Experimental characterization and modeling of thin ply size effect

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In partnership with North-TPT, FHNW, RUAG Technology, RUAG space, and Connova
Introduction: bibliographical background

- **Wisnom & al.**
  - Size effect with geometrical scaling
  - Constant ply thickness

- **Tsai & al.**
  - Thin plies → suppress microcracking and delamination
  - Compared to thick plies = stacking of thin plies

- **Camanho & al.**
  - Thin non-crimp fabrics
  - Compared to aeronautical grade materials


Introduction: structure

1. Experimental study of thin ply size effect on different levels
   • Constant specimen thickness
   • UD prepregs of varying ply weights & number of repetitions:
     • Thick = 300 (2x150) g/m²
     • Intermediate = 100 g/m²
     • Thin = 30 g/m²
   • Minimized scatter factors
     • Fibers (M40JB) & resin (epoxy 80°C system) from the same batches
     • Autoclave
     • Normalization for 55% vf

2. Simulation

3. Implementation in the design process

4. Conclusion
Lamina level ‘thin ply’ effects

- Overall no change in intrinsic lamina properties except compression

**Compressive strength** (ASTM D5467*)

- Thin Ply leads to a more uniform microstructure and improved 0° compressive strength
Laminate properties

Quasi isotropic laminate tensile test (ASTM D3039)

[Image of laminate structure]

Graph showing the tensile strength of different laminate configurations:

- Thick n=1, b=1
- Thin_Ply block n=1, b=10
- Intermediate n=3, b=1
- Thin n=10, b=1
- Threshold

Cumulative acoustic energy [10^-18J]
Laminate properties

Quasi isotropic laminate tensile test (ASTM D3039)

- Ultimate strength: +42%

- Onset of damage: +227%

- Radical change of failure mode
Open Hole Tensile fatigue

Open Hole Tensile: static and fatigue (ASTM D5766 & D7615, R=0.1)

- Lower ultimate strength. No damage around hole means no stress concentration relief but better predictability (Wisnom & al)
- Strong improvement in fatigue life (<20k vs >1M cycles)
Bolted joint bearing strength

Single lap bearing test, standard and Hot Wet condition (ASTM 5961), fastener type EN-6115

Hot Wet cond. 95%RH/70°C, test 90°C

- **Thick Ply 300g/m², n=2**
  - As produced, 20°C
    - $\sigma_{br\_ult} = 156$ MPa
  - Hot Wet 90°C
    - $\sigma_{br\_ult} = 476$ MPa

- **Intermediate 100g/m², n=5**
  - As produced, 20°C
    - $\sigma_{br\_ult} = 294$ MPa
  - Hot Wet 90°C
    - $\sigma_{br\_ult} = 573$ MPa

- **Thin Ply 30g/m², n=18**
  - As produced, 20°C
    - $\sigma_{br\_ult} = 372$ MPa
  - Hot Wet 90°C
    - $\sigma_{br\_ult} = 584$ MPa

- Strength improvement for as produced @ 20°C $\rightarrow$ +18%
- Strength improvement for Hot Wet @ 90°C $\rightarrow$ +58%
Simulation of ‘thin ply’ effects

- Goal: capture the transition in dominant failure mode in order to understand and predict ply size effects

- Hypotheses: no change in lamina and interface properties

First ply: 0° (symmetry)

User material with fiber failure (subroutine)

UD mx. without fiber failure

Between the layers: cohesive surfaces > delamination

Simulation: force controlled (sigmoid ramp, quasi-static)

Cohesive elements > lateral cracking

3D modeling of quasi isotropic unnotched tensile test in Abaqus Explicit

Damage models: cohesive interfaces between plies, cohesive elements for transverse cracking, continuum damage model for fiber failure
Simulation of ‘thin ply’ effects

- First results on thick ply QISO unnotched tension

Damage sequence:
- Cracking of 90° & 45° plies, delamination 90° / -45° plies from free edges
- Shear failure of 45° plies, delamination 0° / -45° from free edges
- Fiber failure in 0° plies
Simulation of ‘thin ply’ effects

Thick, n=1 – EXPERIMENTAL (c-scan)

Thick, n=1 – NUMERIC (CSDMG)

Intermediate, n=3 – NUMERIC (CSDMG)

Intro

Lamina level

Laminate level

Element level

Simulation

Design

Conclusion

250 MPa

300 MPa

350 MPa

400 MPa

450 MPa

500 MPa

550 MPa

600 MPa

650 MPa

700 MPa

Work in progress
Simulation of ‘thin ply’ effects

- First results on QISO unnotched tension
  - Good predictions for thick ply composites (300g/m2) for both onset of damage and ultimate strength.
  - Future: parametric study, extension to open hole and other cases

Numerical modeling
(no tuning)

Experimental results
(normalized for vf 55%)

Ult. str. \(_{\text{THICK}} = 685\) MPa
Onset \(_{\text{THICK}} = 253\) MPa
Ult. str. \(_{\text{THICK}} = 595\) MPa
Onset \(_{\text{THICK}} = 248\) MPa

Failure at a « boundary » condition → to be improved
Towards part level modeling and design

- Thin Ply composites: closer to classical laminate theory?

<table>
<thead>
<tr>
<th>Model</th>
<th>First ply failure</th>
<th>0° ply failure</th>
<th>Experiment</th>
<th>Damage</th>
<th>Ult strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLT with damage</td>
<td>287 MPa</td>
<td>609 MPa</td>
<td>Thick ply 300g/m²</td>
<td>248 MPa</td>
<td>595 MPa</td>
</tr>
<tr>
<td>CLT no damage</td>
<td>287 MPa</td>
<td>819 MPa</td>
<td>Thin ply 30g/m²</td>
<td>821 MPa</td>
<td>847 MPa</td>
</tr>
</tbody>
</table>
Conclusions

Lamina level
- More uniform microstructure
  - Improved longitudinal compressive strength

Laminate and element level
- Delay or suppression of delamination as damage / failure mechanism
- Delayed onset of damage
  - Increased strength for a first ply failure design
  - Increased fatigue strength

Design level
- Easier to predict
Thank you