Analysis of 2D Triaxial Braided Textile Composites & FEXL

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Macro, Meso and Micro Mechanics

Macro-Mechanics

Meso-Mechanics (fiber architecture)

Micro-Mechanics

Thermal Mechanical Loads

COMPOSITE STRUCTURE

UNIT CELL

MACRO-STRESSES

Meso-Stresses of Meso Models

Stress Amplification Factors of Meso Models

Effective Material Properties of Meso Models

Effective Material Properties of Unidirectional Composite

Micro-Stresses of Meso Models

Stress Amplification Factors of Meso Models

Stress Amplification Factors of Unidirectional Tape

Effective Material Properties of Unidirectional Composite

Micro-Stresses of Unidirectional Composite

\[ \sigma = M \bar{\sigma} + A \Delta T \]

\[ \sigma^{(i,k)} = M^{(i,k)} \bar{\sigma}^{(i)} + A^{(k)} \Delta T \]
Introduction to Braided Textile Composites

Advantages

1. Better out-of-plane stiffness, strength, and toughness
2. Lower fabrication costs, and easier handling in production quality than tape laminates

Braid Patterns

- Diamond Braid (1/1)
- Regular Braid (2/2)
- Hercules Braid (3/3)

- Diamond Braid — 1 up, 1 down (1/1)
- Regular Braid — 2 up, 2 down (2/2)
- Hercules Braid — 3 up, 3 down (3/3)
Introduction to Braided Textile Composites

Components of (2/2) Triaxial Braided Composite

1. Axial yarn
2. $-\theta$ Bias yarn
3. $+\theta$ Bias yarn

Key parameters of (2/2) Triaxial Braided Composite

- $\theta$ — braiding angle
- $W_a$ — width of axial yarn
- $W_b$ — width of bias yarn
- $t_a$ — thickness of axial yarn
- $t_b$ — thickness of bias yarn
CAD Model for 2/2 Triaxial Braided Composite

- **CAD Model**

- **Unit Cell for Braided Composite**

  - Bias yarn cross section
  - Axial yarn cross section

  - $a_b$ — width of bias yarn
  - $b_b$ — thickness of bias yarn
  - $a$ — width of axial yarn
  - $b$ — thickness of axial yarn

  **Undulation of bias yarn**

  $z' = A \sin\left(\pi x' / L\right)$

  - $A$ — amplitude of undulation
  - $L$ — wavelength

  **Governing equation**
Unit Cell of Braided Composite

- CAD Model of Repeating Unit Cell (RUC)
  - **Yarn**
    - Red: $\theta$ Bias Yarn
    - White: -$\theta$ Bias Yarn
    - Green: Axial Yarn
  - **Resin**
- FEM Model of RUC
  - Mesh of Unit Cell
  - Mesh of Fiber
  - Mesh of Resin
**Geometry Information**

- Braiding angle: $\theta = 30^\circ$
- Width of axial yarn: $W_a = 3.012\text{mm}$
- Width of bias yarn: $W_b = 3.01\text{mm}$
- Thickness of axial yarn: $t_a = 0.503\text{mm}$
- Thickness of bias yarn: $t_b = 0.498\text{mm}$

**Multi Cell Model**
Assign material properties

Material Properties

<table>
<thead>
<tr>
<th>Fiber</th>
<th>E1(GPa)</th>
<th>E2(GPa)</th>
<th>E3(GPa)</th>
<th>v12</th>
<th>v13</th>
<th>v23</th>
<th>G12(GPa)</th>
<th>G13(GPa)</th>
<th>G23(GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>231</td>
<td>18</td>
<td>18</td>
<td>0.2</td>
<td>0.2</td>
<td>0.35</td>
<td>85</td>
<td>85</td>
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</table>

<table>
<thead>
<tr>
<th>Matrix</th>
<th>E(GPa)</th>
<th>v</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Local Coordinate System (CSYS)

All Repeating Local CSYSs
Load & Boundary Conditions

- **Boundary conditions**

  - X: $U(x) = 0$
  - Y: $U(y) = 0$
  - $X': \text{DOF}_1(x') = \text{DOF}_1(P)$
  - $Y': \text{DOF}_2(y') = \text{DOF}_2(P)$

- **Loads**

  - Analysis 1: $\sigma = 1$
  - Analysis 2: $\varepsilon = 1$
Layers align configuration for NCF

- **Analysis results**

Field Output: Stress, Mises

**Analysis 1**

\[ \sigma = 1 \]

**Analysis 2**

\[ \varepsilon = 1 \]

The two analysis under two different loads have the same stress distribution.
Layers align configuration for NCF

Analysis results

Field Output: Strain, Max, Principal

Analysis 1
\[ \sigma = 1 \]

Analysis 2
\[ \varepsilon = 1 \]

The two analysis under two different loads have the same strain distribution
Summary of Braided Textile Composite

- The unit cell of 2/2 braided composite has been defined;
- The cad model and FEM model of 2/2 braided textile composite have been developed;
- The analysis of multi cell model has been finished.
A finite element program for Axisymmetric Composite Structures: FEXL-AxiCom
What are Axisymmetric Structures?

- Cap
- Water tanks
- Pipes
- Rotors
- Pressure vessels
MS Excel based User-friendly finite element analysis program for Axisymmetric Composite Structures

- Axisymmetric Structure with any cross section
- Two loads (Internal pressure and angular velocity) at any location

The FEXL-AxiCom is an accurate, yet easy-to-use tool, greatly simplifying data input procedures for cross-sections and layup sequences.
Program Flow: FEXL-AxiCom

**Main Analysis Modules**

1. **Step 1: Geometry Selection**
   - Decide the dimensions for the selected model
   - Internal Pressure
   - Angular velocity
   - Number of nodes

2. **Step 2: Material Properties**

3. **Step 3: Loads**
   - Internal Pressure
   - Angular velocity
   - Number of nodes

4. **Step 4: Mesh Generation**

5. **Step 4: Solve**

**Output**
- Displacement
- Global Strains
- Global Stresses

Program Flow:
- FEXL
- AxiCom

3D Graphical Post Processor: JAVA PostProcessor
Introduction of FEXL-AxiCom

- **FEXL-AxiCom “Main” sheet**

  - **Geometry Input**
    - Model: Pressure Vessel, Cylinder, Sphere
    - Pre_Process

  - **Material Properties**
    - Material: Steel
    - Material DB

  - **Load**
    - Load Type: Pressure
    - Magnitude: 100 Pa

  - **Mesh Generation**
    - Num_X: 1
    - Num_Z: 4
    - Tips
    - Mesh

  - **Solve**
    - Calculate
    - Post-Processor

  - **Visualization**

- **FEXL-Vessel**
- **Cylinder**
- **Sphere**
- **Material DB**

<table>
<thead>
<tr>
<th>Material Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<th>11</th>
<th>12</th>
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<th>14</th>
<th>15</th>
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<td>Name</td>
<td>T700</td>
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<td>T800-1030</td>
<td>T800-2030</td>
<td>T800</td>
<td>NT300</td>
<td>T800</td>
<td>NT5304</td>
<td>T800</td>
<td>NT300</td>
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<td>E (GPa)</td>
<td>132</td>
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<td>11</td>
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<td>70</td>
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<td>181</td>
<td>53.48</td>
<td>112</td>
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<td>Ax (MPa)</td>
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</tr>
</tbody>
</table>

Specific gravity [10^-3]: 1.1548, 1.16, 1.16, 1.16, 1.16, 1.16, 1.16, 1.16, 1.16, 1.16, 1.16, 1.16, 1.16, 1.16, 1.16

Return
Application of FEXL-AxiCom
Composite Pressure Vessels
Composite Cylinders
Composite Spherical Cap
Analysis of Composite Cylinder under Internal Pressure

Composite Rotor Model

Section view

FEM Model

Cross section

Layups

Half Model For FEA

$U_y = 0$
1. Material Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_x$ [GPa]</td>
<td>132</td>
</tr>
<tr>
<td>$E_y$ [GPa]</td>
<td>8.9</td>
</tr>
<tr>
<td>$v_{xy}$</td>
<td>0.31</td>
</tr>
<tr>
<td>$E_z$ [GPa]</td>
<td>5.6</td>
</tr>
</tbody>
</table>

2. Load & Boundary conditions

ID = 0.4 m  
OD = 0.7 m  
Height = 0.6 m

$P = 100$ Pa

$U_y = 0$

Composite Cylinders

[±90]$m$

Y — Fiber direction
Z — Thickness direction

Local CSYS
Analysis of Composite Cylinder under internal Pressure

[±90]m
ID=0.4 m
OD=0.7 m
Height=0.6 m

P=100 Pa

Radial disp. vs radius

FEXL
ABAQUS

Path for plot

U, Magnitude
FEXL
ABAQUS

stress
r

FEXL - ABAQUS
Analysis of Composite Cylinder under internal Pressure

ABAQUS

Path for plot

FEXL

\[
\sigma_{\theta \theta} \text{ VS } r
\]

\[\pm 90\]m

ID = 0.4 m

OD = 0.7 m

Height = 0.6 m

P = 100 Pa

Node Stress 1

-3.274E02
-3.043E02
-2.012E02
-2.580E02
-2.349E02
-2.118E02
-1.887E02
-1.656E02
-1.424E02
-1.193E02
-9.618E01
-7.305E01
-4.993E01
1. Material Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value [GPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_x$</td>
<td>132</td>
</tr>
<tr>
<td>$E_y$</td>
<td>8.9</td>
</tr>
<tr>
<td>$\nu_x$</td>
<td>0.31</td>
</tr>
<tr>
<td>$E_s$</td>
<td>5.6</td>
</tr>
</tbody>
</table>

2. Loads & Boundary conditions

ID=0.4 m  
OD=0.7 m  
Height=0.6 m  
Angular Velocity: $\omega = 100$ rpm

Composite Cylinders

[$\pm 90\text{]}^\circ$ m

Y — Fiber direction  
Z — Thickness direction
Analysis of Composite Cylinder in Rotation (Flywheel Rotor)

[±90]m ID=0.4 m

ω = 100 rpm OD=0.7 m

Height=0.6m

Radial disp. vs radius

FEXL

ABAQUS

Path for plot

Radial displacement vs radius

Displacement vs radius
Analysis of Composite Cylinder in Rotation (Flywheel Rotor)

- Material: [±90]m Carbon Fiber
- Diameter: ID=0.4 m, OD=0.7 m
- Height: 0.6 m
- Rotation Speed: $\omega = 100$ rpm

Stress vs. $r$

Path for plot

ABAQUS

FEXL
Analysis of Composite Spherical Cap

Cross section $[+\theta/-\theta]m$

Composite Spherical Cap $\rightarrow$ Section $\rightarrow$ FEM Model

FEA
1. Material Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value [GPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_x$</td>
<td>132</td>
</tr>
<tr>
<td>$E_y$</td>
<td>8.9</td>
</tr>
<tr>
<td>$\nu_{xy}$</td>
<td>0.31</td>
</tr>
<tr>
<td>$E_z$</td>
<td>5.6</td>
</tr>
</tbody>
</table>

2. Loads & Boundary conditions

- ID = 2 m
- OD = 2.15 m
- Angle_s = 0
- Angle_f = 90

- $U_x = 0$
- $U_y = 0$
- $P = 100$ Pa

Local CSYS-1, Local CSYS-m, Local CSYS-n

**Fiber direction**: $Y$

**Thickness direction**: $Z$
Analysis of Composite Spherical Cap under internal Pressure

[±90]m
ID=2 m
OD=2.15 m
P=100 Pa
Angle_s=0
Angle_f=90

Radial disp. vs radius
Analysis of Composite Spherical Cap under internal Pressure

ABAQUS

FEXL

\[ [\pm 90]m \quad \text{ID}=2 \text{ m} \]

\[ \text{OD}=2.15\text{ m} \]

\[ \text{P}=100 \text{ Pa} \]

\[ \text{Angle}_s=0 \]

\[ \text{Angle}_f=90 \]

\[
\sigma_{\theta\theta} \text{ vs } r
\]

Path for plot

\[
\begin{align*}
S, S_{33} \\
(\text{Avg}: 75\%) \\
+2.038e+03 \\
+1.821e+03 \\
+1.604e+03 \\
+1.387e+03 \\
+1.171e+03 \\
+9.538e+02 \\
+7.370e+02 \\
+5.202e+02 \\
+3.034e+02 \\
+8.657e+01 \\
-1.302e+02 \\
-3.470e+02 \\
-5.638e+02
\end{align*}
\]
1. Material Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex [GPa]</td>
<td>132</td>
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<tr>
<td>Ey [GPa]</td>
<td>8.9</td>
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<tr>
<td>nu_x</td>
<td>0.31</td>
</tr>
<tr>
<td>Es [GPa]</td>
<td>5.6</td>
</tr>
</tbody>
</table>

2. Loads & Boundary conditions

- ID = 2 m
- OD = 2.15 m
- Angle_s = 0
- Angle_f = 90
- Angular Velocity: $\omega = 100$ rpm
- $U_x = 0$
- $U_y = 0$

**Fiber direction**

**Thickness direction**

Global CSYS:

Local CSYS-1:

Local CSYS-m:

Local CSYS-n:
Analysis of Composite Sphere in Rotation

[±90]m

\[ \text{ID} = 0.4 \text{ m} \]

\[ \text{OD} = 0.7 \text{ m} \]

\[ \text{Height} = 0.6 \text{ m} \]

\( \omega = 100 \text{ rpm} \)

Radial disp. vs radius

Path for plot

FEXL

ABAQUS
Analysis of Composite Spherical Cap in Rotation

[±90]m

ID = 0.4 m
OD = 0.7 m
Height = 0.6 m

ω = 100 rpm

σ_θθ vs r

Path for plot

Node Stress 1
-7.540E05
-6.911E05
-6.283E05
-5.655E05
-5.027E05
-4.399E05
-3.770E05
-3.142E05
-2.513E05
-1.885E05
-1.257E05
-6.287E04
-4.096E04

ABAQUS

FEXL

Path for plot

Graph showing stress vs r for FEXL and ABAQUS.
Analysis of Cylindrical Pressure Vessel for Various Angles

- \([\theta/\theta_m]\)

**sig_y (transverse direction)**

- Analytic (thin)
- FEXL

**Disp_1 (radial displacement)**

- FEXL
- Analytic (thin)
Dimension input for pressure vessel

Radial disp. vs radius

Transverse stress vs radius

\[ P = 100 \text{Pa} \]