Damage mechanisms of 3D woven hybrid composites in tension. Testing, inspection and simulation.

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SUMMARY

- Introduction
- Material
- Yarn bundle tests
- RVE. Finite element model
- Damage inspection
- Notch sensitivity
- Conclusions
INTRODUCTION

Delamination reduces the strength of the composites, mainly in compression. Several methods exist to overcome this problem, but they are either not feasible for large-scale production or too expensive. 3D composites are a promising solution.
INTRODUCTION

• However, characterization of 3D woven materials is more difficult, requiring additional inspection techniques, like C-Scan and XCT tomography and FEM simulations.

• Lack of experimental data.

• Lack of reliable FEM models.

• Lack of analytical models.

• This study aims to analyze in-depth the mechanical response and failure mechanisms of a 3D woven orthogonal hybrid composite.
3D woven orthogonal hybrid composite S2/C + Epoxy/Vinylester
- S2-glass (69%)
- T700 carbon (25%)
- Dyneema (6%)
- Unsymmetric cross-ply [90,0,90,0,90,0,90]
- Warp: 2S2 + 1Carbon
- Fill: 2S2 + 1 Hybrid Carbon/S2 + 1Carbon
- Thickness= 4.1mm
TENSILE TESTS (BUNDLES)

6 specimens per sample
ASTM D-4018
### TENSILE TESTS (BUNDLES)

\[ MUL = \frac{m_{\text{fiber}}}{\text{length}} \]

\[ X_{\text{fiber}} = P_{\text{max}} \times \frac{\rho_f}{MUL} \]

\[ E_{\text{chord}} = \frac{(P_{\text{max}} - P_{\text{max}}) \times \rho_f}{(\varepsilon_{\text{max}} - \varepsilon_{\text{max}}) \times MUL} \]

<table>
<thead>
<tr>
<th></th>
<th>Tensile Moduli (GPa)</th>
<th>Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manufacturer</td>
<td>IMDEA</td>
</tr>
<tr>
<td>S2-glass</td>
<td>86,9</td>
<td>85,0</td>
</tr>
<tr>
<td>Carbon</td>
<td>231,0</td>
<td>193,2</td>
</tr>
<tr>
<td>Dyneema</td>
<td>113</td>
<td>76,0</td>
</tr>
</tbody>
</table>

* Tow Vf=60%
TENSILE TESTS (COUPON)

Monotonic loading

Cyclic loading
TENSILE TESTS

- Two peaks observed due to hybridization. Failure points match strain to failure of every type of fiber. However:

  - A linear elastic approach leads to significant errors when used to predict the elastic properties of the coupon from those of the yarns and the resin.

  - Matrix cracking, crimping, carbon stiffening, in-situ strengthening, 3D influence and bending-extension coupling seem to play a significant role.

  - More information is then required: advanced damage inspection, numerical simulations, other experimental tests.
FEM MODEL

• A micromechanical approach may help to understand the stress distribution in critical regions.

• Quick 3D FEM model: automatic generation with a python script (less than 1 minute)

• Low computational cost

• Influence of shear stresses and matrix damage can be observed in such a simple model.

• However, other relevant effects like bending-extension coupling or crimping are not well-captured.
FEM MODEL

Python script
FEM MODEL
DAMAGE INSPECTION

- Damage was examined at different stages of the loading process.
- Dye penetrant enhanced X-Ray CT images
- Optical Microscopy
- Scanning Electron Microscope
- C-Scan ultrasound
X-Ray CT-image inspection

Loading in warp direction
X-Ray CT-image inspection

Loading in weft direction
Do transverse cracks trigger delamination at the interfaces?
Damage initiation
OPEN-HOLE TENSION
CONCLUSIONS

• Hybrid material with a complex mechanical response.

• Coupon tensile response cannot be predicted from bundle tests and analytical formulae.

• Multiple damage mechanisms observed, like transverse cracking, debonding bundle-matrix and fiber breakage. Some relevant effects were found, like crimping influence, matrix shear damage and z-yarn stress concentration.

• Quick FEM models can be used to assess mechanical response of 3D woven composites.

• Ductile response. Notch-insensitive behaviour.

• Coupling bending-extension due to unsymmetry.
ACKNOWLEDGMENTS

Vanesa Martínez
Francisca Martínez
Federico Sket
Rocío Seltzer
Joaquim Vilà
Juan Carlos Rubalcaba
Eva Moreno