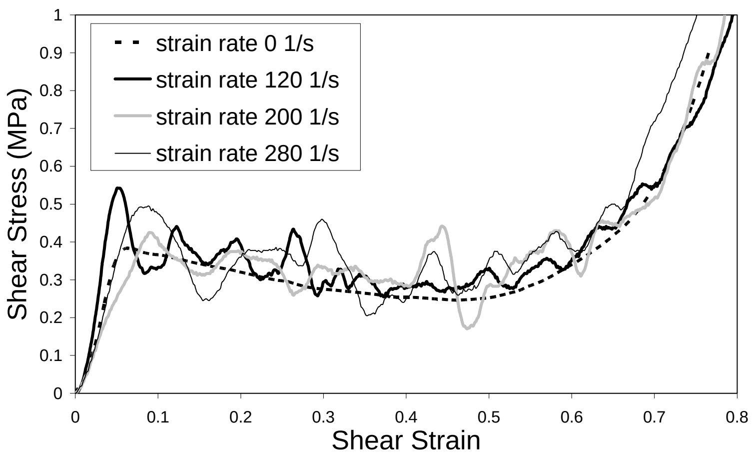
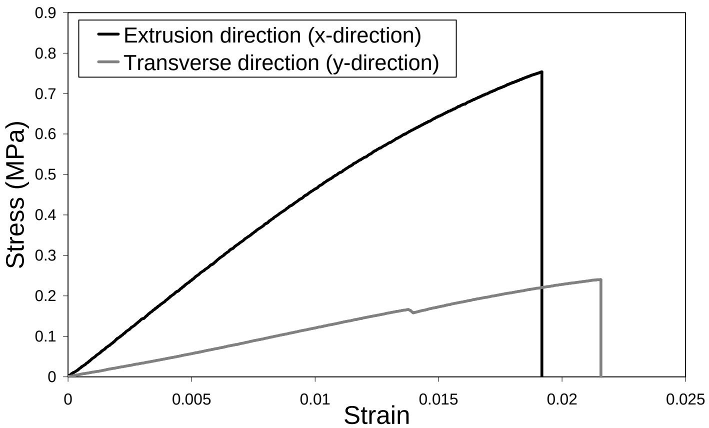
Foam Core Materials Model

Materials Characterisation (Shear)

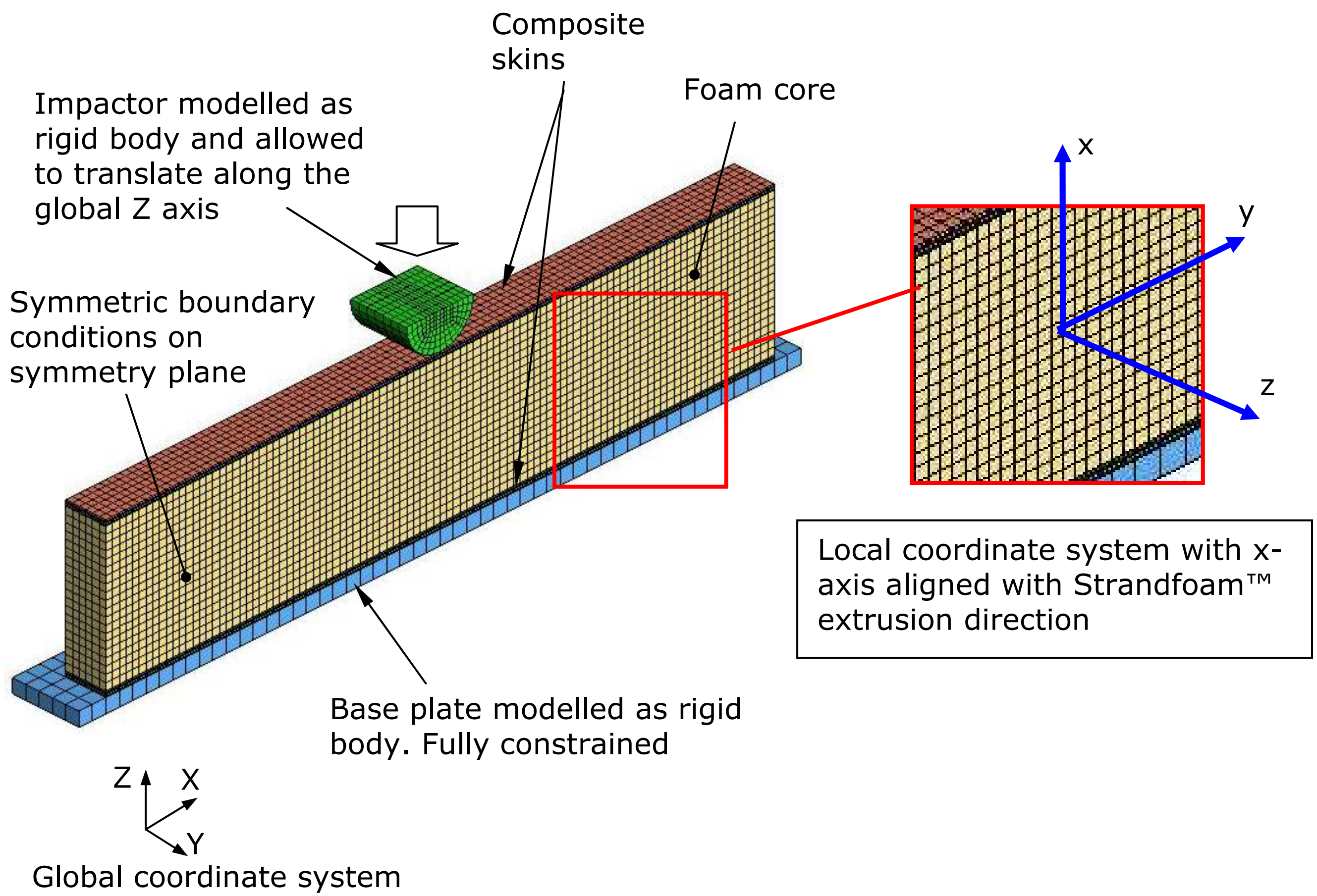




Materials Characterisation (Tension)



TPC Sandwich Structure – Indentation Model



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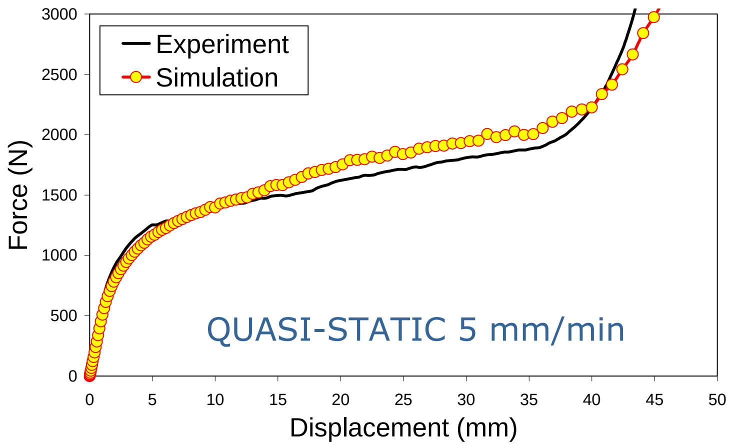
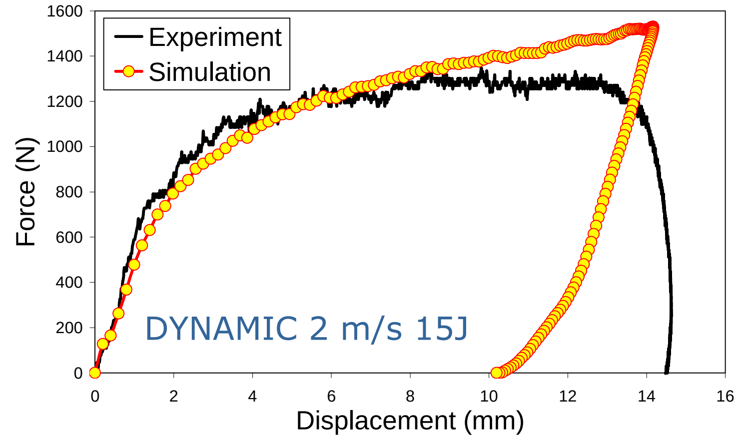
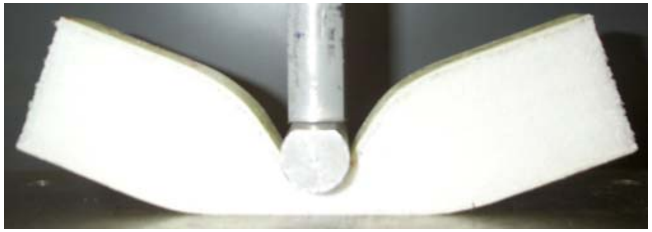
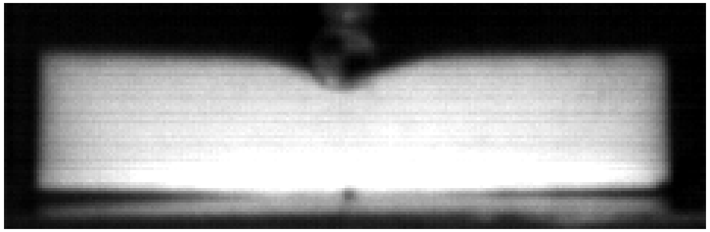
Indentation Results

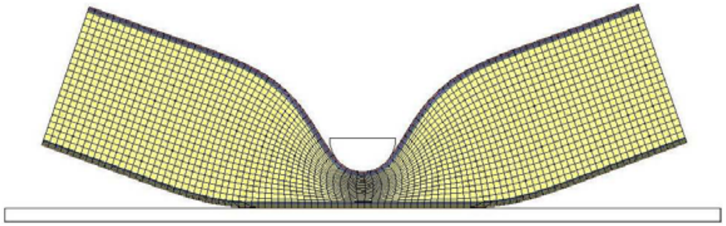


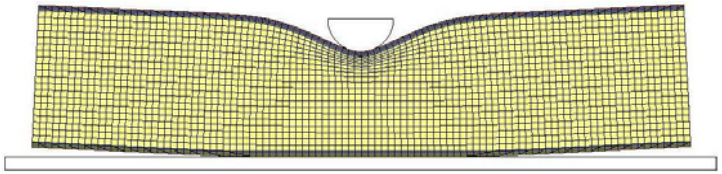




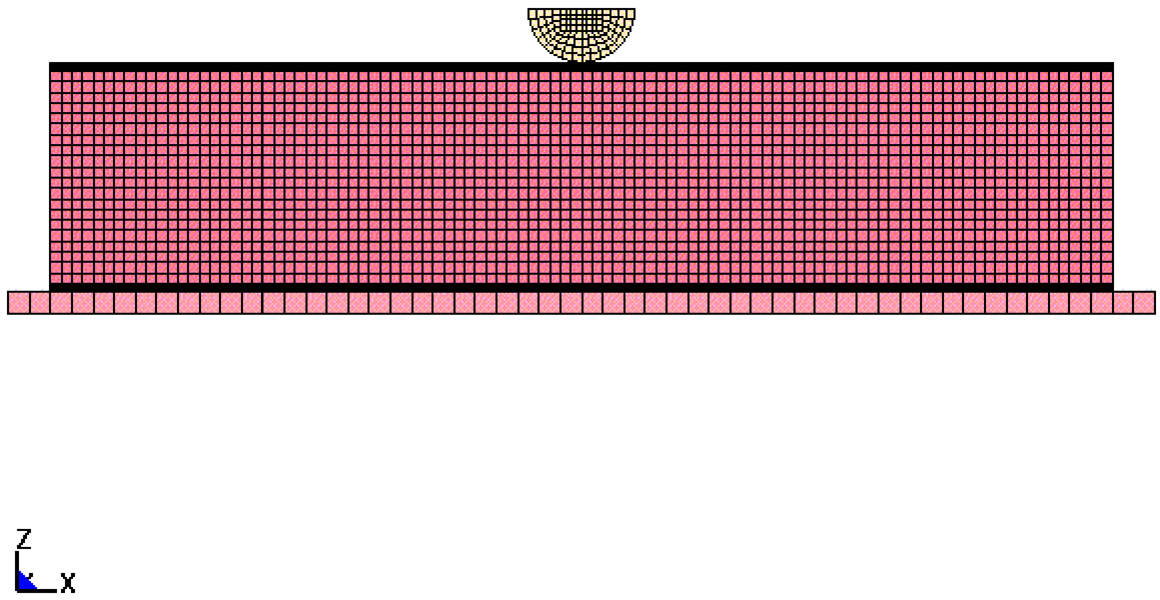
2 mm skins
50 mm core



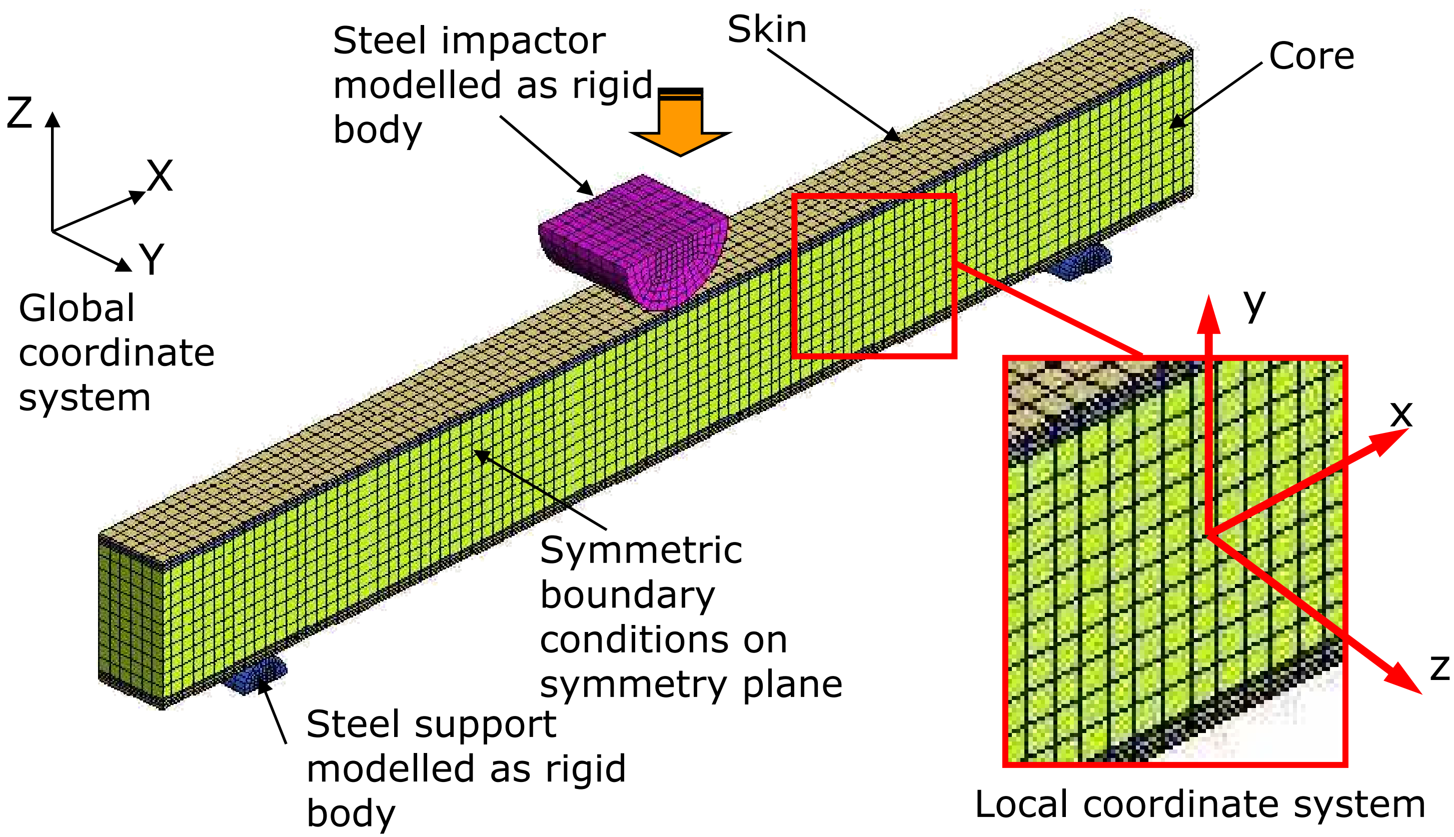




Quasi-static Indentation



TPC Sandwich Structure – 3-Pt Bending Model



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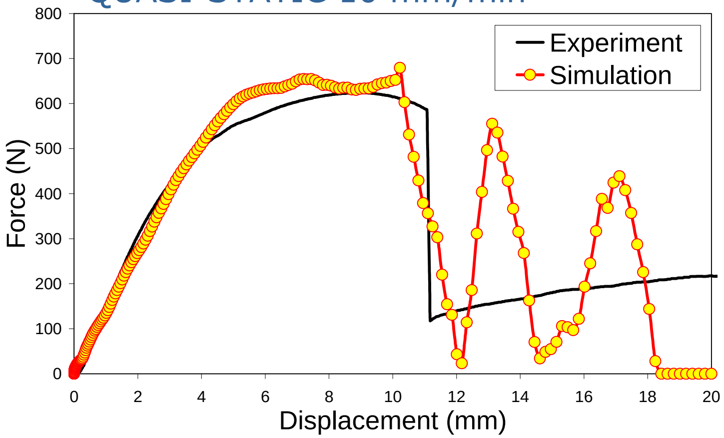
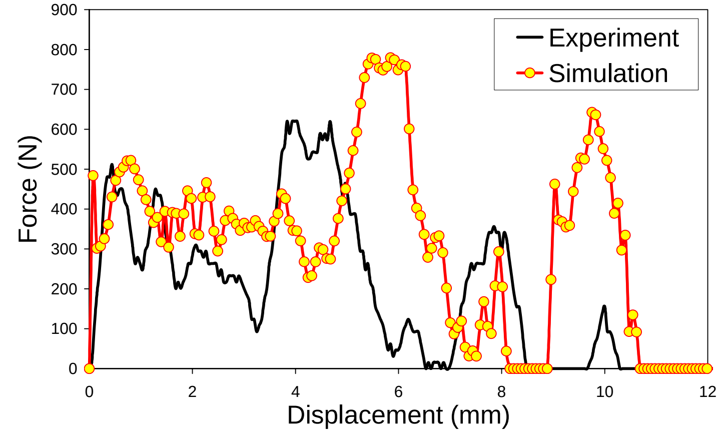
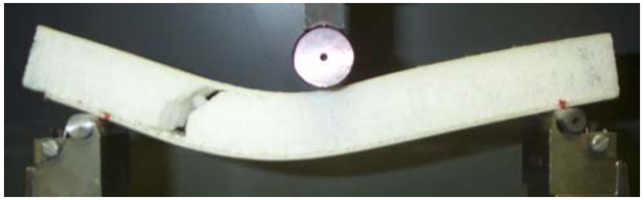
3-Point Bending Results

QUASI-STATIC 10 mm/min

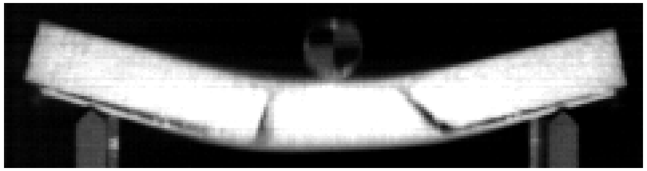


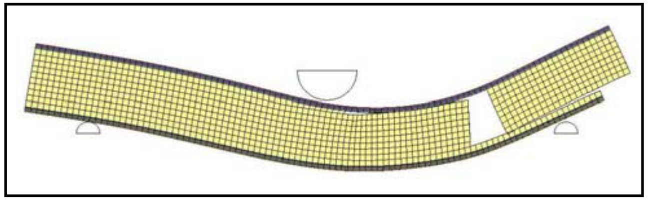
DYNAMIC 5 m/s 100 J

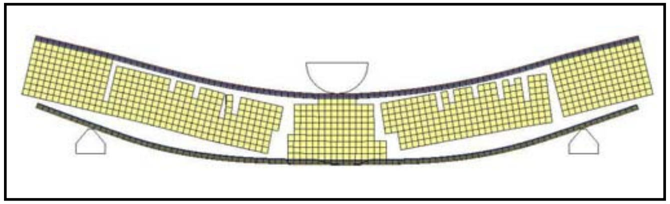




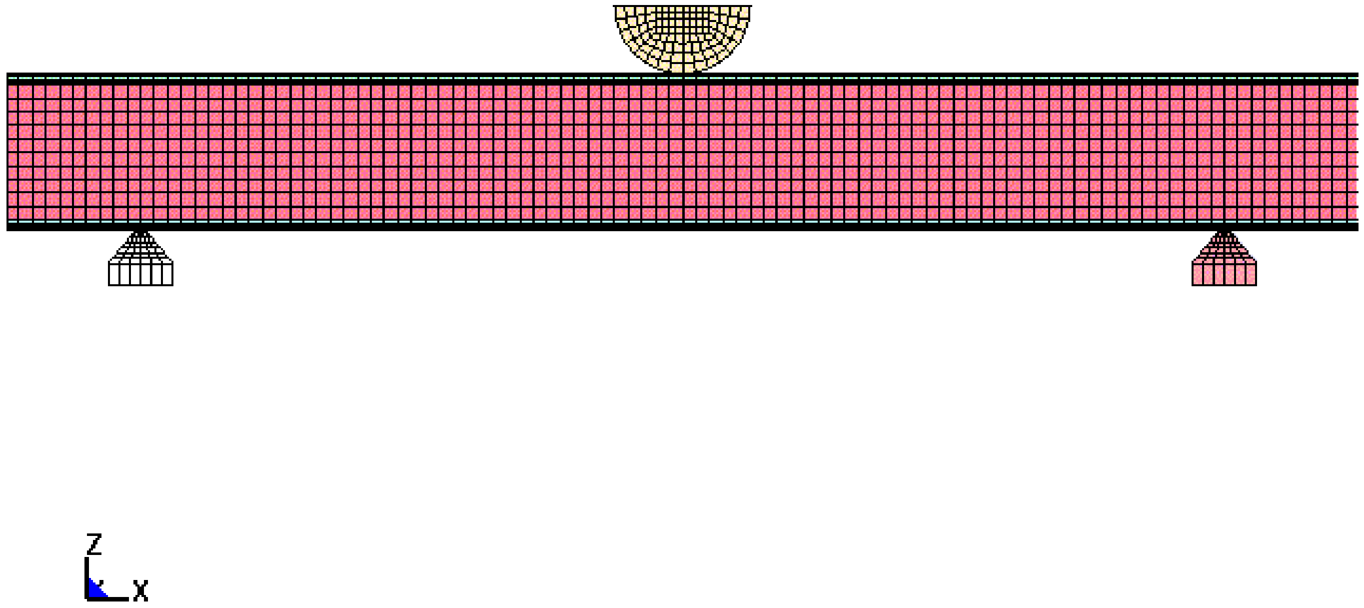
2 mm skins
25 mm core
200 mm span







Dynamic 3-Point Bending



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Conclusions

- TPC sandwich structures can be manufactured cost effectively by a non-isothermal vacuum moulding process
- LS-Dyna MAT 162, composite elastic damage model, can simulate elastic response and damage progression in TPCs under impact loading with good accuracy
- LS-Dyna MAT 142, anisotropic foam model, has been shown to give reasonable predictions of the impact response and failure of a TP foam core under different modes of loading
- Both models require extensive materials characterisation tests and data validation procedures
- The impact response and failure of TPC sandwich structures under indentation and 3-point bending loads has been well predicted using a combination of the above models
- Further work needs to be done on modelling the fracture behaviour of foam cores under impact loading

Acknowledgements

Colleagues Kevin Brown and Nick Warrior

Owens Corning OCV Reinforcements

Dow

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EPSRC Engineering and Physical Sciences Research Council