Adaptive Coupling in Composite Plates

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COMPTEST 2011, Lausanne, Feb 15th
Motivation: adaptive aeroelastic tailoring

Adaptive blade coupling

Passive pitch control

Load alleviation


Concept of adaptive coupling in laminates

- Idea: interfaces with variable shear stress transfer
Concept of adaptive coupling in laminates

- Idea: interfaces with variable shear stress transfer

Polymer layers with variable temperature
Concept of adaptive coupling in laminates

- Idea: interfaces with variable shear stress transfer
- Temperature-variable modulus of polymers

Polymer layers with variable temperature

![Graph showing storage modulus vs. temperature](image)
Concept of adaptive coupling in laminates

- Coupling and decoupling of layers

<table>
<thead>
<tr>
<th>Temperature of adjustable polymer layers</th>
<th>low</th>
<th>high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus of adjustable polymer layers</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Deformation of inner and outer layers</td>
<td>coupled</td>
<td>decoupled</td>
</tr>
<tr>
<td>Deformation mode, bending</td>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
</tr>
<tr>
<td>Deformation mode, torsion</td>
<td><img src="image3" alt="Diagram" /></td>
<td><img src="image4" alt="Diagram" /></td>
</tr>
<tr>
<td>Coupling stiffness, $[0,0]_s$</td>
<td>high</td>
<td>low</td>
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## Concept of adaptive coupling in laminates

- **Coupling and decoupling of layers**

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**Deformation mode, bending**

**Deformation mode, torsion**

**Coupling stiffness, \([0,0]_s\)**

**Low**     **High**
Coupling in laminates

- Extension-twist coupling (antisymmetrical layup)

\[
\begin{pmatrix}
N_x \\
M_{xy}
\end{pmatrix} =
\begin{bmatrix}
\alpha_{11} & \alpha_{12} \\
\alpha_{12} & \alpha_{22}
\end{bmatrix}
\begin{pmatrix}
\varepsilon_x^0 \\
K_{xy}
\end{pmatrix}
\]

\[
\alpha_{11} = A_{11} - \frac{A_{12}^2}{A_{22}}, \quad \alpha_{12} = B_{16} - \frac{A_{12}B_{26}}{A_{22}}, \quad \alpha_{22} = D_{66} - \frac{B_{26}^2}{A_{22}}
\]
Coupling in laminates

- **Extension-twist coupling**
  (antisymmetrical layup)

\[
\begin{pmatrix}
N_x \\
M_{xy}
\end{pmatrix} = \begin{bmatrix}
\alpha_{11} & \alpha_{12} \\
\alpha_{12} & \alpha_{22}
\end{bmatrix} \begin{pmatrix}
\varepsilon_x^0 \\
\kappa_{xy}
\end{pmatrix}
\]

\[
\alpha_{11} = A_{11} - \frac{A_{12}^2}{A_{22}}, \quad \alpha_{12} = B_{16} - \frac{A_{12}B_{26}}{A_{22}}, \quad \alpha_{22} = D_{66} - \frac{B_{26}^2}{A_{22}}
\]

- **Bending-twist coupling**
  (symmetrical layup)

\[
\begin{pmatrix}
M_x \\
M_{xy}
\end{pmatrix} = \begin{bmatrix}
\beta_{11} & \beta_{12} \\
\beta_{12} & \beta_{22}
\end{bmatrix} \begin{pmatrix}
\kappa_x \\
\kappa_{xy}
\end{pmatrix}
\]

\[
\beta_{11} = D_{11} - \frac{D_{12}^2}{D_{22}}, \quad \beta_{12} = D_{16} - \frac{D_{12}D_{26}}{D_{22}}, \quad \beta_{22} = D_{66} - \frac{D_{26}^2}{D_{22}}
\]
Numerical results

- Influence of temperature

\[ [38^\circ, 0^\circ]_{as} \]
\[ [23^\circ, 0^\circ]_{s} \]
Numerical results

- Influence of temperature

\[ [38^\circ, 0^\circ]_{\text{as}} \]
\[ [23^\circ, 0^\circ]_{\text{s}} \]
Numerical results

- Influence of polymer thickness

![Graph showing the influence of polymer thickness]
Numerical results

- Influence of polymer thickness
- Influence of aspect ratio

(a/b=5)  (t_P/t_{CFRP}=4)
Experimental setup

Plate, 250 x 50 mm

[23°,0°]s
Experimental setup

[Image of experimental setup]

Plate, 250 x 50 mm

\([23^\circ, 0^\circ]_s\)
Experiment: deformation measurement by 3D DIC

Diagram showing:
- Computer
- Two cameras labeled as camera 1 and camera 2
- White light sources
- Specimen

Diagramme shows a setup for deformation measurement using 3D Digital Image Correlation (DIC).
Experiment: deformation measurement by 3D DIC
Experimental results: compliance

Deflection due to bending

Twist due to bending

Deflection due to torsion

Twist due to torsion
Experimental results: compliance

Deflection due to bending

Twist due to bending

Deflection due to torsion

Twist due to torsion
Experimental results: Coupling stiffness

- Coupling stiffness $\beta_{12}$
Experimental results: Coupling stiffness

- Coupling stiffness $\beta_{12}$
- Relative coupling stiffness $\beta_{12}/\beta_{11}$
Conclusions and prospect

- Effect of adaptive coupling verified
- Change in coupling stiffness by factor of 10
- Selection of $T_g$ decisive
- Following step: more selective variation of coupling stiffness
Adaptive box profile

- Concept

shear centre

web with variable modulus
Adaptive box profile

- Concept

- First results

<table>
<thead>
<tr>
<th></th>
<th>stiff</th>
<th>compliant</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi_{\text{max}}/Q$ [$^\circ$/N]</td>
<td>-2.24E-04</td>
<td>2.19E-02</td>
</tr>
<tr>
<td>Rel. change [-]</td>
<td></td>
<td>1.01E+00</td>
</tr>
<tr>
<td>$w_{\text{max}}/Q$ [mm/N]</td>
<td>2.51E-01</td>
<td>2.75E-01</td>
</tr>
<tr>
<td>Rel. change [-]</td>
<td></td>
<td>8.73E-02</td>
</tr>
</tbody>
</table>
Conclusions and prospect

- Effect of adaptive coupling verified
- Change in coupling stiffness by factor of 10
- Selection of $T_g$ decisive
- Following step: more selective variation of coupling stiffness