Launch meeting

Oxford Solid Mechanics at the Mathematical Institute

A hierarchical approach to the modelling of 3D composites

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Objective: **characterisation** and **prediction** of the impact response of materials

- **Real life**
- **Experiment**
- **Simulation**
Background & Motivation

Goal: weight reduction of fan system

Use of composite material for fan blade

- Offers direct reduction of fan blade weight
- Increased fatigue life
- Indirect reduction of containment weight

source: Rolls-Royce
Background & Motivation

- Earliest tests of composites as a substitute for metals during the 70s
- Use of UD composite laminates
- High in plane stiffness and strength, but very low delamination resistance

Increased delamination resistance of composite core is required

3D reinforced composites
Background & Motivation: 3D reinforced Composites

Z-Pinning

Tufting

3-D weaving

- surface-warp-weaver
- body-warp-weaver
- layer-to-layer angle interlock
- through the thickness angle interlock
- orthogonal interlock
- 5-D-weaving

stuffer (straight warp)  filler (weft)  binder

Source: TUD Dresden
Background & Motivation: Strategy

Hierarchical modelling strategy based on the constitutive response of the matrix material and the fibre

Carbon fibre strain rate independent, resin matrix dominates rate dependency, nonlinearity, failure and damage

resin matrix forms basis for modelling strategy

How well can we predict the material response only based on information about: resin, fibre and architecture

???
Contents

- Resin-system (RTM-6)
  - Experimental investigations
  - Constitutive model

- Yarn-system (CFRP)
  - Constitutive model

- Interface (Yarn Matrix)
  - Experimental investigations

- 3D weave (TTAIL)
  - Experimental investigations

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**Virtual experiments on Meso scale**

**Global, rate dependent response**
Characterisation of the resin RTM-6

Experiments & Constitutive modelling

![Graph showing stress-strain curves for compression and tension with various strain rates.]
Contents

Resin-system (RTM-6)  
Experimental investigations

Yarn-system (CFRP)  
Constitutive model

Interface (Yarn Matrix)  
Experimental investigations

3D weave (TTAIL)  
Experimental investigations

constituents

composite

σ

Univ of Oxford

Impact Engineering Team  Solid Mechanics and Materials Engineering Group  Department of Engineering Science
Constitutive modelling of CFRP

- At Micro scale, yarns consist of matrix and fibres
- Material model for matrix in place
- Desirable to link of matrix and yarn response

Need to adopt hierarchical strategy linking meso scale and micro scale
Model developed by ABOUDI [2] using the method of cells
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The yarn matrix-pocket interface

- Still unclear how the interface between matrix pockets and yarns should be modelled (contact/perfect bonding)
- Experimental investigation at quasi static and high loading rates
- Results show both interface and intra-yarn failure, at the same stress level

Conclusion: perfect bonding between yarn matrix interface can be used for reasonable fine mesh
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- Virtual experiments on Meso scale
- Global, rate dependent response
Virtual modelling of 3D weaving unit cells

- matrix (RTM-6)
- warp stuffer (x direction)
- weft stuffer (y direction)
- binder (x & z direction)

3 mm

Surface

3% binder micrograph

3% binder geometric volume model

50 μm

6% binder micrograph

6% binder geometric volume model

binder curvature low, half thickness of weft

binder curvature high, thickness of weft

3% binder fills 1/2 of pocket

binder fills matrix pocket

6%
Virtual modelling of 3D weaving unit cells

- Use of single integration point hexahedral elements only
- Focus on regularly sized elements (mapped meshing)
Compression on z direction

- Experimental investigation at QS and HR
- Accurate prediction of stiffness, and rate dependency and damage formation
Intralaminar shear (xy)

- Standard test for model validation, for 6% version
- Highly nonlinear
- Simulations with failure switched of accurately predict nonlinearity and rate dependency
Interlaminar shear

Warp direction (xz shear)

- Simulation captures damage phenomenon well
- Significant difference in energy absorption between RVEs
Conclusions

• Several contributions in a number of areas of 3D composite research have been made
  • Novel pulse shaping techniques enabled characterisation of RTM-6 resin in tension at high strain rates.
  • A constitutive model for RTM-6 has been improved, including a physically based damage model.
  • The resin model has been combined with the GMC, and a computationally efficient failure and damage model has been developed for the yarns.
  • The interface between yarns and matrix pockets has been characterised, and a justification for a perfect bonding modelling strategy has been observed.
  • Two 3D weaves have been experimentally characterised using several novel experimental techniques.

• Resulting virtual RVE models show good predictive capabilities in terms of elastic properties, plasticity, rate dependency and damage evolution.

Potential to **substitute** a large number of experiments with numerical simulations

These simulations can **inform** homogenised modelling strategy
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Unit-Cell (RVE)
Virtual experiments on Meso scale
Global, rate dependent response

ENGINEERING APPLICATION ???
Plate bending: Modelling

- Simple homogenised constitutive model
- Captures deflection-time history and damage growth well