Modelling and Optimisation of a Multiaxial Fabric

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Outline

- Our goal
- The role of the converter
- Optimisation of multiaxial fabrics through physical testing
- Capabilities of PAMFORM simulation
  - Modelling a Multiaxial
  - Simulating forming processes
  - Extraction of useful results
- Case Studies
  - Effects of Stitch Direction
  - Optimisation of Shear Modulus
- Next steps
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Our goal
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Composite engineers..

- Calculate design loads
- Use knowledge of fibre properties
- Use knowledge of composite properties
- Specify a fibre and resin type
- Specify a fabric weight
- Specify a number of layers
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Composite builders..
  Select fabric type/construction
  Work around process problems
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  Use knowledge of composite properties
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  Specify a fabric weight & construction
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Composite builders..
  Help to Select fabric type/construction
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About FORMAX

- Producer of multiaxial and woven reinforcements for composites
- Founded 1998
- Independently owned
- Located in Leicestershire, UK
- 128 full time employees
- 14 lines producing over 8000 tons of glass fabrics, 700 tons of carbon, plus other fabrics using aramid, natural and thermoplastic fibres.
- Turnover 2012: £23.5m
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The role of the converter

PRE-PROCESSING: FIBRES SIZING

POST-PROCESSING: COMPOSITES MANUFACTURE
The role of the converter

**PRE-PROCESSING:** Fibres Sizing

**POST-PROCESSING:** Composites Manufacture

Introduce Processability
The role of the converter

- Group 100’s of tows to allow economic production…
The role of the converter

- Group 100’s of tows to allow economic production…

..and introduce a fabric structure…

INTRODUCE PROCESSABILITY
The role of the converter

- Group 100’s of tows to allow economic production...

..and introduce a fabric structure...

The structure allows us to...

- 
- 
- 

INTRODUCE PROCESSABILITY
The role of the converter

- Group 100’s of tows to allow economic production...

...and introduce a fabric structure...

The structure allows us to...
- Control fabric stability

INTRODUCE PROCESSABILITY
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- Group 100’s of tows to allow economic production...

..and introduce a fabric structure...

The structure allows us to...
- Control fabric stability
- Control fabric drape
The role of the converter

- Group 100’s of tows to allow economic production...

The structure allows us to...
- Control fabric stability
- Control fabric drape
- Control fabric permeability

..and introduce a fabric structure...

INTRODUCE PROCESSABILITY
The role of the converter

FIBRE PROPERTIES

COMPOSITE PROPERTIES

MAXIMISE PERFORMANCE
FORMAX R&D Laboratory

- Established January 2011
- Employs 2 people and 2 interns
- Processability testing of fabrics
- Production & inspection of composite panels
- Test composite performance: mechanical testing
- Optimisation of fabric design and production
- Optimisation of process from fibre to finished component
- Process simulation using PAMFORM
Customers

- Key Markets are Marine, Automotive, Sports, Wind Energy, Oil and Gas.

![Images of various products related to the key markets mentioned.]
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Fabric Selection Process

How are these fabric structures selected?
How are these fabric structures selected?

- feedback during production run
How are these fabric structures selected?

- feedback during production run
- physical testing and optimisation during the design stage
Physical Testing

Aim: To quantify the effect of variation of fabric constructions on processability and performance for a specific component

- 27 fabrics tested, all with same fibre type, weight and orientation

Processability tests conducted:
- Cutting, Drape, Stability, Retain & Permeability
Physical Testing
## Physical Testing

<table>
<thead>
<tr>
<th>Sample</th>
<th>Gauge</th>
<th>Stitch-Type</th>
<th>Length (mm)</th>
<th>Powder</th>
<th>Cutting</th>
<th>Drape</th>
<th>Stability</th>
<th>Retain</th>
<th>Total</th>
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<tr>
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<td>6</td>
<td>Tricot</td>
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<td>1</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>Pillar</td>
<td>4.23</td>
<td>None</td>
<td>2</td>
<td>2</td>
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<td>2</td>
<td>8</td>
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<tr>
<td>6</td>
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<td>Pillar</td>
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<td>None</td>
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<td>4</td>
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<tr>
<td>10</td>
<td>6</td>
<td>3GG tricot cam</td>
<td>2.12</td>
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<td>2</td>
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<tr>
<td>2P</td>
<td>6</td>
<td>Tricot</td>
<td>2.12</td>
<td>Zigzag side</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td>3P</td>
<td>6</td>
<td>½ Pillar Tricot</td>
<td>2.12</td>
<td>Zigzag side</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>9P</td>
<td>3</td>
<td>Tricot</td>
<td>2.12</td>
<td>Zigzag side</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>2</td>
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</tr>
<tr>
<td>2P*</td>
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<td>Tricot</td>
<td>2.12</td>
<td>Loop side</td>
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<td>3</td>
<td>15</td>
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<td>11</td>
<td>-</td>
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<td>-</td>
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<td>4</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>16</td>
</tr>
</tbody>
</table>

Table 1: Results of testing; grey fabrics were selected for the next round of testing.
Fabric Selection Process

How are these fabric structures selected?

- Feedback during production run
- Physical testing and optimisation during the design stage
How are these fabric structures selected?

- Feedback during production run
- Physical testing and optimisation during the design stage
- Simulation and optimisation during the design stage
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Collaboration between FORMAX and ESI

- Objectives of the Collaboration
  - To assess the existing capabilities of PAM-FORM for simulation of multiaxial fabrics
  - To assess the ability for PAM-FORM to model the manual preform process
Primary Challenges

Modelling a Multiaxial
- How can the properties of the stitched fabric be modelled?
- What are the implications on processing time and results?

Modelling the Manual Forming Process
- How can manual operator forces be modelled?
- What are the implications on processing time and results?

Prediction of Required Ply Shapes
- Can we predict the required developed ply shapes?
Modelling a Multiaxial

Multiaxial fabrics (±45) characterised through material testing

| Tensile Test | Bias Test | Bending Test |
Modelling a Multiaxial

Calibrated material model tested using a more complex model
Modelling a Multiaxial

Two methods of modelling asymmetry examined

- **Single Definition**
  - Fabric Model
  - Shear modulus different for positive and negative shear angles
  - Shear modulus can be defined with respect to the angle change

- **Spot Welded UD Layers**
  - Two UD plys modelled
  - Spot weld nodes spaced to replicate stitch

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Modelling a Multiaxial

Two methods of modelling asymmetry examined

- **Single Definition**

- **Spot Welded UD Layers**
Which method is best?

**Single Definition**
- Accuracy of Model
  - Asymmetry shown in the model
  - Further calibration is required to accurately model experiment
- Processing Time
  - Punch Stage – 5 mins

**Spot Welded UD Layers**
- Accuracy of Model
  - Asymmetry shown in the model
  - Further refinement needed to accurately simulate wrinkling
- Processing Time
  - Punch Stage – 40 mins

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Simulating Forming Processes

- **Application of operator force is not straight forward**
  - How do we model the movement and pressure that a hand imparts on the fabric?

- **Method of application in the model must:**
  - Able to cause the ply to conform around a geometry
  - Able to highlight any features that occur during forming

- **Two forming force application methods were found to be successful:**
  - Applying forces to tools
  - Diaphragm forming
Simulating Forming Processes

- **Mould and Punch**
  - Model consists of mould (green) and punch (red)

- **Diaphragm Forming**
  - Diaphragm positioned over ply and geometry
  - Vacuum applied to diaphragm to pull the ply onto the geometry

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Extraction of Useful Results

- **Prediction of Wrinkling**
  - Punch forming process simulated
    - Multiaxial Fabric
    - Concave geometry
  - Location and size of wrinkles were noted and compared with simulated plots
Extraction of Useful Results

- **Prediction of Wrinkling**
  - Ability to visualise the location, pattern and height of wrinkles
  - Ability to extract data from selected nodes for direct comparisons between simulations
Extraction of Useful Results

- **Prediction of Laddering**
  - Occurs when fabric is strained normal to the stitch direction
  - Onset of laddering occurs at a given strain
  - Predicted by comparing model strain to experimental laddering strain
Extraction of Useful Results

- **Prediction of Laddering**

  - There is a directionality to the laddering properties of the multiaxial
    - Leading edge – does not ladder
    - Trailing edge – ladders at a given strain
  
  - Multiaxial model did not discriminate between leading and trailing edge
Extraction of Useful Results

- Modelled laddering strain
  - Taken from edges of Multiaxial ply model
  - Element strain plotted with respect to a defined direction which is orientated across the stitch in a local region of the deformed blank
Generation of Developed Shapes
Simulation Capabilities: Summary

- **Modelling a multiaxial**
  - Single definition is our preferred method of modelling the multiaxial
  - Asymmetric properties can be obtained through assigning different values of shear modulus for positive and negative shear angles

- **Modelling manual forming processes**
  - Investigation into the methods of modelling manual forming techniques
  - Diaphragm and rigid tools used in successful forming simulations

- **Extraction of useful results**
  - Wrinkle patterns have been predicted by the model
  - Prediction of laddering possible by further examination of the laddering strains

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Case Study: Effects of Stitch Direction

- Examined the effects of the stitch orientation in a real automotive component
  - Fibre orientation remained the same relative to the component
  - Fabric models were modified to account for a changing stitch direction
Case Study: Stitch Orientation

- The stitch influences the shear behaviour of the fabric
- Stitch orientation can be altered without changing fibre orientation of the fibres
- Simulation was used to examine the most appropriate stitch orientation
Case Study: Stitch Orientation

- PAMFORM simulation indicated that wrinkles would not form when the stitch was orientated at either 90° or 45° to the part.
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Introduction to Optimisation

- **Without simulation**
  - Prior optimisation carried out physically
  - Required fabrics to be manufactured
  - Required a physical model of the geometry

- **With simulation**
  - Fabric optimisation carried out before geometry has been finalised
  - Can determine the required fabric properties required before the material is specified
How can simulation be used to Optimise a Fabric

- **Idealised optimisation**
  - Looks for the existence of a minimum for a given variable when a material parameter is changed

- **Optimisation through simulation requires**
  - Large numbers of input files
  - Incrementally changing material properties
  - Automation throughout the process

![Graph showing changes in node distance from mould and fabric shear modulus](image.png)
What needs to be optimised?

A trade off exists between wrinkles and stability with regard to the shear modulus of the fabric.

LOW G

HIGH G

G.Cosθ

Wrinkles/Stability
Where is the Optimum Fabric Modulus?

- For **THIS** case desirable fabric will:
  - Not wrinkle when forced into the mould
  - Be as stable as possible

- Therefore the optimum fabric will be a trade off between the two factors i.e.

  The *maximum* shear modulus that will provide a wrinkle free formed component

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Step One: Initial Optimisation

G.Cos $\theta = 0.0001$

G.Cos$\theta = 0.001$
Step One: Initial Optimisation

\[ G.\cos(\theta) = 0.0001 \]

\[ G.\cos(\theta) = 0.001 \]
Step One: Initial Optimisation

G.Cos $\theta = 0.0001$

G.Cos$\theta = 0.001$

Some of Node Z position
Step Two: Refined Optimisation

G.Cos(θ) = 0.0001

G.Cosθ = 0.001
Step Two: Refined Optimisation

- Initial optimisation suggests a desired $G \cdot \cos \Theta$ value of 0.0001
- Further analysis suggests the maximum $G \cdot \cos \Theta$ value of 0.0003
### Optimised Fabric Selection

- **Optimised G fabric**
  - A degree of laddering occurred but the fabric did not wrinkle

<table>
<thead>
<tr>
<th></th>
<th>Low G</th>
<th>Optimised G</th>
<th>High G</th>
</tr>
</thead>
<tbody>
<tr>
<td>No formation of wrinkles</td>
<td>No formation of wrinkles</td>
<td>Severely wrinkled</td>
<td></td>
</tr>
<tr>
<td>Evidence of a significant amount of laddering</td>
<td>Evidence of some laddering</td>
<td>No evidence of laddering</td>
<td></td>
</tr>
</tbody>
</table>
Optimisation Conclusions

- Simulation has been used to examine the trade offs in processability when changing a given material parameter.

- Large numbers of simulations with incremental changes can be created automatically.
  - This can be applied to several areas of process analysis:
    - Examination of material properties
    - Examination of process parameters
    - Examination of geometry
Optimisation Conclusions

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- Large numbers of simulations with incremental changes can be created automatically.
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    - Examination of process parameters
    - Examination of geometry

- **Theoretical** optimum has been calculated.
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Next Steps

- A UK Government funded **Knowledge Transfer Partnership** with **Nottingham University** to begin in April 2013, will develop:

  - A database of all processability and performance parameters for multiaxial fabrics
  - A comprehensive understanding of the effects of processability characteristics on composite performance
  - Develop capabilities for producing the developed shape of preforms
Thank You